



Applied Research and Innovation Branch

Rock Cut Perimeter Blasting Best Management Practices Phase I

**Advanced Explosives Processing Research Group (AXPRO)
Colorado School of Mines**

**Report No. CDOT-2018-07
April 2018**

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Technical Report Documentation Page

1. Report No. CDOT-2018-07		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Rock Excavation Best Management Practice Phase I (Rock Cut Perimeter Blasting BMP)				5. Report Date 2018 April	
				6. Performing Organization Code	
7. Author(s) Vilem Petr, Eduardo Lozano, Erika Nieczkoski				8. Performing Organization Report No. CDOT-2018-07	
9. Performing Organization Name and Address Advanced Explosives Processing Research Group (AXPRO) Colorado School of Mines 1600 Illinois Street, Golden, Colorado 80401				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Colorado Department of Transportation - Research 4201 E. Arkansas Ave. Denver, CO 80222				13. Type of Report and Period Covered	
				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared in cooperation with the US Department of Transportation, Federal Highway Administration					
16. Abstract We examined CDOT design procedures, blasting methods, blast calculations, and aesthetic considerations to specify best management practices for highway rock cut operations for the Colorado Department of Transportation (CDOT) that could be followed when a Contractor or Permittee is proposing to blast. Though aesthetics are highly subjective, we developed a method to assign quantitative values for aesthetics, called the Percent Aesthetic Enhancement (PAE). The PAE is constituted as a quantitative assessment that defines the level of effort required for the enhancement of aesthetic features in final road cuts. By following these practices, the CDOT Engineer-In-Charge can ensure that the Contractor accomplishes the work in a safe manner while preserving scenic, aesthetic, and environmental resources.					
Implementation					
17. Keywords			18. Distribution Statement This document is available on CDOT's website http://www.coloradodot.info/programs/research/pdfs		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages	
				22. Price	

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ACKNOWLEDGMENTS

REFERENCES

1. INTRODUCTION

A. Purpose

This document specifies best management practices for highway rock cut operations for the Colorado Department of Transportation (CDOT) that shall be followed when a Contractor or Permittee is proposing to blast. By following these practices, the CDOT Engineer-In-Charge can ensure that the Contractor accomplishes the work in a safe manner while preserving scenic, aesthetic, and environmental resources. CDOT manages roadways in complex geologic settings and steep, mountainous terrain. Operations in these areas require rock excavation, slope stabilization, and rock fall mitigation before the safe and desired roadway can be achieved. This document will provide a reference for the selection, design, evaluation, and aesthetic construction of rock slopes. Prior to blasting, the Contractor shall submit a written blast plan to the Engineer for conditional approval. Post approval of the blast plan, a pre-blast meeting will be held and attended by the Engineer, the Contractor, the Project Blaster(s)-In-Charge, and representatives of all interested parties so that the proposed blasting operations may be discussed. Final approval to blast will be granted based upon the results of the meeting. Tests blasts may be required and may result in modifications to the blasting plan. All highway rock cut operation blasts will be documented by the Engineer using the *Blasting Report Form*.

B. General

Blasters in the State of Colorado are required to possess a valid Colorado Department of Labor and Employment (CDLE) Division of Oil and Public Safety issued Explosives Permit. A permit issued by the Division is required for the use, manufacture, purchase, possession, sale, storage, transportation, and disposal of explosive materials in the State of Colorado by any individual corporation, firm, partnership, associate, or state or local government agency.

The Contractor shall utilize controlled blasting techniques for all excavations to reduce overbreak and control slope contour. All blasting operations shall be conducted in a skillful manner so as not to cause injury, damage property, adversely affect traffic, or cause the migration/accumulation of noxious gases, and ensure the safety of employees, CDOT personnel, adjacent properties, and the public.

Each Certified Blaster is required to report to CDOT any unusual incident or event that occurs during the blasting operations. They are also required to report any instances of premature detonation, damage from air blast, damage from excessive ground vibration, or instances of fly rock. Damage must be reported even when it is alleged and/or the complaint is made after substantial lapse of time. All damages resulting from rock excavation or rock over-excavation operations shall be repaired and items replaced to the satisfaction of the Engineer, at the Contractor's expense.

Note that mine adits may be encountered during rock excavation. Refer to the Geotechnical Report for the project for more information.

C. Definitions

Active Status – the status of a valid Type I permit when the permittee is authorized to possess and control explosives by a Type II permittee. (7 C.C.R. 1101-9)

Aesthetically Pleasing – a natural roughness angle that preserves the scenic geology by highlighting natural and pre-existing fractures, bedding planes, joints, and roughness of the rock slope.

Aesthetic Contour Blasting – an aesthetically pleasing, safe, and economical method of blasting in which the actual profile of the road cut is as close as possible to the project profile with preservation of the surrounding rock.

Air Overpressure – The airborne shockwave or acoustic transient generated by an explosive. (7 C.C.R. 1101-9)

Ammonium Nitrate – the ammonium salt of nitric acid represented by the formula NH_4NO_3 . (7 C.C.R. 1101-9)

ANFO – A blasting agent composed primarily of ammonium nitrate and fuel oil. (7 C.C.R. 1101-9)

Approved Storage Facility (Approved Magazine) – A facility for the storage of explosive materials conforming to the requirements of Federal and State rules and regulations. (7 C.C.R. 1101-9)

Attend(ed) – The physical presence of an authorized person within the field of vision of explosive or the use of explosives. (7 C.C.R. 1101-9)

Authorized, Approved, or Approval – Terms which mean approved, approval, or authorized by the Division of Oil and Public Safety of the Colorado Department of Labor and Employment. (7 C.C.R. 1101-9)

Authorized Person – A person approved or assigned by management to perform a specific type of duty or duties to be at a specific location or locations at the job site. (7 C.C.R. 1101-9)

Armed Charge – An explosive cartridge that contains a detonator. (7 C.C.R. 1101-9)

Artificial Barricade – An artificial mound, berm, or wall of earth of a minimum thickness of 3 feet or any other approved barricade that offers equivalent protection. (7 C.C.R. 1101-9)

Backbreak – Rock broken beyond the limits of the last row of holes in a blast, synonymous with overbreak.

Barricaded – the effective screening of a building or magazine containing explosive materials from another magazine or building, railway, highway by a natural or artificial barrier. A straight line from the top of any sidewall of the building or magazine containing explosives materials to the eave line of any magazine or building or to a point 12 feet above the center of a railway or highway shall pass through the barrier. (7 C.C.R. 1101-9)

Base Charge – The main explosive charge in the base of a detonator or a heavy charge at the base of a column of presplit powder. (7 C.C.R. 1101-9)

Battered Production Holes – The row of production holes closest to presplit line, drilled at the same angle as the presplit holes.

Bench – A horizontal ledge from which holes are drilled downward into the material to be blasted.

Binary (two-component) Explosive – A blasting explosive formed by the mixing or combining of 2 phosphoric materials (e.g. ammonium nitrate and nitromethane. (7 C.C.R. 1101-9)

Black Powder – A deflagrating or low explosive compound of an intimate mixture of sulfur, charcoal, and an alkali nitrate (usually potassium or sodium nitrate). (7 C.C.R. 1101-9)

Blast Area – Area of the blast within the influence of flying rock missiles, gases, vibration, and concussion. (7 C.C.R. 1101-9)

Blaster – A Type I permitted individual who is permitted by the Division to possess and control the use of explosives. (7 C.C.R. 1101-9)

Blast Plan – A written procedure that details the methods and manner by which a Project blaster will comply with pertinent laws, rules, regulations, and contract documents. The plan should show the details for a typical blast with the understanding that minor modifications in the field will be allowed. Significant changes to the blasting operations will require that a new blast plan be submitted for approval. When deemed necessary by the Engineer, approved blast plans will be required for each individual shot.

Blaster-in-Charge – A Type I permittee who is in charge of and responsible for the loading or preparing of the explosive charges, and either physically initiates the charge or is physically present when the charge is initiated at a specific job site. The individual is in charge of the planning of the blast at a specific job site, the supervision of all persons assisting on the blast and all persons training, and is responsible for the inventory, inventory records, and blast records for the blast. (7 C.C.R. 1101-9)

Blasting Agent – An explosive material, which meets prescribed criteria for insensitivity to initiation.

For storage, a blasting agent is defined as any material or mixture consisting of fuel and oxidizer intended for blasting, not otherwise defined as explosive provided that the finished product, as

mixed for use or shipment, cannot be detonated by means of a No. 8 Blasting Cap when unconfined. (Bureau of Alcohol, Tobacco, Firearms, and Explosives Regulations)

Blasting Galvanometer – An electrical resistance instrument designed specifically for testing electrical continuity of electric detonators and circuits containing them. (7 C.C.R. 1101-9)

Blasting Mat – A mat of woven steel, rope, wire, scrap tires, or other suitable material or construction to cover blastholes for the purpose of preventing flying rock missiles. (7 C.C.R. 1101-9)

Blat Pattern, Drill Pattern – the plan of the drill holes laid out for blasting; an expression of the burden distance and their relationship to each other. (7 C.C.R. 1101-9)

Blasting Site – Area where explosive material is handled during blasting operation, including the perimeter of blast hole and a distance of 50 feet in all directions from explosive charges, loaded boreholes or boreholes to be loaded.

Blasting Vibrations – The energy from a blast that manifests itself in the form of vibrations, which are transmitted through the earth away from the immediate blast area.

Booster – An explosive charge, usually of high detonation velocity and detonation pressure, designed to be used in the explosive initiation sequence between an initiator or primer and the main charge. (7 C.C.R. 1101-9)

Borehole, Blast Hole, Drill Hole – a hole drilled in the material to be blasted, for the purpose of containing an explosive charge. (7 C.C.R. 1101-9)

Bulk Mix – a mass of explosive material prepared for use in bulk form without packaging. (7 C.C.R. 1101-9)

Bulk Mix Delivery Equipment – Equipment (usually a motor vehicle with or without mechanical delivery device), which transports explosive material in bulk form for mixing and/or loading directly into blast holes. (7 C.C.R. 1101-9)

Bullet Resistant – Magazine walls or doors of construction resistant to penetration of a bullet of 150-grain M2 ball ammunition having a nominal muzzle velocity of 2,700 feet per second fired from a .30 caliber rifle from a distance of 100 feet perpendicular to the wall or door.

When a magazine ceiling or roof is required to be bullet resistant, the ceiling or roof shall be constructed of materials comparable to the side walls or of other materials which will withstand penetration of the bullet described above when fired at an angle of 45 degrees from perpendicular.

Tests to determine bullet resistance shall be conducted on test panels or empty magazines which shall resist penetration of 5 out of 5 shots placed independently of each other in an area of at least 3 feet by 3 feet. (7 C.C.R. 1101-9)

Bullet-Sensitive Explosive Materials – Explosive material that can be detonated by a 150 grain M2 ball ammunition having a nominal muzzle velocity of 2,700 feet per second when the bullet is

fired from a .30 caliber rifle at a distance of not more than 100 feet and the test material, at a temperature of 70-75 degrees Fahrenheit, is placed against a backing material of 2-inch steel plate. (7 C.C.R. 1101-9)

Bulk Strength – The strength per unit volume of an explosive calculated from its weight strength and density. (7 C.C.R. 1101-9)

Burden – The distance from the borehole to the nearest free face, or the distance between boreholes measured perpendicular to the spacing. Also, the total amount to be blasted by a given hole, which is usually measured in cubic yards or tons. (7 C.C.R. 1101-9)

Bus Wire – Expendable heavy gauge bare copper wire used to connect detonators or series of detonators in parallel. (7 C.C.R. 1101-9)

Charge-Per-Delay – Any charges firing within any 8-millisecond time period are considered to have a cumulative effect on vibration and air over-overpressure effects. Therefore, the maximum charger-per-delay (w) is the maximum weight of all charges firing within any 8-millisecond time period from the time a blast starts until the time it ends. For example, if two 10-lb charges fire at 100 ms and one 15-lb charge fires at 105 ms, the maximum charge-per-delay (w) for this time period would be 35 lbs. (7 C.C.R. 1101-9)

Collar – The mouth or opening of a borehole. (7 C.C.R. 1101-9)

Column Charge – A long, continuous, unbroken column of explosives in a blasthole. (7 C.C.R. 1101-9)

Connecting Wire – Wire used to extend the firing line or leg wires in the electric blasting circuit. (7 C.C.R. 1101-9)

Continuity Check (Circuit) – A determination that an initiation system is continuous and contains no breaks or improper connections that could cause stoppage or failure of an ignition system. For an electric initiation system, the check is performed both visually and by using a blasting galvanometer or other device. For a non-electric initiation system, the check can only be done visually. (7 C.C.R. 1101-9)

Control – To directly exercise authority, dominating influence over the use, manufacture, acquisition, purchase, sale, distribution, storage, transportation, or disposal of explosive materials. (7 C.C.R. 1101-9)

Cushion Blasting – A method of rock excavation - cushion blast holes are blasted after production blasts. Larger drill hole are used with small diameter, and are lightly loaded. The space around the explosive(s) is filled with crushed rock to cushion the explosive force.

Day Box – A portable magazine for the temporary and attended storage of explosives. Day boxes shall meet construction requirements of a Type 3 magazine. (7 C.C.R. 1101-9)

Dealer – Any person engaged in the business of distributing explosive material at wholesale or retail value. (7 C.C.R. 1101-9)

Deck – An explosive charge that is separated from other charges in the blast hole by stemming or an air cushion.

Deflagration – An explosive reaction such as a rapid combustion that moves through an explosive material at a velocity less than the speed of sound in the material. (7 C.C.R. 1101-9)

Delay Blasting – The practice of initiating individual explosive decks, boreholes, or rows of boreholes at predetermined time intervals using delay detonators, or other delaying methods, as compared to instantaneous blasting where all holes are fired essentially at the same time. (7 C.C.R. 1101-9)

Delay Detonator – An electric or nonelectric detonator used to introduce a predetermined lapse of time between the application of a firing signal and the detonation of a charge. (7 C.C.R. 1101-9)

Design Rock Slope – A cut slope in rock constructed at the angle and location specified in the contract plans. Presplit blasting is usually used to construct the slope so that the finished slope is stable and free from significant rock hazards. (7 C.C.R. 1101-9)

Detonating Cord – A flexible cord containing a center core of high explosives, which may be used to initiate other high explosives. (7 C.C.R. 1101-9)

Detonation – An explosive reaction that moves through an explosive material at a velocity greater than the speed of sound in the material. (7 C.C.R. 1101-9)

Detonator – Any device containing an initiating or primary explosive that is used for initiating detonation in another explosive material. A detonator may not contain more than 10 grams of total explosive by weight, excluding ignition or delay charges. The term includes, but is not limited to, electric blasting caps of instantaneous and delay types, electronic detonators, blasting caps for use with safety fuses, detonating cord delay connectors, and nonelectric instantaneous and delay blasting caps which use detonating cord, shock tube, or any other replacement for electric leg wires. (7 C.C.R. 1101-9)

Division – The Director of the Division of Oil and Public Safety of the Department of Labor and Employment or any designees thereof which may include certain employees of the Division of Oil and Public Safety or other persons. (7 C.C.R. 1101-9)

Down Line – a line of detonating cord or plastic tubing in a blast hole which transmits detonation from the trunkline or surface delay system down the hole to the primer.

Dynamite – A high explosive used for blasting, consisting essentially of a mixture of, but not limited to nitroglycerin, nitrocellulose, ammonium nitrate, sodium nitrate, and carbonaceous materials.

Electric Blasting Circuit – An electric circuit containing electric detonators and associated wiring.

Electric Detonators – A detonator designed for, and capable of, initiation by means of an electric current. (7 C.C.R. 1101-9)

Electronic Detonators – A detonator that utilizes stored electrical energy as a means of powering an electronic timing delay element/module and that provides initiation energy for firing the base charge. (7 C.C.R. 1101-9)

Emulsion – An explosive material containing substantial amounts of oxidizer dissolved in water droplets, surrounded by an immiscible fuel; or droplets of an immiscible fuel surrounded by water containing substantial amounts of oxidizer. (7 C.C.R. 1101-9)

Explosion – A chemical reaction involving an extremely rapid expansion of gases usually associated with the liberation of heat. (7 C.C.R. 1101-9)

Explosive – Any chemical compound, mixture, or device, the primary or common purpose of which is to function by explosion. (7 C.C.R. 1101-9)

Explosive Materials – These include explosives, blasting agents, and detonators. The term includes, but is not limited to, dynamite and other high explosives; slurries, emulsions, and water gels; black powder and pellet powder; initiating explosives; detonators (blasting caps); and detonating cord. (7 C.C.R. 1101-9)

Explosive Oils – Liquid explosive sensitizers for explosive materials (.e.g., nitroglycerin, ethylene glycol dinitrate and metriol trinitrate). (7 C.C.R. 1101-9)

Extra (Ammonia) Dynamite – dynamite in which part of the nitroglycerin is replaced by ammonium nitrate in sufficient quantity to result in the same weight strength.

Extraneous Electricity – Electrical energy, other than actual firing current or the test current from a blasting galvanometer, that is present at a blast site and that could enter an electric blasting circuit. It includes stray current, static electricity, electromagnetic waves, and time-varying electric and magnetic fields.

Fire Extinguisher Rating – A rating set forth in the National Fire Code which may be identified on an extinguisher by a number (5, 20, 70, etc.) indicating relative effectiveness, followed by a letter (A, B, C, etc.) indicating the class or classes of fires for which the extinguisher has been found to be effective. (7 C.C.R. 1101-9)

Fire-Resistant – Construction designed to provide reasonable protection against fire. For exterior walls or magazine constructed of wood, this shall mean fire resistance equivalency provided by sheet metal of not less than #26 gauge. (7 C.C.R. 1101-9)

Flyrock – Rocks propelled from the blast area by the force of an explosion. (7 C.C.R. 1101-9)

Fragmentation – The breaking of a solid mass into pieces by blasting. (7 C.C.R. 1101-9)

Free Face – A rock surface exposed to air or water which provides room for expansion upon fragmentation. Sometimes called open face. (7 C.C.R. 1101-9)

Fuse (Safety) – A flexible cord containing an internal burning medium by which fire or flame is conveyed at a continuous and uniform rate from the point of ignition to a cut end. A fuse detonator is usually attached to that end, although safety fuse may be used without a detonator to ignite material such as deflagrating explosives. (7 C.C.R. 1101-9)

Fuse Detonator, Blasting Cap – A detonator which is initiated by a safety fuse or used in an avalauncher round; also referred to as an ordinary blasting cap. Also see detonator. (7 C.C.R. 1101-9)

Fuse Lighters – Pyrotechnic devices for the rapid and certain lighting of safety fuse. (7 C.C.R. 1101-9)

Fuel – A substance, which may react with oxygen to produce combustion. (7 C.C.R. 1101-9)

Fumes – The gaseous products of an explosion. For the purpose of determining the fume classification of explosive material, only poisonous or toxic gases are considered. (7 C.C.R. 1101-9)

Gelatin Dynamite – A type of highly water resistant dynamite characterized by its gelatinous or plastic consistency.

Geology – A description of the types and arrangement of rock in an area; the description usually includes the bedding dip and strike, the type and extent of pre-existing breaks in the rock, and the hardness and massiveness of the rock, as these affect blast design.

Grains – A weight measurement where 7000 grains are equivalent to 1 lb. (0.45 kg). (7 C.C.R. 1101-9)

Ground Vibration – Shaking the ground by elastic waves emanating from a blast. Usually measured in in/s (mm/s) of particle velocity. (7 C.C.R. 1101-9)

Hardwood – Red Oak, White Oak, Hard Maple, Ash, or Hickory, free from loose knots, wind shakes, or similar defects. (7 C.C.R. 1101-9)

High Explosives – Explosives which are characterized by a very high rate of reaction, high pressure development and the presence of a detonation wave, including, but not limited to, dynamite, detonating cord, cast boosters, detonators, cap-sensitive slurry, emulsion, or water gels, and mixed binaries. (7 C.C.R. 1101-9)

Horizontal Drilling – A method of rock excavation where larger diameter, closely spaced, lightly loaded horizontal borings are used for production style blasting. Used in massive rock to eliminate drill hole or in areas of poor access.

Inactive Status – The status of a valid Type I permit when the Type I permittee is no longer authorized to possess and control explosives by a Type II permittee. (7 C.C.R. 1101-9)

Inhabited Area or Building – A building regularly occupied in whole or in part as a habitation for human beings, or any church, schoolhouse, railroad station, store, or other structure where people are accustomed to assemble, except any building or structure occupied in connection with the manufacture, transportation, storage, and use of explosive materials. (7 C.C.R. 1101-9)

Inspector – An Inspector of the Division. (7 C.C.R. 1101-9)

Initiation – The start of deflagration or detonation in an explosive material. (7 C.C.R. 1101-9)

Initiation System – Combination of explosive devices and accessories (detonators, wire, cord, etc.) designed to convey a signal and initiate an explosive charge. (7 C.C.R. 1101-9)

Lawful Possessor – A Type II permittee who has legally purchased or acquired explosive materials. (7 C.C.R. 1101-9)

Lift – The vertical thickness of rock fragmented from a single blast.

Loading – Placing explosive material in a blast hole or against the material to be blasted.

Loading Density – The weight of explosive loaded per unit length of borehole occupied by the explosive, expressed as lbs/ft (kg/m) of borehole.

Loading Limits – The maximum quantity of explosives allowed per delay period as specified by the Standard Specifications. (7 C.C.R. 1101-9)

Loading Pole – A nonmetallic pole used to assist in placing and compacting explosives charges in boreholes.

Low Explosives – Explosives which are characterized by deflagration or low rate of reaction and the development of low pressure. (7 C.C.R. 1101-9)

Magazine – Any building, structure, or container approved for the storage of explosives materials. (7 C.C.R. 1101-9)

Magazine Distance – Shall mean the minimum distance permitted between any two storage magazines which is expected to prevent propagation of an explosion from one magazine to another from a blast. (7 C.C.R. 1101-9)

Manufacturer – Any individual, corporation, company, firm, partnership, association, or state or local government agency engaged in the business. (7 C.C.R. 1101-9)

Mass Detonation - When a unit or any part or quantity of explosive material explodes and causes all or a substantial part of the remaining material to detonate or explode. (7 C.C.R. 1101-9)

Maximum Particle Velocity – The maximum velocity at which the ground surface moves as a wave passes under it. The customary practice is to apply vibration limits to the peak particle velocity of the largest single component on the seismograph. (7 C.C.R. 1101-9)

Misfire – A blast that fails to detonate completely after an attempt at initiation. This term is also used to describe the explosive material itself that has failed to detonate as planned. (7 C.C.R. 1101-9)

Muckpile – The pile of broken material resulting from a blast. (7 C.C.R. 1101-9)

Natural Barricade – Natural features of the ground, such as hills, or timber of sufficient density that the surrounding exposures which require protection cannot be seen from the magazine when the trees are bare of leaves. (7 C.C.R. 1101-9)

Nitroglycerin – An explosive chemical compound used as a sensitizer in dynamite.

Non-Electric Detonator – A detonator that does not require the use of electric energy to function. (7 C.C.R. 1101-9)

Non- Sparking Metal – A metal that will not produce a spark when struck with other tools, rock, or hard surface. (7 C.C.R. 1101-9)

Overburden – Material of any nature laying on top of the rock that is to be blasted.

Oxidizer or Oxidizing Material – A substance, such as nitrite, that readily yields oxygen or other oxidizing substances to promote the combustion of organic matter or other fuel. (7 C.C.R. 1101-9)

Particle Board – A composition board made of small pieces of wood that have been bonded together. (7 C.C.R. 1101-9)

Particle Velocity - The velocity at which the ground surface moves as a wave passes under it. (7 C.C.R. 1101-9)

Permanent Storage Materials – Type 1 magazines or Type 2, Type 4, or Type 5 magazines that have been at the same location for longer than 90 days. (7 C.C.R. 1101-9)

Permittee – Any user, purchaser, manufacturer, dealer, storer, disposer, or transporter of explosives for a lawful purpose, who has obtained a permit from the Division. (7 C.C.R. 1101-9)

Person – Any individual, corporation, company, firm, partnership, association, or state or local government agency. (7 C.C.R. 1101-9)

PETN – An abbreviation for the name of the high explosive pentaerythritol tetranitrate.

Placards – Division of Transportation Approved Title 49 CFR signs placed on vehicles transporting hazardous materials (including explosive materials) indicating the nature of the cargo. (7 C.C.R. 1101-9)

Plywood – Exterior construction-grade plywood. (7 C.C.R. 1101-9)

Possess – The physical possession of explosives on one's person, or in the person's vehicle, magazine or building. (7 C.C.R. 1101-9)

Powder – A common synonym for explosive materials. (7 C.C.R. 1101-9)

Powder Factor – The amount of explosives used per unit of blasted material. (7 C.C.R. 1101-9)

Pre-blast Survey – A documentation of the preexisting condition of structures near an area where blasting is to be conducted.

Presplitting – A blasting method in which cracks for the final contour or payline are created by firing a single row of holes containing light, well distributed charges, prior to the initiation of the remaining holes in the blast pattern.

Prilled Ammonium Nitrate – Ammonium nitrate in a pelleted or prilled form. (7 C.C.R. 1101-9)

Primer – A unit, package, or cartridge of explosives used to initiate other explosives or blasting agents, which contains either a detonator or a detonating cord to which a detonator designed to initiate the detonating cord is attached. (7 C.C.R. 1101-9)

Production Blasting – A blasting method whose sole purpose is to fragment the rock.

Propagation – The detonation of an explosive charge by an impulse received from an adjacent or nearby explosive charge. (7 C.C.R. 1101-9)

Propellant/Powder-Actuated Power Device – Any tool or special mechanized device or gas generator system which is actuated by a propellant or which releases and directs work through a propellant charge. (7 C.C.R. 1101-9)

Public Conveyance – Any railroad car, streetcar, ferry, cab, bus, aircraft, or other vehicle carrying passengers for hire. (7 C.C.R. 1101-9)

Public Highway – Shall mean any public street, alley, or road. (7 C.C.R. 1101-9)

Public Highway Distance – Shall mean the minimum distance permitted between a public highway and an explosives magazine. (7 C.C.R. 1101-9)

Public Place – A place which the public or a substantial number of the public has access, and includes but is not limited to, highways, transportation facilities, schools, places of amusement, parks, playgrounds, and the common areas of public and private buildings and facilities. (7 C.C.R. 1101-9)

Purchaser – A Type II permittee who acquires explosives. (7 C.C.R. 1101-9)

Pyrotechnics, Fireworks – Any combustible or explosive compositions or manufactured articles designed and prepared for the purpose of producing audible or visible effects. (7 C.C.R. 1101-9)

Railway – Any steam, electric, or other type of railroad or railway. (7 C.C.R. 1101-9)

Relief – The effective distance from a blast hole to the nearest free face (synonymous with burden).

Responsible Person – A Type I permitted individual who is directly responsible for a Type II permittee's compliance with the provisions of the Explosives Act, 9-7, C.R.S., and any rules and regulations promulgated thereunder. (7 C.C.R. 1101-9)

Ripping – A method of rock excavation where a tractor with an attached tooth are teeth is lowered into the rock and then dragged to break up the material for excavation.

Round – A group of boreholes fired or intended to be fired in a continuous sequence.

Safety Fuse – A flexible cord containing an internal burning medium by which fire or flame is conveyed at a continuous and uniform rate from the point of ignition to a cut end. A fuse detonator is usually attached to that end, although safety fuse may be used without a detonator to ignite material such as deflagrating explosives. (7 C.C.R. 1101-9)

Scale Distance (Ds) – A factor relating similar blast effects from various weight charges of explosive material at various distances. Scaled Distance is obtained by dividing the distance of concern by a fractional power of the charge weight per delay of the explosive materials. (7 C.C.R. 1101-9)

Secondary Blasting – Blasting to reduce the size of boulders resulting from a primary blast. (7 C.C.R. 1101-9)

Secured Storage – An area which is protected from weather and is theft-resistant and in compliance with the uniform fire code. (7 C.C.R. 1101-9)

Seismograph – An instrument which records ground vibrations generated by blasting operations. Particle velocity displacement is generally measured and recorded in three mutually perpendicular directions. (7 C.C.R. 1101-9)

Semi-Conductive Hose – A hose used for pneumatic conveying of explosive materials, having an electrical resistance high enough to limit flow of stray electric currents to safe levels yet not so high as to prevent drainage of static electric charges to ground. A hose of not more than 2 mega ohms resistance over its entire length and of not less than 1,000 ohms per foot (3280 ohms per meter) meets this requirement.

Sensitivity – A physical characteristic of an explosive material classifying its ability to be initiated upon receiving an external impulse such as impact, shock, flame, friction, or other influence which can cause detonation. (7 C.C.R. 1101-9)

Shall – Means that the rule establishes a minimum standard which is mandatory. (7 C.C.R. 1101-9)

Shaped Charges – An explosive with a shaped cavity specifically designed to produce a high velocity cutting or piercing jet of product reaction; usually lined with metal to create a jet of molten liner material. They are generally used to cut steel members during superstructure demolition. (7 C.C.R. 1101-9)

Shock Tube – A small diameter plastic tube used for initiating detonators. It contains only a limited amount of reactive material so that the energy that is transmitted through the tube by means of a detonation wave is guided through and confined within the walls of the tube. (7 C.C.R. 1101-9)

Short Delay Blasting – The practice of detonating blastholes in successive intervals where the time distance between any two successive detonations is measured in milliseconds. (7 C.C.R. 1101-9)

Site – Area where active blasting is taking place or the location of explosives storage magazines. (7 C.C.R. 1101-9)

Slurry/Water Gel – An explosive material containing substantial portion of a liquid, oxidizers, and fuel, plus a thickener. (7 C.C.R. 1101-9)

Small Arms Ammunition – Any cartridge for a shotgun, rifle, pistol, or revolver, and cartridges for propellant-actuated power device and industrial guns. Military-type ammunition containing explosive bursting charges, or any incendiary, tracer, spotting, or pyrotechnic projectile is excluded from this definition. (7 C.C.R. 1101-9)

Smooth Blasting – A rock excavation method - smooth blast holes are blasted after production blasts. The hole diameters are small with close spacing, and lightly loaded with distributed charges.

Softwood – Douglas Fir, or other wood of equal bullet-resistance, free of loose knots, wind shakes, or similar defects. (7 C.C.R. 1101-9)

Spacing – The distance between boreholes. In bench blasting, the distance is measured parallel to the free face and perpendicular to the burden. (7 C.C.R. 1101-9)

Static Electricity – Electric charge at rest on a person or object. It is most often produced by the contact and separation of dissimilar insulating materials. (7 C.C.R. 1101-9)

Steel – General purpose (hot or cold rolled) low carbon steel, such as specification ASTM A366 or equivalent. (7 C.C.R. 1101-9)

Stemming – Inert material placed in a borehole on top of or between separate charges. Used for the purpose of confining explosive gases or to physically separate charges of explosive material in the same borehole. (7 C.C.R. 1101-9)

Step Drilling – A rock excavation method. Larger diameter drill holes are drilled vertically, and used as production blasting (although spaced closer and loaded light to minimize radial fractures). A slope face is formed along the base of the blast holes.

Storage – The safekeeping of explosives in unattended magazines. (7 C.C.R. 1101-9)

Subdrilling – The practice of drilling boreholes below floor level or working elevation to insure breakage of rock to working elevation.

Sympathetic Detonation – The detonation of an explosive material as the result of receiving an impulse from another detonation through air, earth, or water. Synonymous with sympathetic propagation. (7 C.C.R. 1101-9)

Tamping – The action of compacting the explosive charge or the stemming in a blasthole. Sometimes refers to the stemming material itself. (7 C.C.R. 1101-9)

Temporary Storage Magazine – A Type 1, Type 2, Type 4, or Type 5 magazine that is at a location for a period not to exceed ninety (90) days. (7 C.C.R. 1101-9)

Theft-Resistant – Construction designed to deter illegal entry into facilities used for the storage of explosive materials. (7 C.C.R. 1101-9)

Transportation – The conveyance or carrying of explosives from one place to another by means of a motorized vehicle or device. (7 C.C.R. 1101-9)

Type I Explosives Permit – A permit issued by the Division to individuals who possess and control explosive materials during the use, manufacture, acquisition, purchase, sale, distribution, storage, transportation, or disposal of explosives materials. (7 C.C.R. 1101-9)

Type II Explosives Permit – A permit issued by the Division to corporations, companies, partnerships, firms, individuals operating a business, associations, or state or local government agencies involved in the use, purchase, sale, manufacture, transportation, acquisition, distribution or disposal of explosives materials. (7 C.C.R. 1101-9)

Type III Explosives Permit – A permit issued by the Division to corporations, companies, partnerships, firms, individuals operating a business, associations, or state or local government agencies for the storage of explosives in approved magazines. (7 C.C.R. 1101-9)

Warning Signal – An audible signal which is used for warning personnel in the vicinity of the blast area of the impending explosion. (7 C.C.R. 1101-9)

Water Gel – An explosive material containing substantial portions of water, oxidizers, and fuel, plus a cross-linking agent. (7 C.C.R. 1101-9)

Water Resistance – The ability of an explosive to withstand the desensitizing effect of water penetration. (7 C.C.R. 1101-9)

Weather Resistant – Construction designed to offer reasonable protection against weather. (7 C.C.R. 1101-9)

Weight Strength – The energy of an explosive material per unit of weight. (7 C.C.R. 1101-9)

D. Units

ENGLISH TO METRIC	METRIC TO ENGLISH
LENGTH (APPROXIMATE) 1 inch (in) = 2.5 centimeters (cm) 1 foot (ft) = 30 centimeters (cm) 1 yard (yd) = 0.9 meter (m) 1 mile (mi) = 1.6 kilometers (km)	LENGTH (APPROXIMATE) 1 millimeter (mm) = 0.04 inch (in) 1 centimeter (cm) = 0.4 inch (in) 1 meter (m) = 3.3 feet (ft) 1 meter (m) = 1.1 yards (yd) 1 kilometer (km) = 0.6 mile (mi)
AREA (APPROXIMATE) 1 square inch (sq in, in ²) = 6.5 square centimeters (cm ²) 1 square foot (sq ft, ft ²) = 0.09 square meter (m ²) 1 square yard (sq yd, yd ²) = 0.8 square meter (m ²) 1 square mile (sq mi, mi ²) = 2.6 square kilometers (km ²) 1 acre = 0.4 hectare (he) = 4,000 square meters (m ²)	AREA (APPROXIMATE) 1 square centimeter (cm ²) = 0.16 square inch (sq in, in ²) 1 square meter (m ²) = 1.2 square yards (sq yd, yd ²) 1 square kilometer (km ²) = 0.4 square mile (sq mi, mi ²) 10,000 square meters (m ²) = 1 hectare (ha) = 2.5 acres
MASS - WEIGHT (APPROXIMATE) 1 ounce (oz) = 28 grams (gm) 1 pound (lb) = 0.45 kilogram (kg) 1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)	MASS - WEIGHT (APPROXIMATE) 1 gram (gm) = 0.036 ounce (oz) 1 kilogram (kg) = 2.2 pounds (lb) 1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE) 1 teaspoon (tsp) = 5 milliliters (ml) 1 tablespoon (tbsp) = 15 milliliters (ml) 1 fluid ounce (fl oz) = 30 milliliters (ml) 1 cup (c) = 0.24 liter (l) 1 pint (pt) = 0.47 liter (l) 1 quart (qt) = 0.96 liter (l) 1 gallon (gal) = 3.8 liters (l) 1 cubic foot (cu ft, ft ³) = 0.03 cubic meter (m ³) 1 cubic yard (cu yd, yd ³) = 0.76 cubic meter (m ³)	VOLUME (APPROXIMATE) 1 milliliter (ml) = 0.03 fluid ounce (fl oz) 1 liter (l) = 2.1 pints (pt) 1 liter (l) = 1.06 quarts (qt) 1 liter (l) = 0.26 gallon (gal) 1 cubic meter (m ³) = 36 cubic feet (cu ft, ft ³) 1 cubic meter (m ³) = 1.3 cubic yards (cu yd, yd ³)
TEMPERATURE (EXACT) $[(x-32)(5/9)]^{\circ}\text{F} = y^{\circ}\text{C}$	TEMPERATURE (EXACT) $[(9/5)y + 32]^{\circ}\text{C} = x^{\circ}\text{F}$

2. ENGINEERING DESIGN PROCEDURES FOR CDOT ROAD CUT BLASTING

A. Percent Aesthetic Enhancement (PAE)

CDOT is currently looking to establish a Visual Resources Program that will objectively measure, following standard methodology, the visual impacts of transportation projects to meet legal requirements and regulations, while maintaining and improving the scenic quality of the State of Colorado. The main reference for such evaluation is the [2015 FHWA Guidelines for the Visual Impact Assessment of Highway Projects](#)¹ which establish national standards for the establishment, inventory, analysis and mitigation of visual resources. Based on these guidelines, the present section 2 will focus on the development of a “measurable aesthetic criteria” and recommended blast design as part as the mitigation phase. The overall goal is to avoid, minimize, and compensate for significant adverse visual impacts associated with a transportation project and identify opportunities for enhancing visual quality. In general, the blast design will be always affected by the Area of Visual Effect (AVE), therefore a Visual Impact Assessment (VIA) shall be conducted in advance according to FHWA-HEP-15-029 and FHWA-CFL/TD/11-002.

Notes:

1. The content of this section only applies when VIA is required and conducted for the particular project.
2. The content of this section only considers the engineering procedures for the aesthetic design of the final face, hence it does not cover any of aspect regarding production blasting.

Many of the existing excavation methods use blasting techniques that were originally developed for use by the mining industry and were mainly focused on maximum rock excavation and rapid production with little attention to environmental protection or the aesthetic impacts of the final cut. For this reason, State DOTs often struggle in designing a safe rock slope that does not appear over-engineered and seems to fit within the project setting. An “aesthetically pleasing” cut slope often becomes a relative term that depends on the individual, therefore we must attempt to make the aesthetic criteria deterministic, rational, biddable, and constructible. In order to achieve this goal, it is critical to determine what measurable physical characteristics will be used in construction as acceptance criteria.

The first step for determining these physical parameters is to establish the visual prioritization. In general, the significant visual impacts will be dependent on the vehicle’s viewshed, thus the designer must consider a short range perspective and a long range perspective. For the short range, the main aesthetic priority must be the textural enhancements such as ledges, slope roughening, planting pockets, or boulder salvage. For the long range, the main priority becomes the slope variations and grading features.

On the other hand, defining the level of effort required for the enhancement of the aesthetic features will be dependent on the time of exposure that a car or bus passenger will have to the particular cut slope. From that time of exposure, we introduce the parameter *Percent Aesthetic Enhancement (PAE)* necessary to apply the particular road cut:

¹ U.S. Department of Transportation, 2015, *Guidelines for the Visual Impact of Highway Projects*, FHWA-HEP-15-029, Federal Highway Administration (FHWA): Washington D.C., assorted pagination.

The Percent Aesthetic Enhancement (PAE) is defined as the percent of mitigation required on an evidence of the construction technique. 100 PAE means full removal of the particular undesired feature while 0 PAE means no aesthetic treatment needed.

The PAE is constituted as a quantitative assessment that defines the level of effort required for the enhancement of aesthetic features in the final road cuts. It can be thought of as the tolerance of a machined part that will provide CDOT and the contractor with a measurable parameter for the level of effort required in the mitigation of, for example, blast hole traces, machinery marks, or slope warping. According to Cummings (2002), the most significant visual impacts are those that will be apparent for longer than 10 seconds, thus we will establish a 100 PAE for average exposure time (t_{exp}) equal or longer than 10 seconds. Using this definition, the PAE is defined as follows:

$$PAE = \frac{\bar{t}_{exp}[s]}{10 [s]} \times 100 = 10\bar{t}_{exp} [s]$$

Where, the average exposure time (t_{exp}) relates to the time that a passenger of motor vehicle will be able to visualize a particular object or feature. Therefore, the general formula for calculating the PAE becomes:

$$PAE [\%] = 10 \times \frac{D_{exp}[ft]}{\bar{V} [mph] \times 1.4667 \left[\frac{ft/s}{mph} \right]}$$

Where, D_{exp} is the distance in feet along which the car is being exposed to the road cut, and V is the design velocity in miles per hour for that particular section of the road. The design velocity is usually determined a priori as part as the road design, however the exposure distance is affected by several parameters such as the vehicle's viewshed and the surrounding topography. Figure 1 was extracted from the U. S. Bureau of Land Management, Visual Resource Management Program and shows the dynamic viewshed of a driver at different speeds.

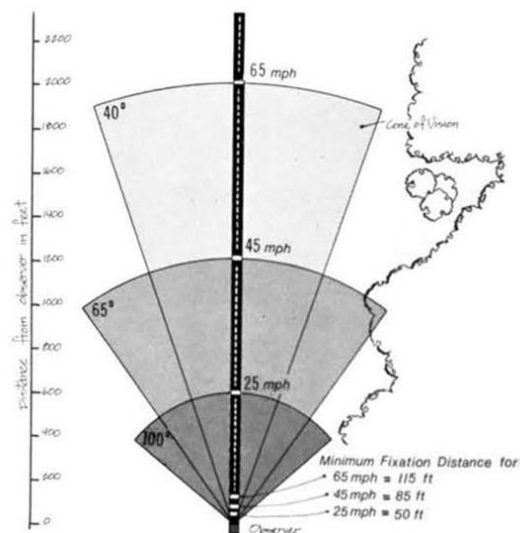


Figure 1. Dynamic viewshed for a vehicle driver (Ref.: FHWA-CFL/TD/11-002)

The faster a person moves, the smaller the area on which they are able to focus their attention. However, the dynamic viewshed for a passenger in a vehicle does not necessarily correspond to the one experienced by the driver who looks straight at the road (Fig.1). For this reason, a cone angle of 100 degrees will be considered independently of the car speed in the PAE calculations. This cone angle captures the AVE of the whole vehicle rather than the AVE of the driver (Fig.2). Note that having a larger dynamic viewshed implies a larger exposure time to the scene or object. This time is primarily dependent on the topographic position, the car speed, and physiological limits of the human sight. Variable external parameters such as light or weather conditions will be neglected for the purpose of this work.

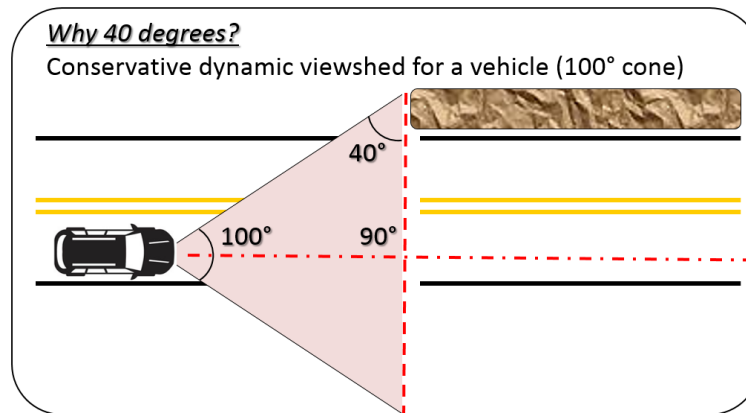


Figure 2. Conservative dynamic viewshed for a motor vehicle

Note: The PAE is applicable for dynamic viewsheds. According to FHWA-HEP-15-029, a static viewshed is defined as what can potentially be seen in 360° from a single view point. The presence of static viewsheds will be considered as a limiting factor and therefore a 100 PAE will be assessed.

As it was previously mentioned, we must differentiate between short range and long range perspectives when establishing the visual prioritization. Thereby, the overall PAE must include both in order to determine the required type of blasting technique and/or post-blast aesthetic treatment. This is accomplished by calculating a Short-Range PAE (SR-PAE) and a Long-Range PAE (LR-PAE) if applicable. The SR-PAE captures the effect of the adjacent roads, however, in the presence of non-adjacent roads in the area of visual effect, the LR-PAE may be more restrictive. In general, we can consider two cases:

- If $SR-PAE > LR-PAE \rightarrow$ The main aesthetic priority must be the textural enhancements such as ledges, slope roughening, planting pockets, or boulder salvage.
- If $SR-PAE < LR-PAE \rightarrow$ The main aesthetic priority must be the slope variations and grading features.

Figure 3 shows the flow chart for the calculation of the overall PAE considering the SR-PAE and LR-PAE. Next, we will illustrate how to perform the calculations using two separate examples.

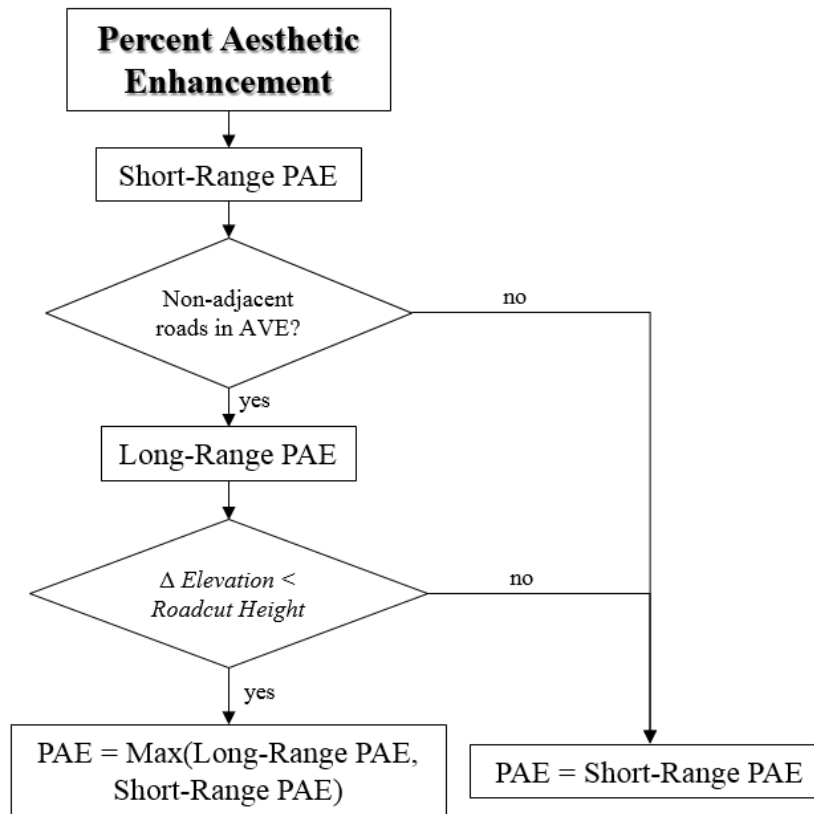


Figure 3. PAE calculation flow chart

In some situations, we may encounter non-adjacent roads in the Area of Visual Effect from an aerial perspective. However, the difference in elevation (or even the presence of vegetation or certain topographical features) can potentially remove the road cut from the Area of Visual Effect, hence eliminating the necessity of a Long-Range PAE. Although the overall PAE will be defined by either the Short-Range PAE or Long-Range PAE, both parameters are equally useful when deciding the aesthetic treatment required for a particular cut slope.

PAE Calculation Example I:

The following calculation example shows how to estimate the t_{exp} and the PAE in one of the road cuts located in Highway 285 at Parmalee Gulch, Colorado. The current slope includes a galvanic mesh that was installed after the design due to rock fall. The steps shown below apply for SR-PAE and LR-PAE, although for this example only the SR-PAE applies.

1. Define the start and end points on the road where the slope enters the dynamic viewshed for both directions (West to East and East to West). This is done by drawing two lines perpendicular to the road at the beginning and at the end of the cut (dashed lines). Then, we draw two lines at 40 degrees from each of the dashed base lines and the intersection with the road marks our start (yellow) and end (green) points. Note that the location of these points depends on the direction of the vehicle.

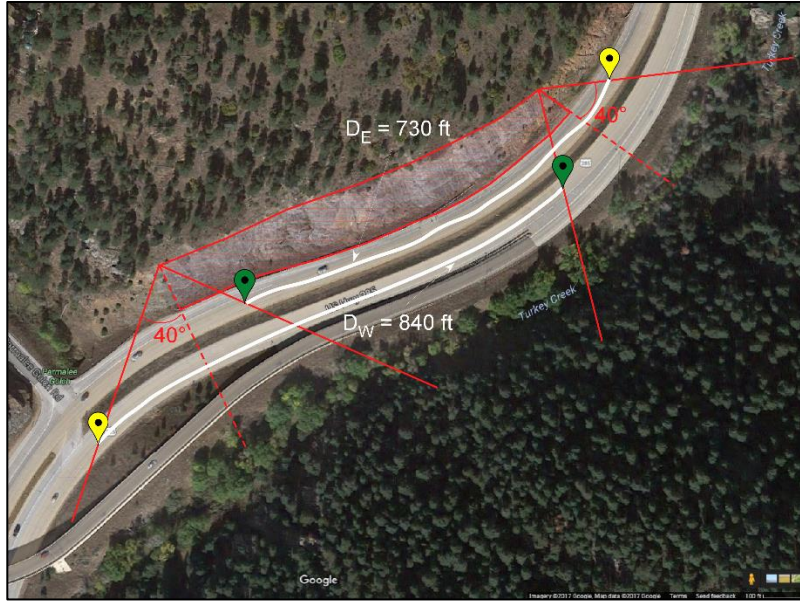


Figure 4. Aerial view of HW285 at Parmalee Gulch, Colorado. The yellow and green markers represent the start and end points where the slope enters in the dynamic viewed

2. Measure the distance between the start and end points for both possible vehicle directions. The longer distance represents the most restrictive case and it must be the one used for the following calculations (in this case D_W).
3. Considering a speed of 65mph for that section of the Highway 285, the Percent Aesthetic Enhancement for the slope is:

$$PAE = 10 \times \frac{D_W [ft]}{\bar{V} [mph] \times 1.4667 \left[\frac{ft/s}{mph} \right]} = 10 \times \frac{840 [ft]}{65 [mph] \times 1.4667 \left[\frac{ft/s}{mph} \right]} = \mathbf{88.1\%}$$

The PAE value for this particular road cut is almost a 90% which reveals the importance of applying mitigation techniques on the final slope design in order to minimize the visual impact on the dynamic viewers. For example, in the presence of half casts, 90% of these traces should be remove from the final face. Ultimately, the PAE for this slope indicates that a vehicle traveling East will be exposed to the road cut for about 9 seconds.

PAE Calculation Example II:

The following calculation example shows how to calculate the *PAE* in one of the road cuts located in Highway 24 at Vail Pass, Colorado. In this case, we must obtain the SR-PAE and the LR-PAE due to the presence of non-adjacent roads and potential influence in the AVE.

Short-Range PAE:

1. Define the start and end points on the road where the slope enters the dynamic viewed for both directions.

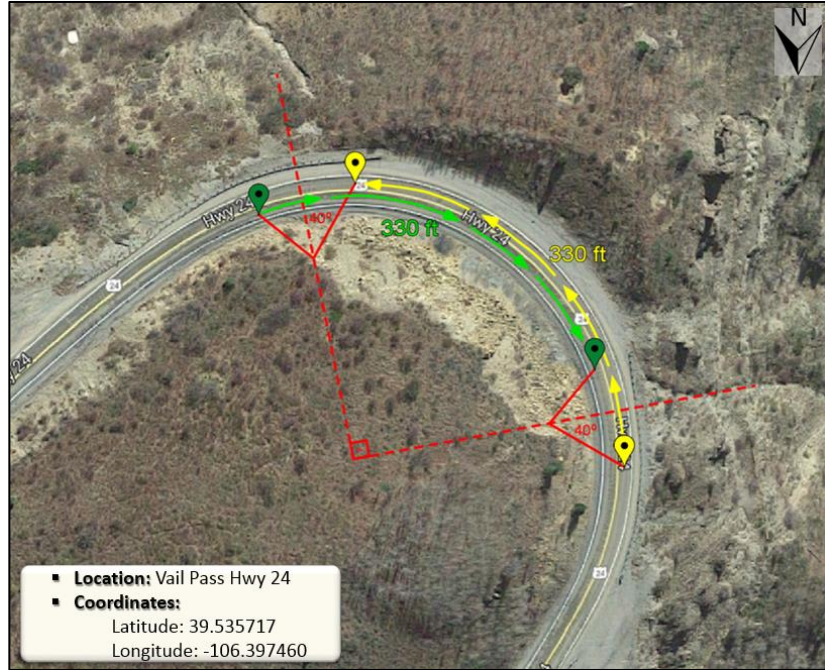


Figure 5. Aerial view of HW24 at Vail Pass, Colorado. The yellow and green markers represent the start and end points where the slope enters in the dynamic viewshed

2. Measure the distance between the start and end points for both possible vehicle directions.
3. Considering a speed of 30mph for that section of the Highway 24, the Percent Aesthetic Enhancement for the slope is:

$$SR_{PAE} = 10 \times \frac{D_w[ft]}{\bar{V} [mph] \times 1.4667 \left[\frac{ft/s}{mph} \right]} = 10 \times \frac{330[ft]}{30 [mph] \times 1.4667 \left[\frac{ft/s}{mph} \right]} = 75\%$$

Next, we proceed to calculate the LR-PAE due to the presence of non-adjacent roads in the Area of Visual Effect.

Long-Range PAE:

1. Define the start and end points on the road where the slope enters the dynamic viewshed for both directions.

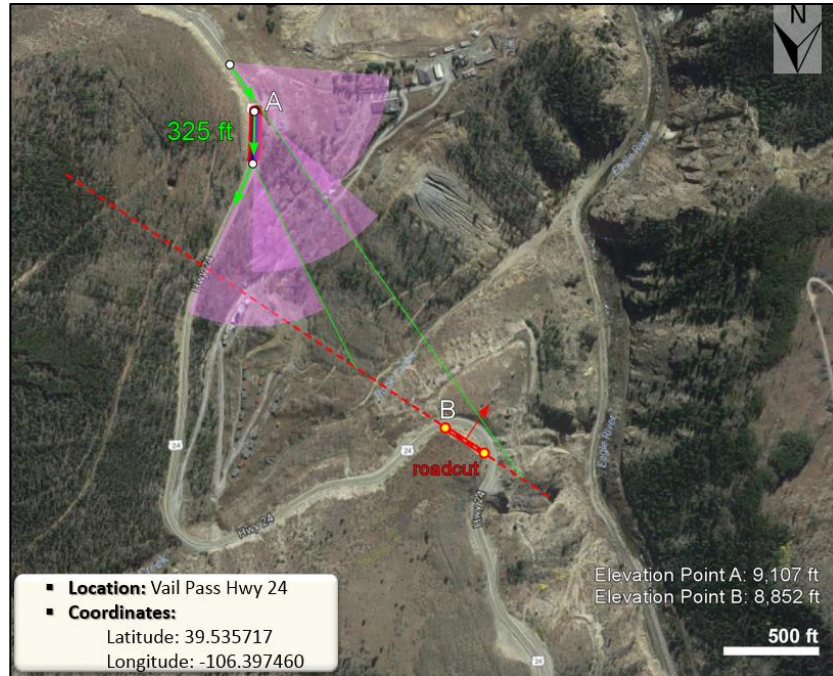


Figure 6. Aerial view of HW24 at Vail Pass, Colorado. Note the presence of non-adjacent roads with potential impact in the PAE

2. Measure the distance between the start and end points for both possible vehicle directions.
3. Considering a speed of 30mph for that section of the Highway 24, the Percent Aesthetic Enhancement for the slope is:

$$LR_PAE = 10 \times \frac{D_w[ft]}{\bar{V} [mph] \times 1.4667 \left[\frac{ft/s}{mph} \right]} = 10 \times \frac{325[ft]}{30 [mph] \times 1.4667 \left[\frac{ft/s}{mph} \right]} = 74\%$$

In this particular case, both SR-PAE and LR-PAE have an almost identical value, thus the designer must initially consider a short range perspective and a long range perspective. However, the next step in the flow chart in Figure 3 is to consider the third dimension and see if the difference in elevation between both locations in the map is larger than the actual road cut height. This step is illustrated in Figure 7.

According to Figure 7, the road cut height is approximately 60 feet but the difference in elevation between a vehicle and the road cut is about 270 feet. Therefore, the LR-PAE obtained before can be neglected since the road cut is not in the Area of Visual Effect. The overall PAE for this example is 75% and corresponds with the SR-PAE.



Figure 7. Three dimensional view of HW24 at Vail Pass, Colorado. Note the difference in elevation between the non-adjacent roads and the road cut

Convex Curves vs Concave Curves:

Another case to take into consideration is the presence of road cuts in road curves. In general, the geometry of a concave curve will be more critical from an aesthetic perspective since the vehicle will be directly facing the evidence of the construction technique (Fig. 8).

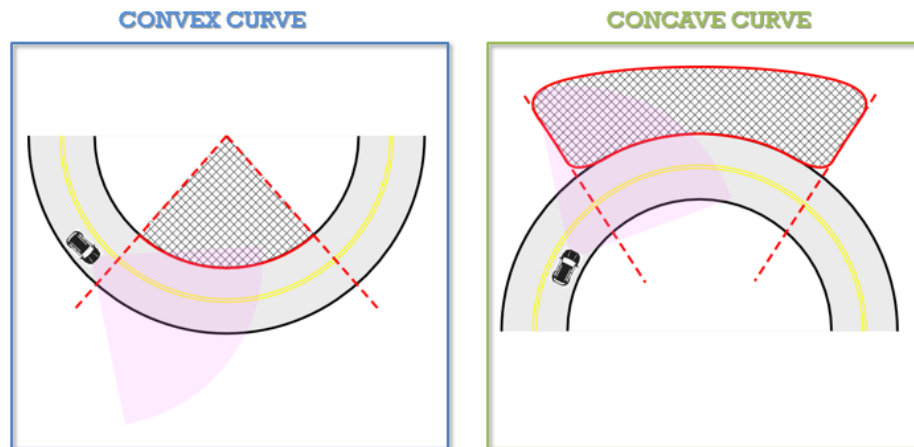


Figure 8. Convex curve vs concave curve

The type of curve and its aesthetic importance will be directly captured by the PAE where a concave curve will generate a higher PAE value than a convex curve. However, it must be remarked that the type of aesthetic treatment required for each can vary drastically.

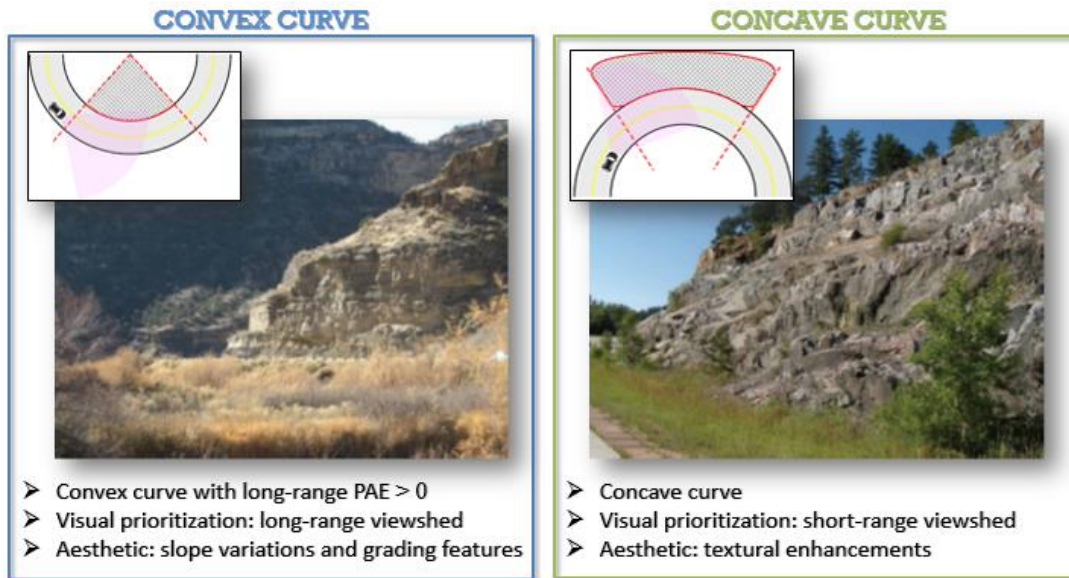


Figure 9. Examples of convex and concave curves, and aesthetic measures

In general, a convex curve will display a significant LR-PAE indicating that the visual prioritization corresponds with the long-range viewshed. This imposes the use of slope variations and grading features in order to mimic the cut slope with the surrounding environment. On the other hand, concave curves will be usually dominated by large SR-PAE values where the textural enhancements play a larger role.

B. Controlled Blasting Methods

Controlled blasting techniques are used when there is a need to preserve the natural strength of rock walls formed by blasting. It is used for removing material along the final slope face. In some cases, controlled blasting is also used before production blasting to create an artificial fracture along the final cut slope, which will prevent the radial cracks caused by production blasting from penetrating back into the finished face. It creates less backbreak than production blasting because it removes less burden and uses more tightly spaced drill holes with lighter charges.

A charge that completely fills a blast hole creates a large crushed zone that induce damage in the final face. However, when two closely spaced charges are fired simultaneously, the radial cracks tend to propagate equally in all directions until the two strain waves collide in the central point producing a central crack that connects the blastholes and decouple the final face from the production blast (Fig.10).

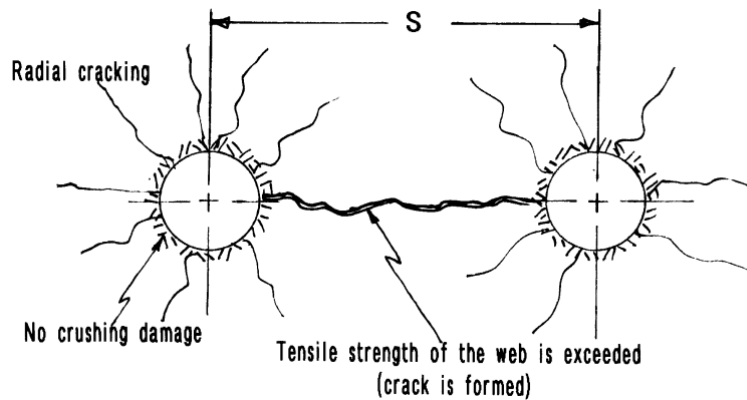


Figure 10. Tensile crack between adjacent holes (Huistrulid, 2007)

The pressure of the gases is a key element in the execution of contour blasting, and for this reason it should be maintained until the cracks of adjacent holes meet, which can be achieved by an adequate stemming height.

There are several types of controlled blasting; they vary most importantly in the amount of burden they remove and the type of powder they use. The discussion below will focus on controlled lasting techniques that best minimize the visual impacts of the blasting process, thus meeting the objectives of CSS design. These techniques are *presplit blasting*, *smooth blasting*, and *cushion blasting*. In addition, an alternative blasting and a drilling will be addressed below.

Presplitting is a protective measure to keep the final wall from being damaged by the production blasting. Presplitting utilizes lightly loaded, closely spaced drill holes, fired before the production blast, with the desired outcome to form a fracture plane across which the radial cracks from the production blast cannot travel. The fracture plane formed may allow for steeper slopes with less maintenance. Perform well in hard competent rock. Does not perform well in highly fractured, weak rock.

Aesthetics: presplitting creates abundant visible drill traces. In some cases, these half casts can be chipped away with a pneumatic hammer, but it is difficult to eliminate them without

completely removing the outer layer of rock. In areas where such scars are not acceptable, presplit blasting will not be the preferred option.

Smooth blasting uses light charges similar to presplitting to produce a smooth final rock wall by removing wall rock damaged during the main production blast. It is not as effective in protect the stability of the final wall since radial fractures from production blasting can penetrate into the final wall. Smooth blasting is best preformed in hard, competent rock, although it can be used in soft or highly fractured rock by increasing the spacing of the drill holes and/or adding uncharged guide holes to the pattern. Smooth slope blasting can be used on a variety of cut slope angles and is effective in developing contoured slopes with benches or other slope variations.

***Aesthetics:** smooth blasting traces are generally less noticeable than the half casts left by presplitting. If the cut slope height is small, the drill traces can be easily removed with a pneumatic hammer or other device.*

Cushion blasting consists of blastholes charged with an explosive strength somewhere between that used for the main production blast and the perimeter control blast. It uses a row of lightly loaded “buffer” holes filled with crushed stone over the entire depth of the hole, which reduce the impact on the blasting holes and protect the surrounding rock mass from the shock caused by the blast, thus minimizing the stress and fractures in the finished slope face. Cushion blasting creates some backbreak, which can make a slope more prone to raveling. Because cushion blasting can increase the danger of rockfall, the catchment area may need to be enlarged. In general, it performs well in all rock types but it is more demanding on the driller.

***Aesthetics:** cushion blasting produces a ragged final slope face and minimize borehole traces. Traces can be removed with a pneumatic hammer. In general, cushion blasting is expected to provide a blocky appearance that the previous two methods with minimum presence of drill hole traces. However, cushion blasting is more demanding than presplit or smooth blasting for the explosives engineer because hole spacing, burden, and charge density must be carefully chosen and continually reassessed in order to minimize backbreak. It also can be more time consuming because more drilling is required and charges take more time to load.*



Figure 11. Presplitting in sandstone (left) and cushion-blasted granitic rock (right) [2]

Aesthetic contour blasting uses a zig-zag drilling pattern that mimics natural landform processes while creating light-shadow regions that distort the visual perception of the evidence of the construction technique. It follows the same breaking mechanism used in controlled blasting and can be applied using presplitting or smooth blasting. Some advantages like minimum backbreak and steep slopes with minimum maintenance are expected using this technique.

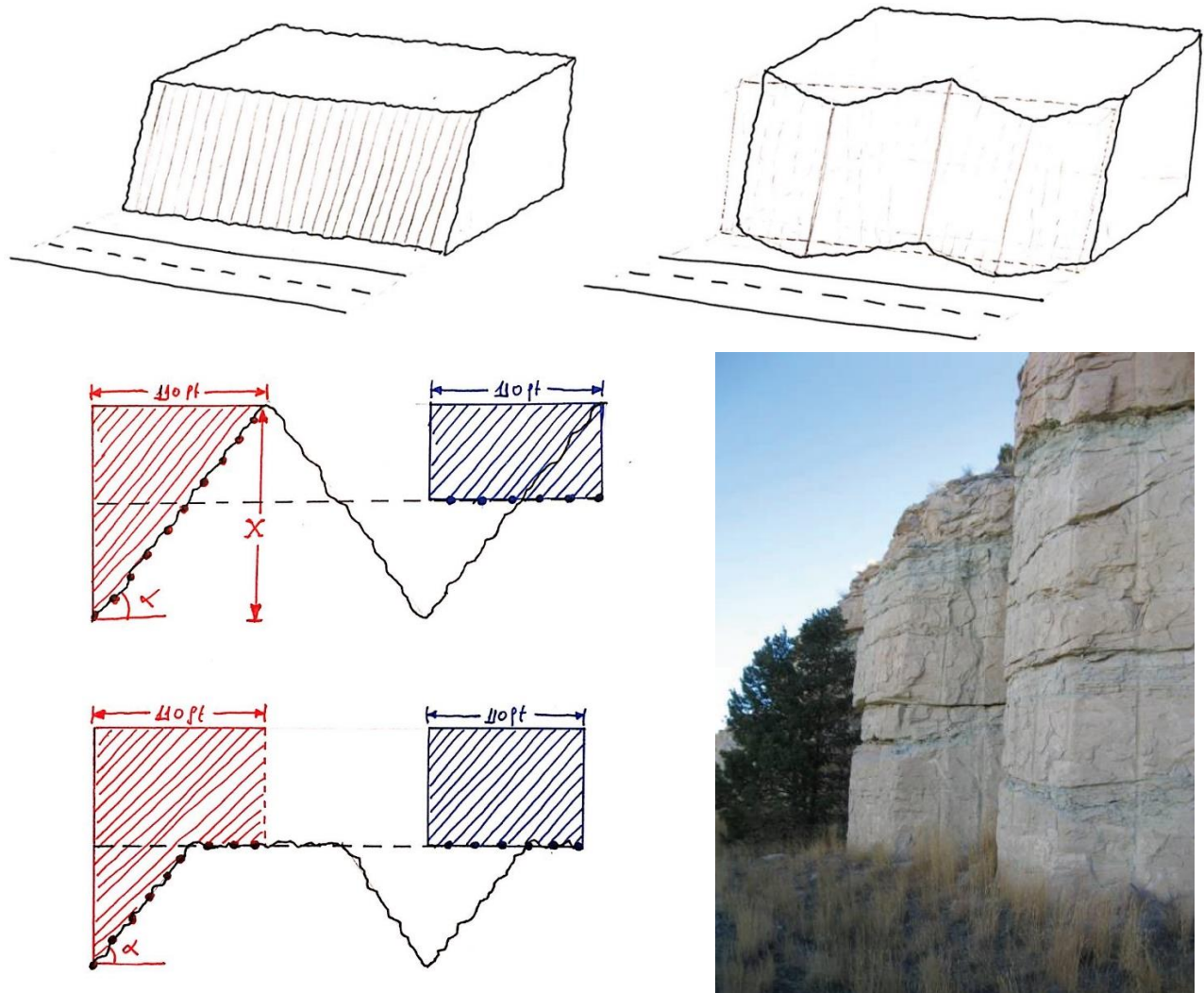


Figure 12. Conventional presplitting and aesthetic contour blasting

***Aesthetics:** the visual perception of an over-engineered slope is distorted while maintaining a highly stable slope with minimum maintenance. Drill hole traces will still be present after the blast; therefore, a visual impact assessment is required in order to determine in what faces the traces must be removed. In such assessment, the light incidence has the same importance as the viewshed, thus the cardinal direction of the slope becomes relevant.*

Horizontal drilling can be used instead of or in conjunction with vertical cushion blasting drill holes to produce natural looking rock slopes and mitigate drill hole traces. In massive rock where drill traces absolutely cannot be tolerated, or in sliver cuts with poor access to the crest for drilling, horizontal hole drilling may be worthwhile.

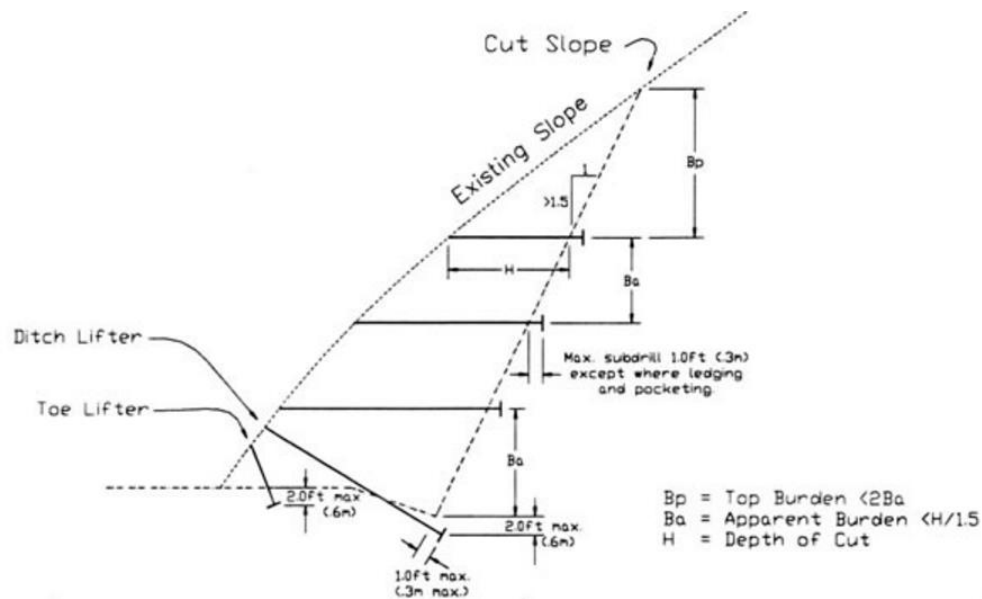


Figure 13. Horizontal hole drilling concept [3]

Horizontal drilling is demanding for the driller, who must maintain orientation, location, and depth accuracy to a greater degree than for any other method. In particular, depth control is critical to prevent bootlegs and special drilling equipment is needed that is capable of the vertical reaches required. The patterns for step drilling must be tighter, because the blast must counteract gravity, and special loading and timing allowances are needed. Also, explosives loading into horizontal holes is more complicated, requiring either packaged product or pneumatic loading of bulk product, and special stemming procedures to prevent ejection and rifling.

C. Blast Design Calculations

This section specifies the steps necessary for the blast design using each of the techniques addressed in the previous section. The equations are included as part as the numerical examples illustrated for each blasting method.

Presplitting Design Guidelines

One method for determining the spacing (S_P) distance between presplit blastholes is based on the blasthole diameter (D_h), the wall pressure for the decoupled explosive charge (P_w), and the rock tensile strength (T). The wall pressure for the decoupled explosive charge (P_w) is based on the explosion pressure and charge diameter for the selected explosive and the specified blasthole diameter. The combination of these factors is selected such that the wall pressure is less than the rock compressive strength (C), and greater than the rock tensile strength (T): $C \geq P_w \geq T$.

The major steps involved in a presplit blast design include:

1. Specify the blasthole diameter for the presplit blastholes.
2. From a list of potential presplit explosives to be evaluated, calculate the blasthole wall pressures for the explosive/blasthole combinations using the procedure for decoupled charges.
3. Select an explosive alternative where the calculated wall pressure is less than the rock compressive strength and greater than the rock tensile strength.

***Example: This example, (Hustrulid, 2008), illustrates the steps involved in evaluating and selecting the explosive and determining the spacing for a pre-split blast design for the final highwall on a highway road cut construction project. The requirement is to recommend an explosive and spacing that will minimize the number of holes to be drilled and yet preserve the final wall. The properties of the rock mass to be blasted and the planned blasthole diameter are:

rock type: granite

unconfined compressive strength (C): 172 MPa

tensile strength (T), (direct pull tests): 4.1 MPa

blasthole diameter (d_h): 50.8 mm

The explosive is to be selected from three available variations of the Atlas Powder pre-split explosive product “Kleen Cut” with the properties:

Explosive	VOD (km/sec)	Density (ρ_e) (g/cm ³)	Diameter (D_e) (mm)
Kleen Cut C	4.268	0.92	28.7
Kleen Cut E	2.805	0.58	28.7
Kleen Cut U	2.805	0.76	28.7

Step 1) Calculate the borehole wall pressure for each of the three explosive-hole combinations. The complete calculations for the explosive “Kleen Cut C” are shown in detail. The calculated values for all three explosives are summarized in table form.

Explosion pressure and wall pressure in MPa, ($\rho_e = 920 \text{ kg/m}^3$, VOD = 4.268 km/sec):

$$P_e = \frac{\rho_e \times VOD^2}{8} = \frac{920 \times 4.268^2}{8} = 2095 \text{ MPa}$$

$$P_w = P_e \left(\frac{d_e}{d_h} \right)^{2.4} = 2095 \left(\frac{28.7}{50.8} \right)^{2.4} = 532 \text{ MPa}$$

Summary of the calculated explosion pressures and the calculated wall pressures for the three explosives:

Explosive	Explosion Pressure (P _e) (MPa)	Wall Pressure (P _w) (MPa)
Kleen Cut C	2095	532
Kleen Cut E	570	145
Kleen Cut U	747	190

Step 2) Select the best alternative from the explosive/blasthole diameter wall pressures evaluated. The calculated wall pressure for the explosive Kleen Cut C and Kleen Cut C of 532 MPa and 190 MPa is greater than the rock compressive strength of 172 MPa, so these explosives are eliminated from further consideration.

The wall pressure for Kleen Cut E is greater than the rock tensile strength of 4.1 MPa, so the explosive should perform well in the pre-split blast.

Step 3) Calculate the presplit blastholes spacing (S_{PS}) for the explosive types remaining. For Kleen Cut E with P_w = 145 MPa.

$$S_{PS} = D_h \frac{(P_w + T)}{T} = 50.8 \times 10^{-3} \frac{(145 + 4.1)}{4.1} = \mathbf{1.85 \text{ m (6.07 ft)}}$$

Step 4) Select the explosive (in case more than one are acceptable) and the adjusted the presplit blastholes spacing (S_{PS}) for the initial trial blasts. Based on actual blast results, the spacing could be increased or decreased.

Smoothwall Blasting Design Guidelines

Smoothwall blasting is a wall control method similar to presplit blasting, with the important difference that the trim holes are fired after the main production blastholes instead of before as is the case with presplit blasting. It is assumed the wall rock has been weakened by the main production blasting, and the purpose is to remove the wall rock between trim holes forming a smooth final wall surface. This subsection summarizes a simple blast design method whereby the coupling ratio (R) for the continuous decoupled presplit charge is assumed to be approximately 3. Simple expressions for determining the drillhole diameter (d_h) for a given explosive with a known charge concentration (M_c) are presented. Conversely, an approximate value for the explosive charge concentration can be estimated for a specified drillhole diameter. A simple expression for estimating the spacing distance (S_{SW}) is also discussed.

Smoothwall blasting uses light decoupled or air-decked charges similar to those used for presplit blasting. The charge diameter (d_c) for the presplit explosive is found from the drillhole diameter (d_h) and the coupling ratio (CR) of 3.0. The linear charge concentration (M_c) written with the explosive charge diameter (d_c) expressed in terms of the drillhole diameter (d_h) and the coupling ratio (R) is:

$$M_c = \rho_e R^2 \left(\frac{\pi d_h^2}{4} \right)$$

A concentrated fully coupled bottom charge is sometimes used in the presplit blastholes in addition to the continuous decoupled explosive charge. The charge weight (Q_B) for the bottom charge is equivalent to 2 to 3 times the charge concentration (M_c) in lb/ft for the decoupled presplit explosive, (Konya, 1991). The spacing (S_{sw}) for trim blasting is somewhat larger than that used for presplit blasting, (Konya, 1991):

$$S_{sw} = 16 \times d_h$$

In general, the spacing can be also calculated using the same procedure presented for presplitting and multiplying the presplit spacing (S_{ps}) by a factor of 1.15 to 1.6. On the other hand, the blasthole confinement with smoothwall blasting is different than with presplit blasting. With presplit blasting, the main production blastholes have not yet been fired, meaning that the burden for the presplit blastholes is essentially infinite. With smoothwall blasting, the main production blastholes have been fired. In order to ensure that fractures between adjacent trim holes link properly, the burden (B_{sw}) should be greater than the 1.3 times the spacing (Konya, 1991).

Cushion Blasting Design Guidelines

Cushion blasting is often used in conjunction with presplit blasting. Blasthole diameters and depths are usually the same as the main product shot. Spacing and burden should be one half to three fourths of the dimensions used in the main product shot. A buffer hole should be bottom loaded to conform to, (Atlas Powder, 1987):

$$d_c = K \times W^{1/3}$$

Where d_c represents the depth of burial of the charge measure from the surface to the center of gravity of the first 6 holes diameters of explosive, regardless of the total explosive column length in feet. W is the weight of explosives in pounds, and K is a design constant.

K = 4	Most conditions assuming minimal cratering at the collar region
K = 4.5	Very competent rock materials
K = 3.5	Less competent rock materials

***Example: Suggest a cushion blast design for a 50 ft tall bench and a 12 in. diameter buffer hole where the bottom loaded with 10 ft of the explosive Apex 220 with a density of 1.25 g/cm³ (61.29 lb/ft).

Step 1) Calculate the explosive weight:

$$W = 10 [ft] \times 61.29 \left[\frac{lb}{ft} \right] = 612.9 lb$$

Step 2) Calculate the design depth of burial d_c

$$d_c = 4 \times 612.9^{1/3} = 33.9 ft$$

Step 3) Calculate actual d_c

10 ft of Apex 220 leave 40 ft of stemming

6 hole diameters of Apex 220 = $6 * (12 \text{ in} * 1ft/12in) = 6 \text{ ft}$

$d_c = 40 + (1/2 * 6) = 43 \text{ ft}$

As long as the design d_c is less than or approximately equal to the actual d_c , cratering will be minimal or nonexistent. In this case, we are quite safe although breakage to the surface will be hindered.

Aesthetic Contour Blasting Design Guidelines

In general, the blast design calculations for aesthetic contour blasting will be the same that those used for presplitting or smooth blasting. The main difference will be the drilling pattern as illustrated in Figure 14.

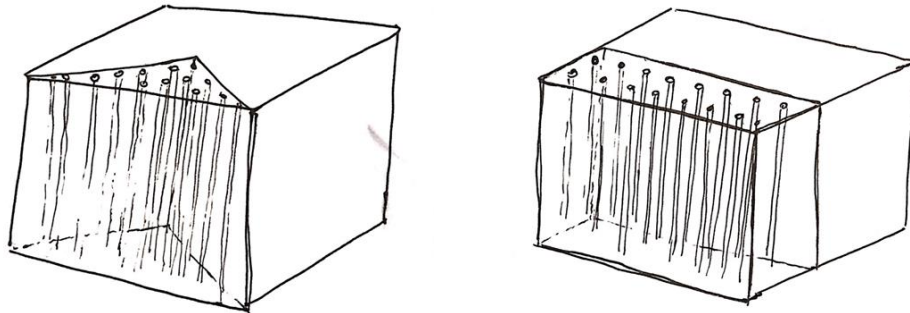


Figure 14. Aesthetic contour blasting and conventional presplitting

Using aesthetic contour blasting will increase the drilling length along the final free surface depending on the desired offset angle α . The choice of α is dependent on various parameters such as viewshed, cardinal orientation, and right of way. The relation between the offset angle and the drilling distance can be obtained by applying the following geometric relation:

$$L_{ACB} = \frac{L_{PS}}{\cos(\alpha)}$$

where L_{ACB} is the drilling distance for the aesthetic contour blasting, L_{PS} is the drilling distance for the conventional presplitting and α is the offset angle. The use of this formula is better understood by observing Figure 15.

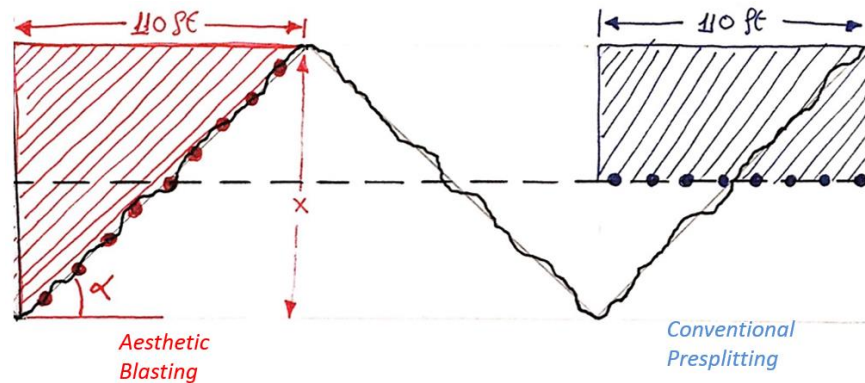


Figure 15. Drilling pattern for aesthetic contour blasting and conventional presplitting

According to Figure 15, the distance that the aesthetic presplitting exceed the presplit base line is $x/2$. Therefore, we can find a relation between that distance, the offset angle, and the drilling length for the aesthetic contour blasting. The next table shows several values for these various parameters:

x (ft)	α (deg)	Length (ft)	% Price Increase
10	5	110.5	0.5
20	10	111.8	1.6
30	15	114.0	3.6
40	20	117.0	6.4
50	24	120.8	9.8
60	29	125.3	13.9
70	32	130.4	18.5
80	36	136.0	23.6

To ensure safety, the angle (or angles) of the rock cut should be developed in accordance with the results of a kinematic analysis. All relevant modes of failure that may occur with an improperly cut slope angle must be considered. If a slope is cut at an angle that allows for one or more of the possible modes of failure, it may require expensive mitigation and maintenance for many years after the initial construction. Designing a slope in a manner that takes into account all relevant failure modes will reduce the stabilization and/or protective measures required, which will minimize costs, and, if context is properly considered, will improve the aesthetics of the slope.

Probably the most effective method of increasing rock cut aesthetics is fitting long-range features into the landscape by mimicking natural landform processes and by creating proper transitions between cut slopes and the natural terrain. Areas with long monotonous cuts, slopes with an extended view, highly variable topography, and geologically significant areas are good candidates for long-range features.

The mitigation and enhancement of the natural environment typically focuses on impacts to topography, hydrology, and vegetation. Grading is a primary source of adverse impacts to topography. This includes a thorough investigation of alternative alignments, profiles, and cross-

sections. Avoiding or minimizing changes to the existing topography or compensating for impacts by mimicking the visual character of the native landscape is crucial for mitigating adverse visual impacts. This is particularly true for grading embankments and creating rock cuts, which often require biotechnical measures (such as retaining walls and mesh fabrics) to stabilize slopes and prevent falling rocks. Working directly with highway geometric engineers to fit the roadway into the existing landscape can be extremely beneficial to mitigating impacts to the natural environment.

Regardless of the number of joints in a slope, one set will usually be the dominant (or weakest) and therefore will dictate the rock slope design. Generally speaking, the direction of this dominant joint will have the greatest influence on blasting results and potential failure modes.

D. Environmental Blasting Requirements

The Contractor shall post signs warning the public that there is blasting being conducted in the area. Warning signs shall be posted in accordance with the Manual on Uniform Traffic Control Devices (MUTCD), and as necessary to ensure public safety and to educate all persons at all roads, trails, paths, and visible to anyone within 20,000 feet of the work area. Warning signs shall conform to Blasting Zone (T-2) of the MUTCD.

In all blasting operations, the Contractor shall use one of the following methods to monitor or control the intensity of the motion in the ground at the nearest dwelling, house, school, church, commercial or occupied building.

1) Maximum allowable particle peak velocity (MAPV) – the intensity of the ground movement, measured with a commercial seismograph shall not exceed the limits specified in Table 6-10 of 7 C.C.R. 1101-9.

Monitoring instruments used to measure MAPV shall have a flat frequency response between 2 and 250Hz, and shall be capable of performing a self-test of velocity transducers. The digital sampling rate for peak particle measurements shall be at least 1,024 samples per second. For all blasts with scaled distance less than 100 ft/lb, seismographs monitoring the motion shall be set to a trigger level of 0.05 in/s.

The following equation is used to calculate scaled distance.

$$Ds = \frac{D}{\sqrt{W}}$$

Where:

Ds = scaled distance (ft/lb)

D = distance to nearest structure (ft)

W = weight of the explosive detonated within any 8 millisecond window (lb)

2) Scaled distance – when seismic monitoring is not performed, the maximum weight of the explosives detonating within an 8-millisecond window shall not exceed the limits specified in Table 6-10 of 7 C.C.R. 1101-9

Table 6-10	Blasting Vibration and Air Over-Pressure Standards	
Distance From Blast (Ft)	Option 1 MAPV (Maximum Allowable Particle Velocity) Measured As Inches/Second In Vertical, Transverse, or Longitudinal Directions	Option 2 Scaled Distance Factor Units Are Ft/Lb
0 to 300	2.00	50
301 to 5000	1.55	55
5001 and Greater	1.00	65

Air pressure shall at the nearest dwelling, house, school, church, commercial or occupied building shall not exceed 133 dB (0.0129 psi). All instruments used to measure air pressure shall employ linear microphones with a flat frequency response between 2 and 200 Hz, have a digital sampling rate of at least 1024 samples per second, and be capable of measuring air over-pressure from 120 to 140 dB-Linear (0.0029 – 0.029 psi).

3. ADMINISTRATIVE PROCEDURES AND DOCUMENTATION WITHIN CDOT

A. Submittal of Written Blast Plan

A blast plan shall be prepared by the Blaster-In-Charge, and shall be submitted by the Contractor to the Engineer a minimum of 10 days prior to the scheduling of a pre-blast meeting. This blast plan may be returned to the Blaster-In-Charge for additional revision or clarification as required, and prior to the scheduling of a pre-blast meeting. The blast plan shall include details on the methods and manners by which the Project Blaster-In-Charge shall comply with the appropriate laws, rules, and regulations of the State of Colorado and CDOT, and include all information that is necessary to evaluate the effectiveness of the proposed blasting operations. The blast plan shall include all measures necessary to ensure that the blasting activities are not the cause of injury, damage property, adversely affect traffic, or the migration/accumulation of noxious gases. As individual blasts on a project are rarely repeated identically, the plan should show the details for a typical blast, but maintain the understanding that minor modifications will be allowed in the field. Significant changes to the blast plan will require that a revised blast plan be resubmitted for approval, and when judged necessary by the Engineer, written blast plans shall be required for each individual shot. The blast plan, in general, shall include the following information:

(a) Preconstruction Survey

This submittal shall be in accordance with the requirements presented in the relevant sections.

(b) Personnel

Written documentation as supporting evidence of personnel qualifications shall be submitted to the Engineer for review:

- Name and qualifications of persons who will be directly responsible for the planning, supervising, loading, and firing of blasts. All blasters and supervising shift foreman shall be properly qualified and licensed in accordance with federal, state, and local regulations.
- Names and professional experience of Blasting Supervisors. Blasting Supervisors are required to have a minimum of 5 years of experience in supervising the loading and firing of charges of rock excavations and shall have all necessary licenses and permits required by the state and other agencies with jurisdiction.
- Name and professional experience of the Contractor's blasting engineer or consultant who is retained to develop all controlled blasting designs and details.

(c) General Excavation Plan

This submittal shall be a narrative containing the following information for blasts:

- A list of equipment that will be available on site for performing blasting work.
- A description of heavy equipment that will be available on site to clear the road and bench of debris generated by the Contractor's blasting operation.
- A list of blasting materials that the Contractor will have on site for performing blasting work. This list shall include the types, sizes, and strengths of explosives proposed for the work, and a description of the initiation systems to be employed.
- Manufacturers' data sheets for all explosives, primers, and initiators to be employed.
- A description of the pre-blast warning system to be used.
- Intended direction of rock movement and delay plan.

- Proposed methods of protecting or stabilizing adjacent roadway structures, waterways, and vegetation.
- Proposed method of preventing rock from entering waterways, including, but not limited to rock fall barriers, delay sequence and blast patterns, and maximum blast size.
- Proposed methods of controlling fly rock.
- Schedule for the construction.
- Expected production rates.
- Monitoring plan with locations, equipment, and schedule.
- Warning sign locations and sign design.
- Equipment and methods for accessing the work area.

(d) Preliminary Blast Plan

Preliminary blast plans shall be submitted for all blast types including, but not limited to test blasts, standard blasts, and Initial Cut Line Crest Blasts. Blast plans shall be descriptions and drawings of the planned blasts. A Standard Blast Plan for each blast type to be used throughout the project shall be submitted, along with individual blast plans for each blast. All plans shall be reviewed and signed by the Blaster-In-Charge. If methods used are not effective in achieving the requirements desired for the project, the Contractor shall alter the methods, and resubmit revised blast plans to the Engineer for review. All preliminary blast plans should include the following:

- Type of blast.
- Location, plan and section views to scale of proposed drilling pattern, including diameters, spacing, depth, and orientation of drill holes, free-faces, burden, and sub-drilling.
- Identification of perimeter control blasting areas and techniques to be used.
- Aesthetic design, shape, and location of the highwall or rock face to remain after the blast, and estimated calculated of the PAE.
- Identification of joints or other features to follow as limits to the highwall or rock face.
- Types and quantities of explosives proposed for use in each hole and for each total blast.
- Blast type designation.
- Distribution of the charge in the holes, priming of each hole and stemming of holes.
- Type, sequence, and number of delays, delay pattern, and diagram for the blast, and type and capacity of initiation devices.
- Signature of Contractor's Blaster-In-Charge.
- Type of detonators.
- Procedures for interfacing with traffic control and for clearing muck and debris.

(e) Blasting Safety Plan

This plan shall be prepared in detail and shall include:

- Description of clearing and guarding procedures to ensure the safety of personnel, staff, visitors, and the general public during blasting operations.
- Description of inspections for and handling of misfires in loaded and/or excavated material.

B. Scheduling Pre-blast Meetings

A pre-blast meeting should be scheduled subsequent to the approval of the blast plan. After approval, the Engineer should contact the Contractor to schedule the meeting. The Contractor is responsible for inviting the Blaster-In-Charge (and all Blaster whom the Contractor wants to be designated as Project Blasters), as well as other interested parties.

C. Conducting Pre-blast Meetings

A pre-blast meeting shall be held at a location designated by CDOT to discuss the proposed blasting operations. In attendance will be the Engineer, the Contractor, the Blaster-In-Charge, and other interested parties. Final approval to blast will be based upon the results of this meeting.

A pre-blast meeting is intended to initiate open communications with the Contractor and Blaster-In-Charge relating to the aesthetic visual requirements for the project. The Engineer will conduct the pre-blast meeting, which would include a discussion of the proposed blast plan and other relevant information as needed.

An additional pre-blast meeting is required to appoint new Project Blasters.

D. Test Blasts

Test blasts may be required for certain types of blasting situations. The Engineer will evaluate the test blast to determine if adjustments to the rock cut design or blasting operations are necessary.

E. Blasting Progress Meetings

Progress meetings may be held at any point during the project at the request of the Engineer. During progress meetings, the progress of the blasting operation is reviewed, and potential modifications to the methods and procedures detailed in the written blast plan could be discussed. The Engineer, the Contract, Blaster-In-Charge, and other interested parties should be in attendance.

F. Blasting Review

In the event that the blasting operations cause injury, damage to surrounding properties, adversely affect traffic, or cause gases to migrate/accumulate in a potentially harmful manner, all blasting operations are required to cease by order of the Engineer for a review of operating procedures. The Engineer shall conduct the review in order to determine if proper procedures and practices were used, and if previously approved procedures need to be revised. If the results of the review indicate that the injury, damage, traffic delay, or accumulation of gases can be attributed to improper blasting procedures, then the Blaster-In-Charge may be removed from the project at the State's discretion.

G. Aesthetics Review

Should the final results of the blasting operations not meet the aesthetic visual requirements for the project, as discussed during the pre-blast meeting, the Engineer shall conduct an aesthetics review to determine if the blast plan and preliminary aesthetic design were properly followed by the Blaster-In-Charge. If the projects results are deemed unsatisfactory by the Engineer, then an Aesthetics Review Meeting shall be held with the Contractor to determine the proper methods and procedures that should occur in order to ensure that aesthetic visual requirements are met as accurately as possible.

APPENDICES

A. **Pre-Blast Meeting Itinerary**

1. Opening Remarks

- a) Statement of CDOT Standard Specifications
- b) Description of the Project by the Engineer
- c) Anticipated Start Date for Blasting Operations
- d) Estimated Time of Completion for Blasting Operations

2. Project Designations

- a) Identification of Contractor
- b) Identification of Blaster-In-Charge
- c) Insurance Details

3. Health and Safety

- a) Federal and State Regulations
- b) Local Laws
- c) Signage and Traffic Control
- d) Audible Warning Signal System
- e) Transportation of Explosive Material
- f) Pre-Blast Survey
- g) Vibration and Airblast Monitoring
- h) Flyrock Control
- i) Control of Post-Blast Fumes
- j) Other Relevant Concerns

4. Review of Blast Plan

- a) Aesthetic Visual Requirements for the Project
- b) Methods and Procedures
 - Blast Type Designation
 - Types of Equipment
 - Blast Design and Proposed Drilling Pattern
 - Explosives to be Used

5. Conclusion

B. Road Cut Classification Catalog

C. Aesthetic Rock Slope Table

Location	Example	Slope Description	Method of Blasting	Failure Mechanisms	Recommended Improvements	Aesthetic Rating	PAE Calculation
Elk Creek Fire Department		Excavation left natural-looking geological features on the rock face Note the "blocky" geology Uniform color slope angle = 30 to 40 degrees	Cushion Blasting	Small boulder debris, potential rock fall hazard complex geology (in terms of blasting)	Best example of slope Small boulders left for aesthetic appeal cause rock fall hazard	90.0 - 100.0%	62.3%
Twin Forks Park and Ride		Natural-looking face Tree growth Color variation	Cushion Blasting	No mesh help required Some potential for sliding	Bolt plate staining so less obvious	90.0 - 100.0%	74.0%
Highway 285 at Parmalee Gulch		Non-uniform color Natural boulders Vegetation growth Steep slope grade	Cushion Blasting	No failure concerns Competent rock	Good results from cushion blasting although steep slope grade	90.0 - 100.0%	N/A
Homestead		Uniform slope design Natural grass growth Note the wall built for tree growth above Long road cut	Bulldozer Excavation	No failure concerns Competent rock and catchment ditch	Variation of slope toe Artificial warping	70.0 - 80.0%	95.5%
Highway 285 at Parmalee Gulch		Difficult natural slope for blasting Foliation Backbreak	Cushion Blasting	Little concern for slope failure	Natural geology greatly affected overall slope appearance	50.0 - 60.0%	N/A
Highway 285 at Parmalee Gulch		Over-blasted slope Galvanized mesh high light reflection	Cushion Blasting	Rock launch hazard into travel lanes	Over-blasting of slope created the need for mesh	10.0-20.0%	88.1%
Exit Ramp 285 - Elk Creek Road		Steep rock face Excavation left unnatural-looking features on the rock face Note the half barrels, rock bolts, and mesh Small ROW slope angle = 50 to 70 degrees	Pre-Split Blasting	Rock fall hazard mitigated by presence of galvanized mesh	Removal of half barrel casts	10.0-20.0%	100%

ACKNOWLEDGMENTS

This research project would not have been possible without the support of CDOT team. A very special thanks to Bryan Roeder, Mike Banovich, Basil Ryer, James Usher, Ty Ortiz, Aziz Khan, Rick Andrews, and Matt DeMarco.

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