ROCKERY DESIGN AND CONSTRUCTION GUIDELINES

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Federal Lands Highway
Commitment to Excellence

Central Federal Lands Highway Division
12300 West Dakota Avenue
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FORWARD

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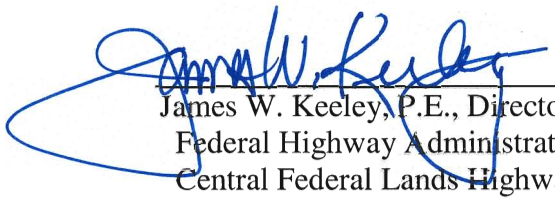
The objective of this study is to review existing analytical methods and construction techniques currently in use for design and construction of rockeries and to develop a unified framework for design and specification of rockeries in modern highway construction. The ultimate goal of the project is to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



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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
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: Volumes greater than 1000 L shall be shown in m^3		
		MASS		
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")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

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

*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)

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LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

A – Acceleration Coefficient per AASHTO Division I-A, Section 3

A* – Amplified peak acceleration

A_a, A_v – 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_{peak} – 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_F, c'_F – Total and effective soil cohesion values in the foundation soil, in kPa

CFLHD – Central Federal Lands Highway Division

C_{IE} – Seismic inertial coefficient

CO – Contracting Officer

d – Depth of soil to neglect when computing passive resisting force, m

d_{peak} – 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_s – Moment eccentricity relative to center of base rock due to seismic forces, m

EFP – Equivalent fluid pressure applied by soil, kN/m^3

EPA – Effective peak acceleration, g

EPV – Effective peak velocity, cm/s

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)

ΔF_{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_μ – 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_{BC} – Factor of safety with respect to bearing capacity

FS_{OT} – Factor of safety with respect to external overturning

FS_{OT_INT} – Factor of safety with respect to internal (inter-rock) overturning

$FS_{seismic}$ – Factor of safety with respect to required rockery weight to limit rockery displacement to Δ or less

FS_{SL} – 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

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

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_{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

Δ – Tolerable rockery displacement for Richards and Elms analysis, in

ΔF_{AE} – Incremental seismic thrust acting on rockery, kN (per meter of rockery)

α – 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.

α_A, α_V, α_D – Newmark and Hall amplification factors

β – Retained ground surface inclination ("backslope"), degrees. Positive angle if slope increases in height with increasing distance from the back of the rockery.

δ – Interface friction angle between retained soil and back of rockery/crushed rock backfill zone, degrees

ϕ, ϕ' – Total and effective soil friction angle / angle of internal friction, respectively. Although effective stresses are most typically used, the term "ϕ" is commonly used throughout this report.

ϕ_{CR} – Friction angle (effective or total) of crushed rock backfill

ϕ_F – Friction angle (effective or total) of foundation soil and soil at toe of rockery

γ, γ_s – Density of retained soil, kN/m^3

γ_{CR} – Density of crushed rock backfill (net density, including voids), kN/m^3

γ_R – Density of rockery facing (net density, including voids), kN/m^3

γ_F – Density of foundation soil, kN/m^3

μ – Friction factor for sliding

ψ – Back cut inclination, degrees