120 psi Concrete Plug Seal

Basic Seal Description: This plain concrete seal is designed to withstand an overpressure of 120 psi from a mine explosion. The seal is designed for a maximum height of 14 feet and a maximum width of 26 feet (as measured after site preparation work is completed). The seal thickness specified in Table 2 is based on the dimensions of the prepared entry. The concrete is required to have a minimum compressive strength of 3000 psi. The seal configuration is shown in figure 1. The MSHA Seal Approval Number is 120-75.336.1.07.02.1. The mine operator may use this approved seal design provided it is certified and the installation is approved in the ventilation plan and the mine operator meets the provisions specified in Section 75.336 (b).

Engineering Design and Analysis: The shear strength of the concrete was based on information contained in the American Concrete Institute (ACI) Code 318. The design is based on comparing the lateral blast loading on the seal to the average shear strength around the perimeter of the seal. The calculations are available from MSHA.

The seal was designed with the assumption that the shear strength at the interface of the concrete plug and surrounding strata and the shear strength of the surrounding strata is greater than or equal to the shear strength of the concrete, such that the shear strength of the concrete governs the design. If either the shear strength of the strata adjacent to the seal, or the shear strength at the interface between the concrete and the surrounding strata, is less than that used in the design (i.e. less than 115 psi), the seal shall be keyed a minimum of 6 inches into the weaker strata.

Pressure-time curve: The seal was designed considering a rapid loading from a 120-psi pulse as could occur in a mine explosion. The seal calculations consider the forces resulting from the 120-psi pulse wave striking and being reflected off the seal in addition to the forces applied as the gases cool. The pressure-time curve was assumed to be rectangular in shape. The load was applied to the seal with instantaneous rise time and 1.5 second duration.

Geologic/Geotechnical Conditions: This seal design is applicable to a wide range of mine geologic formations and shall be placed in an area with competent roof, ribs, and floor. Any loose roof, floor, or rib material shall be removed and/or reinforced prior to seal installation.

If poor ground conditions (e.g., severe cutter roof, floor heave, bedding separation, rib sloughage, etc.) are present, then remediation or an alternate location shall be selected for the seal(s). If water accumulation is possible at the seal location, floor strata that can be affected by water, such as fireclay, shall be removed down to competent rock.

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Maximum Allowable Convergence: This seal is designed for areas that will not be subject to significant convergence. The design is generally applicable to areas such as mains or other mine locations not expected to experience gob loading or a significant change in vertical pressure after the seals have been constructed.

Table 1 – Seal Design - 120 psi Concrete Plug Seal

120 psi Concrete Plug Seal **MSHA Seal Approval Number: 120-75.336.1.07.02.1**				
Maximum Entry Dimensions	**Thickness of Seal**	**Specified Minimum Unconfined Compressive Strength of Concrete**	**Steel Reinforcement**	**Strata Surrounding Plug Seal**
See Table 2	See Table 2	3000 psi (Note: average of quality control samples to be 4200 psi).	None required.	Competent strata with shear strength equal to or greater than 115 psi, including at concrete interface: otherwise hitching is required.
Contact information: For more details on this seal design contact MSHA's Pittsburgh Technical Support Center.				

Table 2 – Concrete Plug Seal – Minimum Required Thickness (in feet) Based on Width and Height of Opening (f'c = 3,000 psi)

Width (feet)

Height (feet)	16	18	20	22	24	26
6	6.9	7.1	7.2	7.4	7.5	7.7
7	7.6	7.9	8.1	8.3	8.5	8.7
8	8.4	8.7	9.0	9.2	9.4	9.6
9	9.0	9.4	9.7	10.0	10.3	10.5
10	9.7	10.1	10.5	10.8	11.1	11.3
11	10.2	10.7	11.1	11.5	11.8	12.1
12	10.8	11.3	11.8	12.2	12.6	12.9
13	11.3	11.9	12.4	12.8	13.2	13.6
14	11.7	12.4	12.9	13.4	13.9	14.3

Material Requirements

Concrete: Concrete shall be capable of reliably achieving a minimum unconfined compressive strength of 3000 psi. The maximum water to cementitious material ratio shall be 0.50 by weight. The minimum concrete slump shall be 4 inches to assure that the concrete can be adequately placed and consolidated. Additional slump is acceptable provided that the minimum strength and maximum water to cementitious material ratio are achieved, and that the concrete mixture does not segregate or excessively bleed. Air entrainment shall not be necessary unless the concrete will be exposed to long term or severe freezing conditions.

The concrete used to construct the seal shall be produced from an established and tested mixture design that is capable of reliably producing concrete of the required quality and performance. Once established, the water to cementitious material ratio of the concrete shall not be changed. Additional slump can be achieved using suitable chemical admixtures provided the concrete constituents do not segregate. The addition of water to achieve slump above the established mixture design shall not be allowed.

The concrete shall be designed to provide adequate sulfate resistance given mine conditions. The concrete shall also be designed and placed with consideration of the effects created by the cementitious material's heat of hydration, shrinkage, and bleed. Thermal cracking, shrinkage, and bleed may result in excessive air leakage through the seal, and potentially weakened planes through the concrete. If severe cracking is allowed to occur, the integrity of the seal may also be compromised. Lowering the temperature of the concrete when it is placed may reduce the thermal effects. Cooling the concrete materials, especially the water and aggregates will help to reduce the concrete placement temperature. Thermal effects may also be controlled by using low heat generating cementitious materials.

Materials used to produce the concrete shall consist of the following:

Cementitious Materials: The cementitious materials shall be selected to provide adequate sulfate resistance given mine conditions and to reduce the heat of hydration. Portland cement shall be ASTM C150, Type I with a maximum tricalcium aluminate content of 8 percent, Type II, Type IV or Type V. Blended cement shall be ASTM C595, Type IP (MS, MH), Type P (MS,LH) or IS (MS,MH). Pozzolan (fly ash) shall conform to ASTM C618, Class F. If pozzolan is used, it shall never be less than 15 percent by weight. Pozzolan with a calcium oxide content less than 10 percent may be beneficial to reducing thermal effects. Ground Granulated Blast-Furnace Slag (GGBFS) shall be ASTM C989, Grade 80 or 100. Low grade GGBFS may be beneficial to reducing thermal effects.

Water: Water for mixing the concrete shall be fresh, clean, potable, and free of deleterious amounts of oil, acid, salt, or alkali, except that non-potable water may be used if it meets the requirements of Table 2 in ASTM C94. If ice is used to reduce the concrete placement temperature, the ice shall also meet this requirement.

Aggregates: Fine aggregate shall conform to the quality and gradation requirements of ASTM C33, or shall comply with the quality requirements for structural concrete specified by the Department of Transportation for the state in which the seal is to be built. Coarse aggregate shall conform to ASTM C33, Class 3M, or shall comply with the quality requirements for structural concrete specified by the Department of Transportation for the state in which the seal is to be built. Coarse aggregate size designation shall be 57 or larger. Larger aggregate may be beneficial to reducing thermal and shrinkage effects.

Chemical Admixtures: Accelerating admixtures are not recommended due to the volume of concrete required for the concrete plug seal. Water-reducing and retarding admixtures shall conform to ASTM C494/C494M, Type A, B, D, F or G, except that the 6-month and 1-year compressive and flexural strength tests are waived.

Storage Conditions for Construction Materials: Cementitious materials shall be stored in weather-tight areas or containers which will exclude moisture and contaminants and keep each material completely separated. Hardened material shall be discarded. Aggregates shall not be stored directly on ground unless a sacrificial layer is left undisturbed. Other materials shall be stored in such a manner as to avoid contamination and deterioration. Admixtures which have been in storage at the project site for longer than 6 months or which have been subjected to freezing shall not be used unless it is retested and proven to meet the specified requirements.

Production of Concrete: Mixing and delivery equipment shall be capable of thoroughly mixing aggregate, cementitious materials, and water in sufficient quantity to maintain continuous and uniform placement.

Curing of the Concrete: The concrete shall be covered for a minimum of 7 days to allow proper curing. The concrete can be covered by leaving formwork in place, by covering with impervious-sheet materials conforming to ASTM C171, or by using a membrane-forming curing compound conforming to ASTM C309. For concrete placed in multiple lifts or pours, the top surface of the lift shall be covered for a minimum of 7 days or until the subsequent lift is placed. Membrane-forming curing compounds shall not be used on the top surface of lifts since this may interfere with the concrete bond between lifts. The forms shall not be loosened until the concrete has achieved adequate strength to prevent damage to the concrete.

Construction Guidelines

Site preparation: The seal shall be located at least 10 feet from the corner of any pillar. The seal shall not be located where a geologic feature, such as a fault or open joint would compromise the performance of the seal.

Standing water shall be pumped from the seal location. Flowing water shall be diverted around the seal location or collected and pumped from a sump to prevent the area of seal construction from becoming wet.

The ribs, floor, and roof shall be scaled to competent strata prior to placement of the seal. All loose material shall be removed from the seal location for a distance of 3 feet on each side of the seal. Should weak conditions persist, the ribs shall be reinforced by bolting or grouting. If the floor strata is weak or soft, or may become weaker or softer from exposure to water, the strata shall be removed at the seal location down to competent rock.

The mine opening geometry in the area of the seal shall be inspected to ensure that the rib, roof, and floor lines do not deviate significantly from parallel through the seal area. The rib lines and the roof and floor lines shall be roughly parallel. Diverging surfaces may significantly reduce the shear resistance along the plane, depending on the location of the explosion. In areas where the floor, roof, or rib lines diverge, the area in contact with the seal shall be excavated to create a surface that is roughly parallel to the opposite side.

The strata at the seal perimeter should be as rough as practically possible and smooth surfaces shall be minimized. Surfaces with roughness less than 1 inch per 4 linear feet must be mechanically roughened to increase the shear resistance at the seal interface. Alternatively, undulations may be cut into the strata to increase the shear resistance along the plane.

Roof or rib support bolting and bearing plates shall be left in place at the seal location. Metal objects such as roof mesh, straps, rails that extends from one side of the seal to the other shall be removed. Mesh that does not extend through the complete seal thickness can be left in place but the concrete shall be worked around the mesh so that voids are eliminated.

Surfaces upon which concrete is to be placed shall be free from dirt, debris, rock dust, oil, standing or running water, and unsound material.

Supplemental roof support shall be provided by cribbing or equivalent on both the outby and inby sides of the seal.

Formwork: Formwork shall be designed in accordance with current methodology of ACI 347 for anticipated loads, lateral pressures, and stresses. Forms shall be capable of withstanding the pressures resulting from placement and vibration of wet concrete with minimal deflection. Forms shall be mortar tight, properly aligned and adequately supported. Specific form requirements shall be determined by a registered professional engineer and submitted in the ventilation plan.

Form ties shall be of a design that will not permit form deflection and will not spall concrete upon removal. Dirt, debris, rock dust, and loose material shall be cleaned from the forms and the area within the forms before depositing concrete.

Supporting forms and shores shall not be removed until the concrete has attained adequate strength to support its own weight and any other imposed loads.

Concrete Placement: Forms shall be positioned to result in the seal having a width of at least the value indicated for Table 2 for the prepared dimensions of the entry. The capacity of the placing system shall be sufficient to supply concrete at a rate which will prevent cold joints in any placement. Concrete shall be worked into the corners and angles of the forms and embedded items without permitting the material to segregate. Concrete shall be deposited as close as possible to its final position in the forms, and there shall be no vertical drop greater than 5 feet. Concrete shall not be dumped at a central location and allowed to spread out on its own. Depositing of the concrete shall be so regulated that it will be effectively consolidated in horizontal layers not more than 18 inches thick.

Concrete for the plug seal may be placed in multiple lifts or pours. Multiple placements may be advantageous for controlling thermal and shrinkage effects, as well as optimizing the loads on the formwork. When the seal is placed in multiple lifts, the time between lifts must be adequate for the concrete to fully set and attain adequate strength to support the next lift. Typically this requires the concrete to attain a strength of at least 500 psi. Additional time may be allowed between lifts to allow the heat in the concrete to dissipate and to allow the majority of the shrinkage to occur before the next lift is placed. The construction joint between lifts shall be cleaned prior to placing the next lift and adequately roughened. Any unsound concrete, detached aggregate, water, debris, or dirt shall be removed before the subsequent lift is placed. The surface of vibrated concrete may impart adequate roughening for engagement of the lifts.

Concrete shall be placed in layers at a placement rate that is adequate to assure that fresh concrete is deposited on concrete that is still plastic. In the event that concrete has partially set and cannot be penetrated by the vibrator, the concrete shall be allowed to fully set a minimum of 24 hours. The surface of the concrete shall be treated and prepared as specified for a multiple lift construction joint.

Immediately as the concrete is placed, each layer of concrete shall be consolidated to a uniform density by internal vibrators to remove air pockets or voids. Vibrators shall be inserted and withdrawn vertically, penetrating through the top layer and into the layer underneath. Backup vibrator capacity shall be available at the construction site to prevent disruption of concrete placement should vibrator breakdown occur.

If the temperature during seal construction is below 32 degrees, measures shall be taken, such as use of a protective enclosure, to ensure that the air temperature at the seal is kept above 40 degrees for at least 72 hours.

Concrete must be tight against the roof with no voids, pockets, gaps or separations. This will require the inby and outby formwork to be tight against the roof. Adequate access shall be provided through the formwork using windows and ports to place and consolidate the concrete so that it is tight against the roof. Pipes for concrete placement may be installed through the formwork so that the concrete may be pumped into the form. The formwork must be adequately designed to support the loads imposed by the pumping.

The spacing of the pipes shall be adequate to assure that the concrete is placed the full depth and width of the seal at the roof. This may require the outlet of the pipes to be staggered and the concrete placement through the pipes staged to ensure the concrete is placed in a continuous and uniform placement across the contact with the roof.

Pipes shall also be provided to allow air within the forms to vent. The vent pipes shall be configured in an L-shape so that the end of the pipe in the seal is positioned vertically and close to the roof. The diameter of pipe shall be adequate to let the air vent and then the pipe to fill with concrete. The gap between the roof and the end of the pipe shall be adequate to allow the pipe to fill with concrete, but as close to the roof as practical to assure that the air is completely evacuated.

Valves shall be provided on the filling ports to allow the flow of concrete to be stopped without the loss of concrete through the filling port. The filling ports must be completely filled with concrete when the placement is completed. Caps or valves shall also be provided on the vent pipes so the vent pipe can be shutoff once the vent pipes are returning concrete. The vent pipes must be filled in the final seal configuration. If the slump of the concrete is not adequate to flow through the vent pipes, the pipes shall be withdrawn or back filled with an expansive grout. Where the roof is uneven such that it creates recessed pockets, a vent pipe shall be installed to allow air to evacuate and allow the concrete to contact the roof. Vent pipes shall also be placed wherever the roof line peaks or crowns.

Seal Construction Equipment: All equipment used in seal construction shall be approved for use in the ventilation plan.

Mixers: The mixer shall be clean of debris and any hardened concrete removed prior to the commencement of batching. The mixing process shall be capable of maintaining a minimum production rate so that all concrete is placed and consolidated in a plastic state to prevent the formation of hardened surfaces. An individual experienced with on-site batching shall oversee the concrete production. If the concrete mixture design or concrete production methods are not well established, performance testing and trial mixing shall be performed prior to the start-up of actual concrete production to determine optimum mixing times.

Scales: Accuracy of scales shall be checked prior to measuring mixture quantities by placing an object of known weight on the scale and recording the scales reading. The scales shall be cleaned from debris build-up to ensure accurate weight and density determination.

Pumps: The use of positive displacement pumps for transportation concrete is an acceptable method provided that the concrete maintains its normal consistency. The consistency of the concrete after it has been the pumped a long distance shall be checked prior to placing in the concrete.

Vibrators: Flexible-shaft vibrators are most suitable for use in consolidating the concrete.

Quality Control Requirements

The concrete practices followed in the mixing, transportation, placement and curing shall achieve the principal objectives of providing uniform quality concrete free from segregation or bleed, with thorough consolidation, and good bond to the strata and concrete lifts. The person certifying the seal construction shall perform the inspections and tests described below and, based upon the results of these inspections and tests, shall take the action required to certify that the seal was constructed to the specifications required of the seal design.

Site Preparation: The person certifying the seal construction shall ensure that site preparation complies with the construction guidelines.

Formwork: The formwork shall be examined prior to placing concrete to verify that field measurements are as shown on the drawings. Formwork shall also be inspected to assure that adequate access openings are provided to place and consolidate the concrete the full width and depth of the seal. Access shall also be adequate to assure that the concrete can be placed and consolidated tight against the roof and ribs.

Concrete:

Materials: The person certifying the seal construction shall assure that the cementitious materials, water, aggregate, and admixtures used in the concrete production are in accordance with the material requirements and the established mixture design.

Slump: Slump tests shall be performed to determine the consistency and uniformity of fresh concrete. Unacceptable slump tests typically indicate improper mix proportions, especially in water content. Slump tests shall be made when test specimens are fabricated and at least four slump tests on randomly selected batches. Tests shall be conducted in accordance with ASTM C143/C143M. Batches of concrete not meeting the mixture design established requirements shall be rejected and shall not be placed in the seal.

Strength: Strength specimens shall be made to determine the unconfined compressive strength of the concrete. Test specimens shall be molded and cured in accordance with ASTM C31/C31M and tested in accordance with ASTM C39/C39M. As required by ASTM C31, the concrete slump, air content, and temperature shall be recorded when the specimens are taken. Sampling for the test specimens shall be done in a completely random and unbiased manner.

A minimum of two sets of strength specimens shall be made per seal. If a seal is placed in more than one lift or pour, a set of specimens shall be made for each lift. A minimum of four concrete cylinders shall be made per set, and shall be field-cured at the seal location. Two field-cured cylinders from each strength specimen set shall be tested at 28 days, and two cylinders from each set shall be held in reserve in the event that the seal does not reached the required minimum strength at 28 days. The reserve cylinders may be used to verify the concrete strength at a later age to determine if the required minimum strength is achieved. If the mixture design is based on achieving the design strength at an age other than 28 days, the first two cylinders should be tested at that age.

In accordance with ACI 318, the required average compressive strength of the tests shall be 4200 psi to assure that all concrete placed in the seal can reliably achieve the minimum design strength of 3000 psi. A lower average strength may be applied if and when a statistical basis for the average compressive strength is established in accordance with ACI 318.

It may be beneficial to prepare additional test cylinders. For example, two additional concrete samples may be cured under laboratory conditions. In the event the field cured samples do not meet the specified strength, tests on the laboratory cured samples would give an indication of whether the problem was with the

concrete or the curing. This would assist with determining what measures may need to be taken to evaluate the adequacy of the seal in the event the field-cured samples show lower than intended strength. In addition, where monitoring behind the seal is required until the seal achieves the required strength, additional field-cured cylinders would allow the strength to be monitored over time to determine when monitoring behind the seal is no longer necessary.

Placement: The person certifying the seal construction shall ensure that the correct quality of concrete has been placed and thoroughly consolidated. The certifying person shall not permit batching and placing to begin until it has been verified that an adequate number of vibrators in working order and with competent operators are available.

Where concrete is placed in multiple lifts or pours, the person certifying the seal construction shall assure that all construction joints are cleaned and adequately prepared in accordance with the Construction Guidelines.

Curing: The person certifying the seal construction shall ensure that the concrete is properly cured using the formwork, impervious sheeting, or sprayable curing compound.

Other Requirements

Air Sampling Pipes: Two gas sampling pipes shall be installed in each seal. One sampling pipe shall extend approximately 15 feet into the sealed area. The other pipe shall extend into the center of the first connecting crosscut inby the seal. The inby ends of the two pipes shall be approximately 12 inches from the roof. The pipes shall be supported by hangers or on cribbing. The sampling pipes shall be ½-inch diameter.

Each sampling pipe shall be equipped with a shut-off valve, rated at a strength to withstand a 120 psi overpressure, and appropriate fittings for taking gas samples. The sampling pipes may be metallic, such as copper. If the sampling tube is conductive material, the pipe shall be grounded.

Water Drainage System: A water drainage system shall be installed during seal construction in the lowest elevation seal(s) of the set. This seal is not designed to impound water other than to a minimal, unavoidable depth. The actual size and number of pipes shall be based on the anticipated maximum flow rate at the seal location. The pipes used shall be corrosion resistant and have equivalent strength properties of a schedule 80 smooth wall steel pipe *(240 psi internal pressure rating*). If more than one drainage pipe is installed in the seal, the horizontal distance between the pipes shall not be less than 3 feet. Pipes shall be installed as low as practical to minimize the depth of water against the seal.

Pipe sections shall be joined in accordance with the pipe manufacturer's installation recommendations. Pipe joints and couplers shall have resistance to internal pressure which is equivalent to the pressure rating for a schedule 80 smooth wall steel pipe. The drainage system shall be equipped to prevent the exchange of air through the pipe(s). A water trap and valve shall be installed on the outby side of each drainage pipe. The valve and its connections shall have blast resistance equivalent to a schedule 80 smooth wall steel pipe. The valve shall be installed on the inby side of the water trap. Water traps shall be U-shaped and the vertical depth of the U shall be large enough that a sufficient quantity of water can be maintained in the trap to prevent evaporation prior to the scheduled periodic examination. The U-portion of the water trap shall be recessed into the mine floor to minimize the depth of water against the seal and to strengthen its blast resistance.

The water drainage system shall be checked weekly and used to ensure that water, other than for a few inches of depth, is not being impounded by the seal. If water adversely affects the floor or ribs to the point where the function of the seal is jeopardized, then remedial measures, such as grouting, shall be taken. If impoundment of more than a few inches of water cannot be avoided, then the structure needs to be redesigned to take water impoundment into account or a water diversion or pumping system needs to be installed.

A low weir(s) or catchment, no more than 12 inches high, shall be constructed across the entry inby the seal to trap sediment and debris that may clog the drainage pipe(s).

Air Leakage: Seals shall be installed at least 10 feet from the corner of any pillar to reduce air leakage around the seal. Measures shall be taken to ensure that the concrete is placed tight against the roof. If necessary to prevent leakage, the perimeter of the seal shall be grouted after the seal cures.

Fire Resistance/Flame Spread Index: The seal is constructed of concrete.

Time Required for Seal to Reach Design Strength: Concrete will typically reach its intended strength after 28 days, unless otherwise specified. Depending on the temperature of the atmosphere inby and outby the seal, additional time may be needed for the concrete to reach its design strength.

During the curing period, the atmosphere behind the seal must be monitored daily or frequently enough to allow a trend to be determined. The atmosphere in the sealed area must be maintained inert as specified in 75.335(b)(3) until the seals reach acceptable strength. The purpose of this sampling is to provide the mine operator with information about the conditions behind the seals and to provide a measure of how well the seals are functioning. Fluctuations in the methane content may be an indication of seal leakage that must be addressed by locating and treating leaks. The information

from monitoring is intended to allow the operator to know the conditions behind the seals so that when conditions dictate, appropriate safety measures can be taken. The protocol in the ventilation plan must include measures to be taken and actions that will be followed during the curing period.

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