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# ROCKERY DESIGN AND CONSTRUCTION GUIDELINES

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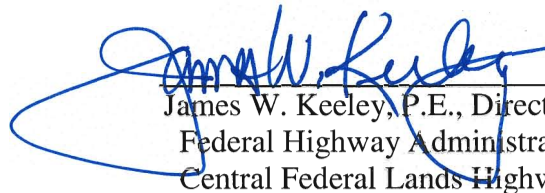


**Central Federal Lands Highway Division  
12300 West Dakota Avenue  
Lakewood, CO 80228**

## FORWARD

The Federal Lands Highway (FLH) of the Federal Highway Administration (FHWA) promotes development and deployment of applied research and technology applicable to solving transportation-related issues on Federal lands. The FLH provides technology delivery, innovative solutions, recommended best practices, and related information and knowledge sharing to Federal agencies, Tribal governments, and other offices within the FHWA.

The objective of this study is to review existing analytical methods and construction techniques currently in use for design and construction of rockeries and to develop a unified framework for design and specification of rockeries in modern highway construction. The ultimate goal of the project is to provide designers, inspectors, and contractors with a basis for evaluating existing rockeries and specifying and constructing new rockeries.



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James W. Keeley, P.E., Director of Project Delivery  
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16. Abstract Rockeries consist of earth retaining and/or protection structures comprised of interlocking, dry-stacked rocks without mortar or steel reinforcement. They have been used for thousands of years and rely on the weight, size, and shape of individual rocks to provide overall stability. Some of the earliest rockeries constructed by the Federal Government date back to 1918. Within the private sector, commercially built rockeries have been constructed in the Pacific Northwest for at least the last four decades and in Northern California and Nevada for at least the last 10 years. As rockery design procedures tend to vary regionally, studies were performed to determine the methods by which rockeries are designed and constructed in various regions throughout the western United States. These design methods were then compared using several typical rockery design loading conditions to determine how the resulting rockery designs differ and which methods are most appropriate for a proposed design for the FHWA's FLH Divisions. Based on the research performed, a rational design methodology, which evaluates rockery stability as a function of the rockery geometry (height, base width, and batter), rock properties and placement, and lateral pressure imposed by the backfill materials, was developed. A sample design problem is included. Recommendations for specifying and constructing rockeries that are consistent with the design methodology are also provided.			
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# SI\* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	645.2	square millimeters	mm <sup>2</sup>
ft <sup>2</sup>	square feet	0.093	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yard	0.836	square meters	m <sup>2</sup>
ac	acres	0.405	hectares	ha
mi <sup>2</sup>	square miles	2.59	square kilometers	km <sup>2</sup>
<b>VOLUME</b>				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft <sup>3</sup>	cubic feet	0.028	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: Volumes greater than 1000 L shall be shown in m <sup>3</sup>				
<b>MASS</b>				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
<b>TEMPERATURE (exact degrees)</b>				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
<b>ILLUMINATION</b>				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>
<b>FORCE and PRESSURE or STRESS</b>				
lbf	poundforce	4.45	newtons	N
lbf/in <sup>2</sup>	poundforce per square inch	6.89	kilopascals	kPa

## APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
<b>AREA</b>				
mm <sup>2</sup>	square millimeters	0.0016	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	10.764	square feet	ft <sup>2</sup>
m <sup>2</sup>	square meters	1.195	square yards	yd <sup>2</sup>
ha	hectares	2.47	acres	ac
km <sup>2</sup>	square kilometers	0.386	square miles	mi <sup>2</sup>
<b>VOLUME</b>				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m <sup>3</sup>	cubic meters	35.314	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.307	cubic yards	yd <sup>3</sup>
<b>MASS</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
<b>TEMPERATURE (exact degrees)</b>				
°C	Celsius	1.8C+32	Fahrenheit	°F
<b>ILLUMINATION</b>				
lx	lux	0.0929	foot-candles	fc
cd/m <sup>2</sup>	candela/m <sup>2</sup>	0.2919	foot-Lamberts	fl
<b>FORCE and PRESSURE or STRESS</b>				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in <sup>2</sup>

\*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised March 2003)

TABLE OF CONTENTS

**EXECUTIVE SUMMARY .....1**

**CHAPTER 1 – INTRODUCTION .....3**

    BACKGROUND ..... 3

    PURPOSE OF STUDY..... 5

    ROCKERY DEFINITIONS ..... 6

        Man Rocks ..... 7

**CHAPTER 2 – SURVEY OF EXISTING DESIGN METHODS.....11**

    HISTORIC ROCKERIES ..... 11

    MODERN ROCKERY DESIGN ..... 13

        Federal Government..... 14

        Pacific Northwest..... 17

            Gifford and Kirkland..... 18

            Hemphill Consulting Engineers..... 23

            Seismic Performance During the Nisqually Earthquake ..... 25

        Gray & Sotir..... 29

        Northern California Region ..... 32

    SUMMARY OF EXISTING DESIGN METHODS ..... 37

**CHAPTER 3 – COMPARISON OF EXISTING DESIGN METHODS .....41**

    COMPARISON OF METHODS ..... 45

        Gray & Sotir Method ..... 46

        Hemphill Sliding and Overturning Stability Analyses ..... 49

        Shallow Back Cuts (Design Case #4) ..... 50

    SUMMARY ..... 51

    CONCLUSIONS..... 52

        Retaining Rockeries..... 52

        Protecting Rockeries ..... 53

**CHAPTER 4 – RECOMMENDED ROCKERY DESIGN GUIDELINES .....55**

    STATIC DESIGN ..... 55

        Design Parameters ..... 55

        Lateral Earth Pressures ..... 58

        Sliding Resistance..... 60

        Overturning..... 65

        Bearing Capacity..... 67

        Global Stability ..... 70

    SEISMIC DESIGN ..... 71

        Governing Regulations ..... 71

        Seismic Analysis..... 72

        Seismic Slope Stability ..... 75

    ROCKERY-FACED MSE, RSS, AND SOIL NAILS ..... 76

    TIERED ROCKERIES ..... 78

    ROCKERY LAYOUT ..... 78

SUMMARY .....	79
<b>CHAPTER 5 – ROCKERY CONSTRUCTION GUIDELINES.....</b>	<b>81</b>
EXCAVATION .....	81
Foundation Excavation .....	82
Back Cut Excavation in Soil .....	86
Back Cut Inclination .....	86
Back Cut Stability .....	86
QUALITY OF BASE AND FACING ROCKS.....	87
ROCK PLACEMENT .....	90
Equipment .....	90
Base Rock Placement .....	91
Facing Rock Placement.....	93
CRUSHED ROCK ZONE .....	96
DRAINAGE SYSTEM.....	97
Backdrain Construction .....	97
Non-Woven Geotextile .....	100
Surface Drainage.....	101
CAP ROCKS .....	102
CHINKING ROCKS .....	103
BACKFILL .....	103
TEST SECTIONS.....	104
<b>CHAPTER 6 – CONSTRUCTION INSPECTION GUIDELINES .....</b>	<b>105</b>
<b>CHAPTER 7 – EVALUATION OF EXISTING ROCKERIES.....</b>	<b>115</b>
PHYSICAL AND GEOMETRIC PROPERTIES .....	115
Rockery Layout.....	115
Drainage.....	118
Evaluation of Base Width .....	119
Physical Evaluation.....	119
Geophysical Evaluation .....	119
GEOTECHNICAL/GEOLOGIC INVESTIGATION .....	122
ROCKERY EVALUATION .....	123
Numerical Analysis.....	124
<b>CHAPTER 8 – GUIDE SPECIFICATIONS.....</b>	<b>125</b>
<b>REFERENCES.....</b>	<b>131</b>
<b>BIBLIOGRAPHY.....</b>	<b>135</b>
<b>APPENDIX A – ALTERNATIVE SEISMIC DESIGN PROCEDURE .....</b>	<b>139</b>
ALTERNATIVE DESIGN PROCEDURE .....	139
COMMENTARY ON ATC MAPS.....	141
<b>APPENDIX B – SAMPLE DESIGN PROBLEM.....</b>	<b>145</b>
<b>APPENDIX C – SAMPLE SECTIONS AND DETAILS.....</b>	<b>155</b>

LIST OF FIGURES

Figure 1. Photograph. Failure of non-engineered rockery in El Dorado Hills, California, 2004. ....5

Figure 2. Graphic. Diagram showing definitions of height (H), base width (B), face batter, and relative rock sizes.....8

Figure 3. Photograph. Hadrian’s Wall, Scotland. ....11

Figure 4. Photograph. Rockery construction at Machu Picchu, Peru. ....12

Figure 5. Photograph. Approximately 9.1-m-tall (30-ft-tall) rockery outside La Grange, California, dating from the late 1800s.....13

Figure 6. Graphic. Typical rockery section from Guanella Pass bid documents.....16

Figure 7. Graphic. Typical rockery schedule from Guanella Pass bid documents. ....16

Figure 8. Photograph. Completed rockery for Guanella Pass Road, Colorado, 2005. ....17

Figure 9. Chart. Critical height-to-base-width (H/B) ratios for poorly constructed rockeries (PCRs) and well-constructed rockeries (WCRs), after Hendron.....21

Figure 10. Graphic. Sample calculation from the Hemphill report demonstrating application of the Hemphill design method. ....24

Figure 11. Photograph. Single-tier, 3-m (10-ft) rockery, Military Road at Enchanted Parkway, Federal Way, Washington (Site 1).....27

Figure 12. Photograph. Two-tier, 7.3-m (24-ft) rockery, 15th Avenue at 12th Street, Puyallup, Washington (Site 2), with guy wire anchored at base of rockery. ....27

Figure 13. Photograph. Single-tier, 1.2-m (4-ft) rockery near state capital building, Olympia, Washington (Site 3). ....28

Figure 14. Photograph. Single-tier, 2.4-m (8-ft) rockery, Nisqually National Wildlife Refuge, Washington (Site 4). ....28

Figure 15. Photograph. Single-tier, 7.6-m (25-ft) rockery in Tacoma, Washington (Site 5).....29

Figure 16. Equation. Height-to-base-width (H/B) as a function of factor of safety, rockery inclination, backslope inclination, and soil and rock properties, from Gray & Sotir.....30

Figure 17. Equation. Definition of the term “b” in Figure 16.....30

Figure 18. Graphic. Assumed geometric relationships to be used for equations shown in Figures 16 and 17. ....31

Figure 19. Photograph. Single-tier rockery constructed in cut condition, El Dorado Hills, California (2001). ....32

Figure 20. Photograph. “Protecting” rockery used as a facing for a 9.1-m-high (30-ft-high) MSE wall with a 5.5-m (18-ft) maximum tier height in Henderson, Nevada (2001). ....33

Figure 21. Photograph. “Protecting” rockery used as a facing material for a two-tier, 7.6-m-high (25-ft-high) soil-nail wall in Rocklin, California (1999). ....33

Figure 22. Photograph. Three-tier, 9.1-m-high (30-ft-high) MSE slope with protecting rockery facing, in Folsom, California (2003). ....34

Figure 23. Graphic. Design geometry for example design Cases #1 and #2. ....43

Figure 24. Graphic. Design geometry for example design Cases #3 and #4. ....44

Figure 25. Equation. Computation of active earth pressure coefficient ( $K_A$ ) by the Coulomb method. ....48

Figure 26. Equation. Corrected equation for height-to-base-width (H/B) ratio for use with Gray & Sotir analysis method. ....48

Figure 27. Equation. Corrected definition of the term “b” in Figure 18. ....48

Figure 28. Graphic. Assumed geometric relationships to be used for equations shown in Figures 25, 26, and 27. ....48

Figure 29. Chart. Typical chart plotting slope inclination ( $\alpha$ ) vs. height-to-base-width (H/B) ratio using the Gray & Sotir method. Chart developed for  $\phi = 32^\circ$ ,  $\gamma = 18.8 \text{ kN/m}^3$  (120 pcf), and FS = 2. ....53

Figure 30. Graphic. Schematic rockery section showing critical dimensions and parameters to be determined for design. ....56

Figure 31. Equation. Determination of lateral earth pressure coefficient,  $K_A$ , using the Coulomb method. ....59

Figure 32. Equation. Horizontal force on back of rockery, equal to the sum of the lateral earth pressure and any surcharge loads. ....61

Figure 33. Graphic. Estimation of rockery weight and centroidal distances. ....62

Figure 34. Equation. Computation of frictional resistance along the base of the rockery. ....63



Figure 35. Equation. Evaluation of passive resistance at the rockery toe.....64

Figure 36. Equation. Expression for factor of safety against sliding ( $FS_{SL}$ ).....65

Figure 37. Equation. Determination of overturning moments about the toe of the rockery. ....66

Figure 38. Equation. Determination of resisting moments about the toe of the rockery .....66

Figure 39. Equation. Determination of factor of safety against overturning.....66

Figure 40. Equation. Calculation of internal overturning moment at a distance  $H'$  from the base of the rockery. ....67

Figure 41. Equation. Calculation of internal resisting moment at a distance  $H'$  from the base of the rockery, with outermost bearing distance  $x'$  from the face of rockery.....67

Figure 42. Graphic. Geometric relationships for determination of internal stability.....68

Figure 43. Equation. Determination of eccentricity,  $e$ , about the center of a base rock of width  $B$ . ....69

Figure 44. Equation. Determination of maximum bearing pressure ( $q_{max}$ ) applied at the toe of the base rock. ....69

Figure 45. Equation. Determination of the term  $\theta$  for computation of  $K_{AE}$  by the Mononobe-Okabe procedure. ....73

Figure 46. Equation. Determination of term  $K_{AE}$  in accordance with the Mononobe-Okabe procedure. ....73

Figure 47. Equation. Determination of total thrust (seismic plus static) on rockery in accordance with the Mononobe-Okabe procedure. ....73

Figure 48. Equation. Vertical distance ( $z$ ) from the base of the rockery to the point of application of  $F_{AE}$  along the back of the rockery.....74

Figure 49. Equation. Determining overturning moment for seismic conditions. ....74

Figure 50. Equation. Determining resisting moment for seismic conditions. ....74

Figure 51. Equation. Determining horizontal driving force to check sliding for seismic conditions.....74

Figure 52. Equation. Determining horizontal resisting force to check sliding for seismic conditions.....74

Figure 53. Equation. Determining eccentricity under seismic conditions.....75

Figure 54. Equation. Determining maximum applied bearing pressure under seismic conditions.....75

Figure 55. Graphic. Minimum embedment required for a sloping toe condition.....83

Figure 56. Graphic. Example of embedment requirements for a rockery adjacent to a roadway with a drainage ditch subject to potential scour. ....83

Figure 57. Graphic. Typical gravel leveling pad beneath base rocks (partial elevation).....85

Figure 58. Graphic. Typical step in rockery foundation (partial elevation). ....85

Figure 59. Graphic. Typical planar failure on an adversely oriented discontinuity that daylights in the back cut. ....88

Figure 60. Graphic. Typical wedge failure on two intersecting discontinuities with a line of intersection that daylights in the back cut. ....88

Figure 61. Graphic. “Rectangular” and “matched irregular” facing rocks (partial elevation).....90

Figure 62. Photograph. Hydraulic excavator with a clamshell constructing a rockery. ....91

Figure 63. Photograph. Placement of facing rocks using an excavator with a “thumb.” .....92

Figure 64. Graphic. Base rock tolerances and use of two base rocks to achieve “B” (partial plan view). ....93

Figure 65. Graphic. Examples of acceptable and unacceptable rockery alignment. ....94

Figure 66. Graphic. Examples of improper rock placement (partial elevation). ....95

Figure 67. Photograph. Example of a relatively well constructed rockery.....95

Figure 68. Photograph. Example of an unacceptable rock bearing. ....96

Figure 69. Photograph. Example of improper rock bearing and lack of chinking.....96

Figure 70. Graphic. Backdrain components (partial section). ....98

Figure 71. Photograph. Example of crushed rock placed behind rockery. ....98

Figure 72. Photograph. Placement of drain blanket and non-woven geotextile behind rockery. ....99

Figure 73. Graphic. V-Ditch and impermeable cap at top of rockery (partial section).....102

Figure 74. Photograph. Example of proper layout, interlock, and chinking of variable shape and size rocks.....117

Figure 75. Photograph. Example of improper rockery layout evidences by vertical seams and rocks inclined out of face. ....117

Figure 76. Photograph. Example of improper rockery layout evidenced by several vertical seams.....118

Figure 77. Equation. Determination of horizontal seismic coefficient,  $k_h$  ( $\Delta$  in inches).....140

Figure 78. Equation. Computation of inertial thrust coefficient.....140

Figure 79. Equation. Computation of weight required to resist seismic forces.....140

Figure 80. Equation. Seismic factor of safety with regard to wall movement.....140

Figure 81. Graphic. Assumed Geometry for Example Problem—2400 mm (8 ft) rockery retaining medium dense clayey sand and subjected to a vehicle surcharge.....146

**LIST OF TABLES**

Table 1. Comparison of man rock definitions. ....9

Table 2. Summary of rockery observations following the 2001 Nisqually  
earthquake. ....26

Table 3. Comparison of prescriptive design methods in different cities. ....38

Table 4. Comparison of analytical design methods. ....39

Table 5. Soil and rockery properties used for benchmarking of analysis procedures. ....42

Table 6. Comparison of computed base rock widths using four design methods.....47

Table 7. Typical friction factors for determination of  $FS_{SL}$ . ....63

Table 8. Recommended factors of safety for static and seismic rockery design. ....79

Table 9. Gradation Requirements for crushed rock backdrain. ....97

Table 10. Physical properties requirements for non-woven geotextiles (from FP-03,  
Section 714, Type I-B geotextiles). ....101

**LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS**

- A – Acceleration Coefficient per AASHTO Division I-A, Section 3
- A\* – Amplified peak acceleration
- A<sub>a</sub>, A<sub>v</sub> – Acceleration coefficients per ATC-3-06
- AASHTO – American Association of State Highway Transportation Officials
- A.D. – Latin, *Anno Domini*, current calendar epoch
- AOS – Apparent Opening Size
- a<sub>peak</sub> – Peak spectral acceleration, gravity (g)
- ARC – Associated Rockery Contractors
- ASTM – American Society of Testing and Materials
- ATC – Applied Technology Council
- B – Base rock width, m
- BMP – “Best Management Practices” as related to site erosion, sediment, and runoff control and reduction
- c, c’ – Total and effective soil cohesion values, respectively, in kPa. Although effective stresses are most typically used, the term “c” is commonly used throughout this report.
- ca. – Latin, *circa*, meaning “about” for dates that are approximately known
- CalTrans – State of California, Department of Transportation
- c<sub>F</sub>, c’<sub>F</sub> – Total and effective soil cohesion values in the foundation soil, in kPa
- CFLHD – Central Federal Lands Highway Division
- C<sub>IE</sub> – Seismic inertial coefficient
- CO – Contracting Officer
- d – Depth of soil to neglect when computing passive resisting force, m
- d<sub>peak</sub> – Peak spectral displacement, cm
- D – Embedment depth at toe of rockery, m
- D\* – Amplified peak displacement
- e – Moment eccentricity relative to center of base rock, m
- e<sub>s</sub> – Moment eccentricity relative to center of base rock due to seismic forces, m
- EFP – Equivalent fluid pressure applied by soil, kN/m<sup>3</sup>
- EPA – Effective peak acceleration, g
- EPV – Effective peak velocity, cm/s

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**LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS**

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- $F_A$  – Active earth pressure force acting on the back of the rockery
- $F_{A,H}$  – Horizontal component of active earth pressure force kN (per meter of rockery)
- $F_{A,V}$  – Vertical component of active earth pressure force, kN (per meter of rockery)
- $F_{AE}$  – Total static plus seismic thrust acting on rockery, kN (per meter of rockery)
- $\Delta F_{AE}$  – Incremental seismic thrust acting on rockery, kN (per meter of rockery)
- $F_H$  – Sum of static horizontal driving forces acting on rockery, kN (per meter of rockery)
- $F_{H,S}$  – Sum of static and seismic horizontal driving forces acting on rockery, kN (per meter of rockery)
- FHWA – Federal Highway Administration
- FLH – Federal Lands Highway
- Foundation Fill – Material conforming to Section 704.01 of the FHWA Standard Specifications (FP-03)
- $F_p$  – Passive resisting force on toe of rockery, kN (per meter of rockery)
- $F_s$  – Horizontal resultant force due to application of vertical surcharge load, kN (per meter of rockery)
- $F_\mu$  – Static resisting friction force of bottom of base rock, kN (per meter of rockery)
- $F_{\mu,S}$  – Static and seismic resisting friction force of bottom of base rock, kN (per meter of rockery)
- FS – Factor of safety
- FS<sub>BC</sub> – Factor of safety with respect to bearing capacity
- FS<sub>OT</sub> – Factor of safety with respect to external overturning
- FS<sub>OT\_INT</sub> – Factor of safety with respect to internal (inter-rock) overturning
- FS<sub>seismic</sub> – Factor of safety with respect to required rockery weight to limit rockery displacement to  $\Delta$  or less
- FS<sub>SL</sub> – Factor of safety with respect to base sliding
- GPR – Ground penetrating radar, a type of geophysical evaluation method
- H – Rockery height, m
- H/B – Height-to-base-width ratio
- HDPE – High density polyethylene, usually referring to a type of plastic pipe
- HEC – Hydraulic Engineering Circular

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**LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS**

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- HP – Ultraseismic Horizontal Profiling Method, a type of geophysical surface wave method
- i – Slope inclination, measured up from horizontal, per A. J. Hendron, Jr., methodology
- IR – Impulse Response, a type of geophysical surface wave method
- $K_A$  – Coefficient of active earth pressure
- $K_{AE}$  – Lateral earth coefficient for computation of static plus seismic thrust force
- $k_h$  – Horizontal seismic coefficient
- $K_p$  – Coefficient of passive earth pressure
- $k_v$  – Vertical seismic coefficient
- LTDS – Long term design strength of geogrid reinforcement
- MARV – Minimum Average Roll Values
- $M_o$  – External overturning moment about toe of rockery imposed by lateral earth pressure (horizontal component) and surcharge loads, kN – m (per meter of rockery)
- $M_{o,s}$  – External overturning moment due to static and seismic loads, kN – m (per meter of rockery)
- $M_{o\_int}$  – Internal (inter-rock) overturning moment about toe of intermediate rock imposed by lateral earth pressure (horizontal component) and surcharge loads, kN – m (per meter of rockery)
- $M_r$  – External resisting moment about toe of rockery imposed by rockery weight, lateral earth pressure (vertical component), and passive pressure, kN – m (per meter of rockery)
- $M_{r,s}$  – External resisting moment about toe of rockery imposed by rockery weight and vertical components of static and seismic lateral earth pressures kN – m (per meter of rockery)
- $M_{r\_int}$  – Internal resisting moment about toe of intermediate rock imposed by partial rockery weight, lateral earth pressure (vertical component), and passive pressure, kN – m (per meter of rockery)
- MSE – Mechanically stabilized earth or embankment
- OSHA – Occupational Safety and Health Administration
- PCR – Poorly constructed rockery as defined by A. J. Hendron, Jr.
- PGA – Peak ground acceleration, g
- PS – Parallel Seismic, a type of geophysical cross-hole logging method
- PVC – Polyvinyl chloride, a type of plastic pipe

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**LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS**

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- $q_{\max}$  – Maximum applied bearing pressure at toe of base rock due to moment eccentricity, kPa
- $q_{\max,s}$  – Maximum applied bearing pressure at toe of base rock due to moment eccentricity under seismic loading, kPa
- $q_s$  – Vertical surcharge pressure acting on the ground surface behind the rockery, kPa
- RSP – Rock slope protection, e.g., riprap
- RSS – Reinforced soil slope
- SAGE – Sanders & Associates Geostructural Engineering, Inc.
- SE – Sonic Echo, a type of geophysical surface wave method
- $T_a$  – Allowable tensile strength for geotextile soil reinforcement, equal to LTDS/FS
- UBC – Uniform Building Code
- U.S. – United States
- UV – Ultraviolet light, such as sunlight
- $v_{\text{peak}}$  – Peak spectral velocity, cm/sec
- $V^*$  – Amplified peak velocity
- $W$  – Total weight of rockery (unit width basis), kg
- WCR – Well-constructed rockery as defined by A. J. Hendron, Jr.
- $W_i$  – Weight of rockery component (unit width basis), kg
- $x_i$  – Moment arm from toe of rockery to centroid of mass for rockery component, m
- $z$  – Point of application of  $F_{AE}$ , measured vertically from base of rockery, m
- $\Delta$  – Tolerable rockery displacement for Richards and Elms analysis, in
- $\Delta F_{AE}$  – Incremental seismic thrust acting on rockery, kN (per meter of rockery)
- $\alpha$  – Angle, measured up from the horizontal, to the back cut or rear face of rockery, degrees. Positive angle is defined as face of back cut sloping up and away from the base of the rockery, starting from the bottom of the cut.
- $\alpha_A, \alpha_V, \alpha_D$  – Newmark and Hall amplification factors
- $\beta$  – Retained ground surface inclination (“backslope”), degrees. Positive angle if slope increases in height with increasing distance from the back of the rockery.
- $\delta$  – Interface friction angle between retained soil and back of rockery/crushed rock backfill zone, degrees



- $\phi, \phi'$  – Total and effective soil friction angle / angle of internal friction, respectively. Although effective stresses are most typically used, the term “ $\phi$ ” is commonly used throughout this report.
- $\phi_{CR}$  – Friction angle (effective or total) of crushed rock backfill
- $\phi_F$  – Friction angle (effective or total) of foundation soil and soil at toe of rockery
- $\gamma, \gamma_s$  – Density of retained soil,  $\text{kN/m}^3$
- $\gamma_{CR}$  – Density of crushed rock backfill (net density, including voids),  $\text{kN/m}^3$
- $\gamma_R$  – Density of rockery facing (net density, including voids),  $\text{kN/m}^3$
- $\gamma_F$  – Density of foundation soil,  $\text{kN/m}^3$
- $\mu$  – Friction factor for sliding
- $\psi$  – Back cut inclination, degrees

