OPEN-GRADED ROCK BASE FOR ASPHALT AND PORTLAND CEMENT CONCRETE PAVEMENTS

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INTRODUCTION

As early as the mid - 1960s, it was common practice in Idaho to place a one or two foot-thick layer of shot rock as a cap over the subgrade in highway pavement construction. Much of the new construction, particularly in Districts 1 and 2 (North Idaho) required significant rock excavation, making the shot rock layer an economical method of improving the subgrade. In the 1970s, this rock layer was being screened to limit the maximum size, to reduce the fines and improve drainage. Because this shot rock layer was first used as a cap on the subgrade, it became known as a Rock Cap.

The first installation of this layer as a truly open-graded base was on the new Lewiston Hill project on US 95, completed in 1978. This was a two-foot layer of 8-inch minus, and essentially 3/4-inch plus, shot rock. In 1985, District 1 constructed a trial section on US 95 south of Coeur d' Alene , two feet thick and graded from 3 inches to 3/4 inches. This section was underlain by a separation geotextile and the first lift of asphalt was placed directly on the open-graded material. Prior to this, all open-graded Rock Cap sections were capped with 0.2 to 0.5 feet of crushed aggregate base.

Since most of the rock for these open-graded sections was obtained either within or adjacent to the roadway prism, the cost was very attractive; on the order of half that of conventional aggregate base. On recent projects in southern Idaho, it was necessary to develop quarries off the job site This increased the cost of the Rock Cap to from 60% to 110% of the aggregate base price. Rock Cap and aggregate base bid prices for several projects constructed since 1985 are listed in Figure 1.

To date approximately 80 miles of pavement reconstruction has incorporated the open-graded Rock Cap base, including 39 miles of Interstate Highway in Districts 1,3 and 4 (Coeur d' Alene, Boise and Shoshone). In addition, at least 10 miles of US 95, utilizing the Rock Cap are in design.

Analysis of the gradation and construction methods for the Rock Cap is continuing with emphasis on stability, cost and smoothness. The currently proposed version of the Standard Special Provision for the Open-Graded Rock Base, SSP 307, is appended.

Figure 1.

ROCK CAP BID PRICES

YEAR	PROJECT	PROJ. NO.	DIST.	QUANTITY (1) CY	QUANTITY (1) TON	PRICE $ / CY	PRICE $ / TON	AGGR BASE (2) $ / CY	AGGR BASE (2) $ / TON
1985	MICA FLATS - COUGAR CK	BR-F-5115(12)	1	35,745	52,903	8.00	5.40	13.23	7.00
1988	MICA CK - MICA FLATS	BR-F-5115(15)	1	74,180	109,786	4.60	3.10	8.22	4.35
1988	COLBURN - PACK RIVER	BR-F-5116(48)	1	43,070	63,743	5.50	3.72	11.34	6.00
1990	HILLTOP - BENNETT BAY	D-I-90(89)16	1	134,382	198,886	4.70	3.18	7.56	4.00
1990	DEVIL'S ELBOW	F-IR-3112(42)	3	122,000	180,560	9.78	6.61	15.12	8.00
1992	I - 84, MP 95 - MP 103.5	IR-84-2(035)95	3	197,704	292,602	10.73	7.25	18.90	10.00
1993	I - 84, MP 103.5 - MP 109	IM-IR-84-2(029)105	3	150,752	223,113	10.36	7.00	15.12	8.00
1993	US 2, JCT US 95 - EAST (3)	STP-NH-F-5101(004)	1	41,735	61,768	8.76	5.92	-	-
1994	ROCK CREEK	NH-STP-IR-5110(100)	1	28,400	42032	3.00	2.03	-	-
1994	KOOTENAI C.O. - COLBURN	NH-IR-F-5116(071)	1	198,586	293,907	3.50	2.36	8.50	4.50
1994	THAMA - WRENCO	NH-F-5121(044)	1	120,070	177,702	3.75	2.53	14.18	7.50
1994	I - 84, US 93 IC - SH 50 IC.	STP-84-3(047)173	4	46,730	69,160	15.91	10.75	14.84	7.85
1995	I - 84, MP 109 - HAMMETT	STP-IM-IR-84-2(036)109	3	80,785	119,563	14.43	9.75	11.81	6.35

NOTE: AVERAGE BID PRICE FOR AGGREGATE BASE 1992 - 94
DISTRICT 1 - $7.38 / TON (13.93 / CY)
DISTRICT 3 - $6.20 / TON (11.72 / CY)

(1) CONVERSION BASED ON ROCK CAP @ 110 PCF
(2) CONVERSION BASED ON AGGR. BASE @ 140 PCF
(3) AVERAGE OF 3 LOWEST BIDS

DRAINAGE AND STRUCTURAL SUPPORT

Drainage. D. H. Mathis, 42nd Road Builders' Clinic, 1991, presented information developed from the first projects constructed using the open-graded shot rock base known as Rock Cap. The controversy he reported, regarding finishing the Rock Cap surface with aggregate base or a sacrificial asphalt plant mix binder course is still active. The most recent projects constructed in District 3 employed an open-graded asphalt binder course, averaging 0.15 feet-thick, over the surface of the Rock Cap prior to placing Portland Cement Concrete pavement on Interstate 84, east of Mountain Home, Idaho. Placing the asphalt concrete binder course under both flexible and rigid surfaces is seen as important in maintaining drainage, and to minimize the potential for pumping of fines through joints and cracks in the pavement.

Based on effective particle size correlations with permeability presented by Cedergren, "Seepage Drainage and Flow nets"., 1967, the coefficient of permeability of the Rock Cap is estimated at from 50,000 to 250,000 feet per day. Based on laboratory tests, the permeable asphalt binder coefficient was on the order of 500 to 1000 feet per day. Experiments involving spraying water on the surface of the permeable asphalt binder course on the I - 84 project east of Mountain Home failed to produce any surface accumulation or runoff. The conventional crushed aggregate base, on the other hand, has an estimated coefficient of permeability of 1 to 2 feet per day. In the author's opinion, the presence of a 0.4 to 0.5 foot-thick aggregate base layer will significantly retard water flow from cracks or joints in the pavement surface into the Rock Cap.

Because of the very high permeability, flow velocity may be in the transition area between laminar and turbulent flow. As a result of the probable high flow velocity, prevention of subgrade erosion by a properly designed filter or geotextile is a high priority. In virtually all Rock Cap sections constructed since 1982, a subgrade separation geotextile has been placed over the subgrade. To date, there has been no evidence of failure of the geotextiles. A section on US 95, constructed in 1988, will be exposed during the 1995 construction season to observe the geotextile condition.

Again, because of the extremely high permeability, continuous edge drains have not been judged necessary where the Rock Cap section is at least 12 inches thick. On earlier projects where, the section is 2 or more feet thick, all drainage is expected to occur through the shoulder fore slope. On the more recent projects on I - 84, intermittent edge drains were constructed in sag curves, at the ends of structures and in areas of very flat grades. Typically, 50 feet of perforated pipe drain were installed about every 800 feet. The Rock Cap section on these projects was 12 inches thick and the drains were viewed as a safety valve in case wind blown soil plugged the foreslope surface. In addition, subdrains were installed across the roadway where grades exceeded 2 1/2 to 3 % and at bridge abutments to intercept water flowing down grade

Structural Support. As reported by Mathis (1991), back calculated layer moduli from falling weight deflectometer measurements of several existing Rock Cap sections indicated values of from 25,000 to 60,000 psi. These moduli were equivalent to or slightly lower than back calculated values for recently constructed conventional aggregate base sections, and there is little seasonal change. Current flexible pavement design in Idaho is based on California's R - value method, using aggregate base equivalencies rather than structural number. Based on the back calculated moduli, the Rock Cap was assigned an equivalency ratio of 1:1 with aggregate base. Prior to 1990, the Rock Cap had been assigned a subbase equivalency, 3/4:1, because equipment limitations prevented determination of a realistic R - value. Because of the variable thickness, the asphalt concrete binder course is given no structural value.

In 1990, two of the Rock Cap sections on US 95 in District 1, were designated as SHRP, Long Term Pavement Performance test sites. One, Mica Flats, south of Coeur d' Alene, was constructed in 1985 with a 0.3 foot temporary asphalt concrete surface.

The other, Colburn to Pack River, north of Sandpoint, was constructed in 1988. Annual deflection data has been collected at each of these sites. However, laboratory tests have not been completed by SHRP and none of the field data has been analyzed.

Deflection tests by the Idaho Transportation Department in 1990 and 1991 at the Mica Flats site, indicated that of the pavement sections constructed on the Cougar Creek to Mica Flats project, only the Rock Cap section with the temporary surface, did not need an overlay to support the projected 20 year traffic. This section shows some transverse cracking, but no load associated distress.

During the design process for the I - 84 reconstruction project from MP 95 to MP 103.5 (the first project to use Rock Cap under a rigid pavement), some comparisons were made between Rock Cap and aggregate base to assess the relative support under construction traffic. For equivalent support, with a fixed surfacing thickness, i.e., the asphalt binder course, the required Rock Cap section was 65% to 75% of the requred thickness of aggregate base. The difference in required thickness was predominently due to the improved drainage. To account for the drainage factor, an increase in the equivalency for Rock Cap to 1.2:1 is proposed.

CONSTRUCTION

Special construction procedures are needed to construct the asphalt binder course over Rock Cap. Because the material contains essentially no material finer than the # 4 screen, the trafficability has often been similar to a truck escape ramp arrester bed. With the gradation specification developed in District 1, there was no control between the 3 inch and 3/4 inch screens. The stability of the sections produced under this specification varied depending on the characteristic size ranges generated in the quarry. On some projects the asphalt binder course could be placed with a paver, and on a few, notably on steeper grades, a scraper was used to place the binder course. Truck tires displace the Rock Cap material to a much greater extent than the larger, lower pressure scraper tires.

A smooth steel drum roller must be used in front of the paver at all times when placing the binder course to restore the shape of the Rock Cap surface. This roller will normally be operated in the static mode, although some intermittent vibration can be used away from the free edges. To minimize the distortion and material degradation, after grade has been established, construction traffic on the Rock Cap surface has been limited to only that needed in the paving operation .

Fine grading of the Rock Cap surface is difficult. Typically, the tolerence from planned grade has been from plus 0 to minus 0.1 foot. This has resulted in average overruns in the asphalt surfacing of about 5%. In addition, setting the Rock Cap surface grade on 50 foot intervals can result in a surface undulation with a 50 foot wave length. Smoothness can be improved by using a wire-line to place the binder course and all subsequent asphalt layers. Even with wire-line placement, the binder course

thickness varies and compaction will be non-uniform. The resulting surface roughness must be taken out in subsequent lifts. Experience has shown that each sucessive lift will remove about half the roughness. Above the binder course, the finished grade is determined by minimum surface thickness. Therefore, the final roadway surface grade may vary slightly from that shown on the plans. We do not see evidence that the departure from planned grades is significant. This is more a philosophical than a physical change.

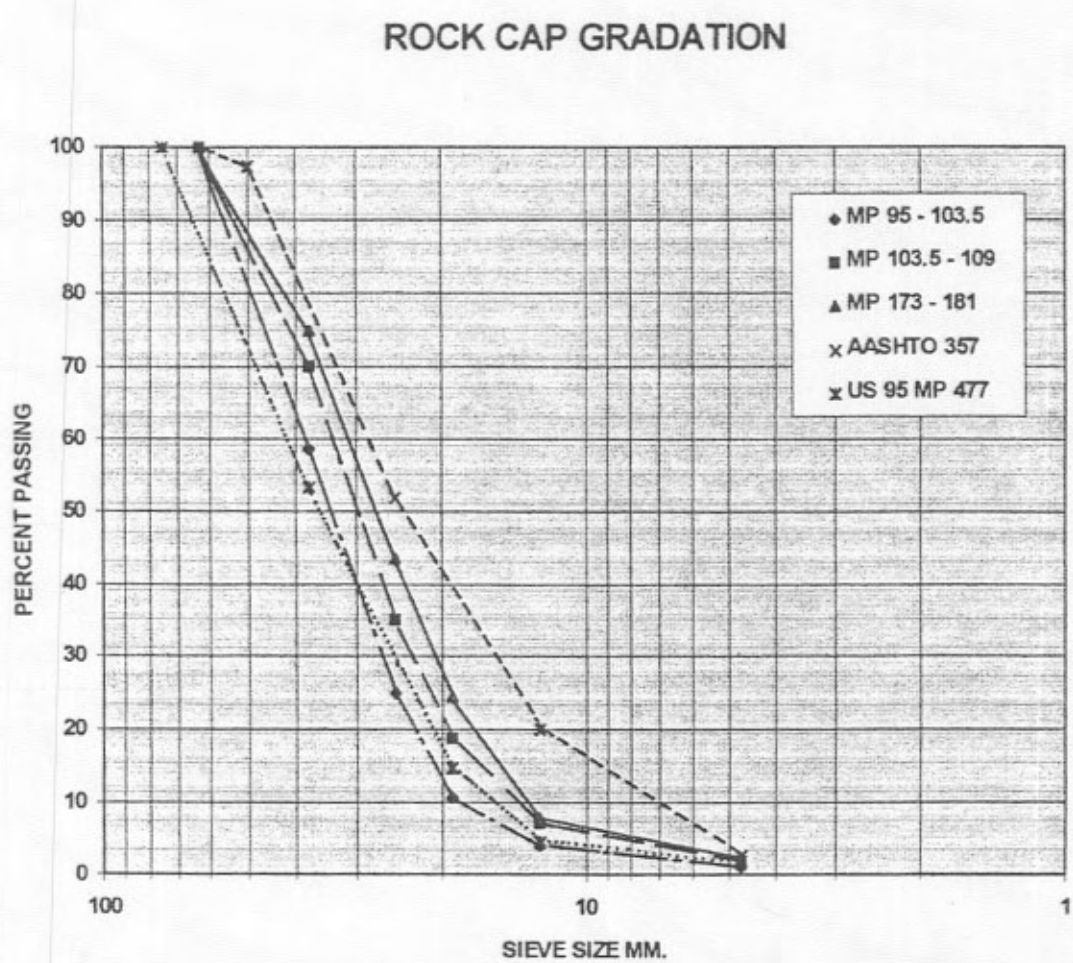
The proponents of topping the Rock Cap with aggregate base feel that this practice improves smoothness and makes placement of the surface courses easier. This is true, at least for short term smoothness. Approximately 25 to 30% of the aggregate base will be lost into the surface of the Rock Cap during placement. The author believes that the settlement process may continue after paving, resulting in increased roughness and possibly loss of support for the surface and/or settlement in the wheel paths. The 0.15 foot-thick asphalt binder course (varies from 0.05 to 0.2 feet-thick) effectively binds the surface of the Rock Cap into a stable surface on which to place the surface pavement, and does not impede drainage.

To address the issue of stability of the Rock Cap, gradation specifications were changed on the I - 84 projects east of Mountain Home. Intermediate sieve sizes of 11/2 inches and 1/2 inches were added to the specification in a attempt to control the uniformity of the material, and the maximum particle size was reduced to 21/2 inches to improve surface smoothness. Following construction of the two projects from MP 95 to MP 103.5 and from MP 103.5 to MP 109, the Rock Cap gradations reported from each project were analyzed with respect to the observed stability during paving of the binder course. The Rock Cap thickness was the same on both projects and the material was produced from the same quarry.

The Rock Cap placed on the project from MP 103.5 to MP 109 appeared to have a tighter surface and was stable enough that the contractor was able to place the permeable binder course using a Ko-Cal (wind row pick-up device). A roller was still needed in front of the paver, but surface distortion under the asphalt hauling units was reduced. Using wind row pick-up to feed the paver also eliminated the distortion caused by the paver pushing the trucks dumping directly into the hopper on the paver.

Analysis of the gradations from each of the two projects showed a significant difference in material finer than the 11/2 and 3/4 inch screens. Rock Cap material from MP 103.5 to MP 109 averaged 11.4 % more material passing the 11/2 inch screen and 8.2% more passing the 3/4 inch screen. Average project gradation curves are shown on Figure 2 along with those from I - 84, MP 173 to MP 181, a current project on US 95 and the mid-point of the AASHTO standard 3-5-7 gradation specification for comparison.

Figure 2.



For the project on I - 84 from MP 173 to MP 181, the Rock Cap gradation specification limits were adjusted to require at least 65 % finer than the 11/2 inch screen. The resulting material was sufficiently tight to allow some truck traffic without excessive distortion. Rock Cap grade was established on this project by setting blue tops at 1/4 points and on 25 foot stations. The binder course grade was set on all of the I - 84 projects using wire line grade control on the initial pass.

Figure 3, shows the mean, standard deviation and 90% confidence limits for each of the I - 84 projects and for partial results for the Kootenai Cutoff to Colburn project on US 95. These data indicate that the current specification limits in SSP 307 are too tight to expect 90% of the material to be produced within specifications for even good crusher control.

The addition of intermediate sieve sizes and the relatively tight specification limits have produced a more stable Rock Cap. However, these changes have impacted the bid price. How much of the price increase is due to gradation requirements is not obvious. The costs associated with opening a new quarry also impacted the bid prices on the Mountain Home projects, and the source used for I - 84, MP 173 to MP 181 required a 14 mile haul. The current objective is to consult with crushing contractors regarding the costs associated with the intermediate screens and the specification limits to achieve the best balance between cost and stability. Costs for placing the binder course will also be affected by the Rock Cap stability and will need to be factored into the analysis.

PERFORMANCE

Long term performance data is still limited. The Lewiston Hill project is now 17 years old and except for replacement of the open graded friction course, the 0.3 to 0.4 foot-thick surface course has not needed major rehabilitation. Here the Rock Cap was placed directly on a predominently rock subgrade and the Rock Cap surface was choked with aggregate base. The Mica Flats section of US 95 is now 10 years old and the temporary 0.3 foot-thick asphalt surface shows no load related distress. Deflection data is being collected periodically and will be analyzed along with the profile data to develop a more comprehensive evaluation of the performance as the sections age.

On I -90, Hilltop to Bennett Bay, construction traffic was routed over the binder course throughout one winter with only minor distress. Construction traffic routed over the completed binder course during the concrete placement on the Mountain Home projects produced very little distress.

The Rock Cap sections may have a higher potential for transverse thermal cracking, but the cracks which have been observed appear to remain tight. Absence of moisture trapped at the bottom of the asphalt surface will reduce or eliminate the stripping or hydraulic fracturing largely responsible for deterioration of transverse cracks.

None of the Rock Cap sections with concrete pavement are more than 3 years old, so long term performance data is not yet available.

One project, constructed in 1988, on which the Rock Cap was choked with aggregate base, is showing severe distress. Longitudinal cracks have occurred near the center of the traffic lane, with some depression in the wheel paths. The cracking

may be caused by tensile stresses associated with settlement of the aggregate base into the Rock Cap in the wheel paths. To date, this is the only Rock Cap project which exhibits load associated distress.

The Idaho Transportation Department has recently added a section in the Materials Manual concerning drainable bases. All Interstate reconstruction and reconstruction on major routes carrying 1000 trucks per day or more will incorporate a drainable base. The use of a drainable base in reconstructing roadway pavements carrying less than 1000 trucks per day will be determined on a case by case basis. The majority of the drainable base sections constructed are expected to be Rock Cap, where suitable quarries are available.

Figure 3

ROCK CAP GRADATION ANALYSIS

SIEVE	I - 84 MP 95 - 103.5 % PASSING			I - 84 MP 103.5 - 109 % PASSING			I - 84 MP 173 - 181 % PASSING			SPECS.
IN. (MM)	X	S	90% (1)	X	S	90%	X	S	90%	SSP 307
3.0 (75)										
2.5 (63)	100	0	100	100	0	100	100	0	100	100
2.0 (50)										
1.5 (37.5)	58.5	8.1	45 - 72	69.9	6.27	60 - 80	74.8	3.4	69.2 - 80.4	65 - 80
1.0 (25)							43.6	4.65	36 - 51	
0.75 (19)	10.6	3.5	4.8 - 16.4	18.8	3.69	12.7 - 24.9	24.4	4.51	17 - 32	15 - 30
0.50 (12.5)	4.1	1.6	1.5 - 6.7	7.1	2.39	3.2 - 11.0	7.9	2.31	4.0 - 11.7	5 - 15
# 4 (4.75)	1.2	0.7	0 - 2.4	1.4	0.84	0 - 2.8	2.0	0.61	1.0 - 3.0	0 - 5
	N = 348			N = 397			N = 108			

SIEVE	US 95 MP 477 - 483 % PASSING			SPECS.	SPECS.
IN. (MM)	X	S	90%	PROJ. SP	3-5-7 (2)
3.0 (75)	100	0	100	100	
2.5 (63)					100
2.0 (50)					95 - 100
1.5 (37.5)	53.3	7.72	40.6 - 66.0		
1.0 (25)					35 - 70
0.75 (19)	14.7	5.37	5.8 - 23.6	0 - 15	
0.50 (12.5)	4.5	4.4	0 - 11.8		10 - 30
#4 (4.75)	1.9	1.59	0 - 4.5	0 - 5	0 - 5
	N = 25				

(1) STATISTICALLY 90 % OF THE DATA WILL FALL WITHIN THESE LIMITS

(2) AASHTO STANDARD SIZE 357

S. S. P. 3 0 7 - OPEN - GRADED ROCK BASE (ROCK CAP)

307.01 Description: This work shall consist of crushing, screening, hauling, placing and compacting open-graded rock base (rock cap) as shown in the typical cross-sections or as directed.

307.02 Materials: Material for open-graded rock base shall be clean, angular quarried/crushed rock, free of clay coatings, lumps, and soft or flaky particales. The materials shall meet the following gradation:

Screen / Sieve Size	% Passing (By Weight)
2 1/2 inch (63 mm)	100
1 1/2 inch (37.5 mm)	65 - 80
3/4 inch (19 mm)	15 - 30
1/2 inch (12.5 mm)	5 - 15
No. 4 (4.75 mm)	0 - 5

The material shall have a loss of not more than 45 % in the Los Angeles Abrasion Test, and shall have a minimum of 90 % retained when tested in accordance with Idaho T - 116, Disintegration of Quarry Aggregates.

307.03 Construction Requirements: The initial lift of open-graded rock base shall be placed not less than 12 inches (300 mm) nor more than 18 inches (450 mm) thick unless otherwise directed. Where the thickness is 18 inches (450 mm) or less, open-graded rock base shall be constructed in one (1) lift. Above the initial lift, the minimum lift thickness shall be 6 inches(150 mm): the maximum lift thickness shall be 12 inches (300 mm).

Compaction shall be achieved by a vibratory roller having a dynamic force of at least 30,000 lbs. (133 kN) per impact (4500 lbs. /ft. of drum width) (67 kN / M) and producing at least 1000 vibrations per minute. Each layer shall be uniformly compacted with a minimum of 3 full coverages of the above roller for each 6 inches (150 mm) of lift thickness or part thereof. Maximum roller speed is 1.5 miles / hour (2.42 km/ hour).

Rolling requirements may be reduced one coverage per 6 inch (150 mm) lift thickness or fraction thereof, for each increase of 10,000 lbs. (44.4 kN) dynamic force per impact. In no case will less than one (1) complete coverage for each 6 inch (150 mm) thickness be allowed.

During the compaction process the open-graded rock base shall be maintained visibly moist.

307.04 Method of Measurement: Measurement of open-graded rock base (rock cap) will abe by the cubic yard (cubic meter), neat line measurement of the roadway section, or by the ton (metric ton).

307.05 Basis of Payment: The accepted quantity for open-graded rock base (rock cap) will be paid for at the contract unit price for the item listed below:

Payment will be made under:

Pay Item	Pay Unit
Open-graded rock base (rock cap)	Ton or Cubic Yard (Metric ton or Cubic Meter)