120 PSI Reinforced Concrete Seal

Basic Seal Description: This reinforced concrete seal is designed to withstand an overpressure of 120 psi from a mine explosion. The seal is designed for a maximum seal height of 7 feet and a maximum seal width of 24 feet (as measured after site preparation work is completed). The seal is 24 inches thick with two mats of vertical and horizontal steel reinforcement each 2 1/2 inches in from the faces of the seal. The vertical reinforcement is doweled into the roof and floor. The concrete is required to have a minimum compressive strength of 4000 psi; all rebar is Grade 60 (60,000 psi yield strength). The seal configuration is shown in Figures 1 and 2. The MSHA Seal Approval Number is 120-75.336.1.07.01.0. The mine operator may use this approved seal design provided its 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 seal was designed based on basic principles from the American Concrete Institute (ACI) Code 318 for Reinforced Concrete Design. The design calculations are available from MSHA. The seal was designed using a single degree of freedom (SDOF) wall analysis program called WAC (Wall Analysis Code) developed by the U.S. Department of Defense. The wall was designed assuming the top and bottom of the wall is fixed to the strata and the vertical ends of the seals are unrestrained. The WAC program calculates the ultimate wall capacity assuming plastic hinges develop at the top and bottom of the wall, as well as at mid-height. Hinge rotations were not to exceed 1 degree.

The resistance around the perimeter of the seal was based on the shear-friction method of the ACI code. The wall shear strength was calculated assuming deep-beam behavior since the span to depth ratio was only 3.5.

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 considered the 120-psi pulse wave to be reflected off the seal. 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 is designed to be placed in an area with competent roof and floor. Any loose roof, floor or rib material must be removed or reinforced prior to seal installation. The design requires that the pull strength of the roof and floor be determined. The vertical rebar are required to be embedded to the depth needed to develop the yield strength of the rebar.

If poor ground conditions (e.g., severe cutter roof, floor heave, bedding separation, rib sloughage, etc.) are present, then remediation or an alternate location must 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, must be removed down to competent rock.
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.

Design References: American Concrete Institute 318 Code for Reinforced Concrete Design; Wall Response to Airblast Loads: The Wall Analysis Code (WAC); TM 5-1300 (NAVFAC P-397, AFR 88-22), "Structures to Resist the Effects of Accidental Explosions," November 1990.

Seal Design Table - 120 PSI Reinforced Concrete Seal

120 PSI Reinforced Concrete Seal **MSHA Seal Approval Number: 120-75.336.1.07.01.0**				
Maximum Entry Dimensions	**Thickness of Seal**	**Specified Minimum Unconfined Compressive Strength of Concrete**	**Steel Reinforcement**	**Foundation Anchorage**
7 feet high by 24 feet wide.	24 inches.	4000 psi (Note: average of quality control samples to be 5200 psi).	Vertically: #9 bars on 10-inch centers. Horizontally: #6 bars on 18-inch centers. Two and one-half inches concrete cover on each face.	Vertical rebar to be grouted into roof and floor to depth required to develop yield strength of bar in pull test.
Contact information: For more details on this seal design contact MSHA's Pittsburgh Technical Support Center.				

Material Requirements

Steel Reinforcement: Reinforcement must conform to ASTM A615/A615M or ASTM A706/A706M, and consist of Grade 60 steel bars, having a yield strength of 60,000 psi. The mats must consist of #9 bars placed on 10-inch centers vertically, and #6 bars

placed on 18-inch centers horizontally. Steel placement is shown on the drawings and described in the construction guidelines.

Depth of embedment for the vertical reinforcement must be determined based on pull-out tests conducted in roof and floor strata representative of the seal locations. A minimum of three tests must be conducted in the floor strata and a minimum of three tests must be conducted in the roof strata to determine the minimum required embedment depth. The minimum depth must be taken as the average of the three tests for each stratum.

Concrete: Concrete must be capable of achieving a minimum unconfined compressive strength of 4000 psi. The maximum water to cementitious material ratio must be 0.50 by weight. The minimum concrete slump must 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 the concrete mixture does not segregate or excessively bleed.

Once established, the water to cementitious material ratio of the concrete must 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 must not be allowed.

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

Cementitious Materials: Portland cement must be ASTM C150, Type I with a maximum 15 percent amount of tricalcium aluminate, or Type II, or Type V. The cementitious materials must be selected to provide adequate sulfate resistance given mine conditions.

Water: Water for mixing the concrete must 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.

Aggregates: Fine aggregate must conform to the quality and gradation requirements of ASTM C33, or must 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 must conform to ASTM C33, Class 3M, size designation 57 or 67, or must 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.

Chemical Admixtures: Accelerating admixtures must conform to ASTM C494/C494M, Type C or E, except that calcium chloride or admixtures containing

calcium chloride must not be used. Water-reducing and retarding admixtures must 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 must be stored in weather-tight areas or containers which will exclude moisture and contaminants and keep each material completely separated. Hardened material will be discarded. Aggregates must not be stored directly on ground unless a sacrificial layer is left undisturbed. Reinforcing bars and accessories must not be placed directly on the ground. Other materials must 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 must not be used unless retested and proven to meet the specified requirements.

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

Curing of the Concrete: The concrete must 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. If the formwork is left in place, the outby side of the forms must be loosened after 24 hours to assure that the formwork is not permanently bonded to the concrete.

Construction Guidelines

Site preparation: The seal must be located at least 10 feet from the corner of any pillar.

The ribs, floor, and roof will be scaled to competent strata prior to placement of the seal. All loose material must be removed from the seal location for a distance of 3 feet on each side of the seal. Should weak conditions persist, the ribs must 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 must be removed at the seal location down to competent rock.

The seal must not be located where a geologic feature, such as a fault or open joint, would compromise the performance of the seal.

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

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

Actions to Prevent Water Accumulations during Seal Construction: Standing water will be pumped from the seal location. Flowing water will be diverted around the seal location or collected and pumped to a sump to prevent the area of seal construction from becoming wet.

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

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

Supporting forms and shores must not be removed until the structural units are strong enough to carry their own weight and any other natural loads.

Steel Reinforcement: Vertical reinforcement consists of #9 bars on 10-inch centers and is required to be grouted into the roof and floor. The vertical bars must be placed so that there is a bar within 5 inches of each rib, but sufficient clearance must be provided to allow the concrete to be properly placed around the bars. Vertical bars must be anchored a sufficient depth into the roof and floor so that the yield strength of the bars would be reached in a pull test. Vertical reinforcement will be spliced using mechanical couplers having a strength greater than or equal to the strength of the bars. Vertical bar splices must be staggered so that the splices do not align in a plane through the seal.

Horizontal reinforcement consists of #6 bars on 18-inch centers with the first bar being no more than 6 inches down from the top of the seal. The horizontal bars are placed on the inside of the vertical bars and the bars are tied together. Each intersection of steel bars must be tied, including the horizontal splices, with minimum 16 gauge wire. The horizontal bars are not required to be embedded into the ribs. Horizontal reinforcement may be lap spliced with a minimum overlap of at least 24 inches. The horizontal splices must be staggered so that the splices do not align in a plane through the seal.

The total seal thickness must be at least 24 inches. The vertical bars must be positioned to provide 2 1/2 inches of concrete cover to the closest face of the seal. The center-to-

center distance between the inby and outby vertical rebar must be a minimum of 17⅞ inches.

Depth of embedment for the vertical reinforcement must be determined based on pull-out tests conducted in roof and floor strata representative of the seal locations. The vertical reinforcement must be grouted into the strata using a commercial formulation suitable for the proposed application.

The bars must be clean and free of any material that would interfere with bonding to the concrete such as dirt, oil, or loose rust.

Concrete Placement: Forms must be positioned to result in the seal having a width of at least 24 inches, with 2 1/2 inches of cover on the rebar. Concrete must be deposited as close as possible to its final position in the forms, and there must be no vertical drop greater than 5 feet. Concrete must not be dumped at a central location and allowed to spread out on its own. Depositing of the concrete must be so regulated that it will be effectively consolidated in horizontal layers not more than 12 inches thick. The concrete must be deposited in layers so that fresh concrete is deposited on concrete that is still plastic. In the event that concrete must be placed on a layer that has partially set, this concrete must be allowed to fully set a minimum of 24 hours. The surface must be clean and free of unsound concrete or loose aggregate before the placement of concrete continues.

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

At the top of the seal, the concrete must be compacted to achieve full contact with the roof.

Concrete must be cured for a minimum of 7 days. If the temperature during seal construction is below 40 degrees, measures must be taken, such as use of a protective enclosure, to ensure that the air temperature at the seal is kept above 50 degrees for at least 72 hours.

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

Mixers: The mixer must be clean of debris and any hardened concrete removed prior to the commencement of batching. The mixing process needs to be capable of maintaining a minimum production rate so that all concrete placed in the formwork

is in a plastic state to prevent the formation of hardened surfaces. An individual experienced with on-site batching should oversee the concrete production. If an experienced individual is not available, performance testing and trial mixing to determine optimum mixing times must be performed prior to the start-up of actual concrete production.

Scales: Accuracy of scales must be checked prior to measuring mix quantities by placing an object of known weight on the scale and recording the scales reading. The scales must be periodically cleaned from debris build-up to ensure accurate 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 should be checked prior to placing it in the formwork.

Vibrators: Flexible-shaft vibrators are most suitable for use in consolidating the concrete. The size of vibrator used must easily fit in the space between the formwork and rebar so that it is able to sufficiently agitate the surrounding concrete.

Quality Control Requirements

The practices followed in the placement of concrete should have the principal objectives of achieving concrete that is bonded to the strata and previous lift, uniform in quality, free from any objectionable segregation, and thoroughly consolidated. The person certifying the seal construction must perform the inspections and tests described below and, based upon the results of these inspections and tests, must 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 must ensure that site preparation complies with the construction guidelines.

Steel Reinforcement: The person certifying the seal construction must ensure that the vertical reinforcement is embedded to the minimum required depth and has been securely grouted in place. After the reinforcement has been placed and before the outby form is constructed, reinforcement must be inspected to assure that the size, spacing, and condition of the steel bars are in accordance with the design.

Formwork: The formwork must be examined prior to placing concrete to verify that field measurements are as shown on the drawings. Formwork must also be inspected to assure that adequate access openings are provided to place and consolidate the

concrete the full width of the seal. Access must also be adequate to assure that the concrete can be placed and consolidated tight against the roof and ribs.

Concrete – Quality Control

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

Strength: Strength specimens must be made to determine the unconfined compressive strength of the concrete. Test specimens must 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 must be recorded when the specimens are taken. Sampling for the test specimens must be done in a completely random and unbiased manner.

A minimum of four concrete cylinder specimens must be made per seal. If a seal is placed in more than one pour, a set of specimens must be made for each pour. At least four cylinders must be field-cured at the seal location. Two field-cured cylinders must be tested at 28 days, and two cylinders must be held in reserve in the event that the seal has not reached the required minimum strength at 28 days. The reserve cylinders can be used to verify the strength at a later age to determine if the required minimum strength is achieved.

In accordance with ACI 318 (Table 5.3.2.2), the average compressive strength of the tests must be 5200 psi to assure that all concrete placed in the seal can reliably achieve the minimum design standard of 4000 psi. A lower average strength would require testing of more samples and establishment of a statistical basis for the required average strength in accordance with ACI 318.

It would be beneficial to take additional test cylinders. For example, at least two additional concrete samples could be cured under laboratory or room temperature 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 mix 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.

Placement: The person certifying the seal construction must ensure that the correct quality of concrete has been placed. The certifying person must 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.

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

Other Requirements

Air Sampling Pipes: Two gas sampling pipes will be installed in each seal. The sampling pipes may be metallic, such as copper. The inby ends of the two pipes must be approximately 12 inches from the roof. The pipes must be supported by hangers or on cribbing. The sampling pipes must be ½-inch in diameter.

One sampling pipe must extend approximately 15 feet into the sealed area. The other sampling pipe must extend into the center of the first connecting crosscut inby the seal. Each sampling pipe must be equipped with a shut-off valve, rated at a strength to withstand a 120 psi overpressure, and appropriate fittings for taking gas samples.

Water Drainage System: A water drainage system must 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 must be based on the anticipated maximum flow rate at the seal location. The pipes used must 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 must not be less than 3 feet. No rebar must be cut, moved, or removed to install a pipe. Pipes must be installed as low as practical to minimize the depth of water against the seal.

Pipe sections must be joined in accordance with the pipe manufacturer's installation recommendations. Pipe joints and couplers must have resistance to internal pressure which is equivalent to the pressure rating for a schedule 80 smooth wall steel pipe.

The drainage system must be equipped to prevent the exchange of air through the pipe(s). A water trap and valve will be installed on the outby side of each drainage pipe. The valve and its connections must have blast resistance equivalent to a schedule

80 smooth wall steel pipe. The valve must be installed on the inby side of the water trap. Water traps must be U-shaped and the vertical depth of the U must 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 must 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 must 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, must 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, must be constructed across the entry inby the seal to trap sediment and debris that may clog the drainage pipe(s).

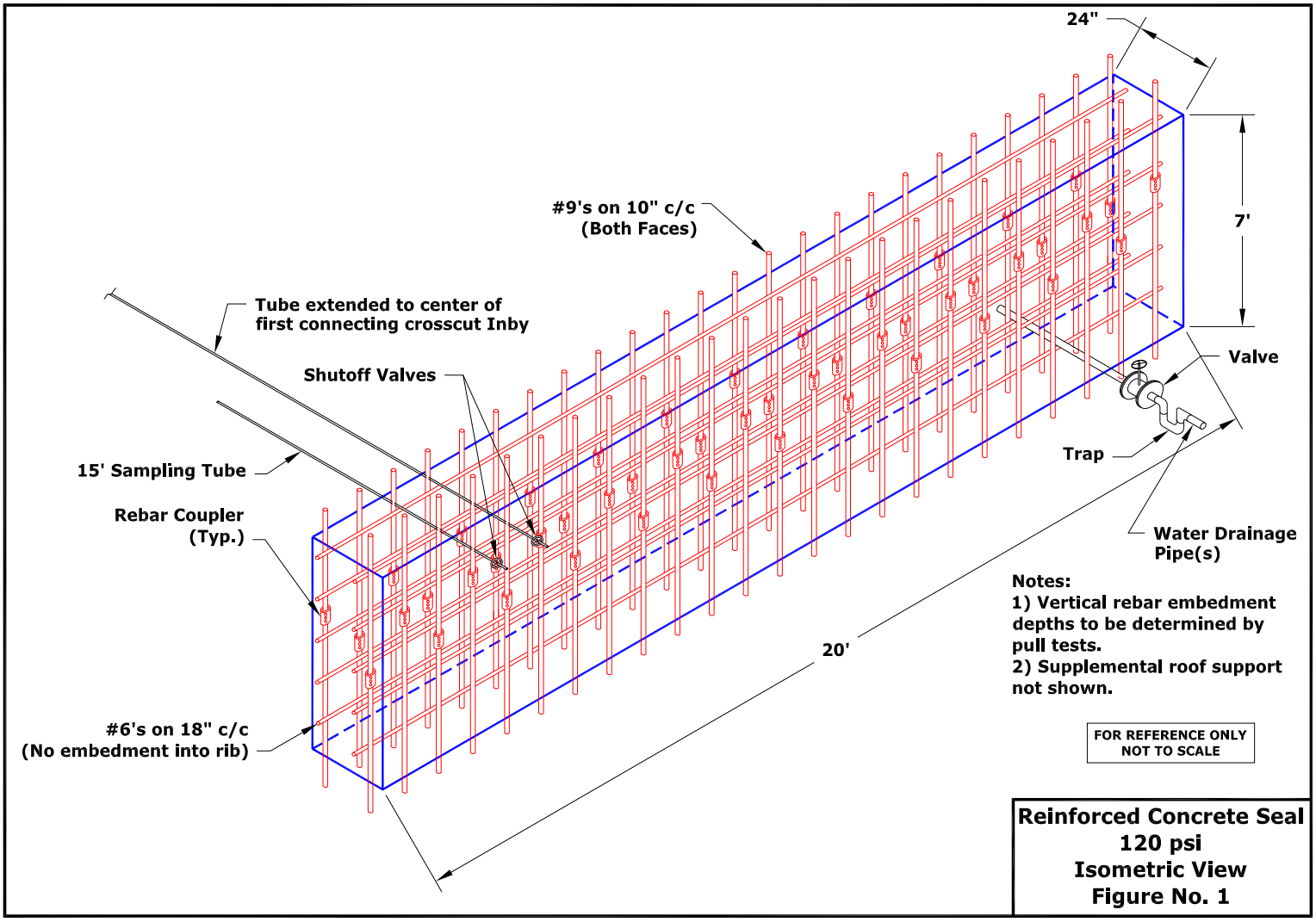
Air Leakage: Seals must be installed at least 10 feet from the corner of any pillar to reduce air leakage around the seal. Measures must be taken to ensure that the concrete is placed tight against the roof. If necessary to prevent leakage, the perimeter of the seal will be grouted after the seal cures.

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

Time Required for Seal to Reach Design Strength: Concrete is typically considered to reach its intended strength after 28 days. 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 their intended 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.

Contact Information: Stanley J. Michalek, Mine Safety and Health Administration, Pittsburgh Safety and Health Technology Center, Cochrans Mill Road, Pittsburgh, PA. 15236. Phone: 412-386- 6974

120 PSI REINFORCED CONCRETE SEAL –
MSHA SEAL APPROVAL NUMBER 120-75.336.1.07.01.0



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