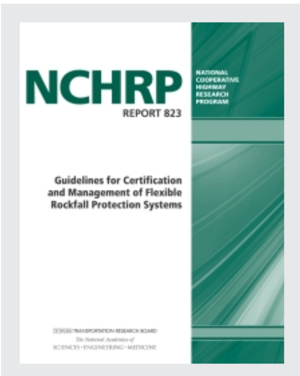

Guidelines for Certification and Management of Flexible Rockfall Protection Systems

DETAILS

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 823

Guidelines for Certification and Management of Flexible Rockfall Protection Systems

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TRANSPORTATION RESEARCH BOARD

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The program is developed on the basis of research needs identified by chief administrators and other staff of the highway and transportation departments and by committees of AASHTO. Topics of the highest merit are selected by the AASHTO Standing Committee on Research (SCOR), and each year SCOR's recommendations are proposed to the AASHTO Board of Directors and the Academies. Research projects to address these topics are defined by NCHRP, and qualified research agencies are selected from submitted proposals. Administration and surveillance of research contracts are the responsibilities of the Academies and TRB.

The needs for highway research are many, and NCHRP can make significant contributions to solving highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement, rather than to substitute for or duplicate, other highway research programs.

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FOREWORD

By David Reynaud
Staff Officer
Transportation Research Board

This report provides guidelines to assist transportation agencies to obtain the data necessary to evaluate the results of rockfall fence systems tested using the procedure recommended for acceptance. Guidelines for asset management for rockfall fence systems were developed and are presented to assist transportation agencies in incorporating these systems into existing transportation asset management plans. This report will be of interest to maintenance and asset management personnel.

Rockfall fence systems have been in service along roadways in Europe and the United States for more than 40 years. However, before 2003, there was no widely accepted means for testing and acceptance of these systems. That year, the National Cooperative Highway Research Program produced "Recommended Procedures for the Testing of Rock-Fall Barriers," which recommended acceptance of the Swiss testing standard and certification process.

In 2008, the European Union developed a standardized testing and certification of rockfall fences program known as European Technical Approval Guideline (ETAG) 27. Most European manufacturers are currently certifying their products in accordance with ETAG 27 guidelines.

Currently U.S. transportation agencies do not have testing standards and certification procedures for flexible rockfall fence systems. Under NCHRP Project 24-35, "Guidelines for Certification and Management of Flexible Rockfall Protection Systems," Yeh and Associates is suggesting that the ETAG 27 test procedure is appropriate for use within the United States, and would eliminate the need for manufacturers to perform additional testing. Agencies would also be able to request manufacturer's data collected during an ETAG test to verify that the product meets their standards.

In addition, the long term performance and maintenance issues of these systems are a growing concern. Asset management offers a framework for monitoring performance of these systems and understanding the condition/deterioration timeline so that agencies can make informed life-cycle cost-based decisions about these assets.

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Guidelines for Certification and Management of Rockfall Fence Systems

Rockfall fence systems have been in service along roadways in Europe and the United States for more than 40 years. In the United States, rockfalls occur each year along highways; consequently, rockfall fence systems have become an important component of highway safety and maintenance. Rockfall fence systems are usually designed and rated based on full-scale testing of energy capacity or energy reduction of a single rockfall event with some consideration for serviceability after specific impacts.

Before 2003, no widely accepted means were available to test and certify flexible rockfall fence systems sold in the United States. In 2003, the National Cooperative Highway Research Program (NCHRP) Project 20-07, Task 138, "Recommended Procedures for the Testing of Rock-Fall Barriers" (Higgins 2003) was submitted to the American Association of State Highway and Transportation Officials (AASHTO). This task report recommended acceptance of the Swiss testing standard and certification process (Gerber 2001).

In 2008, the European Union (EU) implemented standardized testing and certification of rockfall fences known as European Technical Approval Guideline (ETAG) 27. ETAG 27 differs from the Swiss standard making direct comparisons of test results reported from each standard more difficult. Most European manufacturers are certifying their products in accordance with ETAG 27 guidelines.

Currently, U.S. transportation agencies do not have testing standards and certification procedures for these flexible rockfall fence systems. Acceptance of the ETAG 27 test procedure is proposed for use within the United States, thus eliminating the need for manufacturers to perform additional testing. A form has been developed for agencies to request data collected during an ETAG 27 test from manufacturers so the agency can evaluate the system for conformance with a project-specific specification of the rockfall fence system performance.

In addition, the long-term performance and maintenance issues of flexible rockfall fence systems are a growing concern for many transportation agencies that have installed these systems and are faced with significant maintenance, repair, and replacement costs. Currently, there are no well-defined provisions or protocols for inventory, condition assessment, and life-cycle modeling of rockfall fence systems. Asset management offers a framework for monitoring performance of rockfall fence systems and understanding the condition/deterioration timeline so that transportation agencies can make informed life-cycle cost-based decisions about these assets. Combining technical analysis with asset management principles can yield a more efficient and fiscally responsible transportation system that focuses on preservation of assets while maintaining the required level of service set by owners.

Guidelines are presented for the inventory and condition assessment of flexible rockfall fence systems to collect the data necessary for transportation agencies to perform life-cycle and risk analysis to guide project evaluation and prioritization.

CHAPTER 1

Background

1.1 Problem Statement

1.1.1 Certification of Rockfall Fence Systems in the United States

Rockfall fence systems are used to mitigate rockfall and generally consist of flexible nets or panels that are connected to a post system with energy absorbing braking elements. Rockfall fence systems are currently designed and given an energy rating based on full-scale field testing to determine the energy capacity or energy reduction of a single rockfall event with variable considerations for serviceability after specific impacts. Most of the current tested and rated rockfall fence systems manufactured today were developed in Europe and are specific to a manufacturer system. Before 2003, no widely accepted means were available to test and certify fences sold in the United States. In 2003, NCHRP Project 20-07/Task 138, "Recommended Procedures for the Testing of Rock-Fall Barriers" (Higgins 2003) was submitted to the AASHTO. This task report recommended acceptance of the Swiss testing standard and certification process developed by the Swiss Agency for the Environment, Forests and Landscape (SAEFL) and the Swiss Federal Research Institute (WSL) (Gerber 2001). In 2008, the EU implemented standardized testing and certification of rockfall fences known as ETAG 27 for Falling Rock Protection Kits (European Organisation for Technical Approvals [EOTA] 2008). ETAG 27 differs significantly from the Swiss standard. Most European manufacturers are now certifying their products in accordance with ETAG 27. Currently, U.S. transportation agencies do not have testing standards and certification procedures for these rockfall fence systems.

1.1.2 Asset Management of Flexible Rockfall Fence Systems

MAP-21, the Moving Ahead for Progress in the 21st Century Act (P.L. 112-141), was signed into law July 6, 2012, and took effect October 1, 2012. The bill provides funds for surface transportation investments in fiscal years 2013–14, and also establishes a new performance-based management framework. While the language mandates an inventory of pavement and bridge assets on the National Highway System (NHS), it also encourages states to include all infrastructure assets within the right-of-way corridor, requires states to achieve or make significant progress toward achieving its performance targets, and establishes penalties for non-compliance. MAP-21 does not approve or certify a state's asset management plans, but certifies the process used in developing such plans. At the time, it did not specifically contain references for asset management related to geotechnical features but many departments of transportation (DOTs) are developing such processes. By including geotechnical assets within an agency's asset management plan, the potential benefits and staying power of best-practice asset management will be enhanced.

Overall, the desired outcome of geotechnical asset management is the establishment of more predictable and sustainable funding allocation policies and program management decisions. A difficulty that will need to be overcome in developing asset management related to geotechnical features is that steel, concrete, and pavement have well-defined and measureable parameters that relate well to performance-based management systems, whereas soil and rock are generally not well defined and have wide ranges in measurable and non-measureable parameters.

1.2 Research Objectives

The objective of this research was to produce guidelines on rockfall fence systems for transportation agencies that address the following:

- Testing, approval, and certification methodologies, as well as proposed performance-based specifications for flexible rockfall fence systems and components thereof

- Inspection, maintenance, and repair procedures for flexible rockfall fence systems
- Development of an asset management plan, including long-term performance and condition measures, and establishment of critical factors and key components in determining estimates of future performance, life-cycle cost, and cost/benefit analysis for maintenance, repair, and replacement decisions for flexible rockfall fence systems

This guidebook presents the results of the research effort. A detailed discussion of the research can be found in the Final Report, which is available on the NCHRP Project 24-35 web page at www.trb.org.

CHAPTER 2

European ETAG 27 Testing Standards

In 2008, ETAG 27 became effective in the EU. The guideline includes material conformity guidelines and identification tests, which are not summarized here because they apply to specific European standards. The following discussion of ETAG 27 is summarized from EOTA (2008) and Peila and Ronco (2009). The summary describes the test that is being recommended for acceptance by transportation agencies in the United States. The test site must consist of a structure capable of accelerating a concrete block to the test speed and delivering the concrete block into the fence with the necessary precision. The slope downhill of the fence, referred to as the reference slope, must be within 20 degrees of parallel to the block trajectory in the last 1 m before the impact of the block with the fence (Figure 2-1). The trajectory of the block may be vertical or inclined (Figure 2-2 and Figure 2-3, respectively) and inscribed in a vertical plane orthogonal to the line connecting the post bases.

The test fence is required to consist of three functional modules or panels with four posts. The manufacturer is allowed to decide the installation geometry and post spacing. The height of the fence cannot be reduced from that of the tested height and cannot be raised more than 0.5 m (1.6 ft) for fences with a tested height of less than 4 m (13 ft) or 1 m (3 ft) for fences with a tested height of greater than or equal to 4 m (13 ft). Modification of the post spacing and the inclination of the main ropes from those tested are allowed within a tolerance specified by the manufacturer. The manufacturer is responsible for evaluating the forces acting on the structure to demonstrate the fitness for use of any modified fence.

An installation manual is required as part of the certification process and it is required that the manufacturer follow the manual when installing the fence at the test site. The block used for testing can be unreinforced or reinforced concrete in a polyhedral shape (Figure 2-4). The density of the block is required to be between 2,500 and 3,000 kg/m^3 (156 and 187 lb/ft^3). The maximum size of the block is required to be 3 times smaller than the nominal height of the fence. The mass and size of the block is measured before each test. The average velocity of the block within the last 1 m from the fence must be greater than or equal to 25 m/s (82 ft/s) for all tests. The impact energy is calculated as the translational kinetic energy of the block at impact.

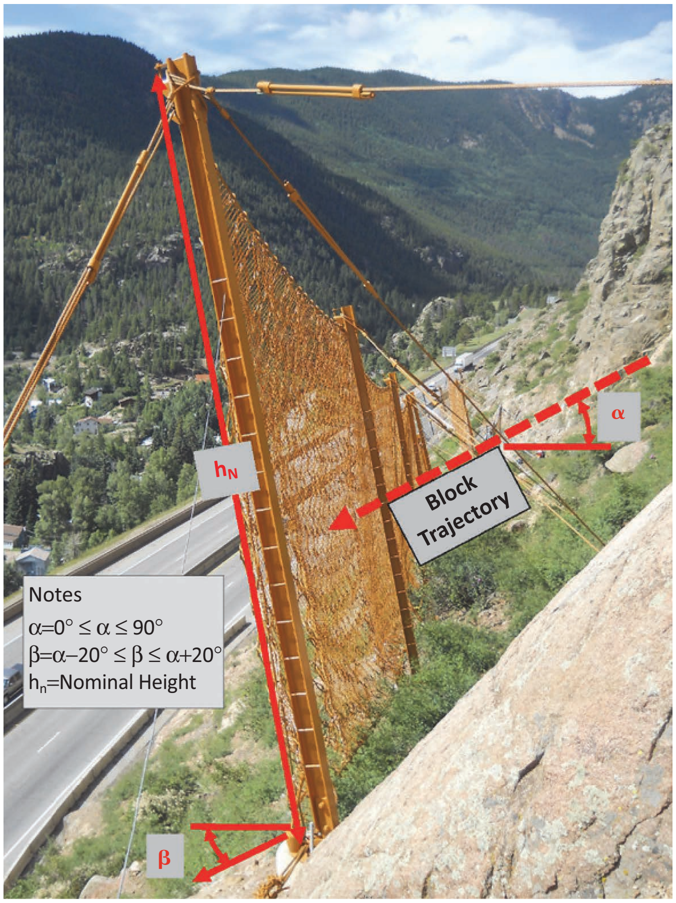
The test procedure consists of two service energy level (SEL) tests and one maximum energy level (MEL) test. The MEL test is chosen by the manufacturer before the test and is required to be greater than or equal to three times the SEL test. There are nine classifications for MEL ranging from 100 to greater than 4,500 kJ (37 to greater than 1,660 ft-tons) (Table 2-1).

The test and fence characteristics recorded before each test include the following:

- Mass of the test block
- Nominal height of the fence
- Photographs of the position and construction of the fence
- Geometric parameters of the fence
- Mechanical and physical characteristics of fence components

The test and fence characteristics recorded during each test include the following:

- Block speed evaluated in the last 1 m before impact with the fence
- Block trajectory
- Maximum elongation of the fence
- Photographic records to give a complete record of the fence behavior including deformation, deflections, braking time, and proof that no ground contact occurred before the maximum elongation is reached
- Foundation peak forces and time-force diagrams



Source: Photo courtesy of Yeh and Associates, Nomenclature adapted from EOTA 2008.

Figure 2-1. Section view of the relationship between the block trajectory and reference slope in ETAG 27.

Source: Photograph courtesy of B. Arndt.

Figure 2-3. Styrian Erzberg test facility in Eisenerz, Austria, set up according to the ETAG 27 guideline for an inclined test.

The test and fence characteristics recorded after each test include the following:

- Residual height of the fence
- Description and photographic records of damage to the fence

Block speed measurements are taken using at least one high-speed video camera with areas of special interest covered by additional cameras as necessary. Measurement of forces on anchorage and ropes is adapted to the specific fence with at least 3 measurements on the main ropes of the center fence panel.

Source: Photograph courtesy of B. Arndt.

Figure 2-2. Test facility in Italy set up according to the ETAG 27 guideline for a vertical drop test.

Source: Photograph courtesy of B. Arndt.

Figure 2-4. Shape and geometry of ETAG 27 test blocks made of unreinforced or reinforced concrete.

Table 2-1. ETAG 27 energy level classifications.

Energy level classification	0	1	2	3	4	5	6	7	8
SEL (kJ)	—*	85	170	330	500	660	1,000	1,500	>1,500
MEL ≥ (kJ)	100	250	500	1,000	1,500	2,000	3,000	4,500	>4,500

*Note: No test performed at SEL for energy level classification 0.
Source: Adapted from EOTA 2008.

The SEL tests are conducted with two launches of a block at the same kinetic energy as specified by the energy level classification. The objective of the tests is to evaluate the ability of the fence system to intercept and contain successive impacts within specified performance criteria. The first SEL test is required to impact the center of the fence system. The fencing passes the test if

- The block is stopped by the fence.
- No ruptures occur in the connection components and the opening of the panel mesh is less than two times larger than the initial size of the mesh openings.
- The residual height of the fence after the test (without removing the block) is greater than or equal to 70 percent of the nominal height of the fence.
- The block does not touch the ground before the fence reaches the maximum elongation during the test.

The block is then removed from the fence and no maintenance is allowed. The second SEL test is also required to impact the center of the fence. The fencing passes the test if

- The block is stopped by the fence.
- The block does not touch the ground before the fence reaches the maximum elongation during the test.

The MEL test is conducted with one launch of the test block into the test fence at the energy specified. The objective of the test is to characterize the maximum energy capacity of the fence system. The manufacturer of the fence is allowed to decide whether the MEL test is conducted using the same fence as used for the SEL tests after being repaired or on a new fence. The test block is launched into the center of the new or repaired fence and the fencing passes the test if

- The block is stopped by the fence.
- The block does not touch the ground before the fence reaches the maximum elongation during the test.

The classification of the residual height of the fence measured after the MEL tests is outlined in Table 2-2.

Table 2-2. ETAG 27 residual height categories for MEL test.

Category	Residual Height
A	≥ 50% of nominal height
B	Between 30 and 50% of nominal height
C	≤ 30% of nominal height

Source: Adapted from EOTA 2008.

CHAPTER 3

Proposed ETAG 27 Acceptance Procedures for Agencies

3.1 Discussion of Acceptance Conditions for Agencies

Table 3-1 summarizes the proposed guideline using the framework of the ETAG 27 guideline. The proposed guideline has been developed to be consistent with the ETAG 27 guideline to allow for acceptance of ETAG 27 testing for rockfall fence systems installed in the United States. The following are the primary differences between the proposed guideline and the ETAG 27 guideline:

- If performing testing in the United States, the manufacturer would be responsible for performing the test because there are currently no governing bodies for rockfall fence testing in the United States.
- The test rock or block may be natural or manufactured.

A current obstacle for agencies is fully evaluating the acceptability of the rockfall fence system because the manufacturer-provided certification documentation of ETAG 27 tests lacks the details necessary for agencies to determine if the system meets their project-specific requirements. However, per the ETAG 27 guidelines, much of this information is recorded during the test and could be made available at the request of the agency as discussed in Section 3.2.

3.2 Proposed Data Request Form for ETAG 27 Tested Systems

The proposed data request form (Table 3-2) would allow agencies to request information and data that are required per the ETAG 27 guideline, but may not be included in typical certification or test documentation. With this information, agencies can evaluate the ETAG 27 tested system for conformance with a project-specific specification of the rockfall fence system performance. It may be useful for agencies to include this form in their rockfall fence system specifications.

Table 3-1. Summary and comparison of the ETAG 27 and the proposed guidelines.

	Guideline	
	ETAG 27	Proposed (Accept ETAG 27)
Location of Development	European Union	United States
Test Responsibility	Governing Body	Manufacturer
Rock/Block Delivery Method	Vertical drop or inclined cable	Vertical drop or inclined cable
Rock/Block Type	Manufactured	Manufactured or natural
Fence Height	Unlimited	Unlimited
Post Spacing/Panel Width	Unlimited	Unlimited
Small Diameter Rock/Block Test	No	No
MEL/SEL	3	3
Tests at Low Energy (SEL)	2	2
Tests at High Energy (MEL)	1	1
Residual Height		
at SEL	1st Test: > 70% 2nd Test: Unlimited	1st Test: > 70% 2nd Test: Unlimited
at MEL	Category A, B, C	Category A, B, C
Elongation		
at SEL	Unlimited	Unlimited
at MEL	Unlimited	Unlimited
Maintenance	Not evaluated	Not evaluated

Table 3-2. Proposed data request form for ETAG 27 rockfall fence testing.

<table>
<tr><th colspan="6">ETAG 27 ROCKFALL FENCE TEST DATA REQUEST FORM</th></tr>
<tr><td colspan="6">This form is intended to be used by federal and state transportation agencies to request rockfall fence test data for fences that have been tested and approved according to ETAG 27. Agencies may send this form to the fence manufacturer to request the documentation and data described below. The manufacturer may fill in the appropriate information and complete the checklist providing the requested information or the manufacturer may provide a separate report containing the requested information.</td></tr>
<tr><td colspan="2">Manufacturer</td><td></td><td colspan="2">Fence Model/Type</td><td></td></tr>
<tr><td colspan="2">Energy Level Classification/Energy</td><td></td><td colspan="2">Test Institution</td><td></td></tr>
<tr><td colspan="2">Test Location</td><td></td><td colspan="2">Rock/Block Delivery Method</td><td>☐ Vertical Drop
☐ Inclined Cable</td></tr>
<tr><td colspan="2">Date of Testing</td><td></td><td colspan="2">Date of Approval</td><td></td></tr>
<tr><td colspan="6">DOCUMENTATION AND TEST DATA CHECKLIST</td></tr>
<tr><td></td><td colspan="5">Provide system documentation including plans, installation manual/guide, and description of system components.</td></tr>
<tr><td></td><td colspan="5">Verify and document that ropes, cables, nets, posts, and other components used in the U.S. have equivalent strength as those tested according to ETAG 27.</td></tr>
<tr><td></td><td>Nominal Height</td><td></td><td></td><td>Post Dimensions (Width/Flange/Thickness)</td><td></td></tr>
<tr><td></td><td>Post to Foundation Connection Type</td><td></td><td></td><td>Panel Width/Post Spacing</td><td></td></tr>
<tr><td></td><td>Panel Type</td><td></td><td></td><td>Applied Mesh Type</td><td></td></tr>
<tr><td></td><td>Retaining Rope Dimensions</td><td></td><td></td><td>Anchor Type and Diameter</td><td></td></tr>
<tr><td></td><td>Type and locations of Energy Dissipating Devices</td><td colspan="4"></td></tr>
</table>

Table 3-2. (Continued).

ETAG 27 ROCKFALL FENCE TEST DATA REQUEST FORM (CONTINUED)					
First Service Energy Level (SEL) Test Data					
	Block Energy at Impact			Residual Height	
	Maximum Elongation			Braking Time	
	Force Measurements				
	Provide a description below of fence behavior including damage and deformations of components.				
Second Service Energy Level (SEL) Test Data					
	Block Energy at Impact			Residual Height	
	Maximum Elongation			Braking Time	
	Force Measurements				
	Provide a description below of fence behavior including damage and deformations of components.				
Maximum Energy Level (MEL) Test Data					
	Maintenance performed after SEL tests		☐ Repair ☐ Replacement ☐ None		
	Block Energy at Impact			Residual Height Category	☐ A ☐ B ☐ C
	Residual Height			Maximum Elongation	
	Braking Time				
	Force Measurements				
	Provide a description below of fence behavior including damage and deformations of components.				
Manufacturer Representative Signature and Date (Attach Original ETAG 27 Document)					

CHAPTER 4

Proposed Inventory and Condition Assessment of Rockfall Fence Systems for Agencies

The following forms are proposed for use in inspecting, inventorying, and assessing flexible rockfall fence systems. Examples of completed forms can be found in the case history presented in the Final Report, which is available on the NCHRP Project 24-35 web page at www.trb.org.

4.1 Condition Rating of Rockfall System Elements

Rockfall systems are composed of elements that contribute to the function and performance of the system. These elements have been divided into primary and secondary elements based on the importance of the element in the system's ability to function as designed. Primary elements are components of the system that, if damaged, significantly reduce the functionality of the system. Secondary elements are components that are important in the functionality of the system to perform as designed, but the system would likely still provide protection from an impact near the design energy level even if the secondary element is damaged.

Condition ratings of primary elements and secondary elements range from 10 (excellent) to 1 (critical). Table 4-1 and Table 4-2 describe the condition state of primary and secondary elements, respectively, and the associated condition rating that would be assigned based on observation during the field inspection. Condition ratings are recorded on the Rockfall System Inventory Form described in Section 4.7.

4.2 Rockfall System Performance Rating

In addition to primary and secondary condition ratings, the overall performance of the system is evaluated. The performance rating is intended to capture the condition of the system related to items and elements that are not captured by the primary and secondary element condition ratings. As with the condition element ratings, performance ratings vary from 10 (excellent) to 1 (critical). Table 4-3 describes the condition state and the associated condition rating for performance.

4.3 Rockfall System Condition and Performance Weighting Factors

Weighting factors are used to account for various levels of element importance in the overall system rating. Proposed weighting factors presented in Table 4-4 are based on experience and calibration using this system to evaluate various rockfall protection measures that are discussed in a case history in the Final Report. Proposed weighting factors for primary elements range from 3 to 10 to reflect the overall importance of the element in the ability of the system to function as designed. A weighting factor of 10 is proposed for elements that are essential to the performance of the system such as panels, posts, bearing ropes, and lateral anchors.

A weighting factor of 1 is proposed for secondary elements because these elements are typically not essential to the function of the system. A weighting factor of 10 is proposed for the performance rating of the system because the overall performance of the system is essential to its function as designed.

The proposed weighting factors may need to be adjusted as the system is implemented and more experience is gained in using the system. Additionally, weighting factors will need to be adjusted to calibrate the system to the practices of specific agencies to account for the varying use of elements and the importance of the elements in the system performance.

4.4 Rockfall System Inventory and Assessment Data Reliability Rating

Data reliability ratings are also included in the Condition Assessment Forms to capture the level of confidence in the data that is used to evaluate the overall system condition. Table 4-5 summarizes data reliability rating guidance.

Table 4-1. Proposed rockfall system condition rating—primary elements.

ROCKFALL SYSTEM CONDITION RATING PRIMARY ELEMENTS			
Element	Condition Ratings		
	10 to 8	7 to 6	5 to 1
	GOOD TO EXCELLENT (A to B)	FAIR (C to D)	POOR TO CRITICAL (F)
Primary System Elements			
Panel	Panel elements are as constructed and show no signs of rockfall impacts that resulted in significant damage.	Panel elements show signs of rockfall impacts that resulted in moderate damage, but can still contain a rockfall event.	Panel elements show signs of rockfall impacts that resulted in severe damage and likely cannot contain a rockfall event.
Post	Posts are as constructed and show no signs of rockfall impacts that resulted in significant damage.	Posts show signs of rockfall impacts that resulted in moderate damage, but are still functional.	Posts show signs of rockfall impacts that resulted in significant damage and are not fully functional.
Bearing/ Retaining Ropes and Anchors	Wire ropes and anchors are as constructed and show no signs of rockfall impacts that resulted in significant damage.	Wire ropes and anchors show signs of rockfall impacts that resulted in moderate damage but are still functional.	Wire ropes and anchors show signs of rockfall impacts that resulted in severe damage and are not fully functional.
Post Foundation	Foundations are as constructed and show no signs of rockfall impacts that resulted in significant damage.	Foundations show signs of rockfall impacts that resulted in moderate damage, but are still functional.	Foundations show signs of rockfall impacts that resulted in severe damage and are not fully functional.
Braking Elements	Braking elements are as constructed and show no signs of rockfall impacts that resulted in significant damage.	Braking elements show signs of rockfall impacts that resulted in engagement, but are still functional.	Braking elements show signs of rockfall impacts that resulted in engagement and are not functional.

Table 4-2. Proposed rockfall system condition rating—secondary elements.

ROCKFALL SYSTEM CONDITION RATING SECONDARY ELEMENTS			
Element	Condition Ratings		
	10 to 8	7 to 6	5 to 1
	GOOD TO EXCELLENT (A to B)	FAIR (C to D)	POOR TO CRITICAL (F)
Secondary System Elements			
Panel Secondary Mesh	Panel elements are as constructed and show no signs of rockfall impacts that resulted in significant damage.	Panel elements show signs of rockfall impacts that resulted in moderate damage, but can still contain a rockfall event.	Panel elements show signs of rockfall impacts that resulted in severe damage and likely cannot contain a rockfall event.
Shackles, Clips, Connections	Elements are as constructed, and no elements are missing.	Elements show signs of moderate damage, but are still functional. Minor elements are missing creating gaps < 3 inches wide.	Elements show signs of severe damage and are not functional. Major elements are missing creating gaps ≥ 6 inches wide.
Corrosion	No evidence of corrosion, staining, contamination, or crack/spalling due to weathering or chemical attack.	Minor evidence of corrosion, staining, contamination, or cracking/spalling due to weathering or chemical attack.	System is compromised by corrosion, staining, contamination, or cracking/spalling due to weathering or chemical attack.
Foundation Protection Systems	Systems are as constructed and show no signs of rockfall impacts that resulted in significant damage.	Systems show signs of rockfall impacts that resulted in moderate damage, but are still functional.	Systems show signs of rockfall impacts that resulted in severe damage and are not functional.
Other	As constructed.	Moderate damage, but still functional.	Severe damage, not functional.

Table 4-3. Proposed rockfall system performance rating.

ROCKFALL SYSTEM CONDITION RATING PERFORMANCE ELEMENTS			
Element	Condition Ratings		
	10 to 8	7 to 6	5 to 1
	GOOD TO EXCELLENT (A to B)	FAIR (C to D)	POOR TO CRITICAL (F)
System Performance			
Performance	No combinations of element distresses that indicate unseen problems or create significant performance problems are observed. No history of remediation or repair to adjacent elements is observed. No impacts from rockfall accumulation or vegetation noted within the system or within adjacent elements.	Some observed distresses to specific elements. Some element distress combinations are observed that indicate fence component problems. Minor work on primary elements or major work on secondary elements has occurred improving overall system function. Minor impacts from rockfall accumulation or vegetation noted within the system or within adjacent elements.	System elements that have failed are apparent, rockfall impacts significantly damaged system. Distresses clearly indicate serious stability problems with components. Major repairs have occurred to structural elements, though functionality has not improved. Adverse impacts from rockfall accumulation or vegetation noted within the system or within adjacent elements interfering with system.

Table 4-4. Proposed rockfall system weighting factor.

ROCKFALL SYSTEM WEIGHTING FACTOR GUIDANCE	
Suggested Weighting Factor	Weighting Factor Definition
3 to 10	Primary Elements (Panel, Posts, Top Bearing Rope, Lateral Anchors)
1	Secondary Elements (Other Elements)
10	Performance

Table 4-5. Proposed rockfall system data reliability rating.

ROCKFALL SYSTEM DATA RELIABILITY RATING GUIDANCE	
Data Reliability Factor	Data Reliability Factor Definition
1	**Very Good** Observed conditions clearly describe system performance. Additional investigations are not needed.
2	**Good** Observed conditions are sufficient to rate the condition of element(s); however, additional investigations would be useful to better understand element performance.
3	**Poor** Conditions cannot be sufficiently observed to rate element(s), warranting additional investigation to better define element performance and/or to determine the cause(s) of poor performance.

Table 4-6. Proposed rockfall system failure consequence rating.

ROCKFALL SYSTEM FAILURE CONSEQUENCE RATING GUIDANCE	
Definitions	
Consequence of Failure	**Low:** No loss of roadway, no-to-low public risk, no impact to traffic during construction **Moderate:** Hourly to short-term closure, low-to-moderate public risk, multiple alternative routes **High:** Seasonal to long-term loss of roadway, substantial loss or public risk, no alternative routes

Table 4-7. Proposed rockfall fence system rating criteria.

ROCKFALL FENCE SYSTEM CONDITION RATING CRITERIA	
Grade	Criteria
A	Fence condition ≥ 9
B	Fence condition rating between 8 and < 9
C	Fence condition rating between 7 and < 8
D	Fence condition between 6 and < 7
F	Fence condition < 6

4.5 Rockfall System Failure Consequence Rating

The Rockfall System Failure Consequence Rating (Table 4-6) is based on the impact to roadway users, public safety, and availability of alternate routes.

4.6 Rockfall System Condition Rating

The overall system condition rating is evaluated using the total of the condition scores and the total of the weighting factors and is assigned a letter grade based on the criteria outlined in Table 4-7. As with the weighting factors, the criteria used to assign grades are based on experience and should be reevaluated as additional data becomes available and to suit specific agencies.

4.7 Proposed Rockfall System Inventory Form

The Rockfall System Inventory Form (Table 4-8) gathers information about the system identification, location, type of components, dimensions, and a summary of the overall system condition based on the detailed condition assessment.

4.8 Proposed Rockfall System Condition Assessment Form

The Rockfall Fence Condition Assessment Form (Table 4-9) is used to guide detailed inspection and documentation of the condition of individual elements of the system. A description of the condition of the elements is recorded and a condition rating and data reliability score are assigned. The condition score is calculated as the condition rating multiplied by the weighting factor.

Table 4-8. Proposed rockfall system inventory form.

ROCKFALL SYSTEM INVENTORY FORM					
Rockfall System ID		Chute or Pathway Location		Roadway and MM Start (Approx)	
Manufacturer		Station		Roadway and MM End (Approx)	
Inspected By		Distance Centerline		Latitude	
Inspected Date		Left or Right of Centerline		Longitude	
Approx. Year Built		Project Code for System		Elevation	
SYSTEM FUNCTION, DIMENSIONS, and DESCRIPTION					
Rockfall Mitigation Type		Panel Lacing Rope Dia.		Post to Foundation (Fixed/Pinned/Hinged)	
Panel Type		Ring Net Designation		Uphill Retaining Anchor Dia.	
Panel Aperture Opening		Post Flange Dimension (bf)		Lateral Retaining Anchor Dia.	
Panel Wire Thickness		Post Depth Dimension (d)		Type and Dia of Anchors	
Secondary Mesh Clip Spacing (ft)		Post Thickness (ft)		Secondary Panel Cover Type	
Rockfall Accumulation (cy)		Post Foundation Diameter, Size and No. bars		Painting/Powder Coating	
Fence General Description Notes (draw in Post/Foundation/Anchors if necessary):					
System Length (ft)		System Panel Face Area (sf)			
System Height (ft)		Vertical Offset (+/- ft)			
Photo Description/No.		Post Batter Down Slope (deg)			
REPAIR/REPLACE RECOMMENDATIONS AND WORK ORDER					
Further Investigation?		Failure Consequence			
System Condition Rating	(Insert from Inspection Form)	Action			
Maintenance/Repair/Replace Recommendations:					

Table 4-9. Proposed rockfall system condition assessment form.

ROCKFALL SYSTEM CONDITION ASSESSMENT						
Element	Photo Number	Condition Narrative	Condition Rating	Weighting Factor	Condition Score	Data Reliability
Primary System Elements						
Panel				10	0	
Post				10	0	
Top Bearing Rope and Anchors				10	0	
Lateral Retaining Rope and Anchors				10	0	
Uphill Retaining Rope and Anchors				7	0	
Post Foundation				3	0	
Braking Elements				3	0	
Secondary System Elements						
Panel Secondary Mesh				1	0	
Shackles, Clips, Connections				1	0	
Corrosion				1	0	
Foundation Protection Systems				1	0	
Other				1	0	
System Performance						
Performance				10	0	
System Rating		Weighting Factor (X 10) and Condition Score Totals		0.0	0	0.0
		Fence Condition Rating (= [Condition Score Total/Weighting Factor Total =] (X 10) X 100)		0.0	System Grade	Data Reliability

CHAPTER 5

Discussion of Management of Rockfall Fence Systems After Inventory and Condition Assessment

After completion of the inventory and condition assessment phase of an asset management plan, the data is analyzed using life-cycle cost models to forecast future investments. The life-cycle cost analysis principles for assets such as pavement are well developed with readily defined variables. However, the data required to perform a life-cycle analysis for a rockfall fence system is not as readily quantified as it is for pavement. Section 5.1 and Section 5.2 provide a comparison of the two systems.

5.1 Pavement Asset Management Concept

For pavement asset management most variables can be quantified or tested. The specific items associated with pavement design and construction include the following:

- pavement thickness
- mix types
- aggregate types
- binders
- compaction
- density testing

The preceding quantities are measurable items associated with pavement asset and used in modeling and design, however the one item that specifically affects the asset is traffic volume.

Traffic volume is also a measurable element that can be quantified in real time relatively inexpensively compared with the cost of an overall pavement project. With the above information and a well-defined deterioration model, a life-cycle analysis can be performed to evaluate treatment options for the short term and long term. This analysis guides the decision making process to maintain the pavement in the best condition possible given budgetary and other constraints.

Figure 5-1 depicts a generalized life-cycle activity profile that ties pavement performance to traffic volume, showing pavement deterioration over time.

The example life-cycle activity profile for pavement illustrates pavement deterioration to the replacement threshold versus performing several surface treatments to maintain the pavement in a better condition over the life cycle. The deterioration models and treatment alternatives that are incorporated into the life-cycle analysis are relatively well known based on the current knowledge of pavement performance.

This concept fits well into asset management and programming of funding given that the parameters are measurable and well defined and can be anticipated and predicted to a reasonable confidence level.

5.2 Rockfall Fence Asset Management Concept

For rockfall fence asset management most variables cannot be readily quantified. The main variables associated with rockfall fence design include the following:

- the estimated design rock diameter
- the estimated design impact energy level associated with a given design rock diameter
- the estimated bounce height for the design rock diameter

These quantities are used in modeling and design of the rockfall fence asset; however, these events would need to be measured to provide a basis for managing the rockfall system.

The rockfall energy, frequency, and bounce height are not readily measurable elements that can be quantified for use in asset management of rockfall fences. These events are more analogous to a catastrophic event for pavements such as a water main break that undermines the pavement section.

Anticipating and attempting to predict the actual rockfall size, frequency, and bounce height is not readily performed. Typically rockfall systems are located in historic rockfall areas, but the time, intensity, frequency, and amount of rockfall from

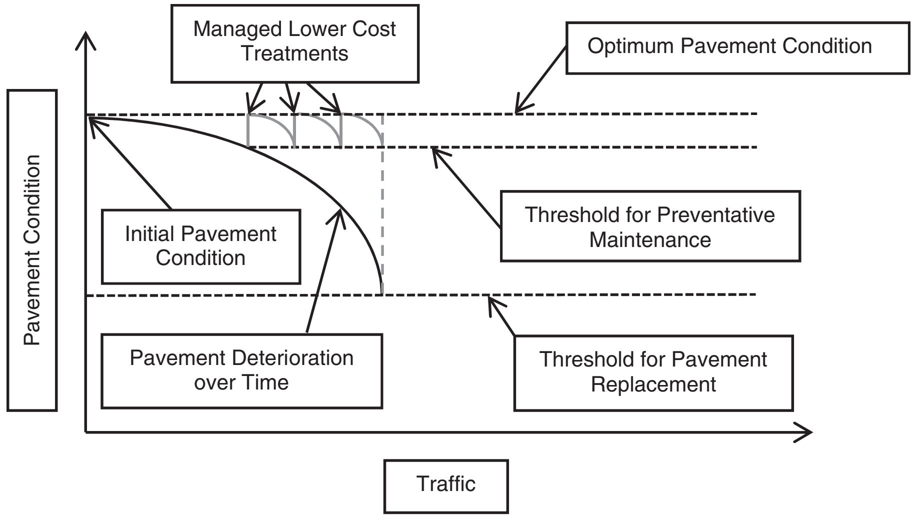


Figure 5-1. Generalized pavement life-cycle activity profile.

the event cannot be predicted with a reasonable confidence level such as can be performed with traffic volumes.

There are systems that can be used to anticipate and predict rock slope failures, but these are generally expensive real-time monitoring systems that collect data on an ongoing basis. For example, the data collection for evaluating stability of a rock slope in an open pit mine may occur for years or even decades in an effort to predict an impending rock slope failure. The prediction of the rock slope failure becomes more accurate as the time nears to the actual failure; however, vast amounts of data are required over long time periods to determine what the threshold may be for an impending rock slope failure. These methods to anticipate and predict rockfall by gathering data are generally many times the cost of the actual rockfall system. For example, in many cases the rockfall fence system may be less than $60,000, but to gather actual data on the rock slope or rockfall activity using radar or LiDAR methods may be in excess of $10,000 to 60,000 a month depending on the system.

To further clarify the comparison between pavement asset management and rockfall fence asset management, the following three scenarios are presented for a rockfall fence system. Figure 5-2 depicts a life-cycle activity profile in which a rockfall event impacts a rockfall fence system with energy in excess of the system capacity. After one large rockfall event the entire system requires repair or replacement.

Figure 5-3 depicts a life-cycle active profile for multiple smaller rockfall events that are within the system capacity but because of the frequency of events, the condition of the system deteriorates to the point of requiring repair or replacement. Figure 5-4 depicts a life-cycle activity profile

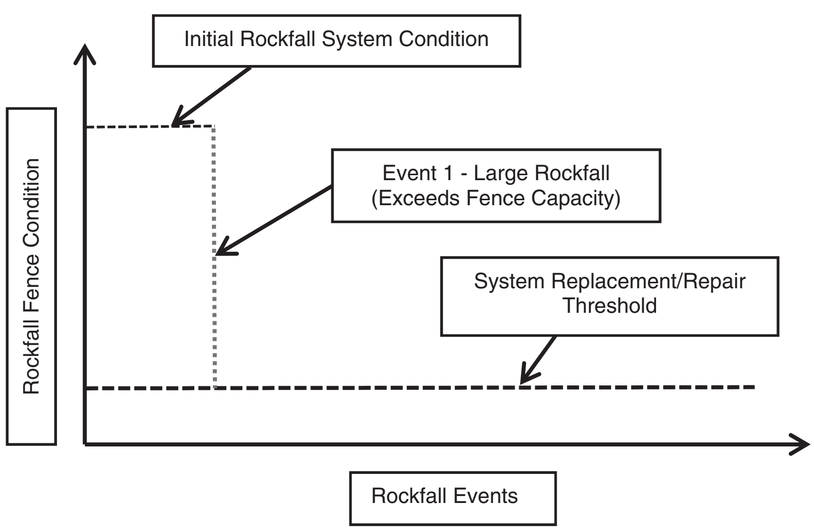


Figure 5-2. Life-cycle activity profile for a rockfall event that exceeds rockfall system capacity.

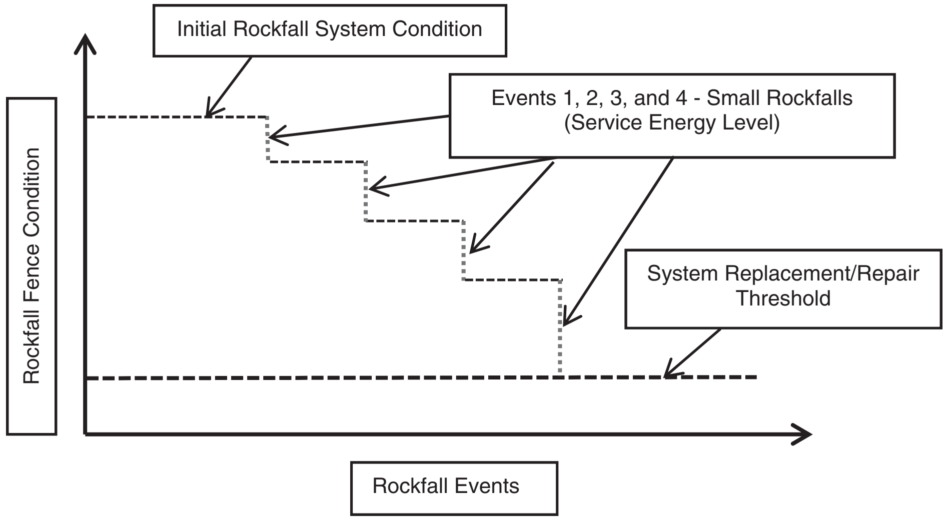


Figure 5-3. Life-cycle activity profile for multiple smaller rockfall events that require repair or replacement of the system.

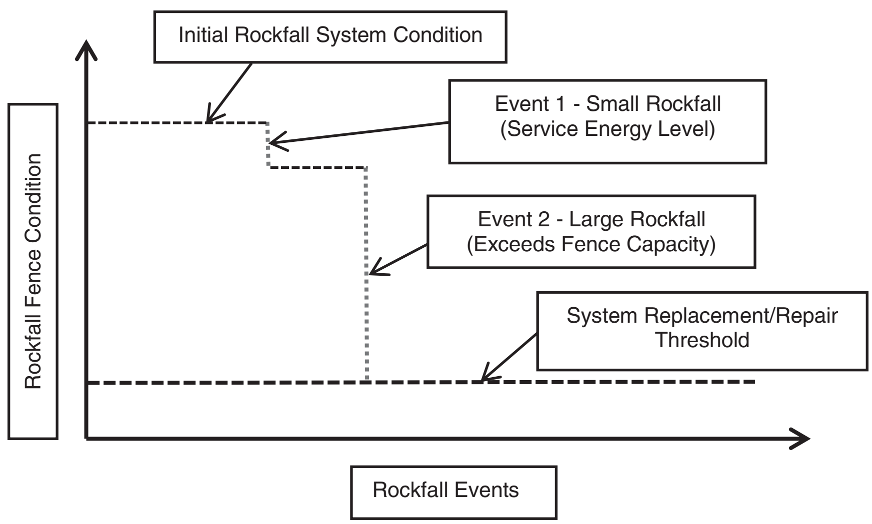


Figure 5-4. Life-cycle activity profile for one smaller rockfall event and one larger rockfall event that requires repair or replacement of the system.

for a single rockfall event at the service energy level resulting in a slight reduction in fence condition followed by a large rockfall event exceeding the system capacity, requiring system repair or replacement.

5.3 Rockfall Fence Asset Management Practice

The preceding example illustrates the difficulty of applying a well-known concept that works well for pavements to rockfall fences. For an agency to apply the principles and concepts of asset management from pavement design to rockfall fences, the following elements would need to be addressed:

- Frequency of rockfall impacts of various energies
- Location of rockfall impacts within the system
- Bounce height of the rockfall
- Climatic conditions including high precipitation events and freeze-thaw cycles that affect rockfall frequency

In lieu of gathering this information through relatively expensive data gathering systems, an agency can estimate the measurements by the following:

- Perform an inventory and condition assessment of the rockfall systems on a periodic basis such as yearly or every 2 years to obtain basic information on the status of the systems.

- Review the inventories and compare the change in system conditions in the time between assessments.
- Program funding based on the rate at which system conditions fall below a threshold defined by the agency.

During project evaluation and prioritization based on condition assessment data and analysis, agencies should consider the following:

- Cost of system repair or replacement versus overall construction contract costs because rockfall fence systems are relatively inexpensive compared with project costs that include traffic control, mobilization, inspection, and so forth
- Cost of repairing a rockfall fence system from an unacceptable condition to an acceptable condition versus complete system replacement
- Potential cost savings of repairing or replacing multiple systems under one project

As agencies collect additional condition assessment data, they can develop deterioration models for life-cycle analysis that will help guide the decision making process. More elaborate models can be developed over time as described in Appendix C of the Final Report. The initial process is dependent on creating a condition inventory and database of the rockfall fence systems and evaluating the performance over time. Rockfall fences in less active areas will require little to no maintenance whereas rockfall fences in highly active areas may require yearly maintenance or repair and funding can be programmed accordingly.

5.4 Discussion of Maintenance and Repair of Rockfall Fence Systems

Based on the survey results from the manufacturers, there does not appear to be a standard maintenance and repair protocol for rockfall fence systems. There are many issues and challenges surrounding a set guideline or protocol for a fence system including but not limited to the following:

- Rockfall fence systems are proprietary and have specific manufacturer designed elements such as braking systems, posts, wire rope anchors, and so forth, that if damaged or broken, would require the manufacturer to provide feedback or specialty parts for a particular system.
- Specific elements of propriety rockfall fence systems may be extremely critical to the manufacturers' tested system whereas similar elements on a competitor's system may not be as critical for a given system.
- Agencies may have spare rockfall fence parts at their disposal and may choose to replace a damaged panel but then would be modifying the manufacturer's system. This may or may not be an issue with an agency maintaining the rockfall fence systems.

Overall, the maintenance of rockfall fence systems needs to be performed on a case-by-case basis, because it will be necessary for the reviewers to evaluate the need to repair and maintain a system rather than attempt to generalize all rockfall damage into one set of pre-determined protocols. An agency will need to assess the amount of repair or replacement necessary and how it aligns with the asset management plan.

CHAPTER 6

Proposed Performance-Based Special Provision for Rockfall Fence Systems

The following is a proposed performance-based special provision for agencies to use when bidding and contracting rockfall fence system work.

REVISION OF SECTION XXX.XX

(Commentary: A performance specification is provided. This is intended to be modified for use with standard or special provisions per agency requirements. Various federal and state agencies have specific standard or special provisions relating to rockfall fences based on design assumptions, past experiences, and in-house procedures and protocols per specific agency requirements).

ROCKFALL FENCE

Section XXX of the Standard Specifications is hereby revised for this project to include the following:

DESCRIPTION

This work consists of construction of a rockfall fence to mitigate potential rockfall as designated on the Plans. Installation shall be at the locations designated on the Plans unless otherwise directed.

(Commentary: Definitions of the systems vary from region to region and state to state. Clarify what the system is, for example, Flexible Rockfall Fence, Rockfall Fence, or Rockfall Barrier).

DEFINITIONS

The bid item for Rockfall Fence is considered a _______ kJ, _____ high, tested rockfall fence system.

(Commentary: The agency or designer typically assesses the energy requirements of the rockfall fence based on an evaluation of the site conditions and rockfall energies using appropriate methods for Design-Bid-Build (DBB) projects. Other contracting methods may have different requirements).

CONSTRUCTION REQUIREMENTS

The rockfall fence shall be installed in accordance with the submitted Shop Drawings and in the locations shown on the plans or as marked by the Engineer for the specified rockfall fence system as shown on the Plans.

(Commentary: The agency or designer typically evaluates the energy requirements of the rockfall fence based on an evaluation of the site conditions and rockfall energies using appropriate methods for DBB projects. Other contracting methods may have different requirements).

SUBMITTALS

Shop Drawings shall be in accordance with Standard Specification _________.

(Commentary: Agencies typically have Shop Drawing standard provisions. The requirement for a Professional Engineer seal on the Shop Drawings can be evaluated by the agency).

At least ______ days prior to the beginning of construction the Contractor shall submit detailed Shop Drawings of the rockfall fence system.

The diameters and dimensions of materials in the submitted Shop Drawing system shall be equal strengths to the metric equivalents for the submitted ETAG 27 tested systems and requirements of this special provision (i.e., diameter of wire rope in fence panels, diameter of lacing ropes, and diameter of anchor ropes shall be sized for equal strength to the metric equivalents). The Contractor and/or Rockfall Fence Manufacturer shall outline differences (if any) between the two systems. If the differences are significant, the Engineer may require written justification for the change or require the tested elements be incorporated into the Shop Drawings.

The Shop Drawings shall include the following minimum information:

(a) Plan view locations for the rockfall fence system showing location of all elements associated with the rockfall system
(b) Description of the construction sequence
(c) Details for the fence panel system

(d) Details for the fence panel mesh layer connection to the fence net panel
(e) Details of the connection between the fence panel and wire support rope
(f) Details for the supporting posts
(g) Details of the net panel's lateral and retaining wire ropes with brakes
(h) Details of the rock and/or soil anchor systems with applicable design pullout loads
(i) Details of the post support and base
(j) Required torque for all bolts and fasteners
(k) Grout and concrete requirements (per agencies' requirements)
(l) Documentation that the rockfall fence system has been tested in accordance with ETAG 27
(m) A completed ETAG 27 Rockfall Fence Test Data Request Form

METHOD OF MEASUREMENT

Rockfall fence will be measured and paid by the linear feet that are installed and accepted.

BASIS OF PAYMENT

The accepted quantity of work will be paid for at the contract price per unit of measurement for the pay items listed below. Payment for a ________ kJ system will be made under Rockfall Fence.

Pay Item	**Pay Unit**
Rockfall Fence	Linear Foot

<table>
<tr><th colspan="6">ETAG 27 ROCKFALL FENCE TEST DATA REQUEST FORM</th></tr>
<tr><td colspan="6">This form is intended to be used by federal and state transportation agencies to request rockfall fence test data for fences that have been tested and approved according to ETAG 27. Agencies may send this form to the fence manufacturer to request the documentation and data described below. The manufacturer may fill in the appropriate information and complete the checklist providing the requested information or the manufacturer may provide a separate report containing the requested information.</td></tr>
<tr><td colspan="2">Manufacturer</td><td></td><td colspan="2">Fence Model/Type</td><td></td></tr>
<tr><td colspan="2">Energy Level Classification/Energy</td><td></td><td colspan="2">Test Institution</td><td></td></tr>
<tr><td colspan="2">Test Location</td><td></td><td colspan="2">Rock/Block Delivery Method</td><td>☐ Vertical Drop
☐ Inclined Cable</td></tr>
<tr><td colspan="2">Date of Testing</td><td></td><td colspan="2">Date of Approval</td><td></td></tr>
<tr><td colspan="6">DOCUMENTATION AND TEST DATA CHECKLIST</td></tr>
<tr><td></td><td colspan="5">Provide system documentation including plans, installation manual/guide, and description of system components.</td></tr>
<tr><td></td><td colspan="5">Verify and document that ropes, cables, nets, posts, and other components used in the United States have equivalent strength as those tested according to ETAG 27.</td></tr>
<tr><td></td><td>Nominal Height</td><td></td><td></td><td>Post Dimensions (Width/Flange/Thickness)</td><td></td></tr>
<tr><td></td><td>Post to Foundation Connection Type</td><td></td><td></td><td>Panel Width/Post Spacing</td><td></td></tr>
<tr><td></td><td>Panel Type</td><td></td><td></td><td>Applied Mesh Type</td><td></td></tr>
<tr><td></td><td>Retaining Rope Dimensions</td><td></td><td></td><td>Anchor Type and Diameter</td><td></td></tr>
<tr><td></td><td>Type and Locations of Energy Dissipating Devices</td><td colspan="4"></td></tr>
<tr><td colspan="6">First Service Energy Level (SEL) Test Data</td></tr>
<tr><td></td><td>Block Energy at Impact</td><td></td><td></td><td>Residual Height</td><td></td></tr>
<tr><td></td><td>Maximum Elongation</td><td></td><td></td><td>Braking Time</td><td></td></tr>
<tr><td></td><td>Force Measurements</td><td colspan="4"></td></tr>
<tr><td></td><td colspan="5">Provide a description below of fence behavior including damage and deformations of components.</td></tr>
<tr><td colspan="6"></td></tr>
</table>

ETAG 27 ROCKFALL FENCE TEST DATA REQUEST FORM (CONTINUED)					
Second Service Energy Level (SEL) Test Data					
	Block Energy at Impact			Residual Height	
	Maximum Elongation			Braking Time	
	Force Measurements				
	Provide a description below of fence behavior including damage and deformations of components.				
Maximum Energy Level (MEL) Test Data					
	Maintenance Performed after SEL Tests			☐ Repair ☐ Replacement ☐ None	
	Block Energy at Impact			Residual Height Category	☐ A ☐ B ☐ C
	Residual Height			Maximum Elongation	
	Braking Time				
	Force Measurements				
	Provide a description below of fence behavior including damage and deformations of components.				
Manufacturer Representative Signature and Date (Attach Original ETAG 27 Document)					

References

EOTA. *ETAG 27: Guideline for European Technical Approval of Falling Rock Kits.* European Organisation for Technical Approvals (EOTA), Brussels, Belgium, 2008, 53 p.

Gerber, W. *Guideline for the Approval of Rockfall Protection Kits.* Swiss Agency for the Environment, Forests and Landscape (SAEFL) and the Swiss Federal Research Institute (WSL), Bern, Switzerland, 2001, 39 p.

Higgins, J. D. Recommended Procedures for the Testing of Rock-Fall Barriers. Report for NCHRP Project 20-07 (Task 138) submitted to AASHTO, Washington, DC, 2003, 24 p.

Peila, D., and C. Ronco. "Technical Note: Design of Rockfall Net Fences and the New ETAG 027 European Guideline." *Natural Hazards and Earth System Sciences*, Vol. 9, 2009, pp. 1291–1298.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation

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