VANN ENGINEERING INC

BOULDER STABILITY EVALUATION

PROPOSED CUSTOM HILLSIDE RESIDENCE
HBL
APN 169-04-007
7550 NORTH HUMMINGBIRD LANE
PARADISE VALLEY, AZ 85253

Prepared for:

Ethan Wessel
Tennen Studio
4702 East Indian School Road
Phoenix, Arizona 85018

July 30, 2018

Project 25998

July 30, 2018 Project 25998

Mr. Ethan Wessel
Tennen Studio
4702 East Indian School Road
Phoenix, Arizona 85018

RE: BOULDER STABILITY EVALUATION
PROPOSED CUSTOM HILLSIDE RESIDENCE
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APN 169-04-007
7550 NORTH HUMMINGBIRD LANE
PARADISE VALLEY, AZ 85253

Mr. Wessel:

Transmitted herewith is a copy of the final report of the boulder stability evaluation for the above-mentioned project. As an additional service, this firm would be pleased to review the project plans and structural notes for conformance to the intent of this report. We trust that this report will assist you in the design and construction of the proposed project. Vann Engineering, Inc. appreciates the opportunity to provide our services on this project and looks forward to working with you during construction and on future projects. **This firm possesses the capability of performing testing and inspection services during the course of construction**. Should any questions arise concerning the content of this report, please feel free to contact this office at your earliest convenience.

Respectfully submitted,

VANN ENGINEERING, INC.

Registered Professional Engineer (Geological)
CERTIFICATE NO. 15206
JEFFRY D. VANN
Date Signed 7/30/18
ARIZONA, U.S.A.
Expires 09/30/19

Austin H. Olaiz, MS, EIT
Staff Geotechnical Engineer

Jeffry D. Vann, MS PE D.GE F. ASCE
Principal Engineer

Copies: (2) Addressee, and via email ethan@tennenstudio.com

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SECTION I

1: INTRODUCTION

This document presents the results of a boulder stability evaluation conducted by Vann Engineering, Inc. for:

PROPOSED CUSTOM HILLSIDE RESIDENCE
HBL
APN 169-04-007
7550 NORTH HUMMINGBIRD LANE
PARADISE VALLEY, AZ 85253

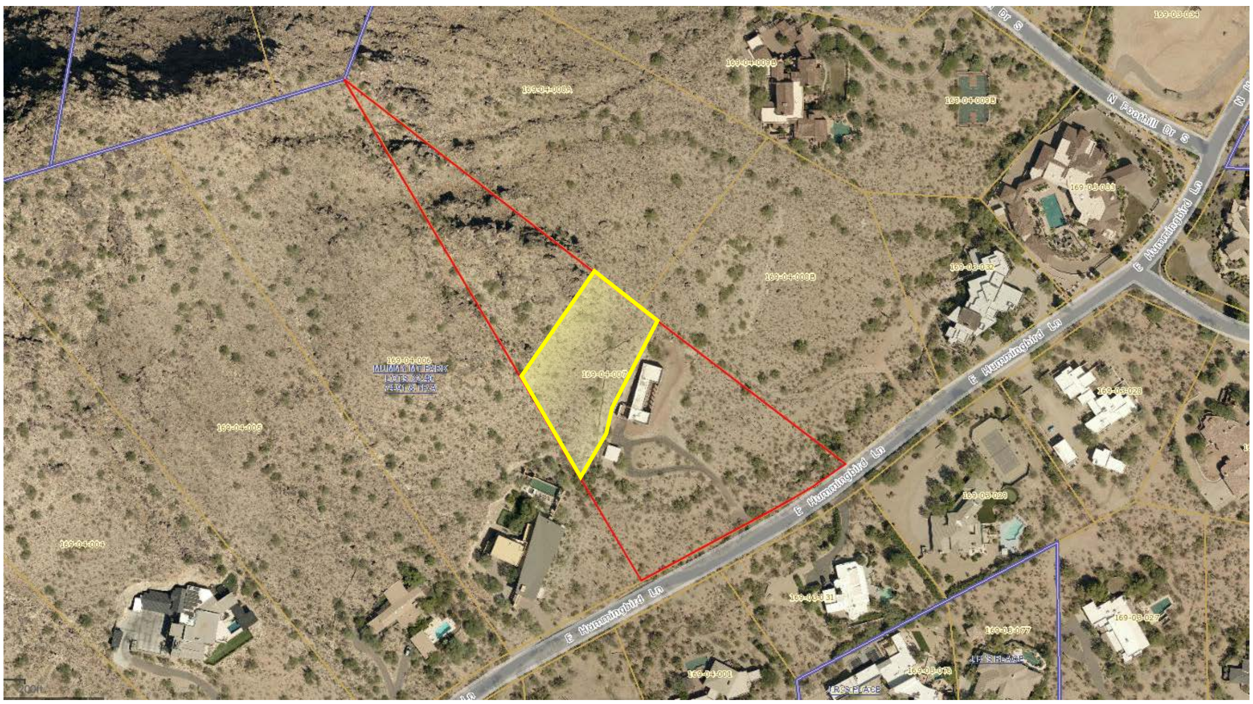


Figure 1: Aerial photograph of site (outlined in red) and general location of the precariously balanced rocks (outlined in yellow)

It must be noted that this report and the recommendations contained herein are predicated on three reports serving in congress; 1) this report, 2) the Geotechnical Investigation Report dated July 30, 2018, and 3) the Rock Cut Slope Stability Analysis dated July 30, 2018. This report is, therefore, a portion of the overall study of the site. Because of the uniqueness of each report, the contents are constrained to separate submittals. Notwithstanding, all three reports will work together. All three reports are identified by the Project Number 25998.

1.1: Purpose

The purpose of the investigation was to deterministically and probabilistically analyze the immediate and long-term stability of a boulder or boulder cluster at the subject site and provide remedial recommendations if warranted.

1.2: Scope of Services

The scope of services for this project includes the following:

- Description of the subject site
- Photographic documentation of boulders of concern
- Site Plan indicating the locations of all boulders that were analyzed
- 2012 IBC site classification
- Description of the local geology
- Pseudo-static modeling to determine the stability of the boulder or boulder cluster
- Recommendations for mitigation, if necessary, of the boulder or boulder cluster to obtain a safe and confident factor of safety against possible boulder mobilization (sliding and rocking)
    - Two-dimensional illustration of recommended boulder stabilization protocol
    - Recommendations for aesthetic modifications to any materials used in the stabilization efforts in order to sustain the natural view of the boulder cluster.

Note: This report does not include, either specifically or by implication, any environmental assessment of the site. If the owner is concerned about the potential for such contamination, other studies should be undertaken. We are available to discuss the scope of work of such studies with you.

It must be noted that this report and the recommendations contained herein are predicated on three reports serving in congress; 1) this report, 2) the Geotechnical Investigation Report dated July 30, 2018, and 3) the Rock Cut Slope Stability Analysis dated July 30, 2018. This report is, therefore, a portion of the overall study of the site. Because of the uniqueness of each report, the contents are constrained to separate submittals. Notwithstanding, all three reports will work together. All three reports are identified by the Project Number 25998.

1.3: Authorization

The obtaining of data from the site and the preparation of this boulder stability evaluation have been carried out according to this firm's revised proposal (**VE18GT0605SM1 dated 06/20/18**), electronically authorized by **Ethan Wessel on 07/02/18**, to proceed with the work. Our efforts and report are limited to the scope and limitations as set forth in the proposal**.**

This study is a portion of the overall project scope, which encompasses the general geotechnical site investigation and a slope stability analysis for which separate reports have been generated. All accompanied reports can be identified by the project number 25998.

1.4: Standard of Care

Since our investigation is based upon review of background data, observation of site materials, and engineering analysis, the conclusions and recommendations are professional opinions. Our professional services have been performed using that degree and skill ordinarily exercised, under similar circumstances, by reputable geotechnical engineers practicing in this or similar localities. These opinions have been derived in accordance with current standards of practice and no other warranty, express or implied, is made. The limitations of this report and geotechnical issues which further explain the limitations of the information contained in this report are listed at 7.0.

2: PROJECT DESCRIPTION

2.1: Site Description

The subject site is currently occupied by an existing residential structure, detached garage, and asphalt driveway. It is the understanding of this firm that all of the existing structures and hardscape are to be demolished as part of the proposed new custom residence. An existing cut slope, ranging from 5.0 to 16.0 feet high, is present along the west edge of the proposed build area. Several boulders were observed within 10.0 feet of the crest of the cut slope. All boulders evaluated in this study (13 in total) were located within a 200 linear-foot radius upslope from the proposed build area. Refer to the aerial site plan, GPS coordinates, and photographs in Section II of this report for the approximate locations of the studied boulders, which are denoted as B-1 through B-13.

2.2: Site Geology

The site is located on Mummy Mountain which is considered part of the Phoenix Mountains. Locally, the site is situated on a thin layer of colluvium overlying early Proterozoic meta-sedimentary rocks comprised primarily of quartz-muscovite schist (Xqms).

The boulders evaluated in this study are large fragments which have broken off from the parent rock up slope. Several of the boulders are considered by this firm to be precariously balanced rocks (PBR) due to the relatively steep underlying slope and the shape of the boulder.

2.2.1: Seismic Design Parameters

This project is not located over any known active faults or fault associated disturbed zones. The 2012 IBC Site Classification **B (should foundations bear within 10 feet of the B / C boundary)**, determined from the seismic refraction survey analysis, will be used to determine the seismic coefficient, described herein, necessary for the pseudo-static analysis of the subject boulders. The results of the seismic refraction surveys are presented in the accompanying Geotechnical Investigation Report (#25998). The following parameters obtained from the U.S. Geologic Survey Earthquake Design Maps (adopted by 2009 NEHRP and 2012 IBC) are required for the determination of the site's seismic coefficient.

Table 1: Seismic Parameters

Parameter	Value (USGS)	Definition
S_1	0.061g	Spectral Response Acceleration Parameter at 1.0-Second Period
F_V	1.0	Site Coefficient[1]
PGA	0.077g	Mapped MCE[2] Geometric Mean Peak Ground Acceleration
F_{PGA}	1.0	Site Coefficient[1]

[1]See Section 11.4.7 of ASCE 7

[2]Maximum considered earthquake

3: STATIC STABILITY MODELING

The static stability of large boulders, also known as precariously balanced rocks (PBRs), is affected by a combination of several parameters including: boulder geology, shape, weight, points of contact with slope/pedestal, slope/pedestal geology, slope/pedestal contact angle, and the potential applied loading.

The probability of potential boulder movement translationally down slope (sliding) and rotationally down slope (rocking) is modeled using a pseudo-static analysis. A pseudo-static analysis allows dynamic forces to be applied to a static scenario via an equivalent force. To account for the variability of the measured parameters in the closed form solution, a 3-point Rosenbleuth analysis was used. The Rosenbleuth 3-point method can be used to determine the reliability of the stability of the boulder (i.e. probability of movement) and the factor of safety (FS).

The magnitude of potential movement resulting from the limit equilibrium analysis cannot be determined. However, due the nature of the contact points between the subject boulders and their underlying rock mass, minimal movement of any boulder can cause an unwanted reaction from any boulder in contact.

The results of the static stability modeling aid in the determination of active mitigation of the subject boulders. Active mitigation is the reduction of driving forces and/or the increase of resisting forces associated potential boulder movement. The stabilization of boulders can be accomplished by a variety of construction methods, including pinning, netting, and grouting. The method for stabilization differs on individual site conditions.

Each boulder will be modeled under 4 separate conditions as listed below:

1. In situ Condition
2. Vibrational shaking from a seismic force
3. Erosion of the underlying slope/pedestal
4. Grouting of the void space between base of the boulder and the underlying slope (possible stabilization technique) if required by the 3 previous simulations.

The results of the models are presented as the factor of safety (FS) and the probability of movement. **A boulder is determined to be stable if the factor of safety is greater or equal to 1.5 and the probability of movement is less than or equal to 10%.** If a boulder does not meet both of the design requirements for a given simulation, stabilization of the boulder is warranted.

3.1: Field Measurements

From the field investigation, the following parameters affecting the stability of the subject boulders were determined and are tabulated below. The accuracy/range is based on the level of confidence in the measurement of described parameter.

Table 2: Measured Parameters Effecting Boulder Stability

Boulder ID	Width (ft)		Height (ft)		Base Length (ft)		Slope Angle (°)		Contact Percentage (%)		Contact Friction Angle (°)	
	w	±	*h*	±	*b*	±	*β*	±	C_p	±	*Φ*	±
B-1	7	0.25	5.5	0.25	5	0.25	20	5	85	10	38	4
B-2	3	0.25	3.5	0.25	2.5	0.25	20	5	90	10	38	4
B-3	3.5	0.25	3.5	0.25	4	0.25	20	5	95	5	38	4
B-4	5	0.25	5.5	0.25	3.5	0.25	10	5	65	15	38	4
B-5	4	0.25	4.5	0.25	3	0.25	15	5	50	15	38	4
B-6	4	0.25	5.5	0.25	3.5	0.25	20	5	85	10	38	4
B-7	4.5	0.25	2.5	0.25	3	0.25	15	5	35	15	40	4
B-8	5.5	0.25	7	0.25	6	0.25	25	5	95	5	38	4
B-9	4.5	0.25	3	0.25	1.5	0.25	15	5	35	15	40	4
B-10	3.5	0.25	3	0.25	2	0.25	10	5	50	10	40	4
B-11	5	0.25	4	0.25	2	0.25	15	5	40	15	40	4
B-12	3.5	0.25	3.5	0.25	3	0.25	20	5	90	10	40	4
B-13	5.5	0.25	3.5	0.25	4	0.25	20	5	70	15	40	4

Based the number of parameters affecting the boulder's stability, and the given ranges, 2187 models were simulated for each specific boulder and loading condition.

3.2: In Situ Condition

Modeling the boulder in its in-situ state, with no externally applied forces (i.e. seismic shaking), provides a maximum factor of safety and probability of movement, which can be used as a base to judge the magnitude of effects of potential earthquake shaking and loss of frictional resistance due to erosion.

The following table summarizes the results from the static condition stability analysis movement. Note that overturning potential is not presented here because a boulder will never have a potential to rock unless an external force is applied.

Table 3: Stability Results – In Situ Condition

Boulder ID	FS	Probability of Movement
B-1	1.83	≤ 10%
B-2	1.94	≤ 10%
B-3	2.05	≤ 10%
B-4	2.90	≤ 10%
B-5	1.47	17%
B-6	1.83	≤ 10%
B-7	1.10	42%
B-8	1.60	≤ 10%
B-9	1.10	41%
B-10	2.39	≤ 10%
B-11	1.26	30%
B-12	2.09	≤ 10%
B-13	1.62	≤ 10%

The analysis of the natural state of the boulder results in B-5, B-7, B-9, and B-11 not meeting the design criteria the factor of safety greater or equal to 1.5 and/or the probability of movement less than or equal to 10%.

3.3: Seismic Loading Condition

Vibrational waves caused by earthquakes, excavation blasting, or heavy construction equipment are a leading cause of soil/rock movement including: slope failures, liquefaction, and boulder/rock falls. The effects of blasting and heavy equipment are able to be monitored and controlled, however seismic shaking from earthquakes cannot be predicted. As such, the stability of the subject boulders was modeled under an applied seismic load.

A pseudo-static analysis approach is used to model the boulder's response to an equivalent seismic force. The equivalent seismic force is determined from the site's seismic coefficient (k_s), which is based on the site's earthquake history, and the weight of boulder. The parameters necessary for the determination of the seismic coefficient are referenced from USGS and were previously presented in Table 1. From these parameters, the site's seismic coefficient has been determined to range from 0.05g to 0.07g.

The following table summarizes the results from the pseudo-static stability analysis with the applied seismic load.

Table 4: Stability Results - Seismic Shaking

Boulder ID	Sliding		Overturning	
	FS	Probability of Movement	FS	Probability of Movement
B-1	1.50	≤ 10%	5.81	≤ 10%
B-2	1.59	≤ 10%	3.9	≤ 10%
B-3	1.68	≤ 10%	7.79	≤ 10%
B-4	2.05	≤ 10%	5.87	≤ 10%
B-5	1.14	36%	4.78	≤ 10%
B-6	1.50	≤ 10%	3.12	≤ 10%
B-7	0.86	64%	9.95	≤ 10%
B-8	1.35	≤ 10%	3.96	≤ 10%
B-9	0.86	66%	2.84	≤ 10%
B-10	1.69	≤ 10%	6.17	≤ 10%
B-11	0.98	52%	2.86	≤ 10%
B-12	1.71	≤ 10%	5.3	≤ 10%
B-13	1.33	17%	7.79	≤ 10%

Although the potential of the subject boulders to rock was increased by the application of the seismic force, the results of the model portray that the subject boulder's probability to rock during a seismic event is low. However, the analysis results in B-5, B-7, B-9, B-11, and B-13 not meeting the design criteria the factor of safety greater or equal to 1.5 and/or the probability of movement less than or equal to 10%.

3.4: Weathering and Erosional Effects

As previously discussed, prolonged rainfall and wind have the ability to reduce a boulder's resistance to potential movement by eroding the frictional strength and/or shrinking the contact area between the boulder and its underlying rock mass. As such, the stability of the subject boulders was modeled with a reduction of frictional resistance of 25% of the current static condition.

The following table summarizes the results from the pseudo-static stability analysis with the reduction of frictional resistance. The potential of rocking movement is not required to be analyzed for weathering effects.

Table 5: Stability Results – Erosion Effects

Boulder ID	FS	Probability of Movement
B-1	1.38	12%
B-2	1.46	≤ 10%
B-3	1.54	≤ 10%
B-4	2.17	≤ 10%
B-5	1.10	42%
B-6	1.38	17%
B-7	0.83	64%
B-8	1.20	20%
B-9	0.83	63%
B-10	1.79	≤ 10%
B-11	0.94	54%
B-12	1.56	≤ 10%
B-13	1.22	29%

The analysis of the effects of potential erosion results in the FS and probability of downhill translation movement (sliding), for B-1, B-2, B-5, B-6, B-7, B-8, B-9, B-11, and B-13, which do not meet the design criteria.

3.5: Summary of Stability Analysis

The following table summarizes the results of the 3 boulder simulations. An "X" indicates that the boulder did not meet both of the design criteria. As previously stated, if a boulder does not meet both of the design requirements for a given simulation, stabilization of the boulder is warranted.

Table 5: Summary of Stability Results

Boulder ID	In Situ	Seismic Shaking		Base Erosion	Stabilization Required
	(Sliding)	(Sliding)	(Toppling)	(Sliding)	
B-1	-	-	-	X	**yes**
B-2	-	-	-	X	**yes**
B-3	-	-	-	-	-
B-4	-	-	-	-	-
B-5	X	X	-	X	**yes**
B-6	-	-	-	X	**yes**
B-7	X	X	-	X	**yes**
B-8	-	X	-	X	**yes**
B-9	X	X	-	X	**yes**
B-10	-	-	-	-	-
B-11	X	X	-	X	**yes**
B-12	-	-	-	-	-
B-13	-	X	-	X	**yes**

Based on the results of the analysis, a total of 9 of the evaluated 13 boulders will require stabilization in order to meet the design stability requirements (B-1, B-2, B-5, B-6, B-7, B-8, B-9, B-11, and B-13). Since the all the potential movement is of the down hill sliding nature, grouting of the void space between the boulder base and the underlying slope/pedestal will be considered as the first stabilization technique.

3.6: Boulder Stabilization Model (Grouting)

Grouting the base of the boulder increases the contact percentage of the boulder to the underlying slope/pedestal and decreases the potential for erosion within that area. To model this scenario, the contact percentage between the base of the boulder and the underlying slope/pedestal was set to 100%. Although B-3, B-4, B-10, and B-12 were determined to be stable in their natural state, they are included in this simulation in the event that an increased FS is desired at the time of construction.

The following table summarizes the results from the pseudo-static stability analysis with the 100% contact between the boulder and the underlying slope/pedestal. The seismic force was also applied in this simulation.

Table 6: Stability Results – Stabilization via Grouting

Boulder ID	FS	Probability of Movement
B-1	2.16	≤ 10%
B-2	2.16	≤ 10%
B-3	2.16	≤ 10%
B-4	4.45	≤ 10%
B-5	2.93	≤ 10%
B-6	2.16	≤ 10%
B-7	3.15	≤ 10%
B-8	1.68	≤ 10%
B-9	3.15	≤ 10%
B-10	4.79	≤ 10%
B-11	3.16	≤ 10%
B-12	2.32	≤ 10%
B-13	2.32	≤ 10%

All of the 13 evaluated boulders, 9 were determined to require stabilization. As such, grouting of the void space between the boulder base and the underlying slope/pedestal is considered by this firm to be a feasible technique to limit potential boulder movement at the site. No rock bolts will be necessary. Further recommendations for grouting and stabilization/removal of boulders not directly evaluated in this study are presented herein.

4: RECOMMENDATIONS FOR BOULDER STABILITY

All boulders within 10.0 feet of the crest of the existing cut slope must be removed prior to any blasting, demolition, earthwork, or other construction activities that may induce vibrations on site. Boulders are defined by rock fragments with any dimension greater than 3.0 feet.

4.1: Boulder Stabilization (Grouting)

It is recommended that the boulder stabilization is conducted before any blasting, demolition, earthwork, or other construction activities that may induce vibrations on site.

The voids between the boulders (B-1, B-2, B-5, B-6, B-7, B-8, B-9, B-11, and B-13). and the underlying slope/pedestal should be filled with 4000 psi non-shrink grout (ASTM C1107). Any smaller boulders wedged between the subject boulders and the underlying rock mass should be encompassed within the grout as well. On the downhill side of the boulder, the top soil should be removed so that the grout makes clean contact with the underlying rock. The grout should be formed on the downhill side of the boulder to create a buttress. Refer to the Boulder Mitigation Protocol detail sheet in Section II of this report.

The location of each boulder to be stabilized must be confirmed by this firm prior to grouting.

Furthermore, any smaller boulders or rock fragments (without a dimension greater than 3.0 feet) which sit atop other boulders should be removed, as depicted in the figure below. The stability of such boulders/rock fragments was not directly evaluated in this study; however, it is the opinion of this firm that such scenario presents a high potential for movement.

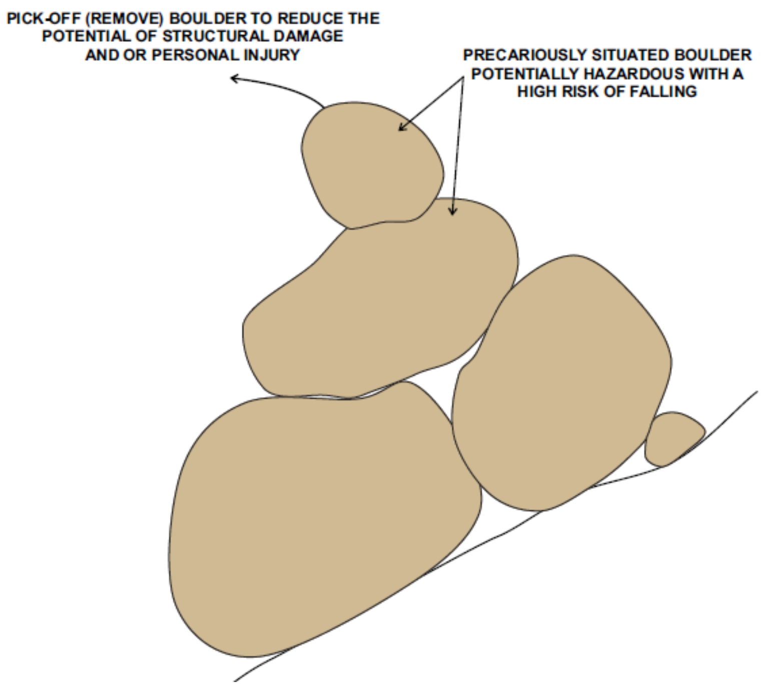


Figure 2: Boulder pick-off illustration

4.2: Aesthetics

In order to maintain the natural aesthetics of the boulder cluster and surrounding environment the following recommendations should be met during the construction process.

- Precautions should be taken during the time of construction to avoid any disturbance or unnecessary removal of existing vegetation caused by the presence and use of construction personal, materials, and equipment such as concrete spillage, placement of drilling tools, depressions from base of scaffolding, etc.
- Forms should be utilized to minimize concrete overflow during the pouring process.
- All exposed concrete should be finished with faux rock, on equivalent textured paint. If the faux rock is mixed into the concrete design, the minimum compressive strength of the mix must still meet the requirements set forth herein.

Vann Engineering, Inc. holds no responsibility for any disturbance to the natural environment of the site, not including the recommended mitigation of the subject boulders.

5: ADDITIONAL SERVICES

As an additional service, this firm would be pleased to review the project plans for conformance to the intent of this report. Vann Engineering, Inc. should be retained to provide documentation that the recommendations set forth are met. This firm possesses the capability of performing testing and inspection services during the course of construction. Such services include, pinning inspections and concrete sampling. Please notify this firm if a proposal for these services is desired.

6: LIMITATIONS

This report is not intended as a bidding document, and any contractor reviewing this report must draw his own conclusions regarding specific construction techniques to be used on this project. The scope of services carried out by this firm does not include an evaluation pertaining to environmental issues. If these services are required by the lender, we would be most pleased to discuss the varying degrees of environmental site assessments.

This report is issued with the understanding that it is the responsibility of the owner to see that its provisions are carried out or brought to the attention of those concerned. In the event that any changes of the proposed project are planned, the conclusions and recommendations contained in this report shall be reviewed and the report shall be modified or supplemented as necessary. Prior to construction, we recommend the following:

1. Consultation with the design team in all areas that concern soils and rocks to ensure a clear understanding of all key elements contained within this report.
2. This firm be notified of all specific areas to be treated as special inspection items (designated by the architect, structural engineer or governmental agency).

Relative to this firm's involvement with the project during the course of construction, we offer the following recommendations:

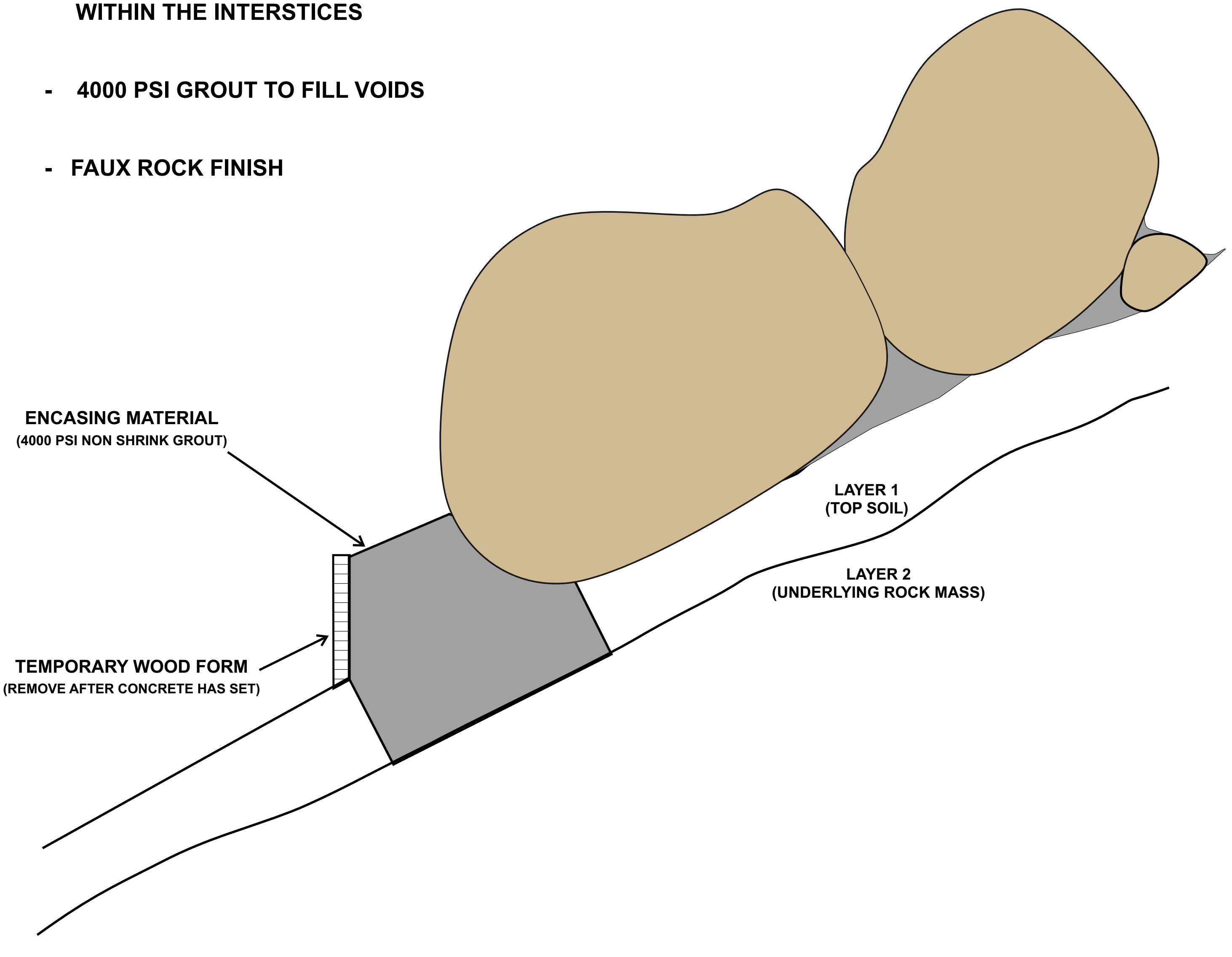
1. The site or development owner should be directly responsible for the selection of the geotechnical consultant to provide testing and observation services during the course of construction.
2. This firm should be contracted by the owner to provide the course of construction testing and observation services for this project, as we are most familiar with the interpretation of the methodology followed herein.
3. All parties concerned should understand that there exists a priority surrounding the testing and observation services completed at the site.

It must be noted that this report and the recommendations contained herein are predicated on three reports serving in congress; 1) this report, 2) the Geotechnical Investigation Report dated July 30, 2018, and 3) the Rock Cut Slope Stability Analysis dated July 30, 2018. This report is, therefore, a portion of the overall study of the site. Because of the uniqueness of each report, the contents are constrained to separate submittals. Notwithstanding, all three reports will work together. All three reports are identified by the Project Number 25998.

SECTION II

BOLDER MITIGATION PROTOCOL

- POWER WASH LOOSE SOIL AND DEBRIS FROM THE AREAS TO BE GROUTED
- REMOVE ALL LOOSE ROCK FRAGMENTS AND VEGETATION WITHIN THE INTERSTICES
- 4000 PSI GROUT TO FILL VOIDS
- FAUX ROCK FINISH



VANN ENGINEERING INC

BOULDER LOCATIONS N

PROPOSED CUSTOM HILLSIDE RESIDENCE
HBL
APN 169-04-007
7550 NORTH HUMMINGBIRD LANE
PARADISE VALLEY, AZ 85253

DATE: 7/30/2018
PREPARED BY: AHO
SCALE: NTS

PROJECT 25998

VANN ENGINEERING INC

Boulder GPS Coordinates & Photographs

PROPOSED CUSTOM HILLSIDE RESIDENCE
HBL
APN 169-04-007
7550 NORTH HUMMINGBIRD LANE
PARADISE VALLEY, AZ 85253

Boulder ID	North	West
B-1	33° 32' 52.1"	111° 57' 7.7"
B-2	33° 32' 51.7"	111° 57' 7.8"
B-3	33° 32' 51.7"	111° 57' 7.8"
B-4	33° 32' 51.7"	111° 57' 7.8"
B-5	33° 32' 51.6"	111° 57' 8.3"
B-6	33° 32' 51.8"	111° 57' 8.3"
B-7	33° 32' 51.4"	111° 57' 9.2"
B-8	33° 32' 51.1"	111° 57' 9.3"
B-9	33° 32' 50.8"	111° 57' 9.6"
B-10	33° 32' 50.5"	111° 57' 9.9"
B-11	33° 32' 50.3"	111° 57' 9.8"
B-12	33° 32' 50.4"	111° 57' 95"
B-13	33° 32' 50.4"	111° 57' 8.9"

B-1 (north facing)

B-2 (southwest facing)

B-3 (south facing)

B-4 (west facing)

B-5 (west facing)

B-6 (northwest facing)

B-7 (south facing)

B-8 (south facing)

B-9 (south facing)

B-10 (north facing)

B-11 (southwest facing)

B-12 (southwest facing)

B-13 (north facing)

VANN ENGINEERING INC
Geotechnical Engineering Enviromental Consulting Construction Testing & Inspection
9013 North 24th Avenue, Suite 7, Phoenix, Arizona 85021-2851