

Preliminary Geotechnical Engineering
Evaluation

Waipi'o Valley Road Hāmākua, Hawai'i

Prepared for
County of Hawai'i
Department of Public Works

January 2022
Job No. 3140023002

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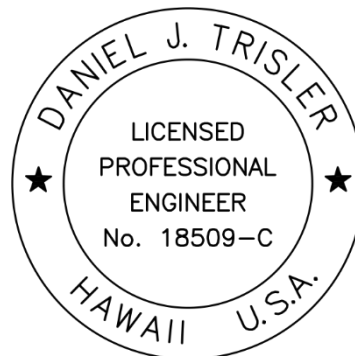
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Prepared by

Hart Crowser, a division of Haley & Aldrich



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ACRONYMS AND ABBREVIATIONS

ADT	average daily traffic
AGS	Australian Geomechanics Society
AVR	average vehicle risk
bgs	below ground surface
County	County of Hawai'i
cy	cubic yard
EOP	edge of roadway pavement
FHWA	Federal Highway Administration
ft/sec	feet per second
GPS	Global Positioning System
Hart Crowser	Hart Crowser, a division of Haley & Aldrich
HDOD	Hawai'i Department of Defense
HDOT	Hawai'i Department of Transportation
kJ	kilo Joules
km/hr	kilometers per hour
lb/sec	pounds per second
LiDAR	light detection and ranging
MSE	Mechanically Stabilized Earth
MSL	mean sea level
NRCS	Natural Resource Conservation Service
pcf	pounds per cubic foot
RHRS	rockfall hazard rating system
ROM	relative order of magnitude
State Route 19	Hāmākua Highway
USGS	United States Geological Society

Waipi'o Valley Road

Hāmākua, Hawai'i

1.0 INTRODUCTION

Hart Crowser, a division of Haley & Aldrich (Hart Crowser), is pleased to submit our preliminary geotechnical engineering evaluation for Waipi'o Valley Road located in Waipi'o Valley on the island of Hawai'i (Figure 1). Our work was conducted for the County of Hawai'i, Department of Public Works (County) in general accordance with Contract Number C.008227 dated April 2, 2020.

Waipi'o Valley Road is approximately 4,100 feet or 0.8 miles long, from the Waipi'o Valley Road Lookout to the Waipi'o Valley floor at the 4-wheel drive beach-bound hairpin turn. The road is situated on the south valley wall near the mouth of the valley. A history of geologic slope hazards and related roadway instability and vehicle safety issues prompted the County to request an assessment of the rockfall risk to Waipi'o Valley Road and evaluate potential options to mitigate risk for the County's consideration.

In support of this preliminary geotechnical engineering evaluation, Hart Crowser conducted the following tasks:

- Performed a background data review of available geologic and soils mapping data, topographic information, and County-provided maintenance and vehicle/pedestrian road-use information;
- Conducted a field reconnaissance of the road including collecting data for evaluating rockfall hazards and roadway instability conditions;
- Performed rappelling traverses and surface reconnaissance to directly assess site conditions and collect data for further rockfall and geotechnical engineering evaluation;
- Evaluated the collected data for rockfall hazards and roadway instability using the Federal Highway Administration's (FHWA) Rockfall Hazard Rating System (RHRS), RocFall software program by RocScience®, and SLIDE2 Modeler™ modeling;
- Summarized the hazard of falling rocks and risks to persons and vehicles using methodology of the Australian Geomechanics Society;
- Considered methods for mitigating risks to the roadway and associated relative costs; and
- Compiled this report with our findings, evaluations, conclusions and recommendations.

A summary of our site work and our preliminary engineering evaluation are presented in the following sections of this report. Referenced figures are presented after the report text followed by ancillary appendices.

2.0 PROJECT BACKGROUND

Waipi'o Valley Road is located on the northern Hāmākua Coast of Hawai'i Island in Waipi'o. The roadway is narrow and winds down along the steep hillside of the south valley wall, losing approximately 800 feet elevation in 0.7 miles. The geomorphology of this part of the island can create significant runoff and storm stages in the streams following rainfall events. Based on information from the County, we understand that a slope failure occurred in March 2019, following heavy rainfall and extremely high stream flows associated with Hurricane Lane. The landslide occurred below Waipi'o Valley Road, approximately 0.3 miles from the Waipi'o Road Lookout and Park (Figure 2).

Hart Crowser conducted an initial site reconnaissance with County staff on April 29, 2020 followed by a detailed field reconnaissance of the roadway on June 1-2, 2020. From August 27 through September 4, Hart Crowser field personnel performed on-rope rappels of the slopes above and below Waipi'o Valley Road to further assess rockfall and slide hazards. Based on our observations, there is one primary slide location, referred to as the March 2019 primary slide described in this report. The primary slide is approximately 500 feet tall and 70 feet wide and extends from the downslope road edge towards the Wailoa Stream valley below (refer to Figure 3). We also observed minor rockfalls along the road edge and numerous line-of-sight hazards for vehicles and pedestrians traveling on the lower portion of the roadway. A photograph log of our field observations is provided in Appendix A-1.

3.0 SITE CONDITIONS

Our understanding of site conditions is based on regional geologic and topographic maps, light detection and ranging (LiDAR) data, field reconnaissance work, and our slope rappel traverses above and below Waipi'o Valley Road. Vertical elevations presented in this report are based on field global positioning system (GPS) measurements and available LiDAR data, and not intended for production engineering design. Collected GPS field data points and features of the road are shown on Figure 2.

3.1 Topographic and Geomorphic Features

Waipi'o Valley, located in the Hāmākua district on the northeastern flank of Kohala, is an amphitheater-headed valley similar to the other Kohala valleys. These valleys formed after the Pololū Slump, a large submarine landslide, whose head scarp corresponds with the present-day Kohala sea cliff that extends from Waipi'o Valley to Pololū Valley. The valley forming process began as dominant streams cascaded over the head scarp as waterfalls, and knickpoints propagated upstream through erosion and resulting undercutting at each waterfalls' vertical plunge pool (Lamb et al. 2007).

Waipi'o Valley's vegetated valley walls taper from inland elevations of roughly 4,000 feet above mean sea level (MSL) to coastal elevations of roughly 1,000 feet MSL. With slopes of approximately 70 to 100 percent, the valley extends inland to the southwest, then makes a sudden turn to the northwest where Waima Stream meets Waipi'o Stream along the valley floor (NRCS 2018). In the valley, several tributary streams flow to form Wailoa Stream, which in turn flows into the sea. The valley floor is nearly flat as a result of alluvial fill deposited during recent sea stands above present sea level (Macdonald and Abbot 1970). This is especially so at the mouth of the valley, which is now mostly wetlands (Fletcher et al. 2002).

Vegetation varies in the upland areas from evergreen forest land to shrub and brush rangeland. In the lowland and valley areas, land coverage varies from forested to non-forested wetlands, as well as cropland and pasture.

3.2 Geologic and Soil Mapping

Regional site geology is provided in *Geologic Map of the State of Hawai'i, Sheet 8—Island of Hawai'i* (Sherrod et al. 2007). Most of the site has been described as Pleistocene Pololū volcanics lava flows (Qpl) consisting of tholeiitic basalt in the older layers and transitional and alkalic basalt in the younger layers, primarily occupying the upper valley walls and the surrounding uplands (Wolfe and Morris 1996). Secondary surficial deposits include Holocene landslide deposits (Qls) consisting of blocks of lava flows mixed with soil and Holocene, and Pleistocene alluvium (Qa) consisting of unconsolidated deposits of gravel, sand, and silt (Sherrod et al. 2007). Where previously mapped, Qls deposits occupy the boundary at the lower slopes and the valley floor, while Qa deposits occupy the remaining valley floor.

Surficial soils in the site area are described in the Natural Resources Conservation Service (NRCS) Web-based soil survey as “Kahena-Niulii-Rock outcrop complex” consisting of 70 to 100 percent slopes (NRCS 2006). The “Kahena-Niulii-Rock outcrop complex” varies from medial to hydrous silty clay loam to very cobbly hydrous silty clay loam down to basalt bedrock at approximately 37 to 47 inches below ground surface (bgs). This soil type has a low to moderately low hydraulic conductivity (approximately 0.00 to 0.06 inches/hour) with high runoff potential. This complex is described as foot slope, backslope, shoulder, and summit within land elevations of 2,000 to 3,600 feet derived from Pāhoehoe lava flows and volcanic ash.

3.3 Subsurface Conditions

Our interpretation of subsurface conditions at the site is based on the regional geologic mapping described above and our field observations in support of this project. We did not conduct subsurface borings at this site and, therefore, subsurface conditions would need to be better defined for design purposes. From this information, we interpret the site subsurface stratigraphy to generally consist of weathered basalt (saprolite) overlying basalt, as described below. A site plan and slope cross-sections are provided in Figures 2 and 4 through 7.

Weathered Basalt (Saprolite). Extremely weathered to highly weathered basalt layers decomposing to soil with residual rock textures and some lesser weathered layers with few core stones within the residual soil mass.

Basalt ('A'a & Pāhoehoe). The basalt varied from extremely weathered to slightly weathered 'A'a and Pāhoehoe layers, with the massive 'A'a core rock generally observed to be less weathered and the Pāhoehoe rock generally observed to be more weathered at the site.

3.4 Groundwater Conditions

No groundwater wells were installed as part of this study. Review of available groundwater data for a U.S. Geological Survey (USGS) well located at the top of Waipi'o Valley, indicates a groundwater level of 2,786 feet MSL (Table 1) (USGS 2020). This water level is likely associated with local shallow perched

groundwater at the well site. Based on this information, perched groundwater could be encountered at various depths below Waipi’o Valley Road.

Table 1 – Groundwater Data from Nearby Wells

Well ID	Highest Recorded Groundwater Elevation (MSL) in Feet	Date/Time span of Data Collection
8-6337-02 Puukapu Shallow Well, Waimea	2,786	3/29/1993

3.5 Geologic and Seismic Hazards

Landslide and rockfall hazards for the State of Hawai’i are described in the *2013 Update of the Multi-Hazard Mitigation Plan* (HDOD 2013). Three main categories of land failure are listed as landslides, debris flows, and rockfalls, which can be distinguished by the initiating phenomena. The initiation point of the various failures are typically along bedding planes or materials that often form weak strata, such as loose or weakly bonded sands, clays, or volcanic ash. Strata of jointed or blocky rock, especially when over a layer of weak strata, are also common points of origin for land failures (Jellinger 1977). Weak strata can also be undermined or lose strength when exposed to natural forces such as rainfall or earthquakes. Two natural forces that have been identified by the state as significant factors in land failures are high intensity rainfall and seismicity. Hawai’i Island is both a volcanically and seismically active region where landslide events are often triggered by earthquakes.

From his doctoral dissertation, Namekar (2013) developed earthquake-induced landslide hazard maps for the Island of Hawai’i. Using empirical and analytical models in conjunction with data of historical earthquake-induced slide locations, the hazard maps show high hazard ratings in several areas of North Kohala, Hāmākua, and North Hilo. These high hazard ratings are a reflection of steep slopes, weak soils, weathered rock, and high rainfall conditions. The study also noted the correlation of rock slope failures that were influenced by the presence of pyroclastic materials. These pyroclastic materials can act as the weak strata described above.

A report on the 2006 Kīholo Bay earthquake offers a mapped distribution of the rockfalls and landslides in the area of the Kohala valleys, which was used in a comparative analysis with a high-resolution ground motion simulation model (Harp et al. 2014). In a three-dimensional finite-element analysis, earthquake shaking was modeled to reproduce the distribution of rockfalls and landslides following the 2006 Kīholo Bay earthquake and identify the leading factors producing the resultant distribution. The report notes the complex distribution of landslides, particularly the preferential locations along east-facing slopes, yet no landslides were reported to have occurred along Waipi’o Valley Road. In a separate 2007 report, a sole rockfall was identified by reconnaissance on Waipi’o Valley Road which may have been attributed to the 2006 Kīholo Bay earthquake (Medley 2007).

3.6 Road Transects and Sections

From our field observations, the length of the road can be divided into three separate sections considering differences in geology, potential roadside and upslope rockfall, and line-of-sight concerns; an Upper Section, Central Section, and Lower Section as shown in Figure 8 and described further in Appendix A-2.

The Upper Section, which includes road transects F-W-01 and -02, is approximately 625 linear feet long, 17 to 19 feet wide, and consists of a hairpin turn in the road and line-of-sight concerns for uphill traveling vehicles and pedestrians. It also has a significant overhang of weathered basalt and residual soil anchored by tree roots along a portion of the slope crest that provide concerns of slope failure and rockfall.

The Central Section, which includes road transects F-W-03 and -04, is approximately 1,570 linear feet long, 16 to 29 feet wide, relatively straight, crowded in places by the cliff on the upslope side, with a moderate to severe drop-off on the downslope side of the road. The 70-foot-wide surficial slide feature along the downslope side of the road reportedly occurred in March 2019. The Central Section has some localized risk of rockfall from upslope rock outcrops and boulders.

The Lower Section, which includes road transects F-W-05 thru F-W-11, encompasses approximately 2,000 linear feet of road that narrows with many curves and line-of-sight concerns in both directions. The road width ranges from 11 to 20 feet. This road section also has potential risk of rockfall from roadside basalt outcrops and boulders from the upslope cliff. Above the crest and upslope of all three road sections is primarily vegetated with strawberry guava and eucalyptus.

4.0 ROCKFALL EVALUATION

We evaluated the occurrence of individual rockfall within the project area using two different methods. First, we considered the FHWA's rockfall hazard rating system (FHWA 1993). This system assigns a relative rockfall hazard rating based on 10 measurable or observable field parameters. It is useful in evaluating the hazard of rockfall from one area compared to others. Where rockfall hazard was present, we conducted numerical modeling of rockfall delivery to the roadway using the RocFall software program by RocScience[®]. This program calculates the trajectory of rocks falling to the roadway, providing the travel distance, bounce height, and energy of those rocks for use in designing mitigation measures, such as rockfall fences. We further evaluated the numerical risk of rockfall using a methodology developed by the Australian Geomechanics Society (AGS 2000). This system calculates the probability of damage or injury from rockfall in a manner that can be compared with societal risk from other hazardous activities or occurrences.

4.1 Rockfall Mechanism

We first considered the potential mechanisms of rock failure at the site from observations made during our field reconnaissance (Appendix A-2) and rappel traverse work (Appendix A-3). We evaluated the potential for individual rocks, rock wedge, planar sliding, and toppling failures within the project area based on joint orientations and characteristics. No kinematic analysis was performed. The 30- to 40-foot high slope observed upslope of the upper road (950 to 825 feet elevation), includes the Upper Section as previously identified, is characterized as saprolite basalt with moderate to severe fracturing (discontinuous

and random), with clay infilling in many locations. With decreasing elevation (Central to Lower Sections), the upslope roadside slope ranged in height from 20 to 30 feet and is characterized as jointed basalt with clinker zones and basalt outcrops with some infilling and residual boulders. We observed less weathering and fracturing of the basalt in the Lower Section of the road (i.e., below 400 feet MSL) (Figure 2).

We accessed the slope area above the road from private property. Two representative vertical transects (WR-3 and WR-4) were traversed with ropes from approximately 1,000 feet MSL to Waipi'o Valley Road (270 to 330 feet MSL) to map the slope geology and potential source(s) of rockfall (Figures 5 through 7). Along each traverse, transect points were documented for slope and geologic features and vegetation type, height, spacing, and diameter (Appendix A-3). For traverse WR-3, weathered basalt outcrops and subangular boulders were observed from approximately 635 to 575 feet MSL with variable jointing and some infilling. Weathered massive basalt outcrops were also observed along traverse WR-4 from approximately 500 to 390 feet MSL. Both observed outcrop areas are potential rockfall sources to areas below, including portions of Waipi'o Valley Road.

Our field observations indicate that the discontinuous and random jointing patterns in the basalt with significant infilling and weathering are relatively unstable and likely would generate localized slope failures immediately above Waipi'o Valley Road. These upslope slope failures are more likely to occur with significant rain events and seismic activity. We observed individual boulders and small shallow soil/colluvial failures along portions of the roadside including some impact marks in the pavement from previous rockfall events. The basalt outcrops located at higher elevations (from 390 to 635 feet MSL) above the road are also potential sources of rockfall, though the density of vegetation in these areas may be a prohibiting factor in travel distance.

4.2 FHWA Road Evaluation

The FHWA uses a quantitative assessment of rockfall hazard to roadways, the "Rockfall Hazard Rating System," or RHRS (FHWA 1993). This publication evaluates 10 parameters related to rockfall occurrence and exposure that are typical of roadways. The system is not intended to be a definitive calculation of risk to the public, but to provide a relative ranking for roadway sites. We evaluated the project site using this methodology and the FHWA guidance document. We considered each road section (Upper, Central, Lower) separately due to differences in geologic features and line-of-sight inferences as described previously. Our scoring methodology followed the criteria noted in Appendix A-2. One criterion, average vehicle risk (AVR), was based on average daily traffic (ADT) from the 2019 annual average daily traffic data (vehicles and pedestrians) documented by the County Department of Parks and Recreation at the Waipi'o Valley Road Lookout.

Table 2 below lists each parameter and the highest value we assigned for each parameter on each section of road. The sum of the criteria is the total value of each road section and is used for comparison purposes as described below. Detailed summary data and score tables for each of the 11 separate transects divided into road sections are provided in Appendix A-2.

Table 2 – Rockfall Hazard Ratings Evaluation Summary

RHRS Category	Rating Criteria Description	Highest Score		
		Upper (F-W-01 to F-W-02)	Central (F-W-03 to F-W-04)	Lower (F-W-05 to F-W-11)
Slope Height (upslope)	Heights range from 18 to 41 feet	9	9	9
Ditch Effectiveness	No catchment	81	81	81
Average Vehicle Risk	AVR ranged from 4 to 24 percent (<25% of the time)	3	3	3
Decision Sight Distance	Sight distance ranged from 27 to 64 percent (limited site distance most of lower road)	81	27	81
Roadway Width	Width range from 11 to 29 feet	81	81	81
Case 1 – Differential Erosion Features	Discontinuous/random, undulating to clay infilling	81	81	81
Or (highest value between Case 1 or 2)				
Case 2 – Difference in Erosion Rates	Occasional differential erosion features, small to moderate difference erosion	9	9	9
Block Size or Quantity of Rockfall	0.3- to 2.0-foot block size, up to 1.0 cy	3	9	9
Climate	High precipitation	27	27	27
History	Occasional falls (assume 6 or more per year)	9	9	9
Total – (highest score for each category)		375	327	381

Note: The RHRS ratings were derived from our road reconnaissance observations only and don’t include observations and rockfall data collected from traverses of the upper slope areas.

Based on the above assessment, the Waipi’o Valley Road rockfall area would receive a score of between 327 and 381 by road section. Without comparative sites, these values do not provide much information. However, in support of SSFM International, Inc. for the Hawaii Department of Transportation (HDOT), Hart Crowser recently conducted rockfall hazard rating assessments along the Hāmākua Highway (State Route 19) in Hawaii County (Hart Crowser 2019). In that study, Hart Crowser assessed 21 upslope sites along 50 miles of the highway and calculated hazard ratings ranging from 81 to 351. Of the 21 upslope sites evaluated during the HDOT study, rockfall mitigation such as drapery netting or retaining walls was recommended for six of the sites. The hazard rating scores for Waipi’o Valley Road are higher than the rating scores for the HDOT study.

4.3 Rockfall Computer Modeling

4.3.1 Rockfall Modeling Method

Data from our field reconnaissance and rappel investigation along two traverses (WR-3 and WR-4) were used to support rockfall trajectory modeling for Waipi’o Valley Road (Figures 5 through 7). Rockfall trajectory modeling addresses discrete rock block failures and is performed using the RocFall software

program by RocScience®. The program allows the user to input detailed cross sections of the slopes, assign material properties to the slope surfaces based on what was observed in the field (including vegetation and tree density), input the weight of the rocks based on observed average size and unit weight, and choose the geometry of the rock blocks (i.e., spherical or tabular, rounded or angular). Initial model trial results are compared to evidence of rockfall observed in the field to ground truth the model inputs, which are then adjusted as needed for the site. The parameters used in the model “trials” for each traverse are given in Table 3 below.

Table 3 – Site-Specific Parameters used in RocFall Model Trials

Parameter	Field Observations	Selected Values
Rock Shape	Weathered basalt outcrops and boulders.	Rounded hexagon and rhombus
Rock Diameter	Typical block size estimated to be 3 feet x 3 feet x 1 feet based on photographs and joint spacing measured in outcrops.	3 feet x 3 feet x 1 feet
Rock Density	No measured values. Average value for basalt selected based on published data.	170 pounds per cubic foot (pcf)
Dynamic Friction Coefficient	Based on the estimated friction angle of surfaces (= tangent of friction angle), estimated friction angle varies from 32 to 35 degrees	0.62 to 0.7
Rolling Friction Coefficient	Varies based on material type, estimated based on published values (in general, harder materials have lower rolling friction coefficients).	0.5 to 0.75
Normal Coefficient of Restitution	Basalt outcrop (0.35), Outcrops with soil and vegetation (0.33), Soil with vegetation, boulders, and outcrops (0.33), Soil with vegetation (0.3), Asphalt roadway (0.4)	0.3 to 0.4
Tangential Coefficient of Restitution	Basalt outcrop (0.8), Outcrops with soil and vegetation (0.78), Soil with vegetation, boulders, and outcrops (0.78), Soil with vegetation (0.7), Asphalt roadway (0.9)	0.7 to 0.9
Forest/Vegetation Damping	Vegetation type, height and spacing estimated in the field. Average height varies from 10 feet to 20 feet. Tree density with 5 to 15-foot spacing estimated to be “medium” with forest drag coefficient = 1100 pounds per second (lb/sec) and tree density with spacing greater than 15 feet estimated to be “open” with forest drag coefficient = 550 lb/sec.	Height: 10 to 20 feet Forest drag coefficient: 550 to 1100 lb/sec

Note: Average values for Normal and Tangential Coefficient taken from Pfeiffer, T.J., and Bowen, T.D., "Computer Simulation of Rockfalls." Bulletin of Association of Engineering Geologists. Vol. 26, No. 1. 1989, pp 135-146.

For each model trial, 1,000 rock blocks are “thrown” from the upper slope of each traverse using a Monte Carlo simulation emanating from select seeder locations that are based on rock block clusters and rock outcrops observed during the field investigation. A data collector is placed at the bottom of the slope at the edge of roadway pavement (EOP), and after running the models, the number, bounce height, and kinetic energy of rock blocks reaching the roadway is recorded by the data collector.

Two models were created for each traverse:

- one assuming static conditions of the rock slope (loose rock blocks falling without an impetus or initial velocity); and
- one that accounts for an impetus to rock motion (like a significant rainfall event, debris flow, earthquake, etc.) by applying an initial horizontal velocity to the rock blocks.

Other parameters in each model run for the site (i.e., slope geometry, material, and rock properties, etc.) are the same.

4.3.2 Rockfall Model Results and Discussion

Table 4 below summarizes the results of our analyses for the two Waipi’o Valley Road traverses. Detailed model outputs are provided in Appendix B.

Table 4 – Trials Rockfall Model Results for Traverse WR-3 and WR-4, Waipi’o Valley Road

Location	Traverse	Initial Velocity Settings	Rock Blocks that Cross the Data Collector	Total Number of Rock Blocks Analyzed	Retention (percent)	Maximum Bounce Height (feet)	Maximum Translational Kinetic Energy (kJ)
Waipi'o Valley Road	WR-3	Static: 0 ft/sec	343	967	64.5%	12.6	37
		With impetus: 10 ft/sec	517	989	47.7%	17.6	65
	WR-4	Static: 0 ft/sec	44	899	95.1%	25.9	16
		With impetus: 10 ft/sec	135	972	86.1%	25.9	16

Note: Less than 1,000 rocks were analyzed during the model trials due to excess computing time or complicated rock block interaction/collisions.

Outputs from the RocFall model trials, annotated with photographs collected during the field investigation, are included in Appendix B. For the two traverses modeled, maximum bounce heights at the edge of the roadway range from approximately 13 to 26 feet without an impetus and from approximately 18 to 26 feet with an impetus to rock motion. Maximum translational kinetic energies range from 16 to 37 kilojoules (kJ) without an impetus and from 16 to 65 kJ with an impetus to rock motion.

Rockfall retention is a percentage of rock blocks in the model trials that do not enter the roadway. Many of the rock blocks in the model trials stopped falling or rolling in upslope locations due to low slope angles along portions of the traverses, or due to thick vegetation/tree density. Typical rockfall mitigation designs are based on the goal of 95 percent retention as defined by FHWA guidelines, which were developed for rockfall mitigation projects adjacent to federal highways. This means that 95 percent of potential rockfall must be contained within a properly designed catchment ditch or otherwise prevented from impacting the

roadway surface using rockfall stabilization or protection measures (i.e., rockfall barrier fencing, anchored or draped systems, shotcrete, etc.).

The WR-4 traverse model in static conditions achieved the greater than 95 percent goal, whereas the other model results for WR-4 with impetus and both static and impetus conditions for WR-3 indicate less than 95 percent retention (**bold** in Table 4). Therefore, rockfall events occurring along the upper slopes adjacent to Waipi'o Valley Road are likely to impact the roadway. The bounce heights and energies of the rockfall events modeled could cause vehicular crashes and injuries or fatalities. During subsequent phases of the project, additional rockfall trajectory models can be evaluated iteratively with adjusted configuration of and/or modifications to the slopes and catchment ditches until the 95 percent retention goal is reached, if possible.

4.4 Australian Geomechanics Society Risk Evaluation

Based on the FHWA evaluation, our rockfall modeling using the RocFall software program by RocScience[®], and historic rockfall occurrence, rockfall hazard is present on Waipi'o Valley Road throughout the project site. However, these methods do not quantify the risk relative to other common exposures or relative to "acceptable" levels of risk. To estimate risk, an analysis must be used that evaluates both the probability of the occurrence of a rockfall event, as well as the consequence from the event. This probability can then be compared to standard acceptable risk levels. The AGS risk evaluation methodology (referred to for the remainder of this report as AGS methodology) provides this evaluation (AGS 2000, 2007). Although the AGS methodology is not specifically adopted in the United States or Hawai'i, it provides a useful framework within which to evaluate potential risk.

According to the AGS methodology, a suggested tolerable risk for loss of life¹ for existing conditions varies between 10^{-4} (1:10,000), the lower threshold or persons most at risk, and 10^{-5} (1:100,000), the upper threshold or average of persons at risk, depending on the vulnerability of those at risk. For example, persons that would be trapped by collapse of a structure or buried by a rapidly moving landslide would be considered more vulnerable, while those that would have a reasonable chance to escape the risk would be considered less vulnerable. To put these values into perspective with common risks in society, the AGS (2007) provides risks for common human activities, shown in Table 5, below. As can be seen by these statistics, the tolerable risk recommended by the AGS methodology varies between that for motor vehicle use to perishing in a fire.

Table 5 – Risks of Death from Common Activities

Activity/Event Leading to Death	Risk (Deaths per Participant per Year)
Motorcycling, horse riding, ultra-light flying	1:1,000 to 1:10,000 (Canada)
Motor vehicle use	1:23,000
Fall	1:30,000
Drowning	1:70,000
Fire/Burn	1:180,000
Choking on food	1:660,000
Scheduled airlines	1:1,000,000 (Canada)

¹ Acceptable risks are usually considered to be one order of magnitude smaller than the above tolerable risks.

Activity/Event Leading to Death	Risk (Deaths per Participant per Year)
Lightning strikes	1:32,000,000

Note: Data from Australia New South Wales for the years 1998 to 2002 and other sources.

We used the AGS methodology to evaluate rockfall risk at the project site. The methodology computes the risk of death of an individual (R_{DI}) with four parameters:

- P_h – the annual probability that rockfall will occur,
- P_{S:H} – the probability that a rock will impact a specific section of the roadway,
- P_{T:S} – the probability a car or pedestrian is present on the road when impacted, and
- V_{D:T} – probability of loss of life if struck by the rock.

Our estimation/determination of these parameters is described below. The parameter P_h is the number of rocks that fall per year. Data has not been collected at the site; however, transient road users reported that rockfall occurs frequently. The County reported at least three rock falls occur per year that require some action by the County. Anecdotal information we received suggests rockfall may occur every time a large storm hits the region. Therefore, we estimated that rockfall occurs about once every other month, resulting in an annual occurrence of six. We used this same frequency for the entire road length. Parameter P_{S:H} is the probability of a vehicle or pedestrian occupying the portion of the road onto which rock falls. For a moving vehicle or pedestrian in the impact zone, the spatial probability of impact is calculated using the following equation (AGS 2000, Appendix E).

$$P_{(S:H)} = \frac{N_V \times L}{24 \times 1000 \times V_V}$$

N_V = Numbers of vehicles/pedestrians per day,
 L = Length of vehicle/pedestrian (meters), and
 V_V = Velocity of (vehicle/pedestrian)/hour (km/hour).

The County provided traffic information for vehicles and pedestrian use on Waipi’o Valley Road. For 2019, the average trips per day in and out of Waipio Valley was reported at 174 vehicles and 137 pedestrians (total 311 trips per day). The average length of a mid-size 4-wheel drive sedan was estimated at approximately 15 feet (4.8 meters) and the velocity of the moving vehicle was estimated at approximately 10 mph (16 km/hr). Pedestrian traffic was also significant most days due to tourism. The average width of a person was estimated to be 1.5 feet (0.46 meter), with an average walking speed of 1.0 mph (1.60 km/hr), recognizing a person will travel faster into but much slower out of the valley. Using these values, the spatial probability of impact is estimated at approximately 2.2 x10⁻³ for a vehicle and 1.6 x10⁻³ for a pedestrian travelling on Waipi’o Valley Road.

Parameter P_{T:S} is the temporal probability that a car or pedestrian is present on the roadway when the rock impacts it. The temporal probability is calculated using the following equation (Bunce, Cruden, and Morgenstern 1997), where *t* is the amount of time in the impact zone.

$$P_{T:S} = t/8760$$

Based on the 4,100-foot length of roadway of concern and the average 15-foot car traveling 10 mph, we estimated that a car takes approximately 280 seconds (4.7 minutes) to traverse the roadway (this doesn't include time for vehicles to stop for oncoming traffic). We multiplied that by 174 trips per day, which places cars on the road for 812 minutes (13.5 hours) per day. We divided that by the number of hours in a year (8,760 hours), resulting in a value of 1.5×10^{-3} . We estimated that a person takes approximately 45 minutes to traverse the roadway [average between traveling down (30 minutes) and up (60 minutes) the road]. We multiplied that by 137 trips per day, which places people on the road for approximately 6,200 minutes (approximately 100-man hours) per day. We assumed pedestrians are on the road in groups of two, for a total of 50-man hours. This resulted in a $P_{T:S}$ value of 5.7×10^{-3} .

$V_{D:T}$ is the probability that someone would be killed should a rock impact their vehicle or them. We estimated this probability at 30 percent (0.3) for a vehicle and 100 percent (1.0) for a pedestrian. Although we believe these values are reasonable, they are largely subjective. Using these parameters in the AGS methodology, we determined the risk to loss of life for pedestrians and vehicular traffic, separately. The values we used, and the results are shown in Table 6.

Table 6 – Calculation of Rockfall Risk along Waipi'o Valley Road

Section	P_h	$P_{S:H}$	$P_{T:S}$	$V_{D:T}$	Probability (R_{DI})	
Pedestrian	6	1.6×10^{-3}	5.7×10^{-3}	1.0	5.5E-05	1:18,000
Vehicle	6	2.2×10^{-3}	1.5×10^{-3}	0.3	5.9E-06	1:170,000

For loss of life, the individual probability can be calculated from:

$$\text{Probability } (R_{DI}) = P_h \times P_{S:H} \times P_{T:S} \times V_{D:T}$$

Based on these results, the estimated risk of loss of life ranges from greater than 1 in 18,000 for pedestrian access to 1 in 170,000 for vehicle access. The AGS methodology suggests that risks of less than 1 in 10,000 (lower threshold) to 1 in 100,000 (upper threshold) are acceptable for existing slopes, depending on a variety of factors. These results indicate that the risk to pedestrians in the project area is between the two risk thresholds and mitigation would be recommended to achieve *acceptable* risk over *tolerable* risk. This finding generally corroborates our observations of the locations of recent rockfall on the road and road shoulder of Waipi'o Valley Road, as well as the known history of several rockfalls per year along this road. We note that these results rely on the estimated parameters described in the paragraphs above and, in particular, the values for rockfall occurrence per year. Given the results and the uncertainty of some of the parameters used, it is our opinion that mitigation is warranted to reduce the level of risk.

Based on the RHRS scoring and rockfall modeling results, and the corresponding risk exceeds the recommended acceptable threshold in the AGS methodology, we evaluated mitigation options as noted in the following sections of this report.

5.0 SOIL SLOPE EVALUATION

The soil conditions upslope and downslope of the road were assessed to determine what, if any, possible mitigation may be necessary to repair and stabilize Waipi'o Valley Road.

5.1 Overhang in Upper Sections (F-W-01 to F-W-02)

The Upper Section of the road (transects F-W-01 and F-W-02) is the beginning of the downhill descent to the valley (Figures 2 and 8). Steep exposed residual soil slopes on the upslope side of the road have been susceptible to instability as indicated by past failures, the most recent of which were landslides in April 2018 and February 2019. In April 2018, overhanging trees and soil were reportedly deposited into the road after heavy rains (refer to Photo 1 below), causing several days of road closure for cleanup. In February 2019, the road was reportedly closed again after another upslope landslide blocked the traveled way. We do not have definitive limits and dimensions of where these past failures have occurred, so a general area is outlined in Figure 9. The instability is due to factors such as the slope steepness, exposure to water and wind, erodibility of the soil, and the proximity of top-heavy vegetation to the slope edge. These conditions have not been addressed to date by the County and it is likely that future instabilities will occur along this portion of Waipi'o Valley Road.

The top of the adjacent upslope slope cut is vegetated with ferns, plants, trees, and bushes (Photo 2). The slope is considered nearly vertical in places along the road. Some areas of the slope face are vegetated, but much of the slope face is either partially- or fully-exposed residual soil from transects F-W-01 to F-W-02 (Photos 3 and 4). During our June 2020 reconnaissance work, water seepage was noted in areas of the upslope face of transect F-W-01 along with approximately one cubic yard (cy) of soil debris possibly washed out/eroded from the uphill area onto the roadside. The road width in this transect is approximately 19 feet and the slope height is 17 feet (observed from the road).

Along transect F-W-02, soil has eroded underneath the vegetation closest to the uphill area edge, thus resulting in overhangs. These overhangs are primarily held together by the root systems of the flora (Photo 4). The road width in this transect is approximately 17 feet and the slope height is approximately 20 feet (observed from the road).

In the 2018 and 2019 upslope slide events, there were no injuries or damage to private property because there were no pedestrians or vehicles on the road. However, should a pedestrian or vehicle be on the road during an event, the road conditions do not allow for much area to avoid debris falling/sliding into the traveled way. To further complicate matters, the line-of-sight within these transects is inadequate, so reaction time will be very short.



Photograph 1. Soil landslide and uphill tree debris resulting from heavy rains in April 2018. Picture from County of Hawai'i Civil Defense Agency (open source).



Photograph 2. Transect F-W-01 looking uphill (north). Note the upslope road cut slope with vegetation.



Photograph 3. Partially-vegetated road cut slope with exposed soil in upper slope area.



Photograph 4. Exposed soil of upslope road cut slope face. Note overhanging soil and vegetation.

5.2 Downhill Slope Evaluation (Downslope of Guardrails)

This section provides our evaluation of erosional/shallow failures in the area downslope of the Waipi'o Valley Road guardrails.

Based on our field observations and available information, the March 2019 slide (noted on Figures 2, 8, 9) appears to be a failure of the thin layer or “veneer” of side-cast fill and/or volcanic soil that overlies the bedrock. The natural slopes downhill of the road edge range from approximately 36 degrees to almost 50 degrees, and in the general area where the failure occurred it is approximately 43 degrees. These slope angles are steeper than the friction angle of most natural soils, and the soil cannot remain stable on the slope through friction alone. Cohesion of the clay and silt in the soils adds some resistance to downward movement. However, when exposed to water, soil strength decreases. In late August 2018, Hurricane Lane introduced enough water to decrease the soil veneer strength and exacerbate the conditions to a point where soil movement occurred at this location. It is important to note that seismic activity would also exacerbate instability with or without water saturation.

Other factors may have played a role, including vegetation and stormwater infiltration. Vegetation from the guardrail or road edge all the way down to the slope toe and valley below is a combination of grasses, ferns, bushes, and small to mid-sized trees. Though vegetation can generally provide erosion control, the size and density of the flora may add to unstable conditions. Trees with shallow root systems can break up the soil veneer and provide preferential pathways for water seepage. If trees are top-heavy and topple over, then unprotected soil is exposed and infiltration pathways increase the potential for landslides. In addition, the road is an impermeable surface, which increases stormwater flow (volume and velocity) down the road and locally concentrates and directs flow over the slope.

6.0 MITIGATION ALTERNATIVE ANALYSIS

The following subsections describe potential rockfall and soil slope mitigation alternatives for Waipi'o Valley Road.

6.1 Rockfall Mitigation Methods

In general, rockfall mitigation alternatives presented in this report follow the approach hierarchy of (1) removal of risk; (2) stabilization of risk; and (3) protection from risk. In most cases, a combination of the three mitigation approaches is used to produce the most effective and feasible mitigation system.

The removal approach physically eliminates the rockfall sources or source zones. This is typically done by rock removal, excavation, or reshaping the slopes with methods such as trim blasting, mechanical hoe ramming, boulder busting, scaling with prybars, use of an excavator bucket, or other mechanical means of removal. Removal approaches can also include relocating the roadway from the rockfall hazard zones.

Stabilization consists of securing and/or reinforcing the rockfall source(s) to prevent rocks from moving or starting to fall. Commonly available methods include rock dowels and rock anchors, cable lashing, anchored rockfall netting, resin or cement grouting, shotcrete, and buttressing.

Protection involves letting the source rocks fall, but intercepting, stopping, or retaining rockfall before it reaches the roadway. Techniques include excavating catchment ditches at the base of the slope, constructing soil berms/embankments, installing rockfall barriers and rockfall fences, and using mesh drapes that allow controlled rockfall descent.

We qualitatively considered all these methods for the project area. We evaluated earthen berms and walls but there is not sufficient room for such structures in most areas of Waipi'o Valley Road. Removing the rock source by excavation, scaling the hilltop (temporary and not as reliable), securing rock sources with anchored netting and/or locally doweling rocks in place, arresting rocks with fencing, and controlling rockfall with netting were all determined to be feasible options for at least one or more locations along the roadway. A discussion of these mitigation methods is provided below.

6.1.1 Excavation

Excavation of the slope using blasting or mechanical rock removal techniques removes the rockfall risk above or adjacent to the roadway. If removal is extensive enough, it can also provide space to create a catchment ditch for rocks falling from upslope to land safely. Perimeter control techniques like pre-splitting (closely spaced drilled holes lightly loaded with explosives) or line drilling (very closely spaced holes that create a perforated edge without the use of explosives) create a planar cut-slope face at the designed orientation. The rock mass adjacent to the roadway can then be removed through drilling and blasting techniques or by using conventional excavating equipment if the rock mass is highly weathered and "rippable."

If sufficient room is created by rock removal, then a catchment ditch can be constructed at the toe of the slope. The surface of such a catchment ditch is typically covered with loose crushed stone to dampen the impact of potential falling rock. Reconfiguration of the roadway may be required to provide sufficient width for installation of catchment ditches. Such reconfiguration may include widening towards the downslope side of the roadway. Refer to Section 6.4 for information about widening the upslope side of the road.

6.1.2 Scaling

Rock scaling is the procedure of removing loose rocks from the hillside and cliff face. Scaling is not considered a permanent method and would typically need to be conducted every 5 to 10 years to maintain its effectiveness, dependent on the specific site. Scaling should not be considered as reliable as structural methods since there is typically some subjectivity in selecting which rocks to remove. In addition, it is not always apparent what rocks are likely to fail within a specific time period. Scaling can be conducted mechanically if equipment can safely reach the specific rock areas from the roadway (e.g., overhangs directly adjacent to the road), though often scaling is done by hand by workers rappelling down the cliff face and prying rocks loose.

6.1.3 Localized Rockfall Stabilization

Localized stabilization methods target rockfall source zones and include rock dowels, cable lashing, shotcrete, and anchored netting systems. Rock dowels are fully grouted steel bars that are not post-tensioned and secure specific unstable rock blocks. Cable lashing systems typically use wire rope to

stabilize rock blocks that cannot be doweled. Shotcrete (concrete propelled by a nozzle) can stabilize shear zones or highly weathered and fractured rock masses and are often paired with dowels or anchors. Anchored netting with erosion control matting, which is secured by boundary cables, cable anchors and patterned or targeted soil nails/rock dowels, can be used on combination soil and rock slopes or larger fractured rock masses. These methods would likely be used in conjunction with other mitigation methods.

6.1.4 Rockfall Fence

Rockfall fences consist of high strength fences installed at the toe of a slope to “catch” falling rock. The fences are manufactured from steel components that have energy dissipation/absorption capabilities built into them. Typically, steel rings and sacrificial components are integrated into the fencing, which deform elastically and then plastically to stop rocks that impact the fence. The fences are generally constructed of posts that are connected to concrete footings or placed into concrete filled holes (where rock is present at the surface). The poles are guyed together laterally, and often in the upslope direction with steel cables. High strength steel fabric runs between the poles (similar to cyclone fencing, but much stronger) and is the primary element that the rock impacts. The rock energy is transferred to the fencing, which transfers it to the posts, cables, and ground anchors/foundations. Some energy is also dissipated by plastic deformation of the rockfall fence components.

Rockfall fencing is designed based on three main characteristics: rock impact energy, rock bounce height, and site soil conditions. Rock impact energy and bounce height were estimated from the computer program RocFall, as noted in Section 4.3 of this report. Foundation conditions were not determined under the scope of this report but would be determined as part of additional work if fencing is selected as a mitigation strategy.

6.1.5 Rockfall Netting

Rockfall netting consists of high strength steel fabric, similar to rockfall fence fabric; however, it is laid over the slope/source area and connected to the slope by cables and rock bolts, usually only along the top of the cliff. Generally, a fallout area is included in the design and the netting placed to allow rocks to drop behind the netting into the fallout area at the base of the cliff/source. This allows for maintenance/removal of the rocks as needed and maintains the useful life of the netting.

Rockfall netting is designed based on rock size, slope gradient, and area covered. Netting is selected that can control rocks of the size expected to be generated from the specific site. The netting must also be of a sufficient strength to support the weight of rocks that might lodge between the slope and netting, along with its own weight, a function of the slope gradient, as well as the dimensions of the area netted. Since netting is typically more expensive than fencing and more difficult to install, netting is typically used only where site conditions do not provide sufficient room for fence installation, such as along numerous stretches of the Lower Section of Waipi'o Valley Road that are narrow.

6.1.6 Hybrid Fencing Systems

A hybrid fencing system combines rockfall netting (described in Section 6.1.5) with rockfall fencing (described in Section 6.1.4) to attenuate, control and direct rockfall into a constructed catchment ditch at the base of the slope. The fencing system is configured with an open “throat,” supported by prop

bars/fence posts, tie-back anchors, wire rope cables and end anchors. A high strength steel fabric is connected to the post and anchor system by a continuous upper support cable, and the netting drapes down the face of the slope unanchored. Typically, the terminal mesh end at the base of slope can be configured as open and unanchored, or finished with a fixed boundary cable to hold rockfall securely, reducing the possibility of rockfall bounce in the catchment ditch.

6.1.7 Concrete Barriers

Concrete barriers are widely used along roadways to protect vehicles from roadside hazards, such as nearby obstructions, steep slopes, and rockfall. For rockfall, they are best suited to control low-impact energies and rollout from the ditch (Turner and Schuster 2012). They have a relatively low cost and narrow footprint. Additionally, they are typically readily available and easy to install. However, since Waipi’o Valley Road is narrow and there is limited to no shoulder space along the upslope side of the road, this mitigation option is not feasible.

6.2 Comparison of Rockfall Mitigation Methods

We evaluated the results of our analysis and found that different mitigation methods would be appropriate for each section (Upper, Central, and Lower). Table 7 below summarizes our general evaluation of typical measures. More in-depth discussions of suitable mitigation methods for each section are provided following the table.

Table 7 – Rockfall Mitigation Methods Comparison

Location/Method	Applicability	Notes/Comments	Relative Cost
<u>Upper Section</u>			
Long-term mitigation for the Upper Section upslope overhangs may include scaling back the vertical faces to a more stable angle, and rockfall drapery or anchored mesh installation with erosion control mats along the face of the exposed soil slope (refer to Section 6.3).			
<u>Central and Lower Sections</u>			
Excavation	Substantial Risk Reduction	<ul style="list-style-type: none"> ■ Potentially difficult to construct ■ May require localized stabilization of weathered rock/soil zones after construction ■ Infrequent maintenance required ■ Would allow roadway to be widened and straightened 	High
Scaling	Insufficient Risk Reduction	<ul style="list-style-type: none"> ■ Temporary solution only ■ Not recommended alone 	Low, but cost would compound over time

Location/Method	Applicability	Notes/Comments	Relative Cost
Hybrid Fencing	Substantial Risk Reduction	<ul style="list-style-type: none"> ■ Some excavation required at base of slope to create small catchment area ■ Periodic maintenance required 	Moderate to high
Anchored Netting with Upslope Fence	Substantial Risk Reduction	<ul style="list-style-type: none"> ■ Anchored netting on exposed rock cuts adjacent to roadway, rockfall fencing upslope ■ Periodic maintenance required 	Moderate to high
Concrete Barrier	Insufficient Risk Reduction	<ul style="list-style-type: none"> ■ Not recommended due to insufficient height 	Low

6.2.1 Upper Section

Refer to soil slope stability recommendations made in Section 6.3.1.

6.2.2 Central and Lower Sections

For long-term rockfall mitigation at Waipi'o Valley Road, we recommend trim blasting and excavating the upslope side rock slopes to expose less-weathered bedrock, create a catchment ditch for future rockfall retention, and improve roadway width and sightlines. It is anticipated that drilling and blasting operations would be necessary to conduct the excavation. Perimeter control techniques like pre-splitting or cushion blasting would be employed to construct a planar cut-slope face, while more typical production blasting methods would be used to remove the remaining rock. Post-blast stabilization methods, like shotcrete (with strip drains) or anchored netting may be necessary, particularly in highly weathered zones or at the interface of soil and bedrock.

Specific details like the alignment of the rock cut, slope angle, catchment ditch width and configuration should be determined in subsequent project phases.

6.3 Soil Slope Mitigation Options

6.3.1 Upslope Soil Slope Mitigation

Due to the history of and potential for soil slope failures on the downslope slope, we recommend the County consider temporary mitigation measures such as mandatory road closures to all non-local traffic during and after significant or prolonged rain events (for a period of days), removal of soil and vegetation overhangs from either the upslope (crews on ropes) or the road (using a cherry-picker, excavator) and, if feasible, cutting back the upslope areas to reduce the vertical face height.

Long-term remedial actions could include rockfall drapery or anchored mesh installation with erosion control mats along the face of the exposed soil slope, and scaling back the vertical slope to a more stable angle (1.75H:1V or gentler), among other options.

The County could also consider building a new road alignment to join the hairpin turn at the base of the slope in the Upper Section of the road. The existing portion of the road would be closed permanently to vehicle access, but it could be used for foot access if the overhead issues are addressed. The advantages of this option are the new alignment could be placed in a more reasonable location, an engineered design would be developed with adequate drainage, appropriate slope setbacks and/or overhead protection, wider travel lanes, separating foot and vehicle traffic, and to support heavier loads (tour buses, school buses, etc.). The disadvantages are that a new road would require several switchbacks to navigate the elevation change, and the installed costs may exceed the currently projected budget for the project.

6.3.2 Downslope Soil Slope Mitigation

The downslope soil veneer is on average approximately 3 feet thick, which does not seem significant at first glance. However, the downhill slope face is estimated to be approximately 28 acres which amounts to an estimated 135,000 cubic yards of soil that could be subject to failure.

Conditions similar to those that occurred during the March 2019 slide area exist across the entire downhill slope of the project site, and it is likely that other portions of the slope will fail without any intervention. We have indicated a generalized area of concern on Figure 9 to identify similar areas at risk based on available open-source LIDAR, topographic, and aerial information. However, a more detailed map should be developed based on a land survey of the area by a Land Surveyor licensed in the State of Hawai'i along with field and lab evaluation of the soils to determine appropriate strength parameters for stability evaluations.

Listed below are various measures that can be considered in managing the risk of slope failure (in general order of least to most complex). These measures can be combined to increase effectiveness.

- Unloading the top of the slope by removing top-heavy vegetation with shallow roots and replacing with deep-rooting grass such as vetiver.
- Re-grading the roadway so that water is not directed over the slope in a concentrated manner and/or designing a stormwater collection system to divert water away from the slope face and pipe it to an appropriate discharge point.
- Locally constructing retaining walls along the edge of the road, where limited shoulder width is present or downslope failures are present (refer to Section 6.4 for additional discussion regarding walls).
- Armoring/reinforcing the toe of the slope by building a fill buttress or using a combination of soil nails and shotcrete.
- Building a barrier at the toe of the slope that will hold back slide debris.

6.4 Retaining Walls

As noted in Section 6.3, retaining walls could be used to isolate the road from downslope failures or as noted in Section 6.1.1 may be used to widen the road to allow for installation of catchments at the toe of the uphill slopes. Furthermore, widening could provide better line-of-sight or provide the ability to install drainage improvements. Roadway widening on the downhill side could be achieved by the construction of retaining walls, including:

- Gabion wall,
- Mechanically Stabilized Earth (MSE) wall, and
- Cantilever soldier pile and lagging.

Construction of any system may be challenging considering the limited horizontal width of the road, especially in the Lower Section.

6.4.1 Gabion Wall

A gabion wall is a type of gravity retaining wall, similar to the lava rock walls at the site. It is constructed by stacking large wire baskets (rectangular prism) filled with rock. The gabion foundation base can be constructed by placing several baskets side-by-side. Construction continues by stacking baskets on top, tied together, and battered back at a slight angle. The advantages of a gabion wall are:

- The system is permeable and can be coupled with a drainage collection system to divert water away from the slope face;
- The baskets do not require concrete, which lessens the cost and logistics of materials and transport;
- Their relatively simple construction means that specialized equipment and labor are not necessary, and that construction may advance more quickly;
- The bedrock at the site is fairly shallow (< 6 feet bgs) and reasonably competent, so excavation for the foundation pad would not need to be deep; and
- Excavated native soil can be placed back to rebuild the road, if it is adequately conditioned and compacted.

However, a disadvantage to the system is that part of the roadway width will be used to construct the wall. This in turn may require some cutback to the upslope area to regain the roadway width, or require the wall to be constructed further down the slope, resulting in a taller retaining wall.

6.4.2 Mechanically Stabilized Earth (MSE) Wall

An MSE wall is a built-up soil retention wall with a precast concrete facing. The soil is placed in compacted layers and reinforced using either geosynthetics (geotextile fabric or grid) or metal reinforcing strips. They can be designed to support traffic on top of the reinforced soil mass, so roadway widening can be limited.

The advantages of an MSE wall are similar to gabion walls, except that they are not as permeable, and materials may need to be procured off-island.

Disadvantages of this system are that the road width may limit the possible reinforcement length, and significant off-haul of excavated material and import of select fill materials may be necessary if the onsite soil is not suitable for MSE backfill use.

6.4.3 Cantilever Soldier Pile Wall with Lagging

A soldier pile wall is constructed by embedding H-beams into a competent stratum, and then placing lagging or shotcrete between the piles to restrain the soil in between. When constructed for an excavation, it is done in a top-down manner. However, for Waipi'o Valley Road, the wall would be installed from the guardrail, and piles would be placed some distance from the existing roadway edge, then backfilled to build up the road.

The advantages of a soldier pile wall are the roadway can be widened and minimal excavation (drill spoils) would be required. Because the bedrock is fairly shallow, the pile lengths would not need to be very long. The disadvantages are that material costs are higher, specialized equipment and crews are necessary for construction (drill rigs and mobile crane to move piles into place), and pile and concrete placement and transport logistics will be considerable.

6.5 Pavement Reconstruction

Visual inspection of the road surface of Waipi'o Valley Road notes rutting and alligator cracking along much of its surface, and tension cracks parallel to the edge of pavement in some areas. Tension cracks are due to downward movement of the soil which may be the result of either the soil veneer moving downward or settlement of inadequately compacted soil underlying the road. Due to the vegetative cover, we were unable to observe obvious soil slumping or sagging along the slope face, so the cause is unknown.

Hart Crowser was not provided information on the road structural section (asphalt concrete and aggregate base thickness). However, the type of damage indicates an inadequate structural section and the extent of damage would merit full-depth pavement reconstruction rather than chip seal, mill and fill, crack sealing, or other surficial repair methods.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Hart Crowser, under contract with the County, conducted a preliminary geotechnical engineering evaluation to address roadway safety due to rockfall and slope instability hazards for Waipi'o Valley Road. From June through September 2020, we conducted a field reconnaissance and on-rope rappels above and below the roadway in support of this evaluation. From this work, we concluded the following:

- Hazard ratings from RHRS scoring and RocFall modeling indicates mitigation for rockfall is recommended for the upslope side of the road. The bounce heights and energies of the modeled rockfall events for the Central and Lower Sections of the roadway could potentially cause vehicular

crashes and injuries or fatalities. Moreover, the risk of rockfall to pedestrians traveling on the road is considered unacceptable based on the AGS risk evaluation.

The rockfall hazards in the Central and Lower Sections of the road would be effectively addressed by trim blasting and excavating the upslope side rock slopes to expose less-weathered bedrock, create a catchment ditch for future rockfall retention, and improve roadway width and sightlines.

- Along the Upper Section of the road, steep, exposed residual soil slopes are susceptible to instability as indicated by past failures, the most recent of which were upslope side landslides in April 2018 and February 2019. The instability is due to factors such as the slope steepness, exposure to water and wind, erodibility of the soil, and the proximity of top-heavy vegetation to the slope edge. Significant and prolonged rain events are likely to exacerbate these contributing risk factors. It is likely instabilities will occur along this portion of Waipi'o Valley Road until these conditions are mitigated.
- We recommend the County consider temporary mitigation measures such as removal of overhangs and, if feasible, cutting back the upslope areas to reduce the vertical face height. While it is not feasible to predict the direct effect individual rainstorm events will have on slope hazards, the County may wish to consider temporary road closures to non-local traffic and/or road hazard advisories to residents when heavy rains are forecasted. Long-term mitigation actions could include rockfall drapery or anchored mesh installation along the face of the exposed soil slope, scaling back the vertical slope to a more stable angle (1.75H:1V or gentler), or changing the road alignment. Based on our field observations and available information, the March 2019 downslope slide appears to be a failure of the thin layer or "veneer" of volcanic soil which overlies the bedrock. The natural slopes downhill of the road range from approximately 36 degrees to almost 50 degrees, and in the general area where the failure occurred it is approximately 43 degrees. These slope angles are steeper than the friction angle of most natural soils, and the soil cannot remain stable on the slope through friction alone. When the slope is exposed to water, soil strength decreases. Other factors, such as vegetation and poorly controlled stormwater, may also have played a role.

Conditions similar to those at the March 2019 slide area exist along most of the downhill slope of Waipi'o Valley Road, and it is likely other downhill slope areas along the road could fail without intervention. Potential mitigation measures for these downslope areas may include vegetation replacement, stormwater improvements, wall construction, and/or slope reinforcement.

The variety of upslope and downslope hazards along Waipio Valley Road mean the remedy(ies) will have to address several challenges to improve road safety. The mitigation options described in this preliminary evaluation can stabilize the road (upslope and downslope) and reduce the risk to vehicle and pedestrian travel from potential rockfall and slope instability. At a minimum, the upslope rock instability should be addressed so that risks to pedestrians and vehicles can be decreased. If the County moves forward with mitigation of the road, further discussion of preferred mitigation option(s) will be required to select the preferred alternative(s) prior to final design.

8.0 LIMITATIONS

Our report is for the exclusive use of the County of Hawai'i for specific application to the subject project and site. We conducted this study in accordance with generally accepted geotechnical practices for the nature and conditions of the work conducted in the same or similar localities, at the time the work was performed. We make no warranty, express or implied.

The work presented in this report is preliminary and conceptual only. A more detailed evaluation will be required for selection and design of mitigation options.

9.0 REFERENCES

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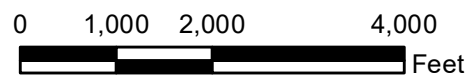
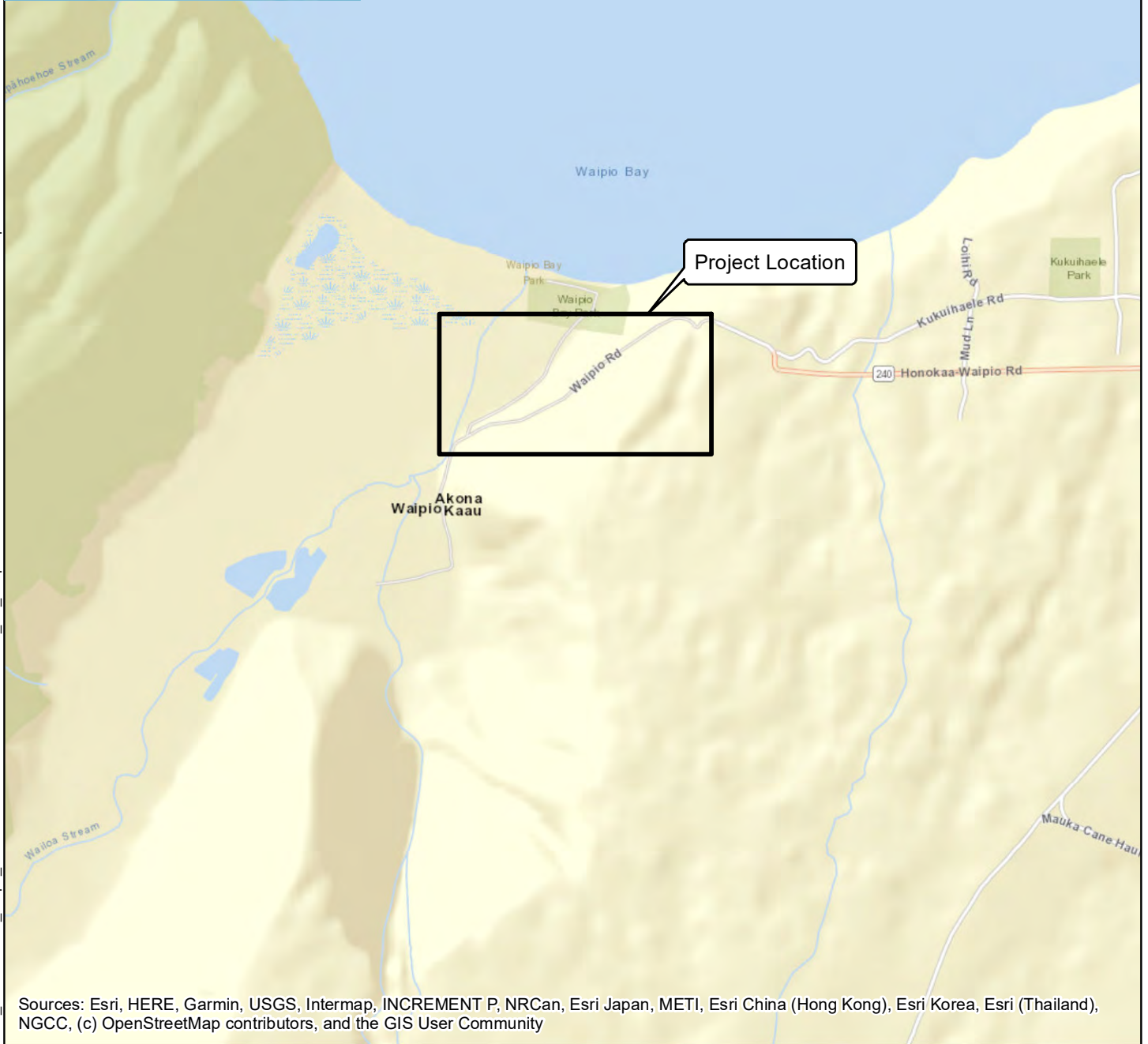
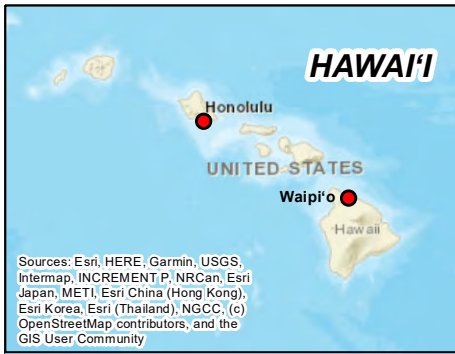
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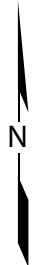
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\\haleyaldrich.com\share\pdx_data\Notebooks\3140023002_Hawaii-Road_Slope_Evaluations\Deliverables\Reports\Final Waipio Report\Waipio_Geotechnical Engineering Evaluation_County Hawaii_Jan 2022.docx

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Note: Feature locations are approximate.



Geotechnical Engineering Services for Waipio Valley Road, County of Hawaii

Vicinity Map

3140-023-002

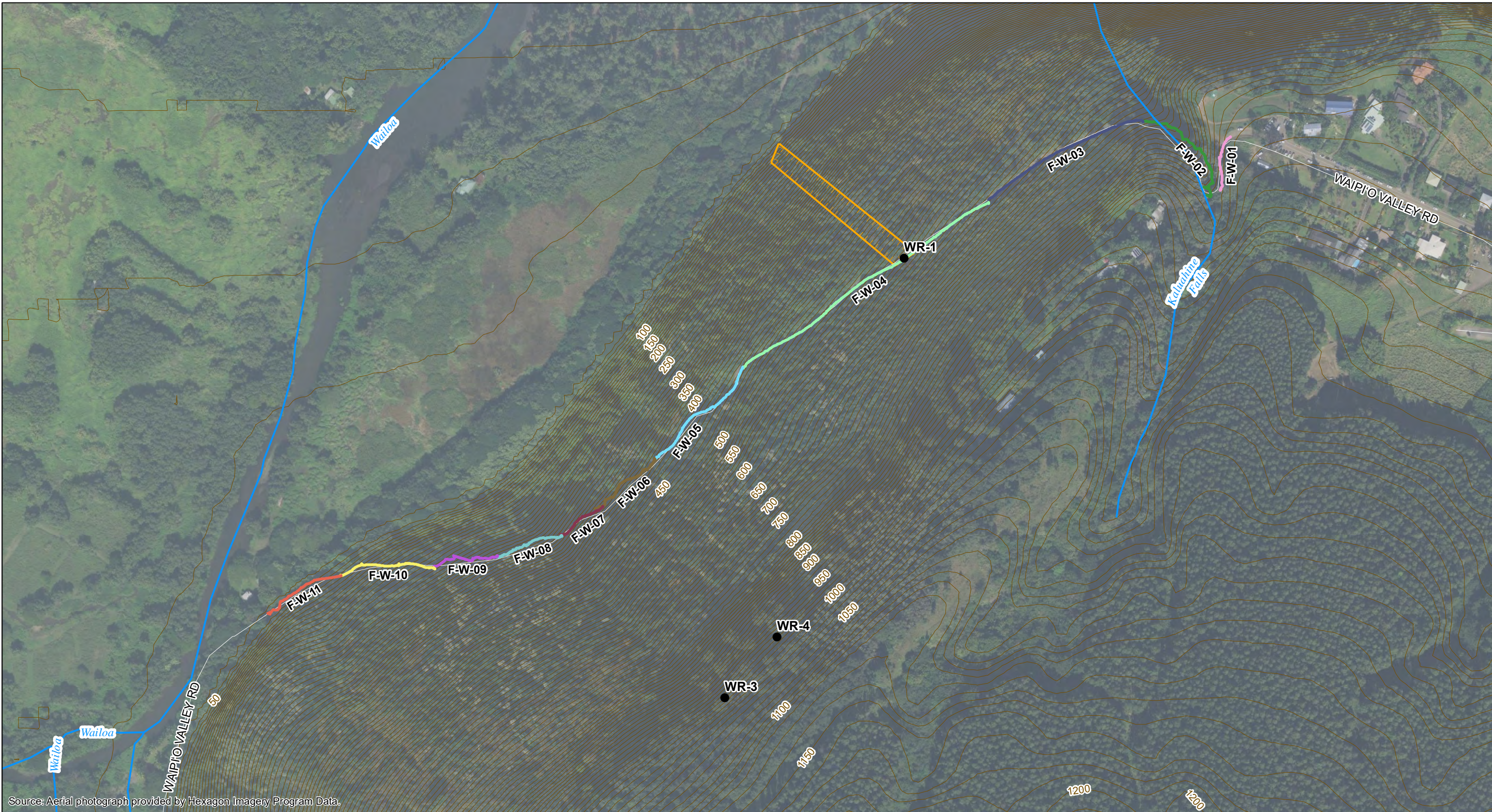
01/21



Figure

1

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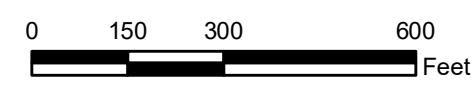
Legend

- WR-1 (Start of Rappel Point)
- Elevation Contour (U.S. Geological Survey, 2013)
- Landslide occurred sometime between March and June 2019

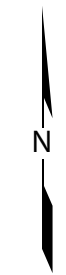
Rockfall Hazard Rating System Survey

- | | |
|--------|--------|
| F-W-01 | F-W-07 |
| F-W-02 | F-W-08 |
| F-W-03 | F-W-09 |
| F-W-04 | F-W-10 |
| F-W-05 | F-W-11 |
| F-W-06 | |

Horizontal Datum: NAD 1983 StatePlane
 Hawaii 1 FIPS 5101 Feet
 Vertical Datum: NAVD88 (ft)



Note: Feature locations are approximate.



Geotechnical Engineering Services for Waipio Valley Road,
 County of Hawai'i

Site Plan

3140-023-002

01/21



Figure

2

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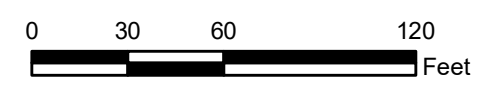


Source: Aerial photograph provided by Hexagon Imagery Program Data.

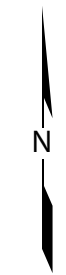
Legend

- EP (Erosion Point)
- GP (Generic Point)
- TP (Transect Point)
- Traverse
- Elevation Contour (U.S. Geological Survey, 2013)

Horizontal Datum: NAD 1983 StatePlane
 Hawaii 1 FIPS 5101 Feet
 Vertical Datum: NAVD88 (ft)



Note: Feature locations are approximate.



Geotechnical Engineering Services for Waipi'o Valley Road,
County of Hawai'i

WR-1 2019 Slide Traverse

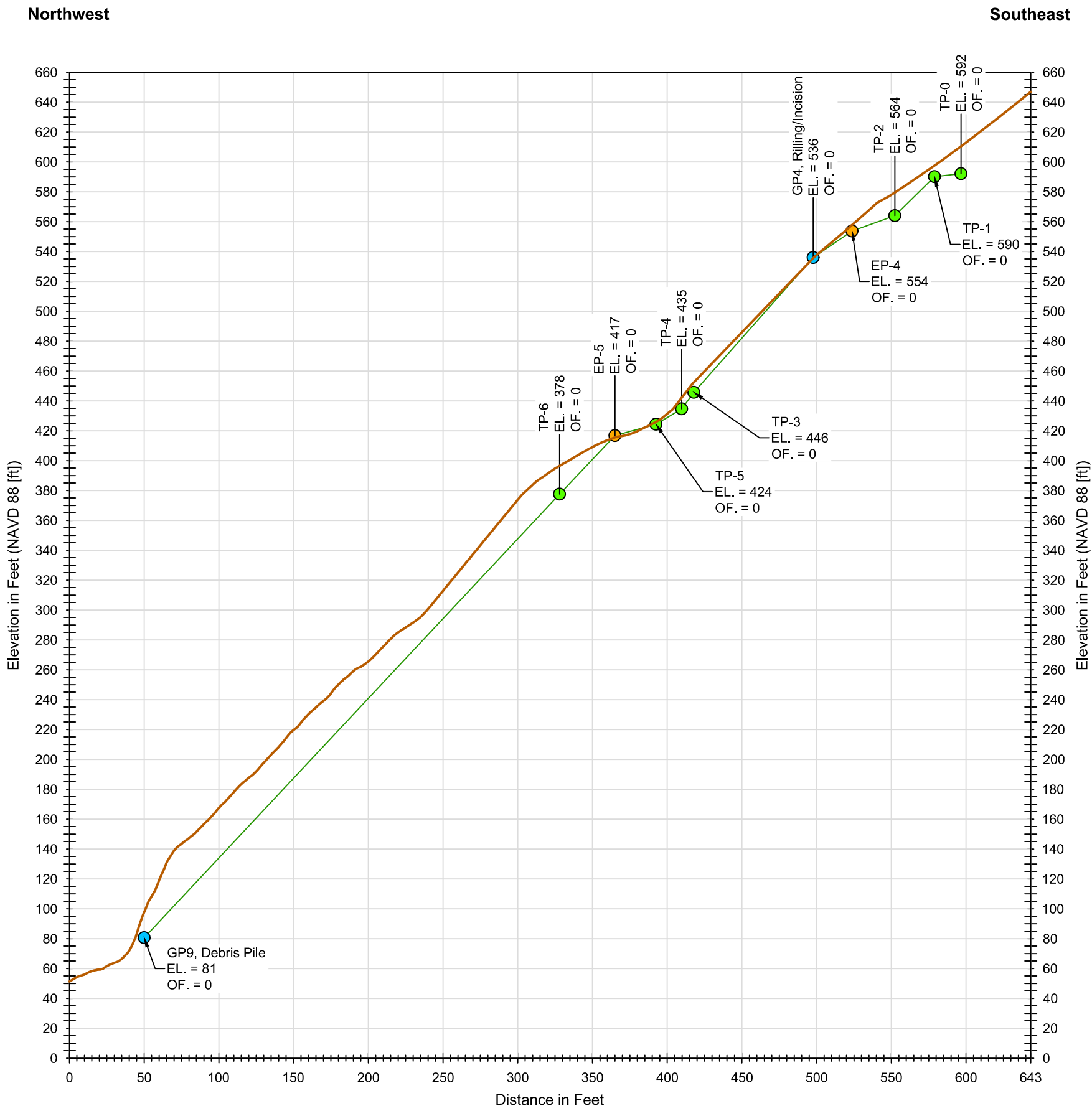
3140-023-002

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Figure

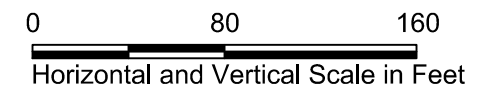
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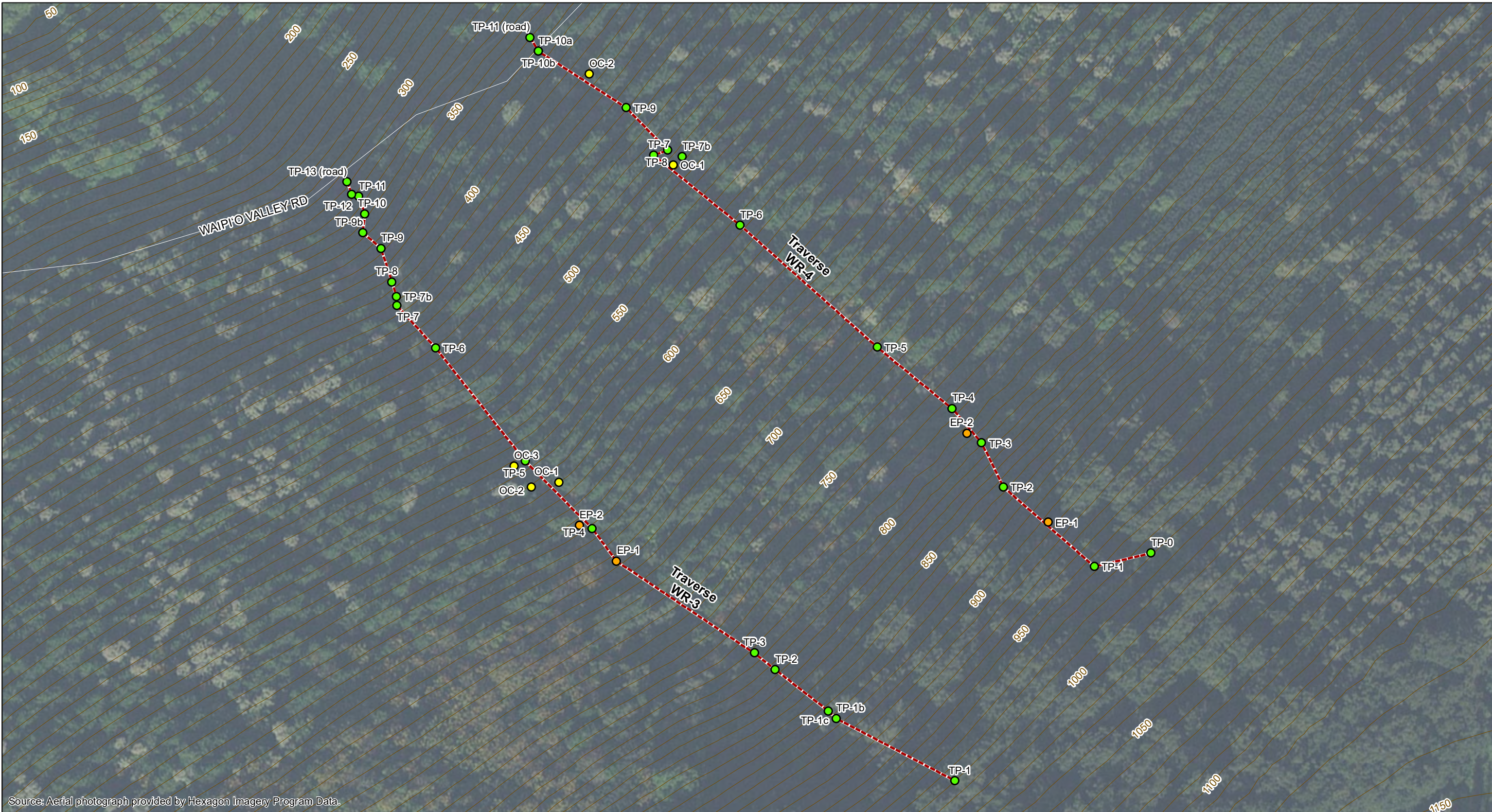
- Lidar Ground Surface
- Ground Surface from Field Data
- GP (Generic Point)
- EP (Erosion Point)
- TP (Transect Point)
- EL Elevation
- OF. Offset from Alignment

- Notes**
1. Surface conditions are generalized from materials observed in soil borings. Variations may exist between profile and actual conditions.
 2. Surface contours are approximate and based on 2013 Lidar information and 2020 field and GPS measurements. GPS and Lidar data may be affected by dense vegetation and satellite signal strength. When appropriate, the ground surface profiles were adjusted to better match the observed field conditions. Profile shown here is preliminary and approximate, and should not be used for design.



Geotechnical Engineering Services for Waipi'o Valley Road, County of Hawai'i	
WR-1 Profile 2019 Waipi'o Slide	
3140-023-002	01/21
 A Division of Healy & Aldrich	Figure 4

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Source: Aerial photograph provided by Hexagon Imagery Program Data.

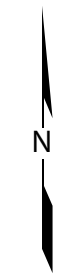
Legend

- EP (Erosion Point)
- OP (Outcrop Point)
- TP (Transect Point)
- Traverse
- Elevation Contour (U.S. Geological Survey, 2013)

Horizontal Datum: NAD 1983 StatePlane
 Hawaii 1 FIPS 5101 Feet
 Vertical Datum: NAVD88 (ft)



Note: Feature locations are approximate.



Geotechnical Engineering Services for Waipi'o Valley Road,
 County of Hawai'i

**WR-3 and WR-4 Traverses
 Rockfall Site Plan**

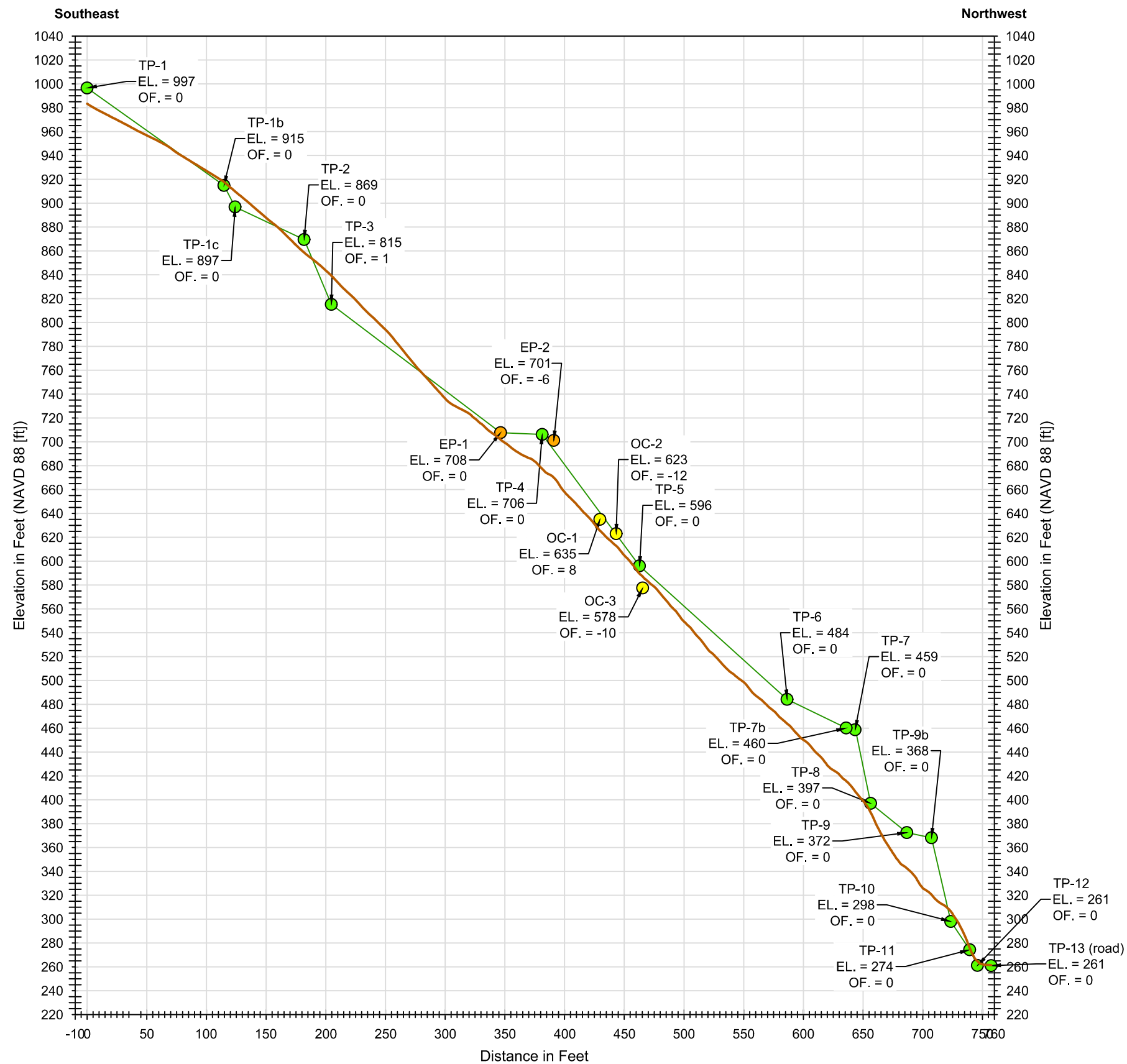
3140-023-002

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Figure

5

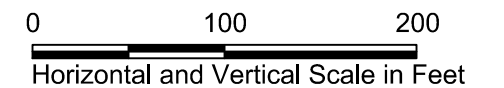


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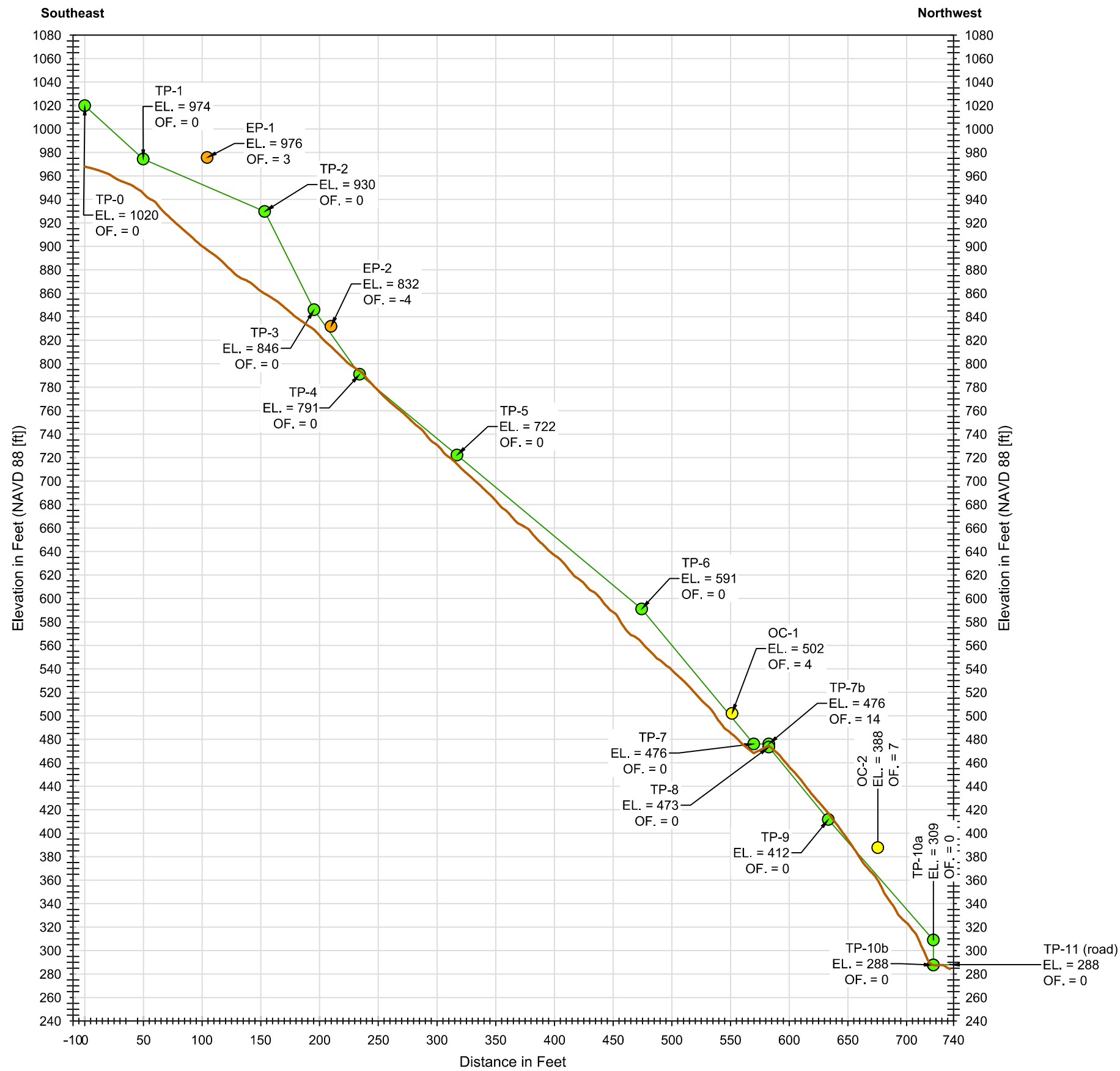
- Lidar Ground Surface
- Ground Surface from Field Data
- GP (Generic Point)
- EP (Erosion Point)
- TP (Transect Point)
- EL Elevation
- OF. Offset from Alignment

Notes

1. Surface conditions are generalized from materials observed in soil borings. Variations may exist between profile and actual conditions.
2. Surface contours are approximate and based on 2013 Lidar information and 2020 field and GPS measurements. GPS and Lidar data may be affected by dense vegetation and satellite signal strength. When appropriate, the ground surface profiles were adjusted to better match the observed field conditions. Profile shown here is preliminary and approximate, and should not be used for design.



Geotechnical Engineering Services for Waipi'o Valley Road, County of Hawai'i	
WR-3 Profile Waipi'o Rockfall Traverse	
3140-023-002	01/21
 <small>A Division of Healy & Aldrich</small>	Figure 6

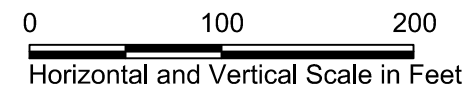


Legend

- Lidar Ground Surface
- Ground Surface from Field Data
- GP (Generic Point)
- EP (Erosion Point)
- TP (Transect Point)
- EL Elevation
- OF. Offset from Alignment

Notes

1. Surface conditions are generalized from materials observed in soil borings. Variations may exist between profile and actual conditions.
2. Surface contours are approximate and based on 2013 Lidar information and 2020 field and GPS measurements. GPS and Lidar data may be affected by dense vegetation and satellite signal strength. When appropriate, the ground surface profiles were adjusted to better match the observed field conditions. Profile shown here is preliminary and approximate, and should not be used for design.



Geotechnical Engineering Services for Waipi'o Valley Road,
County of Hawai'i

WR-4 Profile
Waipi'o Rockfall Traverse

3140-023-002

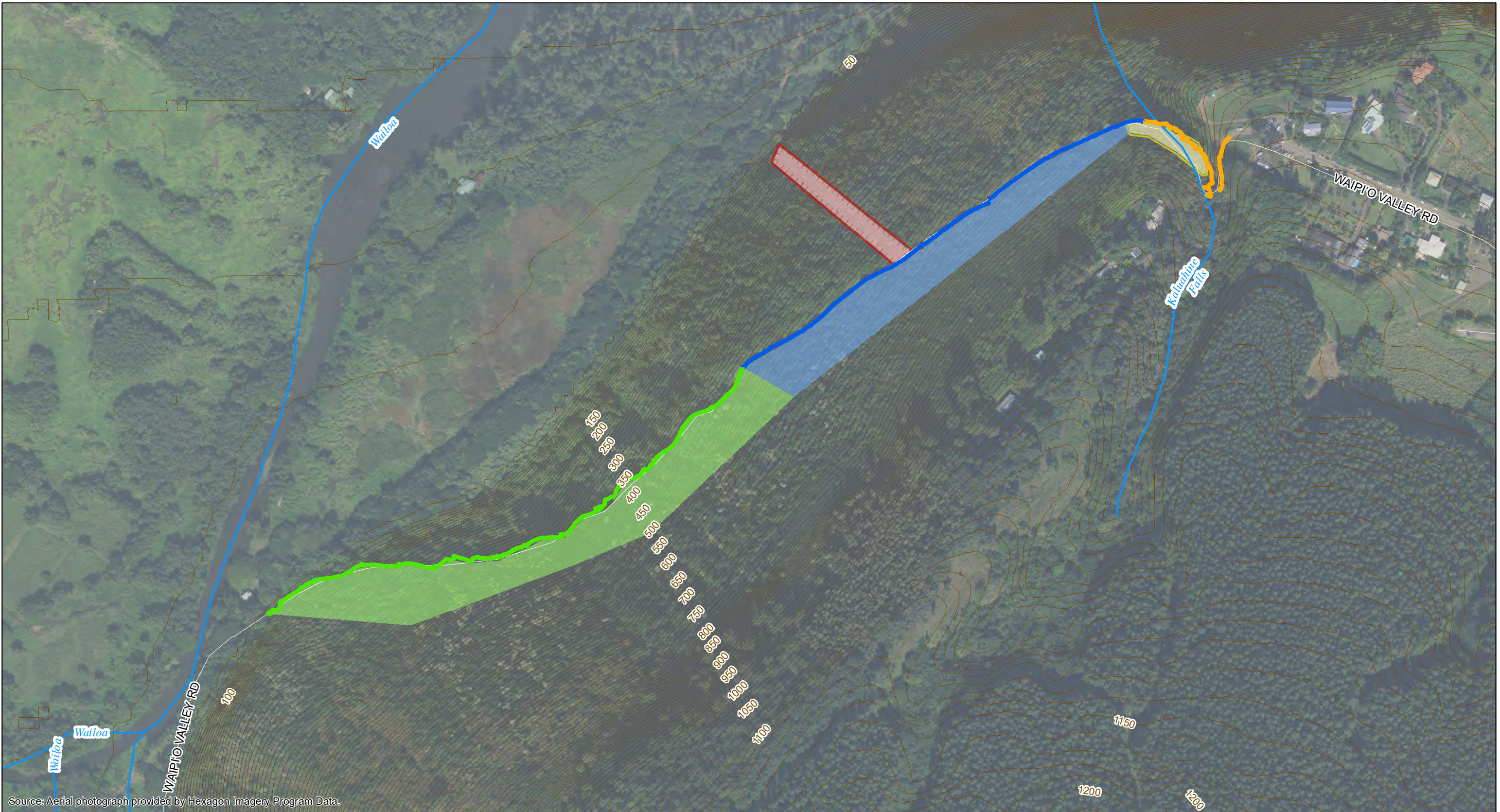
01/21



Figure

7

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Source: Aerial photograph provided by Hexagon Imagery Program Data.

Legend

Hazard Areas

- Upper
- Central
- Lower

Rockfall Areas

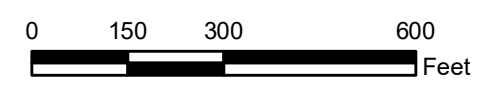
- Central (169,000 square feet)
- Lower (253,000 square feet)

Landslide Areas

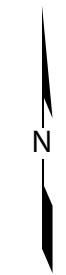
- March 2019 Slide (31,000 square feet)
- Upslope Overhangs (14,000 square feet) and Approximate Area of 2018 and 2019 Overhead Failures

Elevation Contour (U.S. Geological Survey, 2013)

Horizontal Datum: NAD 1983 StatePlane
Hawaii 1 FIPS 5101 Feet
Vertical Datum: NAVD88 (ft)



Note: Feature locations are approximate.



Geotechnical Engineering Services for Waipio Valley Road,
County of Hawaii'i

Geohazards Sections and Areas

3140-023-002

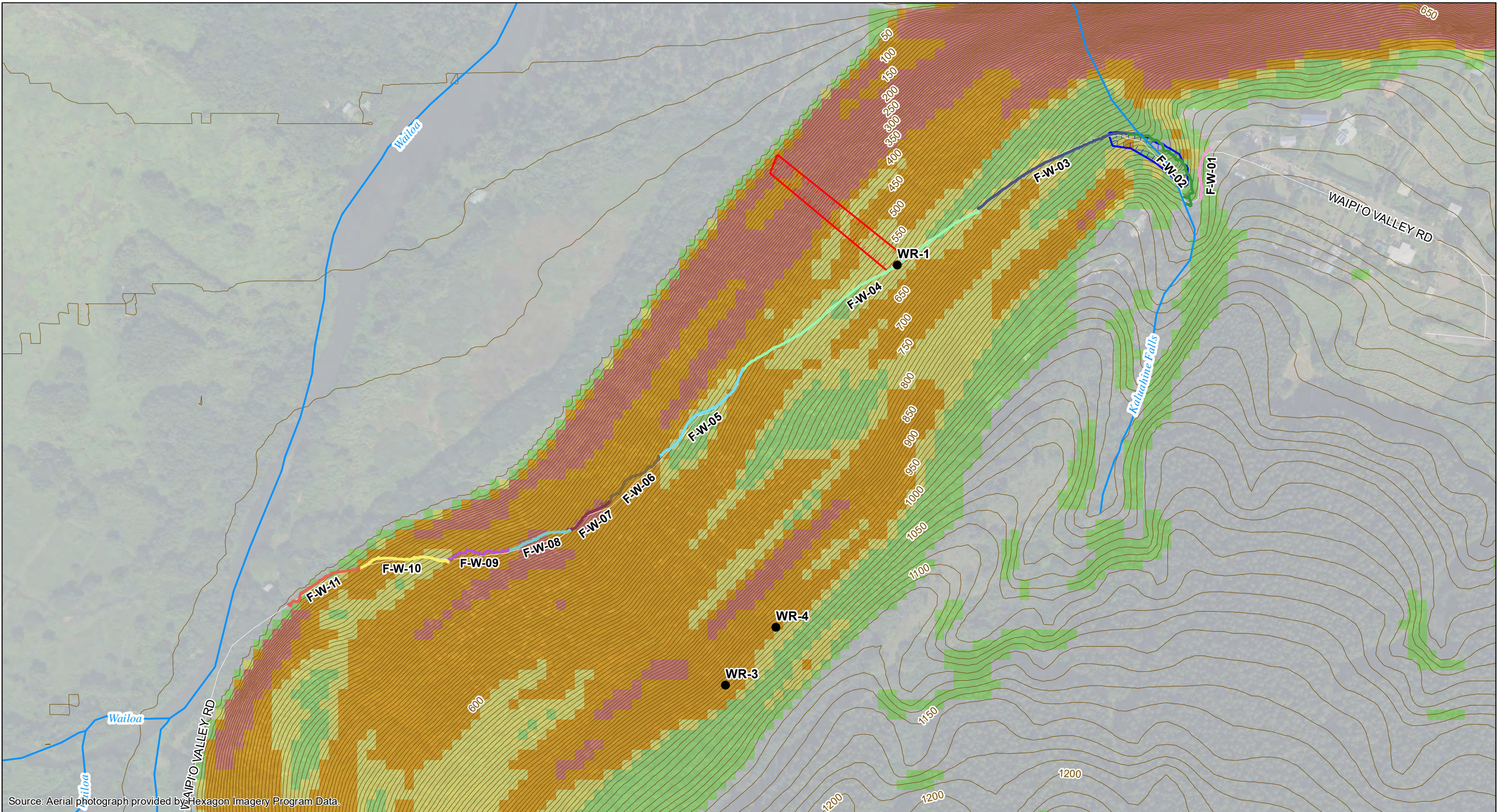
01/21



Figure

8

Document Path: F:\Notebooks\3140023002_Hawaii-Road_Slope_Evaluations\GIS\IMG\IS\3140023002_AL_WaipioSP(Slope).mxd Date: 1/13/2021 User Name: ericindquist



Source: Aerial photograph provided by Hexagon Imagery Program Data.

Legend

- WR-1 (Start of Rappel Point)
- Landslide occurred sometime between March and June 2019
- Overhang Area/Approximate Area of 2018 and 2019 Overhead Failures
- Elevation Contour (U.S. Geological Survey, 2013)

Rockfall Hazard Rating System Survey

<ul style="list-style-type: none"> F-W-01 F-W-02 F-W-03 F-W-04 F-W-05 F-W-06 	<ul style="list-style-type: none"> F-W-07 F-W-08 F-W-09 F-W-10 F-W-11
--	---

Slope Analysis (Percentage Slope)

<ul style="list-style-type: none"> 0 - 33 33 - 66 66 - 75 75 - 100 > 100
--

Horizontal Datum: NAD 1983 StatePlane
Hawaii 1 FIPS 5101 Feet
Vertical Datum: NAVD88 (ft)

0 150 300 600 Feet

Note: Feature locations are approximate.

Geotechnical Engineering Services for Waipi'o Valley Road,
County of Hawai'i

Digital Elevation Model (DEM) Slope Analysis

3140-023-002 01/21

Figure **9**

HARTCROWSER
A division of Haley & Aldrich

APPENDIX A

Field Data

Appendix A-1

Photograph Log

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 1. Transect F-W-01, Upper Section.



Photo 2. Transect F-W-02, Upper Section.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 3. Transect F-W-02, Upper Section. Note the residual overhang upslope of road.



Photo 4. Transects F-W-03 and -04, Central Section. Note the pedestrians on the road.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 5. Transect F-W-03, Central Section Area. Note road wear and some potential rock strikes.



Photo 6. Transect F-W-04, Central Section. Note the rockfall on upslope side of road.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 7. Transect F-W-04, Central Section. Jointed Basalt Outcrop with Residual.



Photo 8. Transect F-W-04, Central Section. Guardrail strike from boulder or vehicle.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 9. Transect F-W-04, Central Section. March 2018 slide area.



Photo 10. Transect F-W-05, Lower Section. Road narrows and reduced line-of-sight.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 11. Transect F-W-05, Lower Section. Looking uphill, note steep upslope basalt outcrop.



Photo 12. Transect F-W-05, Lower Section. Note rock retaining wall makai side of road.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 13. Transect F-W-05, Lower Section. Note guardrail dents from rockfall.



Photo 14. Transect F-W-05, Lower Section. Note previous rockfall makai side of road.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 15. Transect F-W-06, Lower Section. Steep Jointed Basalt outcrop with some residual.



Photo 16. Transect F-W-06, Lower Section. Note the steep upslope and road deformation.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 17. Transect F-W-07, Lower Section. Jointed Basalt outcrop with infilling.



Photo 18. Transect F-W-07, Lower Section. Note small deformed retaining wall makai side of road.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 19. Transect F-W-08, Lower Section. Road narrows, Jointed Basalt with clinker zones observed upslope of road.



Photo 20. Transect F-W-09, Lower Section. Jointed Basalt with clinker zones and infilling.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 21. Transect F-W-10, Lower Section. Line-of-sight issues continue downhill.



Photo 22. Transect F-W-10, Lower Section. Surface water flow path mauka side of road.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 23. Transect F-W-10, Lower Section. Rockfall makai side of road.



Photo 24. Transect F-W-11, Lower Section. Jointed Basalt with infilling.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 25. Transect F-W-11, Lower Section.



Photo 26. Transect F-W-04, Central Section. Rappel work at slide area.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 27. Transect F-W-04, Central Section. Loose soil and rock debris over much of slide area.



Photo 28. Transect F-W-04, Central Section. Base on slide area.

Appendix A-1 – Waipi‘o Valley Road Photograph Log



Photo 29. Transect F-W-04, Central Section. Loose and rock debris at base of slide, setback from road to beach.



Photo 30. Waipi‘o Valley Road slide area from beach road.

Appendix A-2

RHRS Data Sheet

Table A-2. Waipio Valley Road RHRS Field Data

Date	6/1/2020	6/1/2020	6/1/2020	6/1/2020
Transect No.	F-W-01-T/R	F-W-02-T/R	F-W-03-T	F-W-04-T/R
Roadside (L/R) - Mauka	L	L	L	L
GPS Waypoint (NAD83)	-375155 N, 2469404 E	-375061 N, 2469333 E	-374971 N, 2469102 E	-375384 N, 2468424 E
GPS Elevation (MSL) (ft)	937	826	850	670
Feature Beginning Location	TP#1	Stream Channel	TP#2	TP#5
Feature Ending Location	Stream Channel	TP#2	TP#5	TP#9
GPS Feature Length, feet	199	491	580	980
Measured Feature Length, feet	200	356	605	965
Feature Length, Average, feet	200	424	593	973
Feature Length, miles	0.04	0.08	0.11	0.18
Road Mile, Start	0.00	0.04	0.12	0.23
Road Mile, Finish	0.04	0.12	0.23	0.41
ADT (Waipio Lookout 2019)	311	311	311	311
Posted Speed Limit	10	10	10	10
Average Vehicle Risk, %	5	10	15	24
AVR Points	3	3	3	3
Slope Height, measured	29	41	31	26
X (distance between α and β)	19	17	29	16
Mauka Shoulder	0	0	0	0
Makai Shoulder	0	0	0	0
Height Instrument	6	6	6	6
alpha, deg°	70	65	65	66
beta, deg°	40	45	44	34
Slope Height, calculated	17	19	7	6
Slope Height, selected	29	41	31	26
Slope Height Points	9	9	9	9
Ditch Effectiveness	No catchment	No catchment	No catchment	No catchment
Ditch Effectiveness Points	81	81	81	81
Roadway Width	19	17	29	16
Roadway Width Points	81	81	27	81
Sight Distance, N	95(H)	93(V)	80(V)	93(V)
Sight Distance, S	55(H)	105(V)	140(V)	71(V)
Sight Distance, actual	55	93	80	71
Sight Distance, decision	150	150	150	150
% Decision Sight Distance	37	62	53	47
% DSD Points	81	9	27	27
Jointing	irregular	irregular	irregular	irregular
Geology, name	Basalt, Saprolite	Basalt, Saprolite	Basalt, Saprolite	Basalt, Jointed
Case 1, structural	discont., random (9)	discont., random (9)	discont., random (9)	discont., random (9)
Case 1, friction	clay infilling (81)	clay infilling (81)	clay infilling (81)	undulating (9)
Case 1, Points	81	81	81	9
Case 2, structural	occasional (9)	occasional (9)	occasional (9)	occasional (9)
Case 2, erosion rates	moderate (9)	moderate (9)	moderate (9)	moderate (9)
Case 2, Points	9	9	9	9
Rocks/Boulders				
min size	None	None	0.5	0.5
avg size	None	None	0.9	1.0
max size	None	1.0	1.5	1.3
Block Size, feet	None	1.0	1.5	1.3
Volume, cubic yards	1.0	1.0	0.3	1.0
Block Size or Quantity Points	3	3	9	9
Climate Points	27	27	27	27
Rockfall History	9	9	9	9
TOTAL POINTS	375	303	273	255
Notes	Location: From TP#1 to Stream Channel culvert. Debris flow slide volume measured at 1 cy. Seepage but minimal. <u>Feature geologic description</u> : BASALT with residual, moderately to severely fractured, extremely weathered (SAPROLITE), v.soft to soft.	Location: From Stream Channel culvert to TP#2. Major erosion feature (overhang) at rim or crest of slope. No seepage observed. <u>Feature geologic description</u> : BASALT with residual (boulders), moderately to severely fractured, extremely weathered (SAPROLITE), v.soft to soft.	Location: from TP#2 to TP#5. Slide feature on Makai side of road. Debris pile (~2cy) near TP#3. Largest rock (angular) measured 18"x12"x6". <u>Feature geologic description</u> : BASALT with some residual, moderately to severely fractured, extremely weathered (SAPROLITE), v. soft to soft.	Location: from TP#5 to TP#9. Large boulder on Makai side of road measuring 7'x4'x4', undercut ~1 ft on downslope side. <u>Feature geologic description</u> : Jointed BASALT with infilling over entire feature, slightly to closely fractured, moderately to highly weathered, soft to m.hard. Additional line of sight measurements at transect: 160 ft north, 95 ft south (vertical).

Notes:

TP = telephone pole

H = horizontal line of sight

V = vertical line of sight

Table A-2. Waipio Valley Road RHRS Field Data

Date	6/1/2020	6/2/2020	6/2/2020	6/2/2020
Transect No.	F-W-05-T	F-W-06-T	F-W-07-T	F-W-08-T
Roadside (L/R) - Mauka	L	L	L	L
GPS Waypoint (NAD83)	-375932 N, 2467709 E	-376132 N, 2467524 E	-376254 N, 2467372E	-376325 N, 2467240 E
GPS Elevation (MSL) (ft)	393	381	350	337
Feature Beginning Location	TP#9	TP#11	~70 ft S of TP#12	93 ft S of TP#13
Feature Ending Location	TP#11	~228 ft N of TP#11	93 ft S of TP#13	~115 ft N of TP#13
GPS Feature Length, feet	432	312	191	263
Measured Feature Length, feet	419	228	170	225
Feature Length, Average, feet	426	270	181	244
Feature Length, miles	0.08	0.05	0.03	0.05
Road Mile, Start	0.41	0.49	0.55	0.58
Road Mile, Finish	0.49	0.55	0.58	0.63
ADT (Waipio Lookout 2019)	311	311	311	311
Posted Speed Limit	10	10	10	10
Average Vehicle Risk, %	10	7	4	6
AVR Points	3	3	3	3
Slope Height, measured	28	28	26	26
X (distance between α and β)	20	15	15	11
Mauka Shoulder	0	0	0	0
Makai Shoulder	0	0	0	0
Height Instrument	6	6	6	6
alpha, deg°	65	75	78	75
beta, deg°	41	50	50	50
Slope Height, calculated	9	18	13	14
Slope Height, selected	28	28	26	26
Slope Height Points	9	9	9	9
Ditch Effectiveness	No catchment	No catchment	No catchment	No catchment
Ditch Effectiveness Points	81	81	81	81
Roadway Width	20	15	15	11
Roadway Width Points	81	81	81	81
Sight Distance, N	83(H)	60(V)	65(H)	70(H)
Sight Distance, S	70(H)	43(V)	40(H)	80(V)
Sight Distance, actual	70	43	40	70
Sight Distance, decision	150	150	150	150
% Decision Sight Distance	47	29	27	47
% DSD Points	27	81	81	27
Jointing	irregular	irregular	irregular	irregular
Geology, name	Basalt w/Residual	Basalt Outcrop, Jointed	Basalt Outcrop, Jointed	Basalt, Jointed, w/Clinker
Case 1, structural	discont., random (9)	discont., random (9)	discont., random (9)	discont., random (9)
Case 1, friction	clay infilling (81)	undulating (9)	undulating (9)	undulating (9)
Case 1, Points	81	9	9	9
Case 2, structural	occasional (9)	occasional (9)	occasional (9)	occasional (9)
Case 2, erosion rates	moderate (9)	small (3)	small (3)	small (3), moderate (9)
Case 2, Points	9	9	9	9
Rocks/Boulders				
min size	0.7	0.4	None	1.3
avg size	0.85	0.7	None	1.3
max size	1.0	1.1	None	1.3
Block Size, feet	1.0	1.1	None	1.3
Volume, cubic yards	1.0	0	None	0.5
Block Size or Quantity Points	3	3	0	9
Climate Points	27	27	27	27
Rockfall History	9	9	9	9
TOTAL POINTS	321	303	300	255
Notes	Location: from TP#9 to TP#11. Transect located at sharp turn potentially planned for widening. Transmission lines located between TP#9 and TP#10. <u>Feature geologic description</u> : BASALT outcrop (steep) with residual, slightly to closely fractured, highly weathered, soft to m.hard. Vegetation includes grass, moss, and shrubs.	Location: from TP#11 to ~228 ft north of TP#11. At transect, localized overhang at crest. 19 ft max road width, 9 ft narrowest road width. SW flow path observed ~100 ft north of TP#11. Minimal rockfall observed. <u>Feature geologic description</u> : Jointed BASALT with infilling, slightly to closely fractured, highly weathered, soft to m.hard. Line of sight measurement (vertical) made at TP#11. Additional line of sight measurement (horizontal) 50 ft south and 50 ft north.	Location: from ~70 ft south of TP#12 to 93 ft south of TP#13. Small retaining wall and SW flow feature at northend boundary of feature. <u>Feature geologic description</u> : Jointed BASALT outcrop with infilling, slightly to closely fractured, slightly to highly weathered, soft to m.hard. No seepage observed. Vegetation includes moss, ferns, small brush.	Location: from 93 ft south of TP#13 to ~115 ft north of TP#13. SW flow path observed near north boundary of feature. Seasonal seepage in clinker zone near Stop sign. <u>Feature geologic description</u> : Jointed BASALT with clinker zones and infilling in lower portion of feature, slightly to closely fractured, moderate to highly weathered, soft to m.hard. Vegetation includes moss, small brush, and tree roots. Rockfall at SW flow feature only.

Notes:

TP = telephone pole

H = horizontal line of sight

V = vertical line of sight

Table A-2. Waipio Valley Road RHRS Field Data

Date	6/2/2020	6/2/2020	6/2/2020
Transect No.	F-W-09-T	F-W-10-T	F-W-11-T
Roadside (L/R) - Mauka	L	L	L
GPS Waypoint (NAD83)	-376383 N, 2466971 E	-376420 N, 2466849 E	-376469 N, 2466520 E
GPS Elevation (MSL) (ft)	259	225	142
Feature Beginning Location	~115 ft N of TP#13	75 ft N TP#14	95 ft S TP#17
Feature Ending Location	75 ft N TP#14	95 ft S TP#17	TP#18
GPS Feature Length, feet	247	353	311
Measured Feature Length, feet	215	315	275
Feature Length, Average, feet	231	334	293
Feature Length, miles	0.04	0.06	0.06
Road Mile, Start	0.63	0.67	0.73
Road Mile, Finish	0.67	0.73	0.79
ADT (Waipio Lookout 2019)	311	311	311
Posted Speed Limit	10	10	10
Average Vehicle Risk, %	6	8	7
AVR Points	3	3	3
Slope Height, measured	26	18	26
X (distance between α and β)	17	14	18
Mauka Shoulder	0	0	0
Makai Shoulder	0	0	0
Height Instrument	6	6	6
alpha, deg°	75	65	70
beta, deg°	40	40	40
Slope Height, calculated	17	71	17
Slope Height, selected	26	18	26
Slope Height Points	9	3	9
Ditch Effectiveness	No catchment	No catchment	No catchment
Ditch Effectiveness Points	81	81	81
Roadway Width	17	14	18
Roadway Width Points	81	81	81
Sight Distance, N	65(H)	83(H/V)	82(H)
Sight Distance, S	55(H)	68(H/V)	65(H)
Sight Distance, actual	55	68	65
Sight Distance, decision	150	150	150
% Decision Sight Distance	37	45	43
% DSD Points	81	27	27
Jointing	irregular	irregular	irregular
Geology, name	Basalt Outcrop, Jointed	Basalt, Jointed	Basalt Outcrop, Jointed
Case 1, structural	discont., random (9)	discont., random (9)	discont., random (9)
Case 1, friction	undulating (9)	undulating (9)	undulating (9)
Case 1, Points	9	9	9
Case 2, structural	occasional (9)	occasional (9)	occasional (9)
Case 2, erosion rates	small (3)	small (3)	small (3)
Case 2, Points	9	9	9
Rocks/Boulders			
min size	0.3	0.5	0.4
avg size	0.3	1.2	0.7
max size	0.3	2.0	1.0
Block Size, feet	0.3	2.0	1.0
Volume, cubic yards	0.25	0.33	0.25
Block Size or Quantity Points	3	9	3
Climate Points	27	27	27
Rockfall History	9	9	9
TOTAL POINTS	303	249	249
Notes	Location: from ~115 ft N of TP#13 to 75 ft north of TP#14. Small SW flow path (#1) on the upper portion of feature ~60 ft south of TP#14. Second SW flow feature observed at north end of feature. Overhang at crest of slope and "void" with previous seepage observed at transect location. Old concrete guardrails seen below (Makai side) road near #1 SW flow path. <u>Feature geologic description</u> : Jointed BASALT outcrop with infilling, slightly to closely fractured, moderate to highly weathered, soft to m.hard. Vegetation includes moss, grass, and small brush.	Location: 75 ft north of TP#14 to 95 ft south of TP#17. Transect located ~40 ft south of TP#15. SW flow path (#1) ~50 ft north of TP#15 and includes fallen tree. SW flow path (#2) ~95 ft south of TP#17. 19 ft maximum road width and 12 ft narrowest road width. Second line of sight (H/V) 85 ft north and 80 ft south. <u>Feature geologic description</u> : Jointed BASALT with infilling, slightly to closely fractured, moderately weathered, soft to m.hard. Vegetation includes moss, ferns, shrubs and tree roots.	Location: from 95 ft south of TP#17 to TP#18. Significant SW flow path at TP#18. Transect ~20 ft south of TP#17. Rock outcrop and source area ~80 ft south TP#18. Small collapsible void north of transect location. <u>Feature geologic description</u> : Jointed BASALT with infilling, slightly to closely fractured, moderate to highly weathered, soft to m.hard.

Notes:

TP = telephone pole

H = horizontal line of sight

V = vertical line of sight

Appendix A-3

Rappel Traverse Data

Date: 8/27/2020

Name: Waipio Rappel 1, WR-1

Description: Primary slide, downslope traverse

GPS ID	Northing ¹	Easting ¹	Elevation ²	Cell Information						Horizontal Distance ⁷ (ft)	Total Horizontal Distance (ft)	Vertical Distance ⁸ (ft)	Total Vertical Distance (ft)	Cell Material			Cell Vegetation						
				Cell ID ⁴	Top of Cell ⁵ (ft)	Bottom of Cell ⁵ (ft)	Cell Length (ft)	Cell Gradient ⁶ (Degrees)	Cell Gradient (Radians)					Cell Type	Cell Material	Cell Description	Vegetation Type	Vegetation Description	Veg. Height	Veg. Spacing	Veg. Diameter		
TP-0	466030.97	1610530.597	592.148	TP-0	20	0				0.0	-	-	-	-	n/a		width of road 20'						
TP-1	466045.018	1610519.862	590.072	TP-1	0	0	20	0.0	0.0	20.0	20.0	0.0	224.4	(road)	asphalt concrete	(Waipio Valley Road) top of WR1, 70' wide, edge of road above March 2019 slide							
TP-2	466057.801	1610496.576	563.98	TP-2	0	45	45	41.6	0.7	33.7	53.7	29.9	194.6	slope	scarp/failure source		Grass/Ferns		<1'-3'+	<2'-8'	<0.5"		
TP-3	466126.497	1610392.205	445.732	TP-3	45	220	175	43.0	0.8	128.0	181.6	119.3	75.2	slope	saprolite with residual soil and cobbles	15' outcrop below TP3							
TP-4	466132.082	1610386.203	434.694	TP-4	220	235	15	57.6	1.0	8.0	189.7	12.7	62.6	slope	bedrock/saprolite	exposed bedrock section	Shrubs/Bushes	small plants and vines	4'+	dense	<1"		
TP-5	466144.131	1610373.869	424.404	TP-5	235	255	20	32.8	0.6	16.8	206.5	10.8	51.7	slope	bedrock/saprolite with cobbles		Shrubs/Bushes	dense vines	6'-7'+		<1"		
TP-6	466179.869	1610332.874	377.562	TP-6	255	330	75	43.6	0.8	54.3	260.8	51.7	0	slope	bedrock/saprolite with veg	bedrock bench at bottom	Shrubs/Bushes	small plants and vines	6'-7'+	dense	<1"		

Notes:

1. Coordinates and elevations reported using North American Datum 1983 (NAD83) State Plane Hawaii 1 FIPS 5101 (Feet).
2. Elevation values in MSL.
3. Max PDOP = Maximum Position Dilution of Precision. Greater position accuracy for lower PDOP value. Greater error in higher PDOP values.
4. Cell ID = Cell Identification represents a zone of similar slope gradient, vegetation material, and/or the presence of outcrops or source rock.
5. Top and Bottom of Cell were physically measured in the field from the start of rappel/upgradient location.
6. Cell Gradients were physically measured in the field and recorded in degrees of slope.
7. Horizontal Distance represents distance of cell along the X-Axis plane (horizontal axis)
8. Vertical Distance represents distance of a cell along the Y-Axis Plane (vertical axis)

GPS ID = GPS Identification

TP-1 = Transect Point Number 1

OC-1 = Outcrop Point Number 1

Date: 8/31/2020 - 9/1/2020
Name: Waipio Rappel 3, WR-3
Description: Traverse upslope of Waipio Valley Road

GPS ID	Northing ¹	Easting ¹	Elevation ²	Cell Information						Horizontal Distance ⁷ (ft)	Total Horizontal Distance (ft)	Vertical Distance ⁸ (ft)	Total Vertical Distance (ft)	Cell Material			Cell Vegetation				
				Cell ID ⁴	Top of Cell ⁵ (ft)	Bottom of Cell ⁵ (ft)	Cell Length (ft)	Cell Gradient ⁶ (Degrees)	Cell Gradient (Radians)					Cell Type	Cell Material	Cell Description	Vegetation Type	Vegetation Description	Veg. Height	Veg. Spacing	Veg. Diameter
TP-1	464633.958	1609943.774	996.501	TP-1	0	0	0	0.0	0.0	-	-	-	-	Other	n/a	WR3, access trail, top of rappel	Trees	sb (strawberry) guava	<15'	<3'-5'+	<2"-3", 5"-9"+
TP-1b	464687.295	1609842.292	914.874	TP-1b	0	142	142	39.0	0.7	110.4	110.4	89.4	704.6	Slope	soil slope with veg	transition to gully bench	Trees	sb guava	<15'	<3'-5'+	<2"-3", 5"-9"+
TP-1c	464693.708	1609835.428	896.829	TP-1c	142	156	14	56.0	1.0	7.8	118.2	11.6	615.3	Slope	soil slope with veg	bottom of transition to gully bench	Trees	sb guava	<15'	<3'-5'+	<2"-3", 5"-9"+
TP-2	464729.205	1609789.874	869.451	TP-2	156	217	61	36.0	0.6	49.4	167.5	35.9	603.7	Slope	soil slope with veg		Trees	sb guava, eucalyptus, ti leaf	<15'+	<3'-5'+	<1"-3"+, 1'
TP-3	464743.645	1609772.153	815.218	TP-3	217	275	58	39.6	0.7	44.7	212.2	37.0	567.8	Slope	soil slope with veg		Trees	sb guava, eucalyptus, ti leaf	<15'+	<3'-5'+	<1"-3"+, 1'
TP-4	464849.99	1609633.066	706.193	TP-4	275	420	145	39.0	0.7	112.7	324.9	91.3	530.8	Slope	soil slope with veg	5' east of gully	Trees	eucalyptus, less sb guava, more ti leaf	<15'+	<3'-5'+	<1"-3"+, 1'
EP-1	464822.095	1609653.989	707.749	TP-4b	420	483	63	29.6	0.5	54.8	379.7	31.1	439.6	Slope	soil slope with veg	incised gully: highly weathered basalt and colluvium	Trees	eucalyptus, less sb guava, more ti leaf	<15'+	<3'-5'+	<1"-3"+, 1'
TP-5 [OC-1/2/3]	464907.802	1609575.603	595.954	TP-5	483	613	130	47	0.8	88.7	468.3	95.1	408.5	Slope	soil slope with veg	incised gully	Mixed	sb guava, xmas (christmas) berry, ferns	15'+	<10'-20'+	<2"-3", 5"-9"+
TP-6	465004.754	1609498.904	484.227	TP-6	613	781	168	46	0.8	116.7	585.0	120.8	313.4	Slope	soil slope with veg and outcrops	various rockfall deposits: cobbles to boulders on gully benches, 1.5'x1'x0.5'	Mixed	sb guava, xmas berry, ferns	15'+	<10'-20'+	<2"-3", 5"-9"+
TP-7	465041.207	1609465.607	460.09	TP-7	781	838	57	40	0.7	43.7	628.7	36.6	192.5	Slope	soil slope with veg and outcrops	outcrops in/along gully; multiple fallen trees in gully	Mixed	sb guava, xmas berry, ferns	15'+	<10'-20'+	<2"-3", 5"-9"+
TP-7b	465048.852	1609465.354	458.738	TP-7b	838	843	5	0	0.0	5.0	633.7	0.0	155.9	Bench	soil slope with veg and outcrops	bench between TP7 and TP8	Trees	sb guava, iron wood trees with needle bed on ground	15'-30'+	5'-10'+	<2"-14"
TP-8	465061.283	1609461.55	397.028	TP-8	843	888	45	50	0.9	28.9	662.6	34.5	155.9	Slope	outcrops covered by soil/veg debris	above vertical section	Trees	sb guava, iron wood trees with needle bed on ground	15'-30'+	5'-10'+	<2"-14"
TP-9	465090.065	1609452.018	346.891	TP-9	888	941	53	63	1.1	24.1	686.7	47.2	121.4	Slope	outcrops covered by soil/veg debris	weathered basalt outcrop with veg/debris	Trees	xmas berry trees, ferns	<5', 10'-15'+	10'+	0.5'-1'+
TP-9b	465103.635	1609436.491	368.229	TP-9b	941	951	10	0	0.0	10.0	696.7	0.0	74.2	Bench	outcrops covered by soil/veg debris	weathered basalt outcrop with veg/debris	Trees	xmas berry trees, ferns	<5', 10'-15'+	10'+	0.5'-1'+
TP-10	465119.648	1609438.197	298.047	TP-10	951	990	39	52	0.9	24.0	720.7	30.7	74.2	Slope	outcrops covered by soil/veg debris	weathered basalt outcrop with veg/debris	Trees	xmas berry trees, ferns	<5', 10'-15'+	10'+	0.5'-1'+
TP-11	465134.744	1609433.153	274.25	TP-11	990	1021	31	60	1.0	15.5	736.2	26.8	43.5	Slope	outcrops covered by soil/veg debris	weathered basalt outcrop with veg/debris	Trees	xmas berry trees, sb guava, ferns	<5', 10'-15'+	10'+	0.5'-1'+
TP-12	465136.381	1609426.883	261.166	TP-12	1021	1038	17	78	1.4	3.5	739.7	16.6	16.6	Outcrop	roadcut	TP12 on Waipio Valley Road					
TP-13	465147.169	1609423.09	270.862	TP-13	1038	1049	11	0	0.0	11.0	750.7	0.0	16.6	(road)	asphalt concrete						

Date: 8/31/2020 - 9/1/2020

Name: Waipio Rappel 3, WR-3

Description: Traverse upslope of Waipio Valley Road

GPS ID	Northing	Easting	Elevation	Outcrop	Taped Distance	Outcrop Width	Outcrop Height	Rock Type	Rock Description	Joint Strike	Joint Dip	Spacing	Persistence	Aperture	Joint Roughness	i, 1st Order Roughness	Weathering	Infilling	Source?	Notes	Schmidt Hammer Value ⁹
OC-1	464889.659	1609604.533	634.926	OC-1	560	-	-	basalt	weathered basalt outcrop/boulders	variable	variable	<1'-1.5'	<1'-1.5'	>1/8"	Rough Undulating	-	moderately to highly weathered	Organic, soil	Yes	Subangular blocks/boulders.	11*
OC-2	464885.384	1609580.886	623.021	OC-2	588	-	-	basalt	weathered basalt outcrop/boulders	variable	variable	<2'-4'	<2'-4'	<1'	-	-	-	-	Yes	Subrounded blocks/boulders. Climbers right of incised gully.	-
OC-3	464903.644	1609566.081	577.551	OC-3	627	-	-	basalt	weathered basalt	variable	variable	<1'-1.5', 2'	<1'-1.5', 2'	-	-	-	-	-	Yes	Subangular blocks/boulders. Boulder: (2.5' x 1' x 1.5')	-

GPS ID	Northing	Easting	Elevation	Erosion Point	Taped Distance	Horizontal Length	Vertical Length	Slope Gradient	Slide Gradient	Slide Depth	Soil Depth	Soil Type	Rock Type	Rock Weathering	Rock Infilling	Vegetation	Track to Flow Feature?	Estimated Cause	Estimated Cause Comments	Notes
EP-1	464822.095	1609653.989	707.749	EP-1	tape 420'-483', head to toe	7	30	0	29.6000004	9	0	Other	highly weathered basalt and colluvium	-	-	-	-	natural	surface flow, ephemeral streams	head of incised gully
EP-2	464852.66	1609622.112	701.215	EP-2	tape 498' at toe	5	13	0	55	1.5	0		highly weathered basalt and colluvium	-	-	moss	-	natural	surface flow, ephemeral streams	incised gully

Notes:

- Coordinates and elevations reported using North American Datum 1983 (NAD83) State Plane Hawaii 1 FIPS 5101 (Feet).
- Elevation values in MSL.
- Max PDOP = Maximum Position Dilution of Precision. Greater position accuracy for lower PDOP value. Greater error in higher PDOP values.
- Cell ID = Cell Identification represents a zone of similar slope gradient, vegetation material, and/or the presence of outcrops or source rock.
- Top and Bottom of Cell were physically measured in the field from the start of rappel/upgradient location.
- Cell Gradients were physically measured in the field and recorded in degrees of slope.
- Horizontal Distance represents distance of cell along the X-Axis plane (horizontal axis)
- Vertical Distance represents distance of a cell along the Y-Axis Plane (vertical axis)
- Corrected Schmidt Hammer readings provided. Values with asterisk are reference values based on an average. See Schmidt Hammer Readings sheet.
- Lidar data in North American Datum 1983 (NAD83) State Plane Hawaii 1 FIPS 5101 (Feet).

GPS ID = GPS Identification

TP-1 = Transect Point Number 1

OC-1 = Outcrop Point Number 1

Date: 9/2/2020 - 9/3/2020

Name: Waipio Rappel 4, WR-4

Description: Traverse upslope of Waipio Valley Road

GPS ID	Northing ¹	Easting ¹	Elevation ²	Cell Information						Horizontal Distance ⁷ (ft)	Total Horizontal Distance (ft)	Vertical Distance ⁸ (ft)	Total Vertical Distance (ft)	Cell Material			Cell Vegetation					
				Cell ID ⁴	Top of Cell ⁵ (ft)	Bottom of Cell ⁵ (ft)	Cell Length (ft)	Cell Gradient ⁶ (Degrees)	Cell Gradient (Radians)					Cell Type	Cell Material	Cell Description	Vegetation Type	Vegetation Description	Veg. Height	Veg. Spacing	Veg. Diameter	
TP-0	464828.98	1610111.695	1019.89	TP-0	0	0		0.0	0.0	0.0	0.0	0.0	711.6	Other	n/a	start of rappel						
TP-1	464817.555	1610063.194	974.399	TP-1	0	58	58	28.4	0.5	51.0	51.0	27.6	711.6	Slope	soil slope with trees and veg debris		Trees	sb (strawberry) guava, eucalyptus	<25'+	<5'-20'+	<2"-4"+, 12"+	
TP-2 [EP1]	464885.633	1609985.319	929.736	TP-2	58	187	129	38.0	0.7	101.7	152.7	79.4	684.0	Slope	soil slope with soil and veg/debris	incised gully: stepped outcrops/benches in gully		sb guava, african tulip, ti leaf, ferns	<20'+	<3'-5'+	<2"-4"+	
TP-3	464923.332	1609966.763	846.026	TP-3	187	255	68	40.0	0.7	52.1	204.8	43.7	604.6	Slope	soil slope with veg/debris	incised gully	Trees	sb guava, african tulip, ti leaf, ferns	<20'+	<3'-5'+	<2"-4"+	
TP-4 [EP-2]	464952.822	1609941.417	790.949	TP-4	255	320	65	45.0	0.8	46.0	250.7	46.0	560.9	Slope	soil slope with veg/debris	incised gully	Trees	xmas (christmas) berry, ti leaf, sb guava, ferns	<5'-15'+	<2'-5'+	<2"-4"+, 12"+	
TP-5	465005.381	1609877.201	722.27	TP-5	320	427	107	41.0	0.7	80.8	331.5	70.2	514.9	Slope	soil slope with veg		Trees	xmas berry, ti leaf, sb guava, ferns	<5'-15'+	<2'-5'+	<2"-4"+, 12"+	
TP-6	465109.971	1609759.864	591.063	TP-6	427	639	212	48.0	0.8	141.9	473.3	157.5	444.7	Slope	soil slope with veg		Trees	xmas berry, sb guava, hau, ti leaf, african tulip	<10'-20'+	dense, <20'	<6"-12"+	
TP-7	465170.102	1609685.603	629.958	TP-7	639	707	68	43.0	0.8	49.7	523.1	46.4	287.2	Slope	soil slope with veg	incised gully	Trees	xmas berry, sb guava, hau, ti leaf, african tulip	<10'-20'+	dense, <20'	<6"-12"+	
TP-7b	465168.754	1609710.238	521.316	TP-7b	707	732	25	57.6	1.0	13.4	536.5	21.1	240.8	Outcrop	outcrop	stepped outcrop						
TP-8 [OC-1]	465174.234	1609697.663	473.422	TP-8	732	781	49	48.8	0.9	32.3	568.7	36.9	219.7	Slope	slope with outcrops covered with soil/veg	weathered basalt	Trees	dense xmas berry, sb guava, ti leaf, ferns, soapbush/koster's curse	<8'-20'+	<3'-8'+	<2"-4"+, 12"+	
TP-9	465210.621	1609662.321	411.639	TP-9	781	860	79	48.0	0.8	52.9	621.6	58.7	182.8	Slope	soil slope with veg	outcrop in gully	Trees	dense xmas berry, sb guava, ti leaf, ferns, soapbush/koster's curse	<8'-20'+	<3'-8'+	<2"-4"+, 12"+	
TP-10a [OC-2]	465259.003	1609586.977	306	TP-10	860	988	128	56.0	1.0	71.6	693.2	106.1	124.1	Slope	outcrops slope with veg	slightly to moderately weathered basalt	Trees	dense xmas berry, sb guava, ti leaf, ferns, soapbush/koster's curse	<8'-20'+	<3'-8'+	<2"-4"+, 12"+	
TP-10b [OC-3]	465259.003	1609586.977	287.717	TP-11	988	1006	18	88.0	1.5	0.6	693.8	18.0	18.0	Outcrop								
TP-11	465271.078	1609579.791	308.931	TP-12	1006	1016	10	0.0	0.0	15.0	708.8	0.0	0.0	(road)	asphalt concrete							

Notes:

- Coordinates and elevations reported using North American Datum 1983 (NAD83) State Plane Hawaii 1 FIPS 5101 (Feet).
- Elevation values in MSL.
- Max PDOP = Maximum Position Dilution of Precision. Greater position accuracy for lower PDOP value. Greater error in higher PDOP values.
- Cell ID = Cell Identification represents a zone of similar slope gradient, vegetation material, and/or the presence of outcrops or source rock.
- Top and Bottom of Cell were physically measured in the field from the start of rappel/upgradient location.
- Cell Gradients were physically measured in the field and recorded in degrees of slope.
- Horizontal Distance represents distance of cell along the X-Axis plane (horizontal axis)
- Vertical Distance represents distance of a cell along the Y-Axis Plane (vertical axis)
- Corrected Schmidt Hammer readings provided. Values with asterisk are reference values based on an average. See Schmidt Hammer Readings sheet.
- Lidar data in North American Datum 1983 (NAD83) State Plane Hawaii 1 FIPS 5101 (Feet).

GPS ID = GPS Identification
 TP-1 = Transect Point Number 1
 OC-1 = Outcrop Point Number 1

Date: 9/2/2020 - 9/3/2020

Name: Waipio Rappel 4, WR-4

Description: Traverse upslope of Waipio Valley Road

GPS ID	Northing	Easting	Elevation	Outcrop	Taped Distance	Outcrop Width	Outcrop Height	Rock Type	Rock Description	Joint Strike	Joint Dip	Spacing	Persistence	Aperture	Joint Roughness	i, 1st Order Roughness	Weathering	Infilling	Source?	Notes	Schmidt Hammer Value ⁹
OC-1	465161.594	1609702.616	502.024	OC-1	707'-752'	-	45'	basalt	weathered basalt			-	-	<1"-3"	Smooth Undulating	-	-	Soil and organics	Yes	boulder source, 7'x4'x4.5', subangular	32, 34
OC-2	465239.349	1609630.664	387.6	OC-2	900'	-	-	pahoehoe, massive basalt	-	5, 278, 350, 349, 82, 50, 89	76 W, 87 N, 61 E, 84 W, 83 NW, 64 SE, 81 NW	6"-12"	<3'	<1"	Rough Undulating	-	slightly weathered	None	Yes	boulders: (1'-2' x 1' x 1'), (2' x 1.3' x 0.1'-1', tapers) localized jointing in pahoehoe, otherwise massive basalt	30
-	-	-	-	OC-3	988'-1006'	-	18'	pahoehoe, massive basalt	-	269, 357	85 NW, 88 W	-	-	-	-	-	-	-	-	-	-

GPS ID	Northing	Easting	Elevation	Erosion Point	Taped Distance	Horizontal Length	Vertical Length	Slope Gradient	Slide Gradient	Slide Depth	Soil Depth	Soil Type	Rock Type	Rock Weathering	Rock Infilling	Vegetation	Track to Flow Feature?	Estimated Cause	Estimated Cause Comments	Notes
EP-1	464855.336	1610023.86	975.746	EP-1	113'	4	0	0	40	2	1	residual soil	highly weathered basalt	highly weathered to saprolite	soil and organics/ moss	moss on rocks	Yes	natural	surface flow, ephemeral streams	incised gully
EP-2	464931.616	1609954.288	831.932	EP-2	255'-277'	6.5	0	40	65	4	1.5	residual soil	highly weathered to saprolite basalt	highly weathered to saprolite	soil and organics	-	Yes	natural	surface flow, ephemeral streams	incised gully

Notes:

- Coordinates and elevations reported using North American Datum 1983 (NAD83) State Plane Hawaii 1 FIPS 5101 (Feet).
- Elevation values in MSL.
- Max PDOP = Maximum Position Dilution of Precision. Greater position accuracy for lower PDOP value. Greater error in higher PDOP values.
- Cell ID = Cell Identification represents a zone of similar slope gradient, vegetation material, and/or the presence of outcrops or source rock.
- Top and Bottom of Cell were physically measured in the field from the start of rappel/upgradient location.
- Cell Gradients were physically measured in the field and recorded in degrees of slope.
- Horizontal Distance represents distance of cell along the X-Axis plane (horizontal axis)
- Vertical Distance represents distance of a cell along the Y-Axis Plane (vertical axis)
- Corrected Schmidt Hammer readings provided. Values with asterisk are reference values based on an average. See Schmidt Hammer Readings sheet.
- Lidar data in North American Datum 1983 (NAD83) State Plane Hawaii 1 FIPS 5101 (Feet).

GPS ID = GPS Identification

TP-1 = Transect Point Number 1

OC-1 = Outcrop Point Number 1

Waipio Schmidt Hammer Readings

WR-4				WR-5			
Total Tape Location (feet)	Relative Rock Weathering	Hammer Reading Number	Rebound Value ¹ (%)	Total Tape Location (feet)	Relative Rock Weathering	Hammer Reading Number	Rebound Value ¹ (%)
105	Basalt, moderately to highly weathered	1	12	Not Applicable ¹	Basalt, moderately weathered	1	30
		2	9			2	36
		3	10			3	39
		4	10			4	34
		5	13			5	30
		6	11			6	42
		7	10			7	32
		8	10			8	30
		9	10			9	36
		10	10			10	39
		11	10			11	35
		12	10			12	32
			Avg_{WR4,105}			10	
269	Basalt, moderately to highly weathered	1	11				
		2	13				
		3	11				
		4	10				
		5	10				
		6	19				
		7	10				
		8	10				
		9	10				
		10	11				
		11	11				
		12	11				
	Avg₂₆₉	11					
577	Basalt, moderately weathered	1	25				
		2	42				
		3	38				
		4	40				
		5	46				
		6	36				
		7	18				
		8	34				
		9	30				
		10	38				
		11	31				
	Avg₅₇₇	35					
715 [OC-1]	Basalt, moderately weathered	1	32				
		2	34				
		3	35				
		4	34				
		5	31				
		6	35				
		7	35				
		8	34				
		9	38				
		10	28				
		11	35				
		12	39				
	Avg₇₁₅	34					

Notes

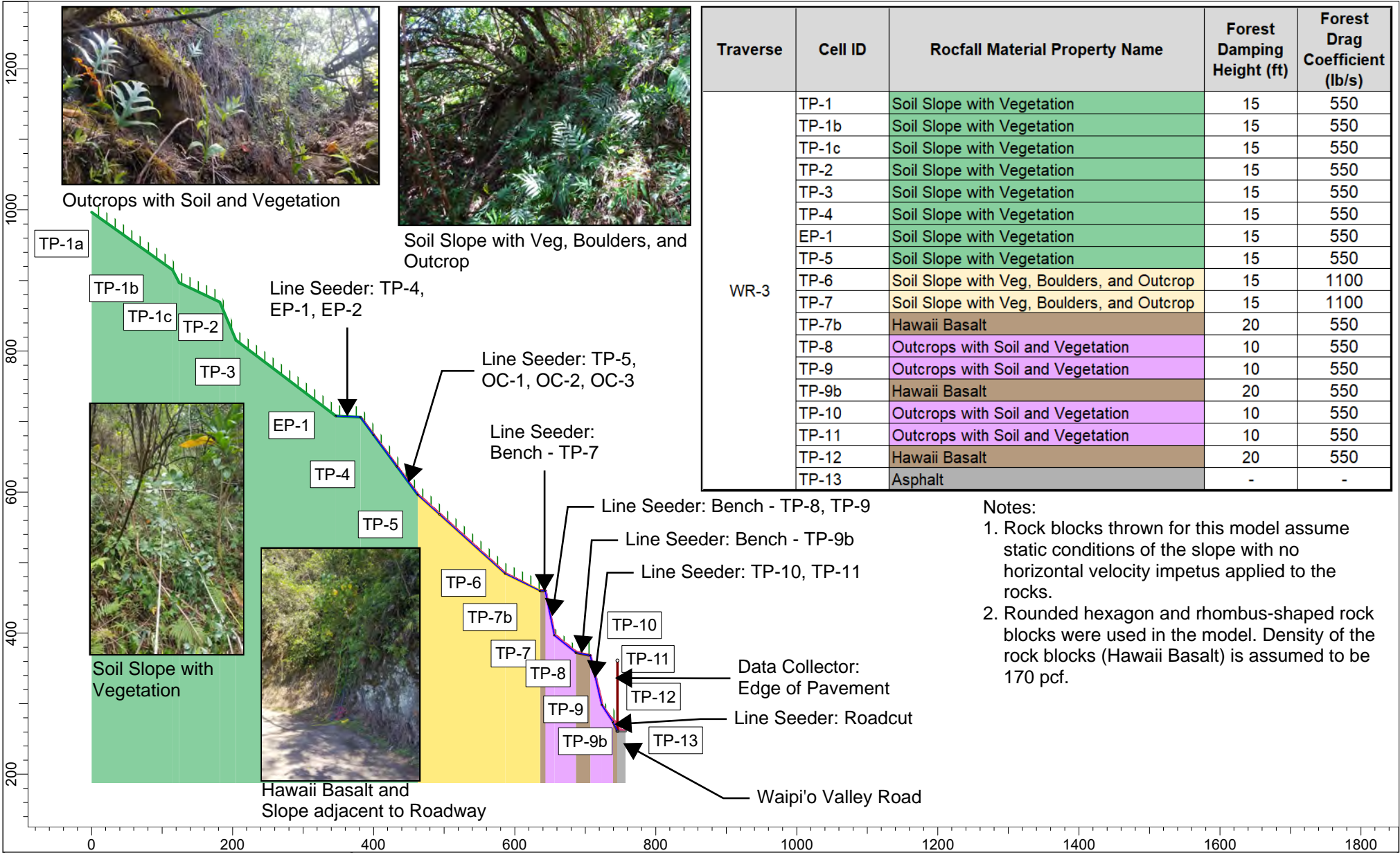
1. Lowest and highest values not included in average. Red values denote field reading that were less than 10 and not able to be read on hammer scale.
2. Limited outcrops observed, normal transect measurements were not necessary.

Waipio Schmidt Hammer Readings			
WR-4			
Total Tape Location (feet)	Relative Rock Weathering	Hammer Reading Number	Rebound Value ¹ (%)
753 [OC-1]	Basalt, moderately weathered	1	22
		2	32
		3	34
		4	28
		5	41
		6	31
		7	34
		8	44
		9	23
		10	35
		11	17
		12	27
		13	42
900 [OC-2]	Basalt, moderately to slightly weathered	1	22
		2	30
		3	30
		4	28
		5	18
		6	33
		7	30
		8	32
		9	32
		10	28
		11	31
		12	32
976	Basalt, moderately to slightly weathered	1	32
		2	38
		3	40
		4	35
		5	38
		6	30
		7	30
		8	36
		9	40
		10	44
		11	37
		12	36

Notes

1. Lowest and highest values not included in average. Red values denote field reading that were less than 10 and not able to be read on hammer scale.
2. Limited outcrops observed, normal transect measurements were not necessary.

APPENDIX B
Rockfall Evaluation Data

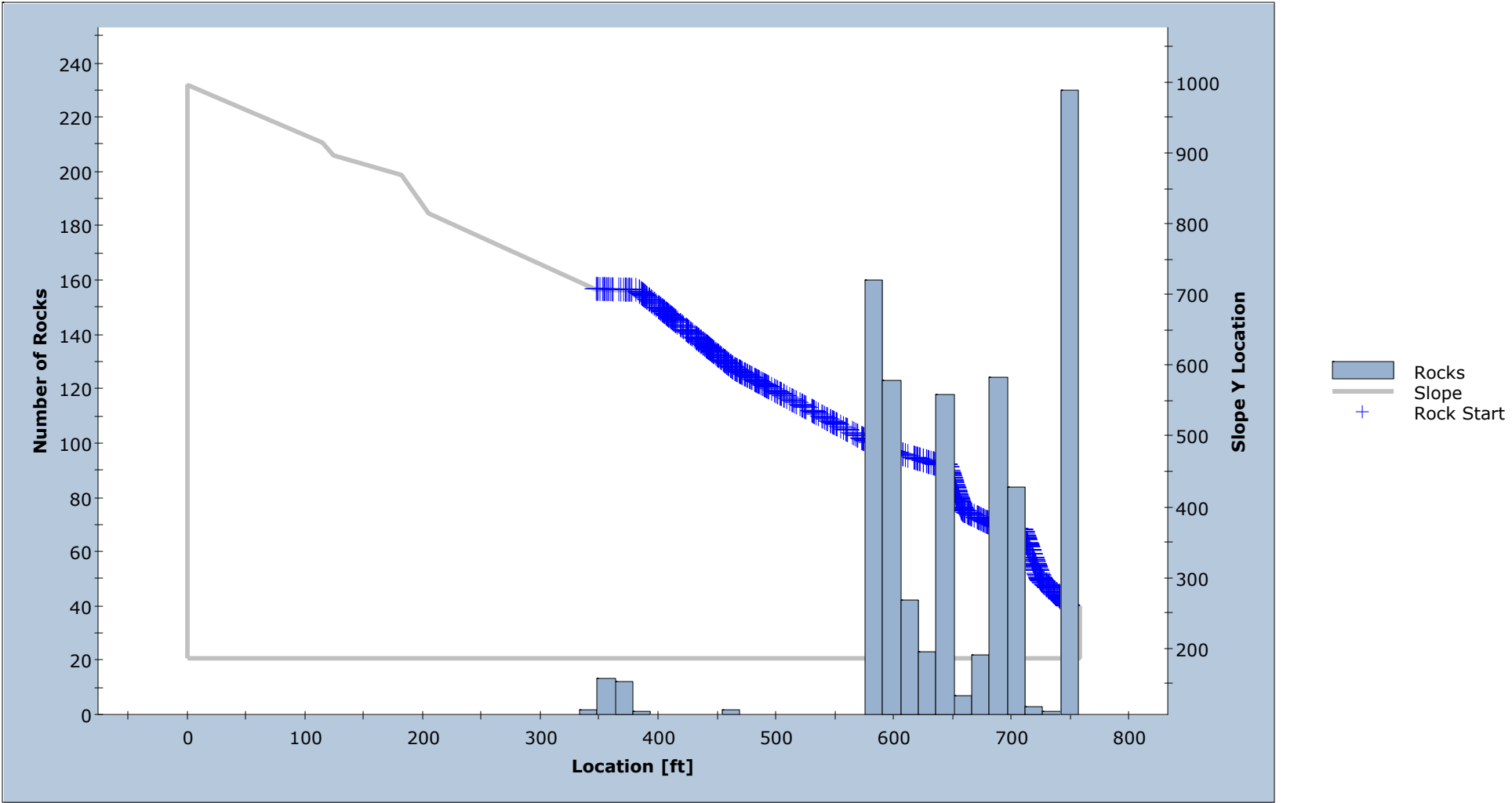


Traverse	Cell ID	Rocfall Material Property Name	Forest Damping Height (ft)	Forest Drag Coefficient (lb/s)
WR-3	TP-1	Soil Slope with Vegetation	15	550
	TP-1b	Soil Slope with Vegetation	15	550
	TP-1c	Soil Slope with Vegetation	15	550
	TP-2	Soil Slope with Vegetation	15	550
	TP-3	Soil Slope with Vegetation	15	550
	TP-4	Soil Slope with Vegetation	15	550
	EP-1	Soil Slope with Vegetation	15	550
	TP-5	Soil Slope with Vegetation	15	550
	TP-6	Soil Slope with Veg, Boulders, and Outcrop	15	1100
	TP-7	Soil Slope with Veg, Boulders, and Outcrop	15	1100
	TP-7b	Hawaii Basalt	20	550
	TP-8	Outcrops with Soil and Vegetation	10	550
	TP-9	Outcrops with Soil and Vegetation	10	550
TP-9b	Hawaii Basalt	20	550	
TP-10	Outcrops with Soil and Vegetation	10	550	
TP-11	Outcrops with Soil and Vegetation	10	550	
TP-12	Hawaii Basalt	20	550	
TP-13	Asphalt	-	-	


- Notes:
1. Rock blocks thrown for this model assume static conditions of the slope with no horizontal velocity impetus applied to the rocks.
 2. Rounded hexagon and rhombus-shaped rock blocks were used in the model. Density of the rock blocks (Hawaii Basalt) is assumed to be 170 pcf.

	Project		Laupahoehoe Point and Waipi'o Valley Road Project		
	Analysis Description		Traverse WR3 - Existing Conditions, Static Scenario		
	Drawn By		A. Granger and N. Lescalleet	Company Haley & Aldrich, Inc.	
	Date		November 2020	File Name 135500-003_WR3-Traverse.fal8	
	ROCFALL 8.012				

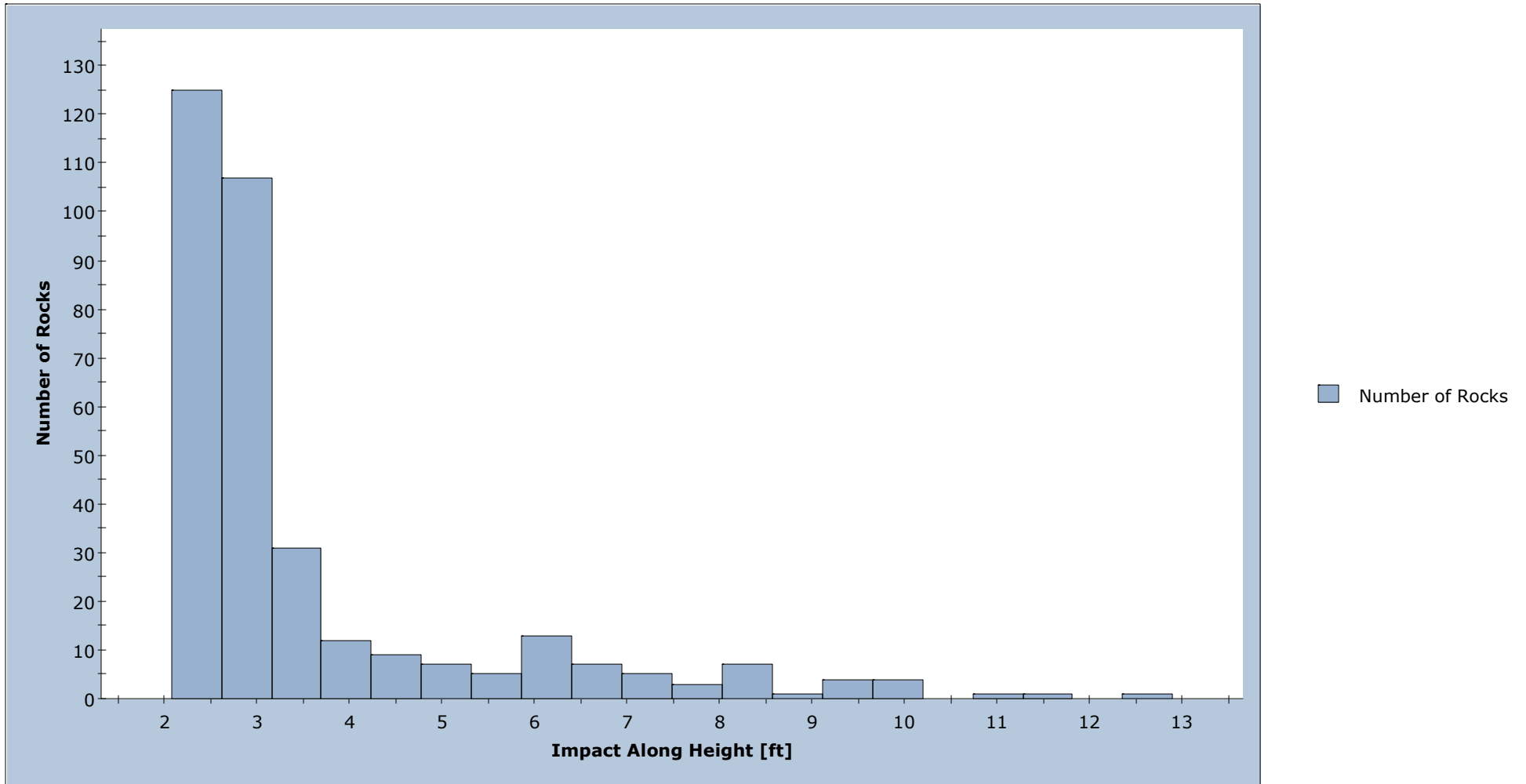
Distribution of Rock Path End Locations



Total number of rock paths: 967

	<i>Project</i> Laupahoehoe Point and Waipi'o Valley Road Project		
	<i>Analysis Description</i> Traverse WR3 - Existing Conditions, Static Scenario		
	<i>Drawn By</i> A. Granger and N. Lescalleet		<i>Company</i> Haley & Aldrich, Inc.
	<i>Date</i> November 2020		<i>File Name</i> 135500-003_WR3-Traverse.fal8

Impact Along Height on EOP

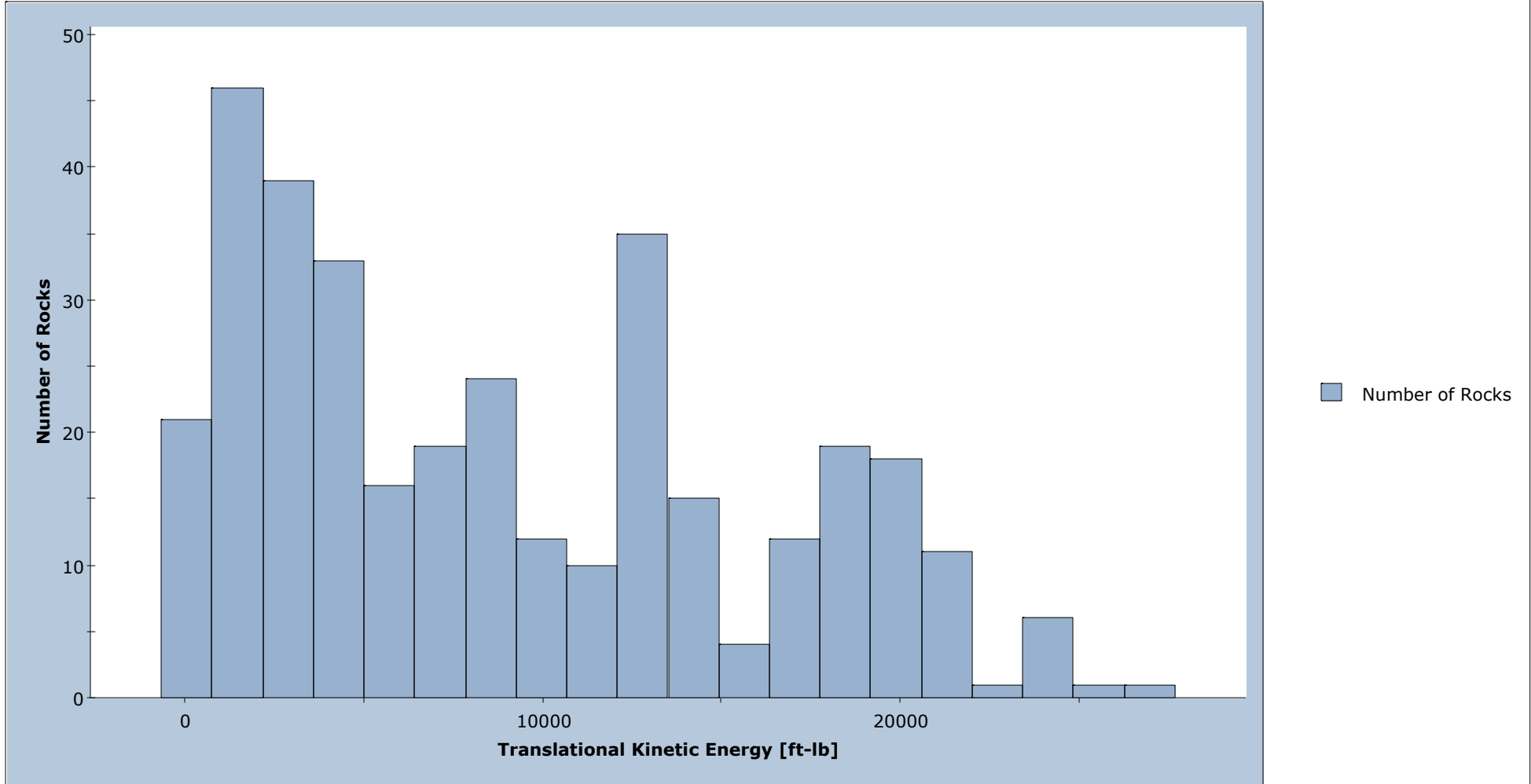


Total number of rocks on EOP: 343
Impact Along Height: min = 2.34567, max = 12.6299



<i>Project</i>	Laupahoehoe Point and Waipi'o Valley Road Project		
<i>Analysis Description</i>	Traverse WR3 - Existing Conditions, Static Scenario		
<i>Drawn By</i>	A. Granger and N. Lescalleet	<i>Company</i>	Haley & Aldrich, Inc.
<i>Date</i>	November 2020	<i>File Name</i>	135500-003_WR3-Traverse.fal8

Translational Kinetic Energy on EOP



Total number of rocks on EOP: 343
Translational Kinetic Energy: min = 48.1157, max = 26987.3



<i>Project</i>	Laupahoehoe Point and Waipi'o Valley Road Project		
<i>Analysis Description</i>	Traverse WR3 - Existing Conditions, Static Scenario		
<i>Drawn By</i>	A. Granger and N. Lescalleet	<i>Company</i>	Haley & Aldrich, Inc.
<i>Date</i>	November 2020	<i>File Name</i>	135500-003_WR3-Traverse.fal8

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135500-003_WR3-Traverse

Laupahoehoe Point and Waipi'o Valley Road Project

Project Summary

File Name	135500-003_WR3-Traverse.fal8
File Version	8.012
Project Title	Laupahoehoe Point and Waipi'o Valley Road Project
Analysis	Traverse WR3 - Existing Conditions, Static Scenario
Author	A. Granger and N. Lescalleet
Company	Haley & Aldrich, Inc.
Date Created	November 2020

Project Settings

General Settings

Engine	Rigid Body
Units	Imperial Foot-Pounds (ft, lb, ft-lb)
Rock throw mode	1000 rocks thrown overall
Use tangential CRSP damping	Yes

Engine Conditions

Maximum time per rock (s)	10
Maximum steps per rock	200000
Normal velocity cutoff (ft/s)	0.33
Stopped velocity cutoff (ft/s)	0.33
Maximum timestep (s)	0.01
Switch velocity (ft/s)	-3.3e-09

Random Number Generation

Sampling method	Monte-Carlo
Random seed	Pseudo-random seed: 12345234

Slope Geometry

Vertex	X	Y	X Std.Dev.	Y Std.Dev.
1	0	996.5		
2	114.64	914.87		
3	124.04	896.83		
4	181.79	869.45		
5	204.61	815.22		
6	346.44	707.75		
7	381.31	706.19		
8	462.82	595.95		
9	586.44	484.23		
10	635.82	460.09		
11	643.46	460.09		
12	656.46	397.03		
13	686.78	372.47		
14	707.41	368.23		
15	723.51	298.05		
16	739.43	274.25		
17	745.91	261.17		
18	757.34	261		


Slope Material Assignment

Material	From Vertex	To Vertex
Soil Slope wth Veg	1	8
Soil Slope with Veg, Boulders, and Outcrop	8	10
Hawaii Basalt	10	11
Outcrops with Soil and Veg	11	13
Hawaii Basalt	13	14
Outcrops with Soil and Veg	14	16
Hawaii Basalt	16	17
Asphalt	17	18

Material Properties

Hawaii Basalt

"Hawaii Basalt" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.8	Normal	0.04	0.12	0.12
Dynamic Friction	0.7	Normal	0.04	0.12	0.12
Rolling Friction	0.5	Normal	0.02	0.06	0.06

"Hawaii Basalt" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		20.00
Forest Drag Coefficient(lb/s)		550.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	

Outcrops with Soil and Veg

"Outcrops with Soil and Veg" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.33	Normal	0.04	0.12	0.12
Tangential Restitution	0.78	Normal	0.04	0.12	0.12
Dynamic Friction	0.62	Normal	0.04	0.12	0.12
Rolling Friction	0.7	Normal	0.02	0.06	0.06
Slope Roughness	5	Normal	0.2	0.6	0.6
Spacing					
Slope Roughness	0.5	Normal	0.1	0.3	0.3
Amplitude					

"Outcrops with Soil and Veg" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		10.00
Forest Drag Coefficient(lb/s)		550.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	

Soil Slope with Veg, Boulders, and Outcrop


"Soil Slope with Veg, Boulders, and Outcrop" Properties

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.33	Normal	0.04	0.12	0.12
Tangential Restitution	0.78	Normal	0.04	0.12	0.12
Dynamic Friction	0.65	Normal	0.04	0.12	0.12
Rolling Friction	0.6	Normal	0.02	0.06	0.06

"Soil Slope with Veg, Boulders, and Outcrop" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		15.00
Forest Drag Coefficient(lb/s)		1100.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	


Soil Slope wth Veg**"Soil Slope wth Veg" Properties**

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.3	Normal	0.04	0.12	0.12
Tangential Restitution	0.7	Normal	0.04	0.12	0.12
Dynamic Friction	0.58	Normal	0.04	0.12	0.12
Rolling Friction	0.75	Normal	0.02	0.12	0.12

"Soil Slope wth Veg" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		15.00
Forest Drag Coefficient(lb/s)		550.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	

Asphalt**"Asphalt" Properties**

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.4	None			
Tangential Restitution	0.9	None			
Dynamic Friction	0.58	None			
Rolling Friction	0.4	None			

"Asphalt" Advanced Properties

Forest and Vegetation Damping	Disabled
Scarring	Disabled
Viscoplastic Damping	Disabled

Seeders

Bench - TP-7

Seeder Properties

Name	Bench - TP-7
Location	(643.46, 460.09), (635.82, 460.09)

Rocks to Throw

Number of Rocks	Set in Project Settings
Rock Types	HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Bench - TP-9b

Seeder Properties

Name	Bench - TP-9b
Location	(707.41, 368.23), (686.78, 372.47)

Rocks to Throw

Number of Rocks	Set in Project Settings
Rock Types	HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Roadcut

Seeder Properties

Name Roadcut
 Location (745.91, 261.17),
 (739.43, 274.25)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-5, OC-1, OC-2, OC-3**Seeder Properties**

Name TP-5, OC-1, OC-2,
 OC-3
 Location (432.901, 636.414),
 (462.82, 595.95),
 (493.455, 568.264)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-8, TP-9

Seeder Properties

Name TP-8, TP-9
 Location (643.46, 460.09),
 (656.46, 397.03),
 (686.78, 372.47)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-4, EP-1, EP-2**Seeder Properties**

Name TP-4, EP-1, EP-2
 Location (346.44, 707.75),
 (381.31, 706.19),
 (399.862, 681.099),
 (432.901, 636.414)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-6, TP-7

Seeder Properties

Name TP-6, TP-7
 Location (635.82, 460.09),
 (586.44, 484.23),
 (493.455, 568.264)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-11, TP-12**Seeder Properties**

Name TP-11, TP-12
 Location (707.41, 368.23),
 (723.51, 298.05),
 (739.43, 274.25)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks


Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Rock Types

HI Basalt Rock Blocks

Properties

Name	HI Basalt Rock Blocks				
Color					
Smooth Shapes	Hexagon,		Rhombus		
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (lb)	1529.8	Normal	10	30	30
Density (lb/ft3)	170	Normal	5	15	15

Collectors

Record paths' first impacts only? No

EOP

Name EOP

Location (745.91, 261.17) to (745.91, 361.17)

Summary Results

Run Properties

Simulation Time (s)	756.94		
Envelope data:			
	Max	Mean	95%
Envelope Bounce Height (ft)	11.87	4.34	7.95
Envelope Total Kinetic Energy (ft-lb)	3.222e+04	1.986e+04	3.222e+04
Envelope Translational Kinetic Energy (ft-lb)	3.222e+04	1.983e+04	3.222e+04
Envelope Rotational Kinetic Energy (ft-lb)	4743	1805	4743
Envelope Translational Kinetic Velocity (ft/s)	36.91	27.85	36.91
Envelope Rotational Kinetic Velocity (rad/s)	17.61	10.24	17.61

Stopping Reason

CONTINUE	0
Invalid Start Location	0
Invalid Slope Geometry	0
Invalid bad crest loss definition	0
Invalid relative size between rock and slope	0
Max Compute Time	46
Max Steps	0
Edge Model	52
Stopped	869
Stopped (wedged)	0
Stopped (chattering)	0
Hit Barrier	0
Hit Berm with infinite capacity	0
No collision found	2
Bad Collision Geometry (location before)	31
Rock is freefalling onto a spike or a trough	0
END_ERROR_UNKNOWN	0
END_ERROR_POSITIVE_GAP	0
Bad collision calculation	0
Bad Collision Geometry (0 intersection)	0
Bad Collision Geometry (location after)	0
Bad Collision Geometry (missing intersection)	0
Error during results reading	0
Total Rocks	1000

Collector(s) Impact Results

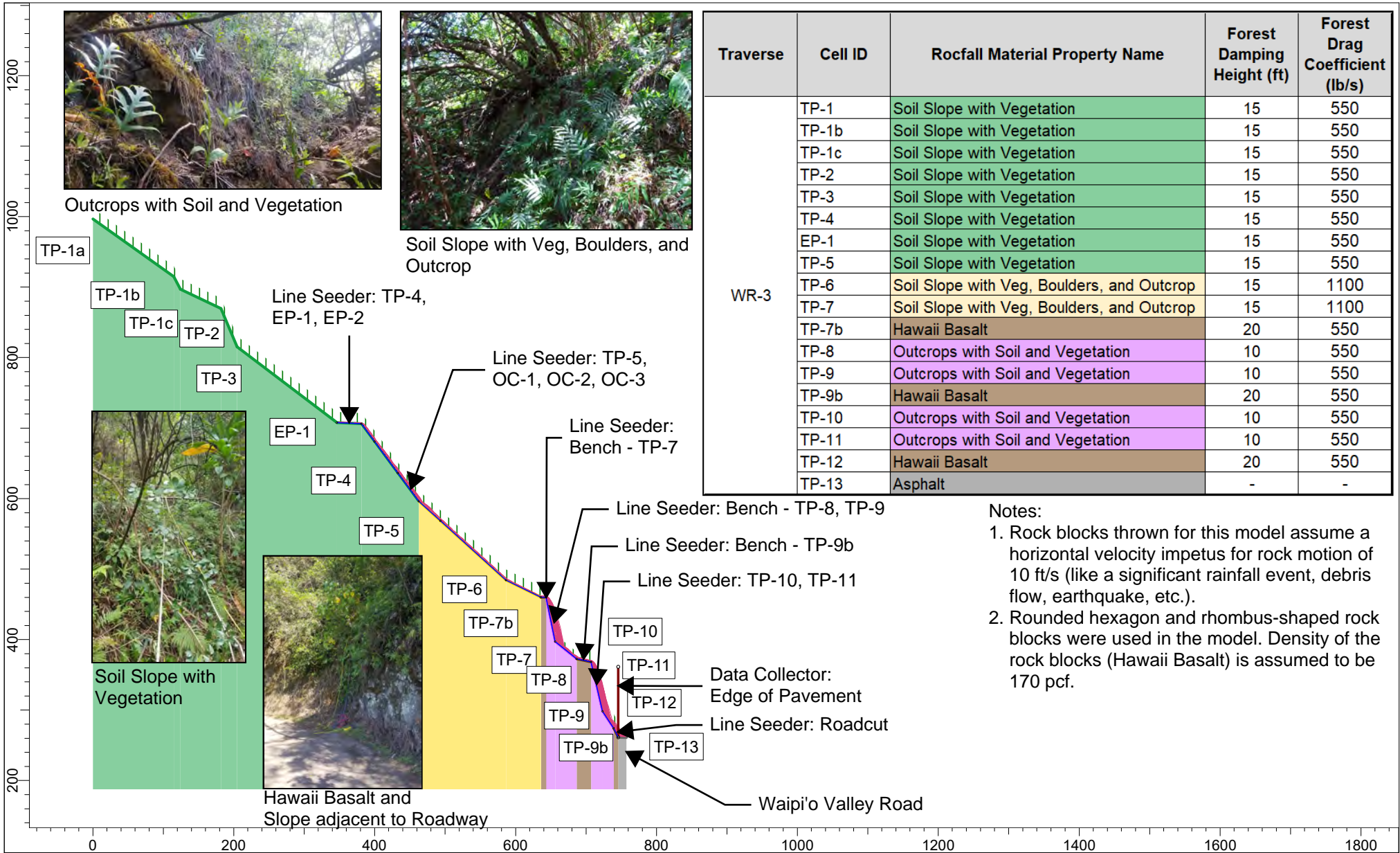
EOP

Barrier Name EOP
Hits 343 / 1000 rocks

Impact Statistics

Based on actual values for all impacted rocks.

	Mean	Min	Max
Impact Along Height (ft)	3.61	2.35	12.63
Translational Velocity (ft/s)	17.76	1.42	33.58
Translation Energy (ft-lb)	9001.35	48.12	26987.26

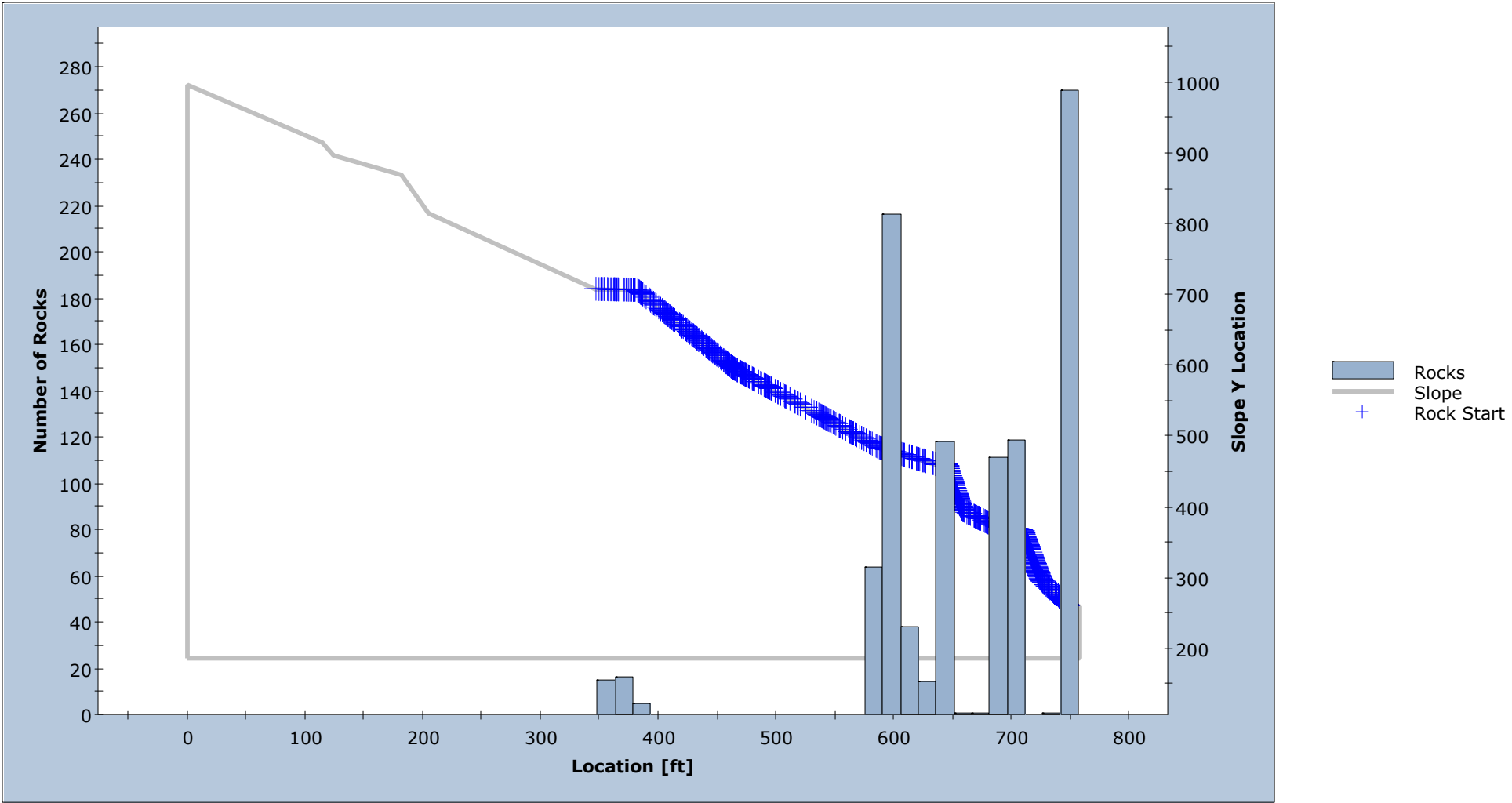


Traverse	Cell ID	Rocfall Material Property Name	Forest Damping Height (ft)	Forest Drag Coefficient (lb/s)
WR-3	TP-1	Soil Slope with Vegetation	15	550
	TP-1b	Soil Slope with Vegetation	15	550
	TP-1c	Soil Slope with Vegetation	15	550
	TP-2	Soil Slope with Vegetation	15	550
	TP-3	Soil Slope with Vegetation	15	550
	TP-4	Soil Slope with Vegetation	15	550
	EP-1	Soil Slope with Vegetation	15	550
	TP-5	Soil Slope with Vegetation	15	550
	TP-6	Soil Slope with Veg, Boulders, and Outcrop	15	1100
	TP-7	Soil Slope with Veg, Boulders, and Outcrop	15	1100
	TP-7b	Hawaii Basalt	20	550
	TP-8	Outcrops with Soil and Vegetation	10	550
	TP-9	Outcrops with Soil and Vegetation	10	550
TP-9b	Hawaii Basalt	20	550	
TP-10	Outcrops with Soil and Vegetation	10	550	
TP-11	Outcrops with Soil and Vegetation	10	550	
TP-12	Hawaii Basalt	20	550	
TP-13	Asphalt	-	-	


- Notes:
1. Rock blocks thrown for this model assume a horizontal velocity impetus for rock motion of 10 ft/s (like a significant rainfall event, debris flow, earthquake, etc.).
 2. Rounded hexagon and rhombus-shaped rock blocks were used in the model. Density of the rock blocks (Hawaii Basalt) is assumed to be 170 pcf.

	Project		Laupahoehoe Point and Waipi'o Valley Road Project		
	Analysis Description		Traverse WR3 - Existing Conditions with Horizontal Velocity		
	Drawn By		A. Granger and N. Lescalleet	Company Haley & Aldrich, Inc.	
	Date		November 2020	File Name 135500-003_WR3-Traverse.fal8	
	ROCFALL 8.012				

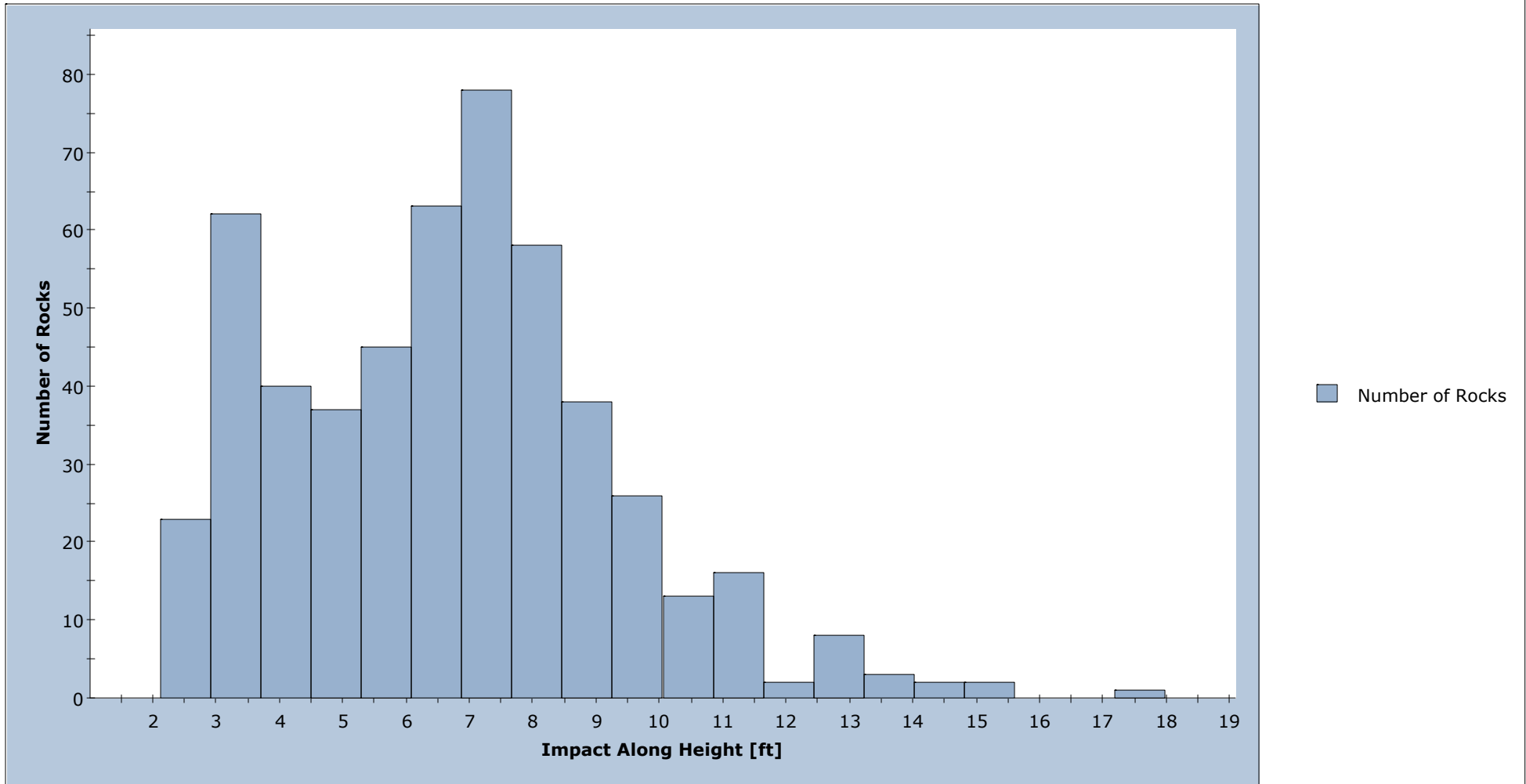
Distribution of Rock Path End Locations



Total number of rock paths: 989

	<i>Project</i> Laupahoehoe Point and Waipi'o Valley Road Project	
	<i>Analysis Description</i> Traverse WR3 - Existing Conditions with Horizontal Velocity	
	<i>Drawn By</i> A. Granger and N. Lescalleet	<i>Company</i> Haley & Aldrich, Inc.
	<i>Date</i> November 2020	<i>File Name</i> 135500-003_WR3-Traverse.fal8

Impact Along Height on EOP

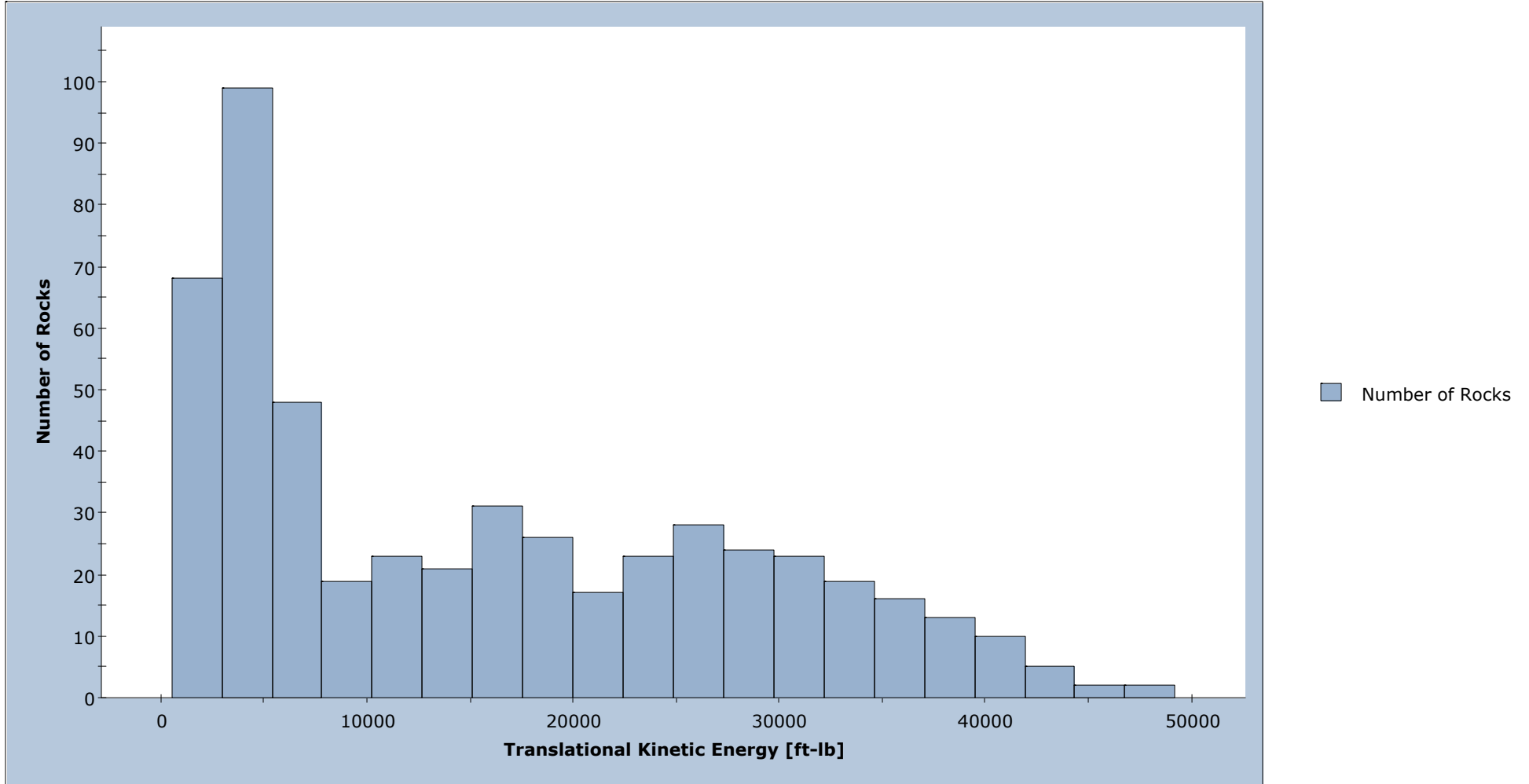


Total number of rocks on EOP: 517
Impact Along Height: min = 2.52041, max = 17.5865



<i>Project</i>	Laupahoehoe Point and Waipi'o Valley Road Project		
<i>Analysis Description</i>	Traverse WR3 - Existing Conditions with Horizontal Velocity		
<i>Drawn By</i>	A. Granger and N. Lescalleet	<i>Company</i>	Haley & Aldrich, Inc.
<i>Date</i>	November 2020	<i>File Name</i>	135500-003_WR3-Traverse.fal8

Translational Kinetic Energy on EOP



Total number of rocks on EOP: 517
Translational Kinetic Energy: min = 1735.29, max = 47994.5



<i>Project</i>	Laupahoehoe Point and Waipi'o Valley Road Project		
<i>Analysis Description</i>	Traverse WR3 - Existing Conditions with Horizontal Velocity		
<i>Drawn By</i>	A. Granger and N. Lescalleet	<i>Company</i>	Haley & Aldrich, Inc.
<i>Date</i>	November 2020	<i>File Name</i>	135500-003_WR3-Traverse.fal8

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135500-003_WR3-Traverse

Laupahoehoe Point and Waipi'o Valley Road Project

Project Summary

File Name	135500-003_WR3-Traverse.fal8
File Version	8.012
Project Title	Laupahoehoe Point and Waipi'o Valley Road Project
Analysis	Traverse WR3 - Existing Conditions with Horizontal Velocity
Author	A. Granger and N. Lescalleet
Company	Haley & Aldrich, Inc.
Date Created	November 2020

Project Settings

General Settings

Engine	Rigid Body
Units	Imperial Foot-Pounds (ft, lb, ft-lb)
Rock throw mode	1000 rocks thrown overall
Use tangential CRSP damping	Yes

Engine Conditions

Maximum time per rock (s)	10
Maximum steps per rock	200000
Normal velocity cutoff (ft/s)	0.33
Stopped velocity cutoff (ft/s)	0.33
Maximum timestep (s)	0.01
Switch velocity (ft/s)	-3.3e-09

Random Number Generation

Sampling method	Monte-Carlo
Random seed	Pseudo-random seed: 12345234

Slope Geometry

Vertex	X	Y	X Std.Dev.	Y Std.Dev.
1	0	996.5		
2	114.64	914.87		
3	124.04	896.83		
4	181.79	869.45		
5	204.61	815.22		
6	346.44	707.75		
7	381.31	706.19		
8	462.82	595.95		
9	586.44	484.23		
10	635.82	460.09		
11	643.46	460.09		
12	656.46	397.03		
13	686.78	372.47		
14	707.41	368.23		
15	723.51	298.05		
16	739.43	274.25		
17	745.91	261.17		
18	757.34	261		


Slope Material Assignment

Material	From Vertex	To Vertex
Soil Slope wth Veg	1	8
Soil Slope with Veg, Boulders, and Outcrop	8	10
Hawaii Basalt	10	11
Outcrops with Soil and Veg	11	13
Hawaii Basalt	13	14
Outcrops with Soil and Veg	14	16
Hawaii Basalt	16	17
Asphalt	17	18

Material Properties

Hawaii Basalt

"Hawaii Basalt" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.8	Normal	0.04	0.12	0.12
Dynamic Friction	0.7	Normal	0.04	0.12	0.12
Rolling Friction	0.5	Normal	0.02	0.06	0.06

"Hawaii Basalt" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		20.00
Forest Drag Coefficient(lb/s)		550.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	

Outcrops with Soil and Veg

"Outcrops with Soil and Veg" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.33	Normal	0.04	0.12	0.12
Tangential Restitution	0.78	Normal	0.04	0.12	0.12
Dynamic Friction	0.62	Normal	0.04	0.12	0.12
Rolling Friction	0.7	Normal	0.02	0.06	0.06
Slope Roughness	5	Normal	0.2	0.6	0.6
Spacing					
Slope Roughness	0.5	Normal	0.1	0.3	0.3
Amplitude					

"Outcrops with Soil and Veg" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		10.00
Forest Drag Coefficient(lb/s)		550.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	

Soil Slope with Veg, Boulders, and Outcrop


"Soil Slope with Veg, Boulders, and Outcrop" Properties

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.33	Normal	0.04	0.12	0.12
Tangential Restitution	0.78	Normal	0.04	0.12	0.12
Dynamic Friction	0.65	Normal	0.04	0.12	0.12
Rolling Friction	0.6	Normal	0.02	0.06	0.06

"Soil Slope with Veg, Boulders, and Outcrop" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		15.00
Forest Drag Coefficient(lb/s)		1100.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	


Soil Slope with Veg**"Soil Slope with Veg" Properties**

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.3	Normal	0.04	0.12	0.12
Tangential Restitution	0.7	Normal	0.04	0.12	0.12
Dynamic Friction	0.58	Normal	0.04	0.12	0.12
Rolling Friction	0.75	Normal	0.02	0.12	0.12

"Soil Slope with Veg" Advanced Properties

Forest and Vegetation Damping	Enabled	
Effective Forest Height(ft)		15.00
Forest Drag Coefficient(lb/s)		550.00
Scarring	Disabled	
Viscoplastic Damping	Disabled	

Asphalt**"Asphalt" Properties**

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.4	None			
Tangential Restitution	0.9	None			
Dynamic Friction	0.58	None			
Rolling Friction	0.4	None			

"Asphalt" Advanced Properties

Forest and Vegetation Damping	Disabled
Scarring	Disabled
Viscoplastic Damping	Disabled

Seeders

Bench - TP-7

Seeder Properties

Name	Bench - TP-7
Location	(643.46, 460.09), (635.82, 460.09)

Rocks to Throw

Number of Rocks	Set in Project Settings
Rock Types	HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Bench - TP-9b

Seeder Properties

Name	Bench - TP-9b
Location	(707.41, 368.23), (686.78, 372.47)

Rocks to Throw

Number of Rocks	Set in Project Settings
Rock Types	HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Roadcut

Seeder Properties

Name Roadcut
 Location (745.91, 261.17),
 (739.43, 274.25)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-5, OC-1, OC-2, OC-3**Seeder Properties**

Name TP-5, OC-1, OC-2,
 OC-3
 Location (432.901, 636.414),
 (462.82, 595.95),
 (493.455, 568.264)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-8, TP-9

Seeder Properties

Name TP-8, TP-9
 Location (643.46, 460.09),
 (656.46, 397.03),
 (686.78, 372.47)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-4, EP-1, EP-2**Seeder Properties**

Name TP-4, EP-1, EP-2
 Location (346.44, 707.75),
 (381.31, 706.19),
 (399.862, 681.099),
 (432.901, 636.414)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-6, TP-7

Seeder Properties

Name TP-6, TP-7
 Location (635.82, 460.09),
 (586.44, 484.23),
 (493.455, 568.264)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-11, TP-12**Seeder Properties**

Name TP-11, TP-12
 Location (707.41, 368.23),
 (723.51, 298.05),
 (739.43, 274.25)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks


Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Rock Types

HI Basalt Rock Blocks

Properties

Name	HI Basalt Rock Blocks				
Color					
Smooth Shapes	Hexagon,		Rhombus		
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (lb)	1529.8	Normal	10	30	30
Density (lb/ft3)	170	Normal	5	15	15

Collectors

Record paths' first impacts only? No

EOP

Name EOP

Location (745.91, 261.17) to (745.91, 361.17)

Summary Results

Run Properties

Simulation Time (s)	217.23		
Envelope data:			
	Max	Mean	95%
Envelope Bounce Height (ft)	45.13	23.64	38.25
Envelope Total Kinetic Energy (ft-lb)	9.978e+04	4.126e+04	9.978e+04
Envelope Translational Kinetic Energy (ft-lb)	9.978e+04	3.976e+04	9.978e+04
Envelope Rotational Kinetic Energy (ft-lb)	1.164e+04	5876	1.164e+04
Envelope Translational Kinetic Velocity (ft/s)	64.95	37.83	64.95
Envelope Rotational Kinetic Velocity (rad/s)	27.64	18.08	27.64

Stopping Reason

CONTINUE	0
Invalid Start Location	0
Invalid Slope Geometry	0
Invalid bad crest loss definition	0
Invalid relative size between rock and slope	0
Max Compute Time	8
Max Steps	0
Edge Model	132
Stopped	849
Stopped (wedged)	0
Stopped (chattering)	0
Hit Barrier	0
Hit Berm with infinite capacity	0
No collision found	1
Bad Collision Geometry (location before)	10
Rock is freefalling onto a spike or a trough	0
END_ERROR_UNKNOWN	0
END_ERROR_POSITIVE_GAP	0
Bad collision calculation	0
Bad Collision Geometry (0 intersection)	0
Bad Collision Geometry (location after)	0
Bad Collision Geometry (missing intersection)	0
Error during results reading	0
Total Rocks	1000

Collector(s) Impact Results

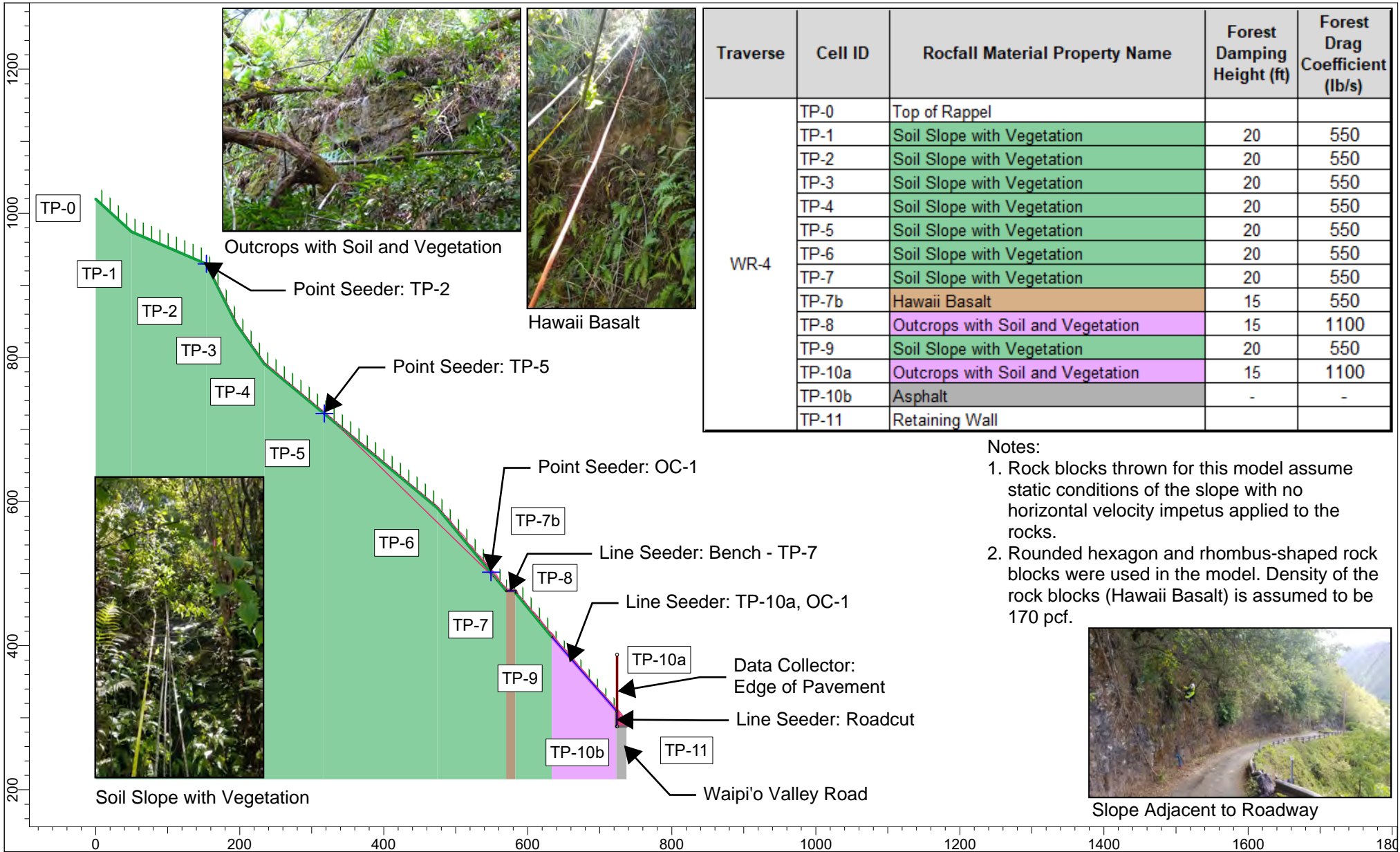
EOP

Barrier Name EOP
Hits 517 / 1000 rocks

Impact Statistics

Based on actual values for all impacted rocks.

	Mean	Min	Max
Impact Along Height (ft)	6.68	2.52	17.59
Translational Velocity (ft/s)	23.52	8.51	45.00
Translation Energy (ft-lb)	15719.83	1735.29	47994.48



Traverse	Cell ID	Rocfall Material Property Name	Forest Damping Height (ft)	Forest Drag Coefficient (lb/s)
WR-4	TP-0	Top of Rappel		
	TP-1	Soil Slope with Vegetation	20	550
	TP-2	Soil Slope with Vegetation	20	550
	TP-3	Soil Slope with Vegetation	20	550
	TP-4	Soil Slope with Vegetation	20	550
	TP-5	Soil Slope with Vegetation	20	550
	TP-6	Soil Slope with Vegetation	20	550
	TP-7	Soil Slope with Vegetation	20	550
	TP-7b	Hawaii Basalt	15	550
	TP-8	Outcrops with Soil and Vegetation	15	1100
	TP-9	Soil Slope with Vegetation	20	550
	TP-10a	Outcrops with Soil and Vegetation	15	1100
TP-10b	Asphalt	-	-	
TP-11	Retaining Wall			

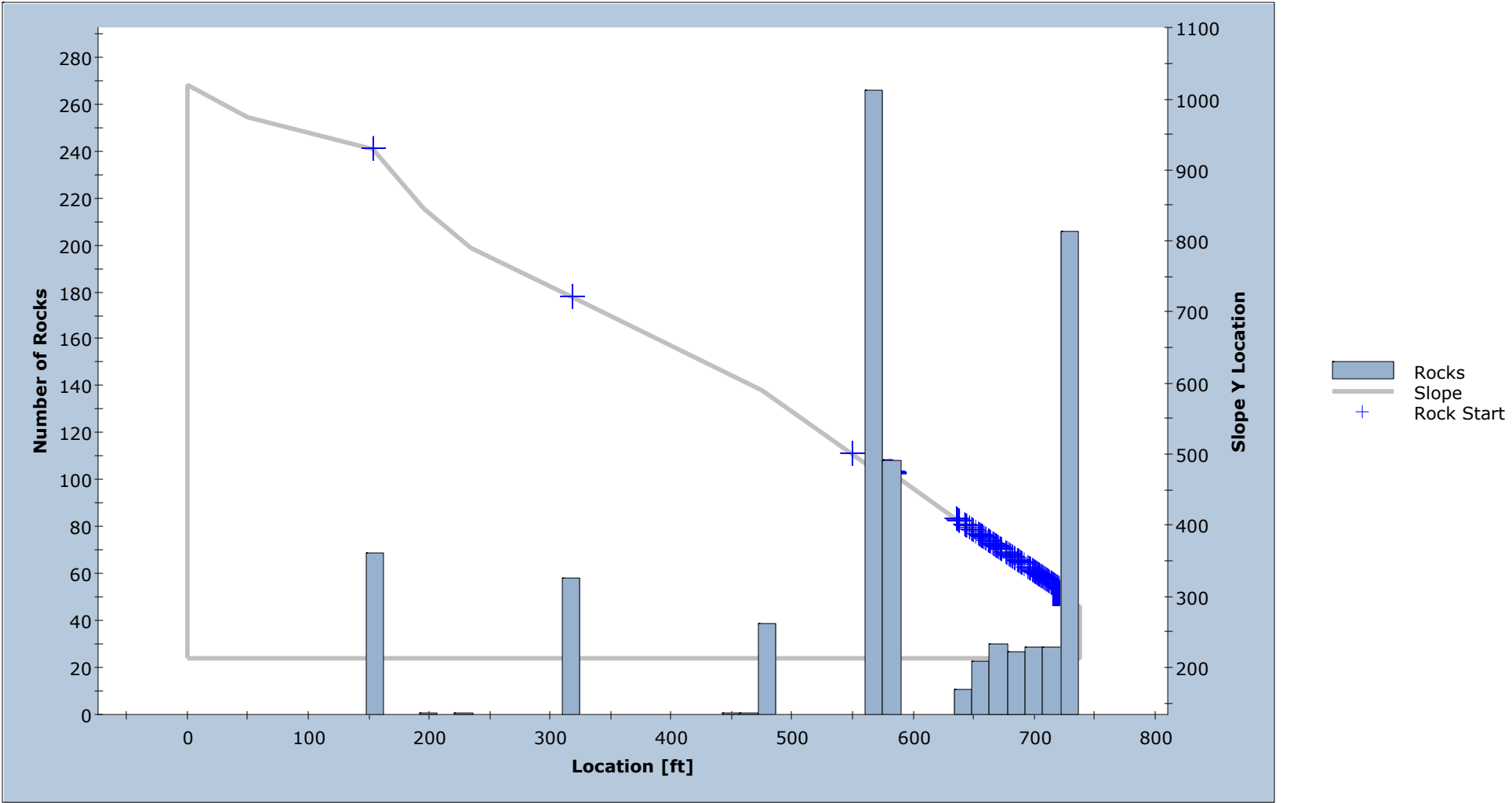
- Notes:
1. Rock blocks thrown for this model assume static conditions of the slope with no horizontal velocity impetus applied to the rocks.
 2. Rounded hexagon and rhombus-shaped rock blocks were used in the model. Density of the rock blocks (Hawaii Basalt) is assumed to be 170 pcf.




Slope Adjacent to Roadway

	Project		Laupahoehoe Point and Waipi'o Valley Road Project		
	Analysis Description		Traverse WR4 - Existing Conditions, Static Conditions		
	Drawn By		A. Granger and N. Lescalleet	Company Haley & Aldrich, Inc.	
	Date		November 2020	File Name 135500-003_WR4-Traverse.fal8	
	ROCFALL 8.012				

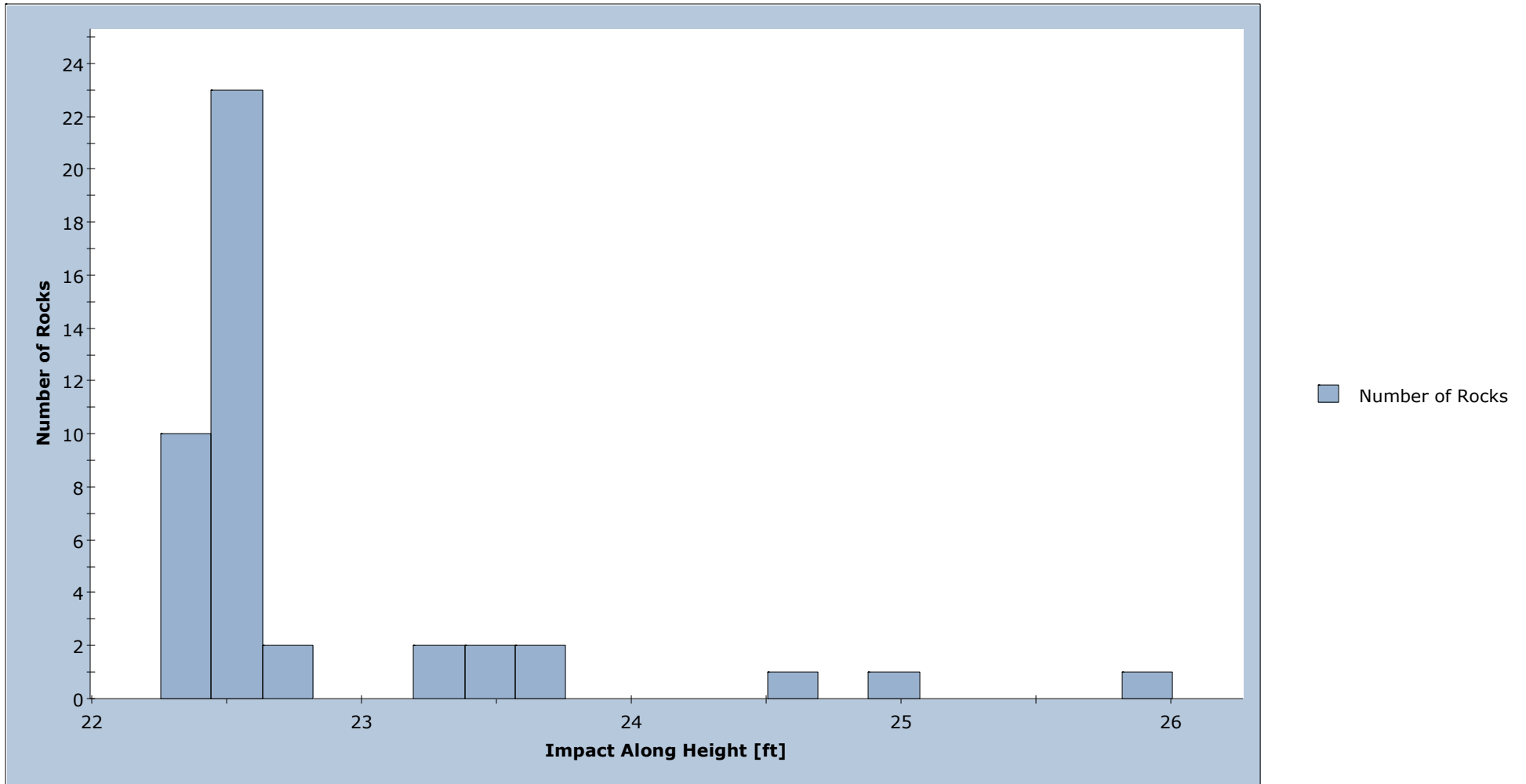
Distribution of Rock Path End Locations



Total number of rock paths: 899

	<i>Project</i> Laupahoehoe Point and Waipi'o Valley Road Project	
	<i>Analysis Description</i> Traverse WR4 - Existing Conditions, Static Conditions	
	<i>Drawn By</i> A. Granger and N. Lescalleet	<i>Company</i> Haley & Aldrich, Inc.
	<i>Date</i> November 2020	<i>File Name</i> 135500-003_WR4-Traverse.fal8

Impact Along Height on EOP

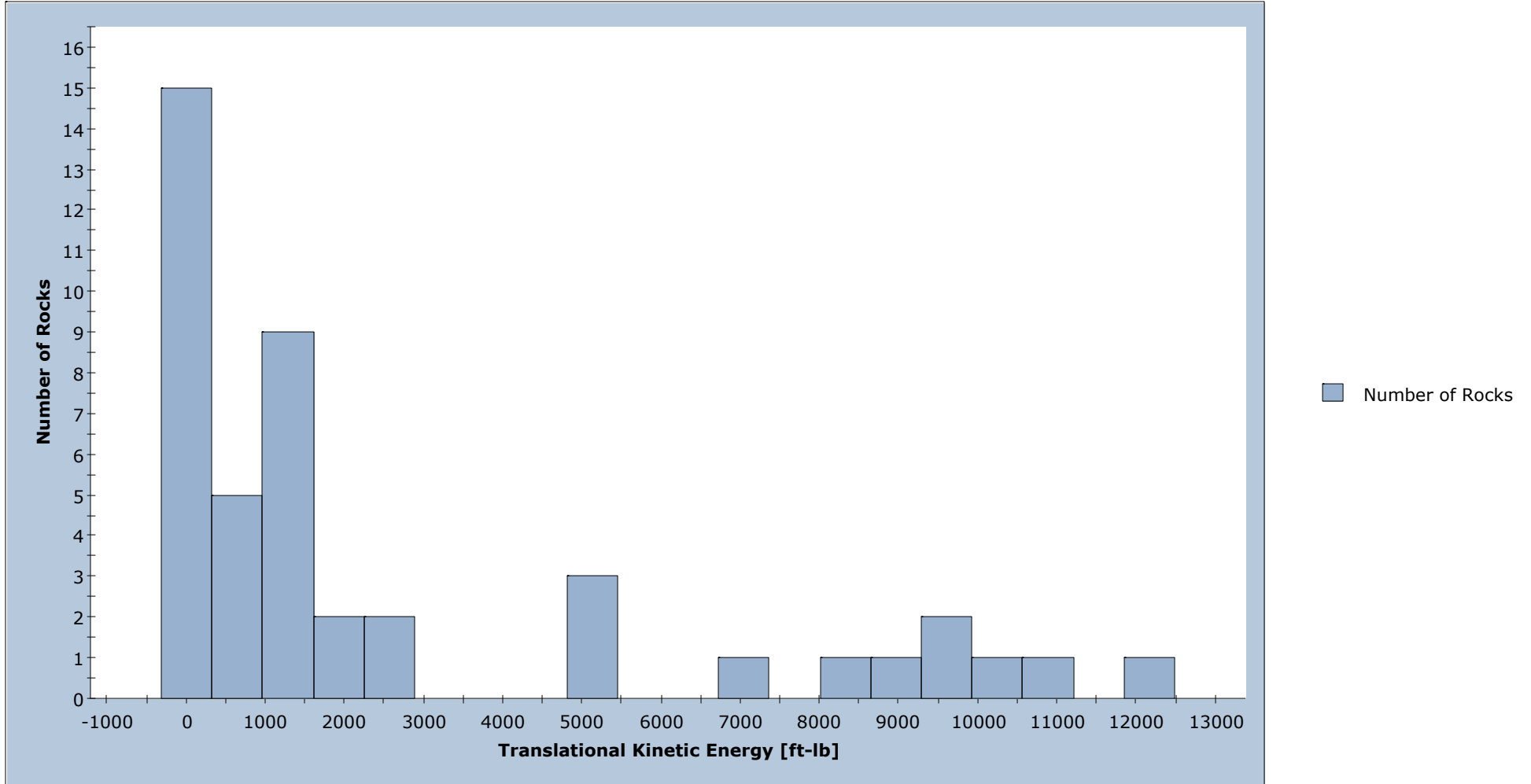


Total number of rocks on EOP: 44
Impact Along Height: min = 22.3492, max = 25.91



<i>Project</i>	Laupahoehoe Point and Waipi'o Valley Road Project		
<i>Analysis Description</i>	Traverse WR4 - Existing Conditions, Static Conditions		
<i>Drawn By</i>	A. Granger and N. Lescalleet	<i>Company</i>	Haley & Aldrich, Inc.
<i>Date</i>	November 2020	<i>File Name</i>	135500-003_WR4-Traverse.fal8

Translational Kinetic Energy on EOP



Total number of rocks on EOP: 44
Translational Kinetic Energy: min = 9.57296, max = 12168.4


	<i>Project</i>		
	Laupahoehoe Point and Waipi'o Valley Road Project		
	<i>Analysis Description</i>		
	Traverse WR4 - Existing Conditions, Static Conditions		
<i>Drawn By</i>		<i>Company</i>	
A. Granger and N. Lescalleet		Haley & Aldrich, Inc.	
<i>Date</i>		<i>File Name</i>	
November 2020		135500-003_WR4-Traverse.fal8	

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TP-5	9
TP-2	9
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135500-003_WR4-Traverse

Laupahoehoe Point and Waipi'o Valley Road Project

Project Summary

File Name	135500-003_WR4-Traverse.fal8
File Version	8.012
Project Title	Laupahoehoe Point and Waipi'o Valley Road Project
Analysis	Traverse WR4 - Existing Conditions, Static Conditions
Author	A. Granger and N. Lescalleet
Company	Haley & Aldrich, Inc.
Date Created	November 2020

Project Settings

General Settings

Engine	Rigid Body
Units	Imperial Foot-Pounds (ft, lb, ft-lb)
Rock throw mode	1000 rocks thrown overall
Use tangential CRSP damping	Yes

Engine Conditions

Maximum time per rock (s)	10
Maximum steps per rock	200000
Normal velocity cutoff (ft/s)	0.33
Stopped velocity cutoff (ft/s)	0.33
Maximum timestep (s)	0.01
Switch velocity (ft/s)	-3.3e-09

Random Number Generation

Sampling method	Monte-Carlo
Random seed	Pseudo-random seed: 12345234

Slope Geometry

Vertex	X	Y	X Std.Dev.	Y Std.Dev.
1	0	1019.89		
2	49.83	974.29		
3	153.27	929.63		
4	195.28	845.92		
5	234.17	790.84		
6	317.15	722.16		
7	474.34	590.95		
8	569.89	476.08		
9	582.64	476		
10	582.64	473.31		
11	633.36	411.53		
12	722.9	309		
13	722.9	287.61		
14	736.96	288		


Slope Material Assignment

Material	From Vertex	To Vertex
Soil Slope wth Veg	1	8
Hawaii Basalt	8	9
Bedrock Outcrops	9	10
Soil Slope wth Veg	10	11
Outcrops with Soil and Veg	11	12
Bedrock Outcrops	12	13
Asphalt	13	14

Material Properties

Bedrock Outcrops

"Bedrock Outcrops" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.85	Normal	0.04	0.12	0.12
Dynamic Friction	0.55	Normal	0.04	0.12	0.12
Rolling Friction	0.15	Normal	0.02	0.06	0.06

"Bedrock Outcrops" Advanced Properties

Forest and Vegetation Damping	Disabled
Scarring	Disabled
Viscoplastic Damping	Disabled

Hawaii Basalt

"Hawaii Basalt" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.8	Normal	0.04	0.12	0.12
Dynamic Friction	0.7	Normal	0.04	0.12	0.12
Rolling Friction	0.5	Normal	0.02	0.06	0.06

"Hawaii Basalt" Advanced Properties

Forest and Vegetation Damping	Enabled
Effective Forest Height(ft)	15.00
Forest Drag Coefficient(lb/s)	550.00
Scarring	Disabled
Viscoplastic Damping	Disabled

Outcrops with Soil and Veg


"Outcrops with Soil and Veg" Properties

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.33	Normal	0.04	0.12	0.12
Tangential Restitution	0.78	Normal	0.04	0.12	0.12
Dynamic Friction	0.62	Normal	0.04	0.12	0.12
Rolling Friction	0.7	Normal	0.02	0.06	0.06
Slope Roughness	5	Normal	0.2	0.6	0.6
Spacing					
Slope Roughness	0.5	Normal	0.1	0.3	0.3
Amplitude					

"Outcrops with Soil and Veg" Advanced Properties

Forest and Vegetation Damping	Enabled
Effective Forest Height(ft)	15.00
Forest Drag Coefficient(lb/s)	1100.00
Scarring	Disabled
Viscoplastic Damping	Disabled

Soil Slope wth Veg**"Soil Slope wth Veg" Properties**


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.3	Normal	0.04	0.12	0.12
Tangential Restitution	0.7	Normal	0.04	0.12	0.12
Dynamic Friction	0.58	Normal	0.04	0.12	0.12
Rolling Friction	0.75	Normal	0.02	0.06	0.06

"Soil Slope wth Veg" Advanced Properties

Forest and Vegetation Damping	Enabled
Effective Forest Height(ft)	20.00
Forest Drag Coefficient(lb/s)	550.00
Scarring	Disabled
Viscoplastic Damping	Disabled

Asphalt

"Asphalt" Properties

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.4	None			
Tangential Restitution	0.9	None			
Dynamic Friction	0.58	None			
Rolling Friction	0.4	None			

"Asphalt" Advanced Properties

Forest and Vegetation Damping	Disabled
Scarring	Disabled
Viscoplastic Damping	Disabled

Seeders

OC-1

Seeder Properties

Name OC-1
Location (548.348, 501.978)

Rocks to Throw

Number of Rocks Set in Project
Settings
Rock Types HI Basalt Rock
Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-5

Seeder Properties

Name TP-5
Location (317.15, 722.16)

Rocks to Throw

Number of Rocks Set in Project
Settings
Rock Types HI Basalt Rock
Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-2

Seeder Properties

Name TP-2
 Location (153.27, 929.63)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Bench - TP-7**Seeder Properties**

Name Bench - TP-7
 Location (569.89, 476.08),
 (582.64, 476),
 (582.64, 473.31)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Roadcut

Seeder Properties

Name Roadcut
 Location (722.9, 309),
 (722.9, 287.61)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-10a, OC-2**Seeder Properties**

Name TP-10a, OC-2
 Location (722.9, 309),
 (633.36, 411.53)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks


Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	0	None			
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Rock Types

HI Basalt Rock Blocks

Properties

Name	HI Basalt Rock Blocks				
Color					
Smooth Shapes	Hexagon,		Rhombus		
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (lb)	1529.8	Normal	10	30	30
Density (lb/ft3)	170	Normal	5	15	15

Collectors

Record paths' first impacts only? No

EOP

Name EOP

Location (723.4, 287.61) to (723.4, 387.61)

Summary Results

Run Properties

Simulation Time (s)	1124.04		
Envelope data:			
	Max	Mean	95%
Envelope Bounce Height (ft)	24.81	23.08	24.2
Envelope Total Kinetic Energy (ft-lb)	4.125e+04	3.106e+04	4.125e+04
Envelope Translational Kinetic Energy (ft-lb)	3.805e+04	3.106e+04	3.805e+04
Envelope Rotational Kinetic Energy (ft-lb)	6761	1741	6761
Envelope Translational Kinetic Velocity (ft/s)	39.93	36.05	39.93
Envelope Rotational Kinetic Velocity (rad/s)	20.74	10.52	20.74

Stopping Reason

CONTINUE	0
Invalid Start Location	0
Invalid Slope Geometry	0
Invalid bad crest loss definition	0
Invalid relative size between rock and slope	0
Max Compute Time	260
Max Steps	0
Edge Model	14
Stopped	625
Stopped (wedged)	0
Stopped (chattering)	0
Hit Barrier	0
Hit Berm with infinite capacity	0
No collision found	95
Bad Collision Geometry (location before)	6
Rock is freefalling onto a spike or a trough	0
END_ERROR_UNKNOWN	0
END_ERROR_POSITIVE_GAP	0
Bad collision calculation	0
Bad Collision Geometry (0 intersection)	0
Bad Collision Geometry (location after)	0
Bad Collision Geometry (missing intersection)	0
Error during results reading	0
Total Rocks	1000

Collector(s) Impact Results

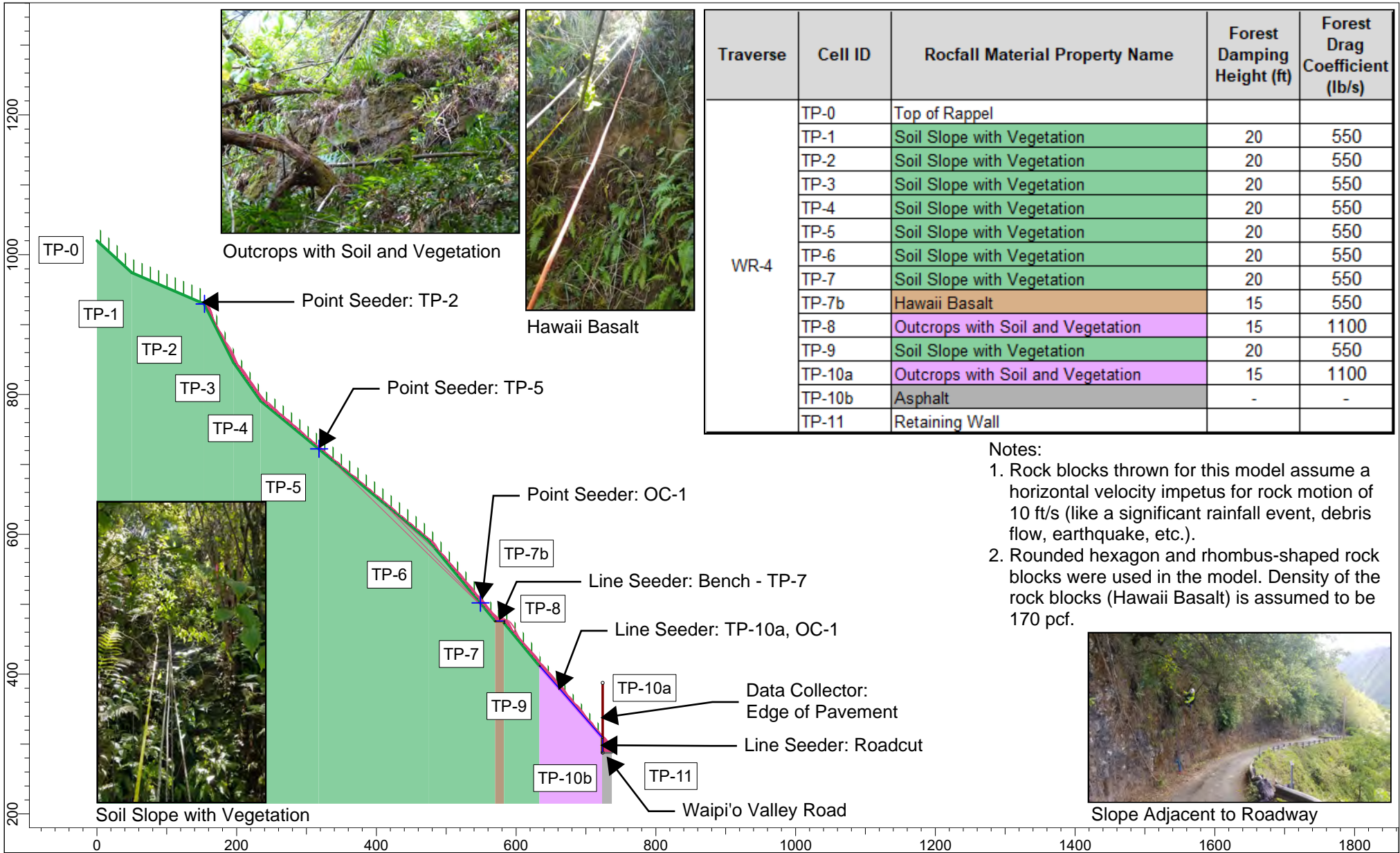
EOP

Barrier Name EOP
Hits 44 / 1000 rocks

Impact Statistics

Based on actual values for all impacted rocks.

	Mean	Min	Max
Impact Along Height (ft)	22.81	22.35	25.91
Translational Velocity (ft/s)	8.38	0.64	22.61
Translation Energy (ft-lb)	2665.19	9.57	12168.43



Traverse	Cell ID	Rocfall Material Property Name	Forest Damping Height (ft)	Forest Drag Coefficient (lb/s)
WR-4	TP-0	Top of Rappel		
	TP-1	Soil Slope with Vegetation	20	550
	TP-2	Soil Slope with Vegetation	20	550
	TP-3	Soil Slope with Vegetation	20	550
	TP-4	Soil Slope with Vegetation	20	550
	TP-5	Soil Slope with Vegetation	20	550
	TP-6	Soil Slope with Vegetation	20	550
	TP-7	Soil Slope with Vegetation	20	550
	TP-7b	Hawaii Basalt	15	550
	TP-8	Outcrops with Soil and Vegetation	15	1100
	TP-9	Soil Slope with Vegetation	20	550
	TP-10a	Outcrops with Soil and Vegetation	15	1100
TP-10b	Asphalt	-	-	
TP-11	Retaining Wall			

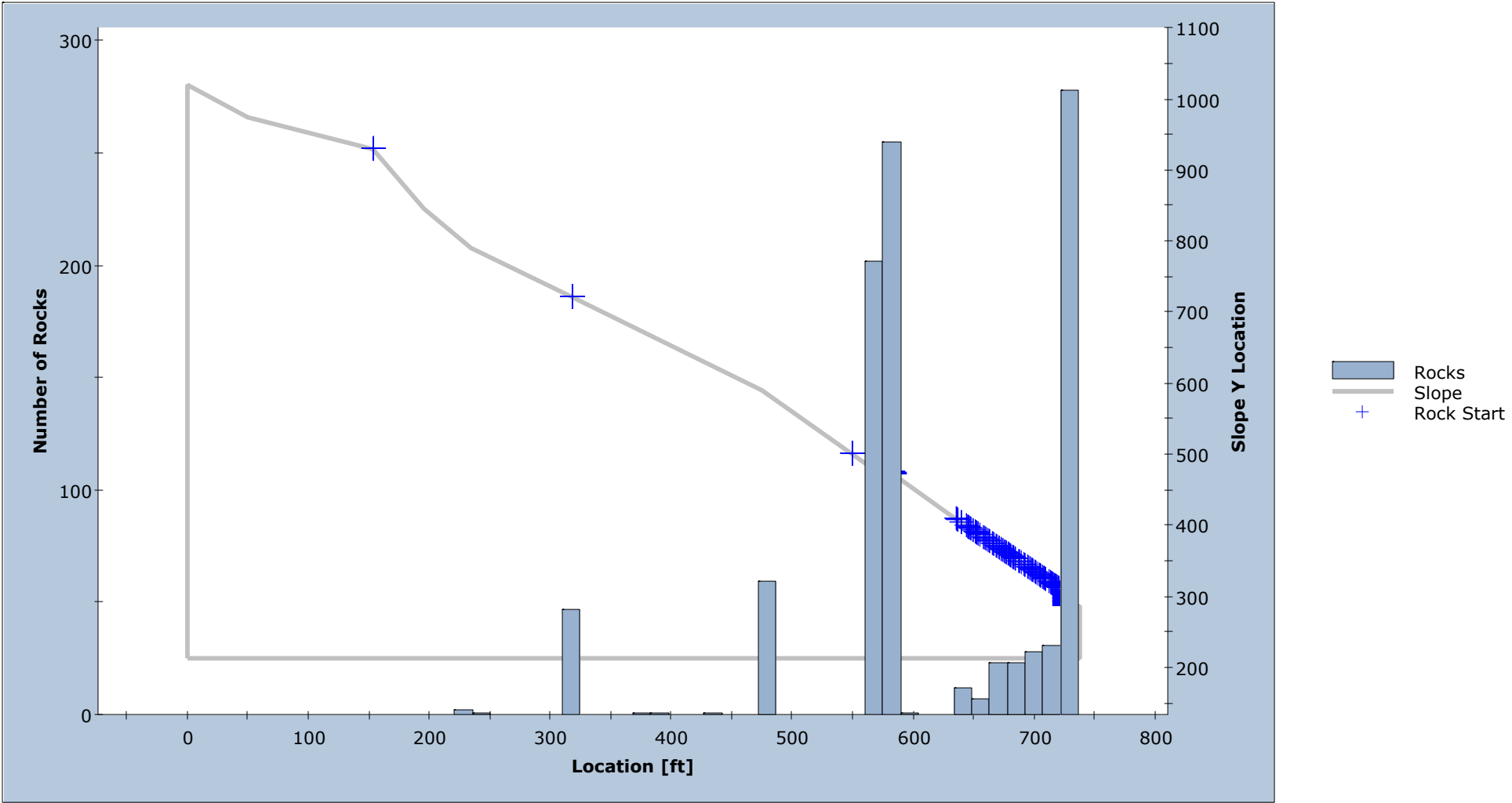
- Notes:
1. Rock blocks thrown for this model assume a horizontal velocity impetus for rock motion of 10 ft/s (like a significant rainfall event, debris flow, earthquake, etc.).
 2. Rounded hexagon and rhombus-shaped rock blocks were used in the model. Density of the rock blocks (Hawaii Basalt) is assumed to be 170 pcf.




Slope Adjacent to Roadway

	Project		Laupahoehoe Point and Waipi'o Valley Road Project		
	Analysis Description		Traverse WR4 - Existing Conditions with Horizontal Velocity		
	Drawn By		A. Granger and N. Lescalleet	Company	Haley & Aldrich, Inc.
	Date		November 2020	File Name	135500-003_WR4-Traverse.fal8
	ROCFALL 8.012				

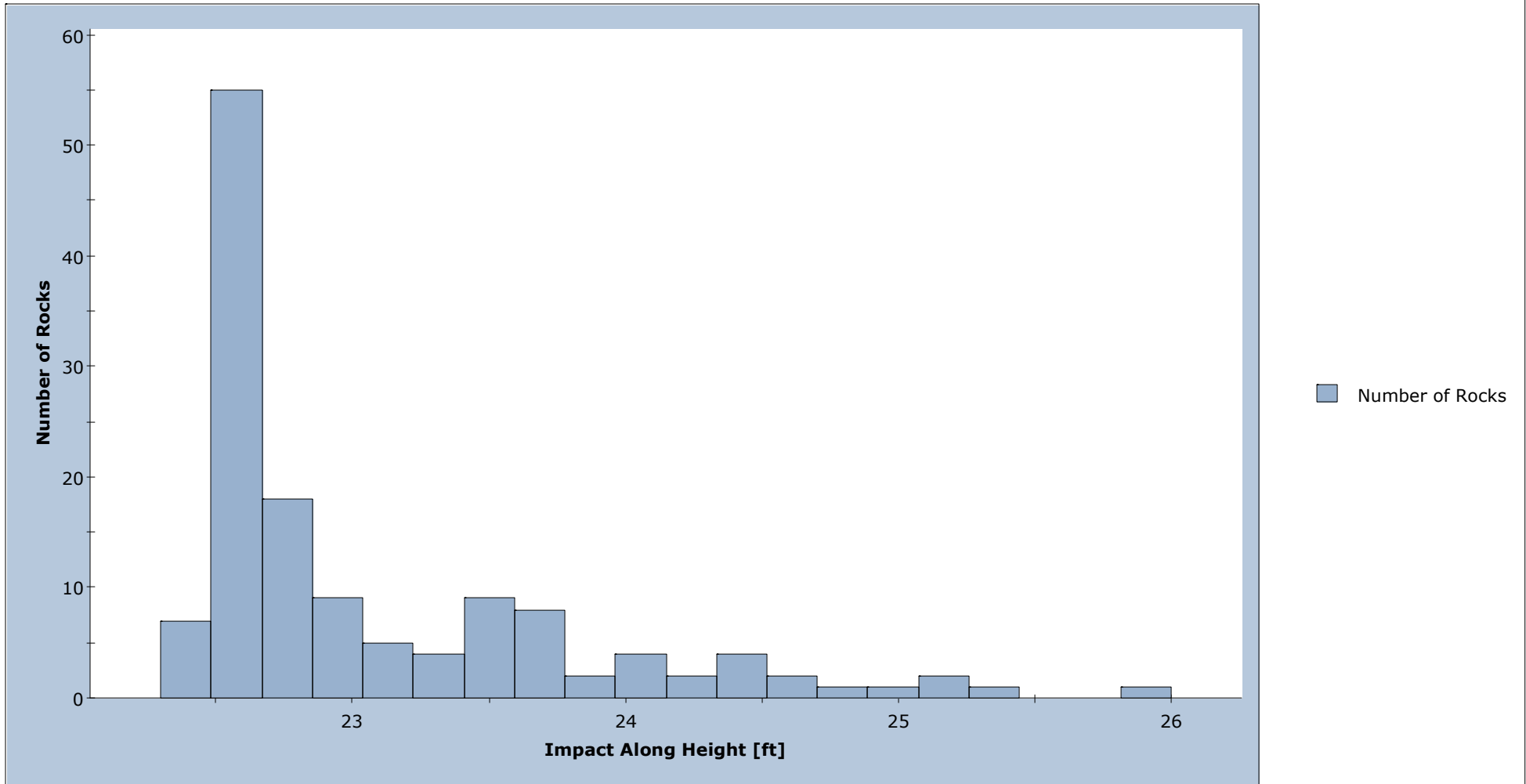
Distribution of Rock Path End Locations




Total number of rock paths: 972

	<i>Project</i> Laupahoehoe Point and Waipi'o Valley Road Project	
	<i>Analysis Description</i> Traverse WR4 - Existing Conditions with Horizontal Velocity	
	<i>Drawn By</i> A. Granger and N. Lescalleet	<i>Company</i> Haley & Aldrich, Inc.
	<i>Date</i> November 2020	<i>File Name</i> 135500-003_WR4-Traverse.fal8

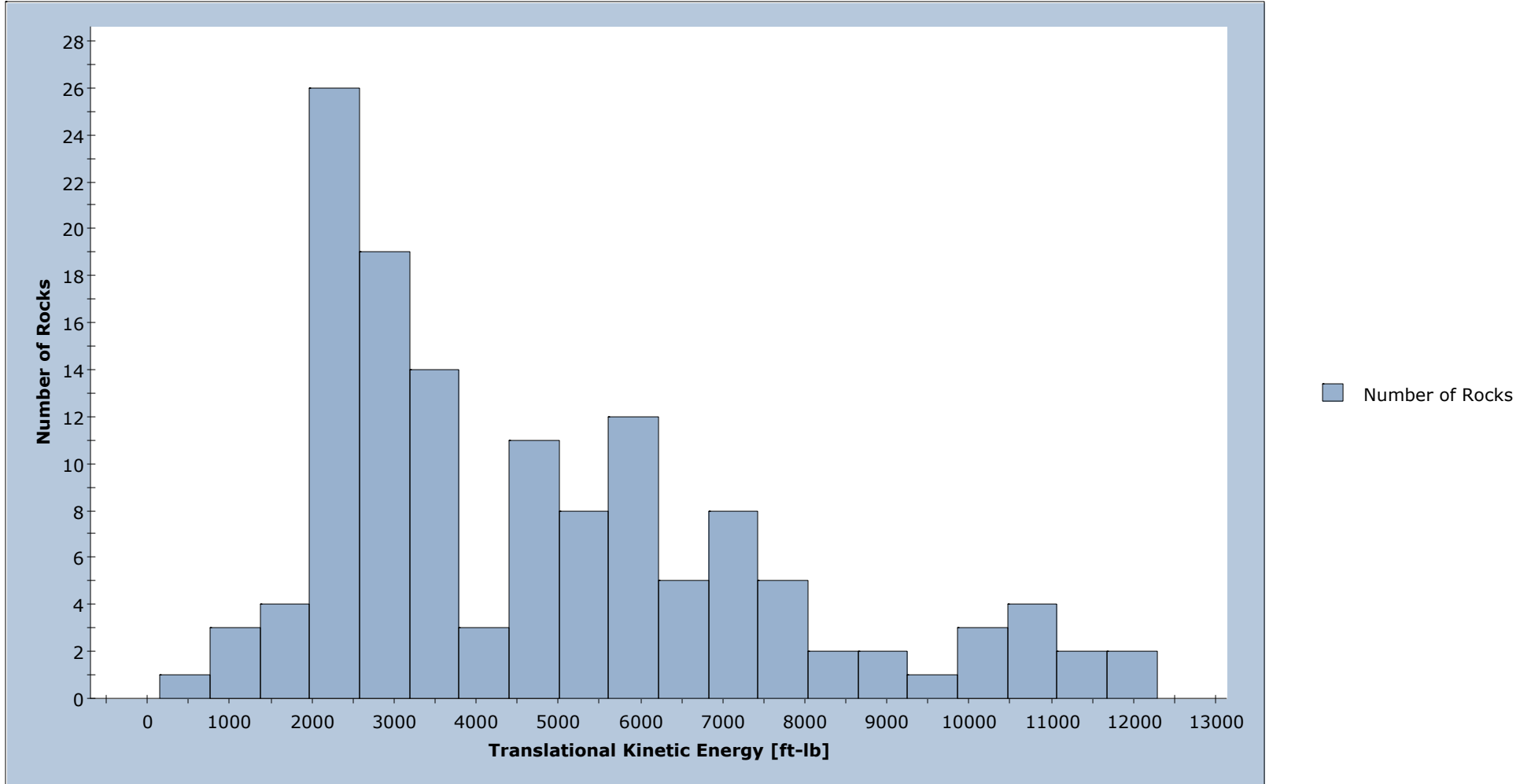
Impact Along Height on EOP



Total number of rocks on EOP: 135
Impact Along Height: min = 22.391, max = 25.9056

	<i>Project</i> Laupahoehoe Point and Waipi'o Valley Road Project	
	<i>Analysis Description</i> Traverse WR4 - Existing Conditions with Horizontal Velocity	
	<i>Drawn By</i> A. Granger and N. Lescalleet	<i>Company</i> Haley & Aldrich, Inc.
	<i>Date</i> November 2020	<i>File Name</i> 135500-003_WR4-Traverse.fal8

Translational Kinetic Energy on EOP



Total number of rocks on EOP: 135
Translational Kinetic Energy: min = 457.477, max = 11981.5


	<i>Project</i> Laupahoehoe Point and Waipi'o Valley Road Project		
	<i>Analysis Description</i> Traverse WR4 - Existing Conditions with Horizontal Velocity		
	<i>Drawn By</i> A. Granger and N. Lescalleet		<i>Company</i> Haley & Aldrich, Inc.
	<i>Date</i> November 2020		<i>File Name</i> 135500-003_WR4-Traverse.fal8

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135500-003_WR4-Traverse

Laupahoehoe Point and Waipi'o Valley Road Project

Project Summary

File Name	135500-003_WR4-Traverse.fal8
File Version	8.012
Project Title	Laupahoehoe Point and Waipi'o Valley Road Project
Analysis	Traverse WR4 - Existing Conditions with Horizontal Velocity
Author	A. Granger and N. Lescalleet
Company	Haley & Aldrich, Inc.
Date Created	November 2020

Project Settings

General Settings

Engine	Rigid Body
Units	Imperial Foot-Pounds (ft, lb, ft-lb)
Rock throw mode	1000 rocks thrown overall
Use tangential CRSP damping	Yes

Engine Conditions

Maximum time per rock (s)	10
Maximum steps per rock	200000
Normal velocity cutoff (ft/s)	0.33
Stopped velocity cutoff (ft/s)	0.33
Maximum timestep (s)	0.01
Switch velocity (ft/s)	-3.3e-09

Random Number Generation

Sampling method	Monte-Carlo
Random seed	Pseudo-random seed: 12345234

Slope Geometry

Vertex	X	Y	X Std.Dev.	Y Std.Dev.
1	0	1019.89		
2	49.83	974.29		
3	153.27	929.63		
4	195.28	845.92		
5	234.17	790.84		
6	317.15	722.16		
7	474.34	590.95		
8	569.89	476.08		
9	582.64	476		
10	582.64	473.31		
11	633.36	411.53		
12	722.9	309		
13	722.9	287.61		
14	736.96	288		


Slope Material Assignment

Material	From Vertex	To Vertex
Soil Slope wth Veg	1	8
Hawaii Basalt	8	9
Bedrock Outcrops	9	10
Soil Slope wth Veg	10	11
Outcrops with Soil and Veg	11	12
Bedrock Outcrops	12	13
Asphalt	13	14

Material Properties

Bedrock Outcrops

"Bedrock Outcrops" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.85	Normal	0.04	0.12	0.12
Dynamic Friction	0.55	Normal	0.04	0.12	0.12
Rolling Friction	0.15	Normal	0.02	0.06	0.06

"Bedrock Outcrops" Advanced Properties

Forest and Vegetation Damping	Disabled
Scarring	Disabled
Viscoplastic Damping	Disabled

Hawaii Basalt

"Hawaii Basalt" Properties


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.35	Normal	0.04	0.12	0.12
Tangential Restitution	0.8	Normal	0.04	0.12	0.12
Dynamic Friction	0.7	Normal	0.04	0.12	0.12
Rolling Friction	0.5	Normal	0.02	0.06	0.06

"Hawaii Basalt" Advanced Properties

Forest and Vegetation Damping	Enabled
Effective Forest Height(ft)	15.00
Forest Drag Coefficient(lb/s)	550.00
Scarring	Disabled
Viscoplastic Damping	Disabled

Outcrops with Soil and Veg


"Outcrops with Soil and Veg" Properties

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.33	Normal	0.04	0.12	0.12
Tangential Restitution	0.78	Normal	0.04	0.12	0.12
Dynamic Friction	0.62	Normal	0.04	0.12	0.12
Rolling Friction	0.7	Normal	0.02	0.06	0.06
Slope Roughness	5	Normal	0.2	0.6	0.6
Spacing					
Slope Roughness Amplitude	0.5	Normal	0.1	0.3	0.3

"Outcrops with Soil and Veg" Advanced Properties

Forest and Vegetation Damping	Enabled
Effective Forest Height(ft)	15.00
Forest Drag Coefficient(lb/s)	1100.00
Scarring	Disabled
Viscoplastic Damping	Disabled

Soil Slope wth Veg**"Soil Slope wth Veg" Properties**


Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.3	Normal	0.04	0.12	0.12
Tangential Restitution	0.7	Normal	0.04	0.12	0.12
Dynamic Friction	0.58	Normal	0.04	0.12	0.12
Rolling Friction	0.75	Normal	0.02	0.06	0.06

"Soil Slope wth Veg" Advanced Properties

Forest and Vegetation Damping	Enabled
Effective Forest Height(ft)	20.00
Forest Drag Coefficient(lb/s)	550.00
Scarring	Disabled
Viscoplastic Damping	Disabled

Asphalt

"Asphalt" Properties

Color					
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Normal Restitution	0.4	None			
Tangential Restitution	0.9	None			
Dynamic Friction	0.58	None			
Rolling Friction	0.4	None			

"Asphalt" Advanced Properties

Forest and Vegetation Damping	Disabled
Scarring	Disabled
Viscoplastic Damping	Disabled

Seeders

OC-1

Seeder Properties

Name OC-1
Location (548.348, 501.978)

Rocks to Throw

Number of Rocks Set in Project Settings
Rock Types HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-5

Seeder Properties

Name TP-5
Location (317.15, 722.16)

Rocks to Throw

Number of Rocks Set in Project Settings
Rock Types HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-2

Seeder Properties

Name TP-2
 Location (153.27, 929.63)

Rocks to Throw

Number of Rocks Set in Project Settings
 Rock Types HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Bench - TP-7**Seeder Properties**

Name Bench - TP-7
 Location (569.89, 476.08),
 (582.64, 476),
 (582.64, 473.31)

Rocks to Throw

Number of Rocks Set in Project Settings
 Rock Types HI Basalt Rock Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Roadcut

Seeder Properties

Name Roadcut
 Location (722.9, 309),
 (722.9, 287.61)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks

Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

TP-10a, OC-2**Seeder Properties**

Name TP-10a, OC-2
 Location (722.9, 309),
 (633.36, 411.53)

Rocks to Throw

Number of Rocks Set in Project
 Settings
 Rock Types HI Basalt Rock
 Blocks


Initial Conditions

	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Horizontal Velocity (ft/s)	10	Normal	1	3	3
Vertical Velocity (ft/s)	0	None			
Rotational Velocity (deg/s)	0	None			
Initial Rotation (deg/s)	0	Uniform		0	360

Rock Types

HI Basalt Rock Blocks

Properties

Name	HI Basalt Rock Blocks				
Color					
Smooth Shapes	Hexagon,		Rhombus		
Polygons	None				
	Mean	Distribution	Std.Dev.	Rel. Min	Rel. Max
Mass (lb)	1529.8	Normal	10	30	30
Density (lb/ft3)	170	Normal	5	15	15

Collectors

Record paths' first impacts only? No

EOP

Name EOP

Location (723.4, 287.61) to (723.4, 387.61)

Summary Results

Run Properties

Simulation Time (s)	1196.87		
Envelope data:			
	Max	Mean	95%
Envelope Bounce Height (ft)	25.05	23.26	24.43
Envelope Total Kinetic Energy (ft-lb)	3.801e+04	2.503e+04	3.801e+04
Envelope Translational Kinetic Energy (ft-lb)	3.536e+04	2.419e+04	3.536e+04
Envelope Rotational Kinetic Energy (ft-lb)	6977	3484	6977
Envelope Translational Kinetic Velocity (ft/s)	38.74	31.36	38.74
Envelope Rotational Kinetic Velocity (rad/s)	21.18	14	21.18

Stopping Reason

CONTINUE	0
Invalid Start Location	1
Invalid Slope Geometry	0
Invalid bad crest loss definition	0
Invalid relative size between rock and slope	0
Max Compute Time	267
Max Steps	0
Edge Model	153
Stopped	552
Stopped (wedged)	0
Stopped (chattering)	0
Hit Barrier	0
Hit Berm with infinite capacity	0
No collision found	0
Bad Collision Geometry (location before)	27
Rock is freefalling onto a spike or a trough	0
END_ERROR_UNKNOWN	0
END_ERROR_POSITIVE_GAP	0
Bad collision calculation	0
Bad Collision Geometry (0 intersection)	0
Bad Collision Geometry (location after)	0
Bad Collision Geometry (missing intersection)	0
Error during results reading	0
Total Rocks	1000

Collector(s) Impact Results

EOP

Barrier Name EOP
Hits 135 / 1000 rocks

Impact Statistics

Based on actual values for all impacted rocks.

	Mean	Min	Max
Impact Along Height (ft)	23.07	22.39	25.91
Translational Velocity (ft/s)	13.63	4.39	22.54
Translation Energy (ft-lb)	4773.05	457.48	11981.55