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Technical Letter
No. 1110-1-177 31 December 96

Engineering and Design
USE OF RESIN MODIFIED PAVEMENT (RMP)

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1. Purpose. This letter provides state-of-the-art guidance on the design and use of resin modified pavement (RMP).

2. Applicability. This Engineer Technical Letter (ETL) is applicable to all HQUSACE elements and USACE Commands having military and civil works construction responsibility.

3. References. References providing necessary general information, background, definitions and design guidance for resin modified pavements are listed in Appendix A.

4. Discussion.

a. Description. Resin modified pavement (RMP) is a composite pavement surfacing that uses a unique combination of asphalt concrete (AC) and portland cement concrete (PCC) materials in the same layer. The RMP material is generally described as an open-graded asphalt concrete mixture containing 25- to 35-percent voids which are filled with a resin modified portland cement grout. The open-graded asphalt mixture and resin modified cement grout are produced and placed separately. The open-graded mixture is produced in a typical asphalt concrete plant and placed with standard asphalt paving equipment. After the open-graded layer has cooled, the grout is poured onto the porous surfacing and vibrated into the internal voids. The RMP layer is typically 50 mm (2 in.) thick and has a surface appearance similar to a rough-textured PCC.

b. Materials and Construction. The open-graded asphalt mixture is designed to be the initial "skeleton" of the RMP. A coarse aggregate gradation with very few fines is used along with a low asphalt cement content (typically 3.5 to 4.5 percent by total weight) to produce 25- to 35-percent voids in the mix after construction. The open-graded asphalt mixture can be produced in a conventional batch plant or drum-mix plant. After placing, the open-graded asphalt material is smoothed over with a minimal number of passes (usually 2 or 3) from a small (3-tonne maximum) steel-wheel roller.

(1) The resin modified cement grout is composed of fly ash, silica sand, cement, water, and a cross polymer resin additive. The resin additive is generally composed of five parts water, two parts polymer resin of styrene and butadiene, and one part water-reducing agent. The grout water/cement (w/c) ratio is

between 0.65 and 0.75, which provides a very fluid consistency. The cement grout material can be produced in a conventional concrete batch plant or a small portable mixer. After the asphalt mixture has cooled, the grout is poured onto the open-graded asphalt layer and squeegeed over the surface. The grout is then vibrated into the voids with the 3-tonne vibratory steel-wheel roller to ensure full penetration of the grout. This process of grout application and vibration continues until all voids are filled with grout.

(2) Depending upon the specific traffic needs, the freshly grouted surface may be hand broomed or mechanically textured to improve skid resistance. In most circumstances, however, the excess grout is squeegeed off of the pavement surface, and a natural rough texture is achieved through evaporation of surface bleed water. Spray-on curing compounds, typical to the PCC industry, are generally used for short-term curing. The new RMP surfacing usually achieves full strength in 28 days, but it may be opened to pedestrian traffic in 24 hours and light automobile traffic in 3 days.

c. Pavement Design. The pavement thickness for the RMP is to be determined using flexible pavement criteria. The total pavement thickness for a pavement structure including the RMP should be determined using TM 5-822-5 and TM 5-825-2. After the pavement thickness has been determined for a particular load and level of traffic, the top 50 mm of the asphalt concrete layer are to be replaced with 50 mm of the RMP. This is a conservative design approach, but pending the outcome of further research in this area, all RMP projects should be designed as a conventional flexible pavement in this manner.

(1) In rehabilitation projects such as overlays, the overlay pavement thickness should be determined to satisfy traffic and load requirements. The minimum overlay thickness is 50 mm when using the RMP. If additional thickness is required, the remaining pavement thickness underlying the RMP surface should consist of high-quality asphalt concrete.

(2) RMP has been successfully constructed as an overlay material over rigid and flexible pavements as well as in original construction. No transverse or longitudinal joints are required for original, full-depth RMP designs although joints have been cut in RMP when overlaying jointed PCC pavement. Cracking and seating of existing PCC and then overlaying with an AC interlayer and RMP surfacing has been a successful design approach. Pavement joints are required between RMP and adjacent PCC pavements but are not required between RMP and adjacent AC

pavements. These joints are constructed by saw cutting to the bottom of the RMP layer once the RMP material has sufficiently cured. The joint is then filled with a sealant material suitable for the particular site conditions.

(3) Mix design methodologies for RMP have not been previously documented. All RMP military construction projects to date have had Government provided mix designs, provided by the U.S. Army Engineer Waterways Experiment Station, CEWES-GP, Vicksburg, MS, 39180. The mix design method found in Appendix B provides suitable job-mix formulations for both the open-graded asphalt concrete and grout materials when designing an RMP. This mix design method also contains appropriate procedures for quality control testing of open-graded AC voids and grout viscosity.

d. Applications. RMP may be used in new pavement construction or in the rehabilitation of existing pavement structures. A new RMP surfacing may be placed as an overlay over existing flexible or rigid pavements. RMP is typically used as a low-cost alternative to a PCC rigid pavement or as a means of improving the pavement performance over an AC surfaced flexible pavement. Field experience indicates that RMP may be used in practically any environmental conditions.

(1) In general, the RMP is best suited for pavements that are subjected to low-speed traffic that is channelized or abrasive by nature. Pavement areas with heavy static point loads and heavy fuel spillage are also ideal RMP application candidates. The practical limit for the surface slope of an RMP section is 2 percent. Pavement slopes up to 5 percent can be constructed, but excess hand work and grout overruns are to be expected with slopes greater than 2 percent.

(2) The RMP process has been used in a variety of applications on the international market, including airport and vehicular pavements, industrial and warehouse floorings, fuel depots and commercial gasoline stations, city plazas and malls, railway stations, and port facilities. Since its first commercial application in the United States in 1987, RMP has been used mostly on airport and airfield pavement projects. These applications have included taxiways, aprons, equipment and fuel storage areas, and warehouse parking lots. As of September 1996, there were 17 known RMP project sites in the United States, totaling over 180,000 sq m (216,000 sq yd) of pavement area.

e. Costs. The cost of a 50-mm-thick (2-in.) RMP layer is currently about $9.60 to 19.20 per sq m ($8 to 16 per sq yd) as compared to a typical cost of $3.60 to 6.00 per sq m ($3 to 5 per sq yd) for a 50-mm-thick (2-in.) layer of dense-graded asphalt concrete. The initial cost of a full-depth RMP design is generally 50 to 80 percent higher than a comparable asphalt concrete design when considering a heavy-duty pavement. A more important cost comparison is between the RMP design and the rigid pavement design since the RMP is usually used as a cost saving alternative to the standard PCC pavement. In the case of a standard military heavy-duty pavement application, the RMP design is generally 30 to 60 percent less in initial cost than a comparable PCC pavement design. In many circumstances, the RMP also provides life cycle cost savings from reduced or eliminated maintenance efforts when compared to flexible pavements and jointed rigid pavements.

5. Action. The enclosed mix design method should be used for determining job-mix formulations relating to the construction of RMP. Guidance on the use of RMP is available from the U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, CEWES-GP, Vicksburg, MS 39180.

6. Implementation. This letter will have routine application for military construction as defined in paragraph 6c, ER 1110-345-100.

FOR THE DIRECTOR OF MILITARY PROGRAMS:

2 Appendices
APP A-References
APP B-Resin Modified Pavement
(RMP) Mix Design Method

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Chief, Engineering Division
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APPENDIX A: REFERENCES

A-1. Required References.

a. Engineer Regulation.

ER 1110-345-100
Design Policy for Military Construction

b. Technical Manuals.

TM 5-822-5
Engineering and Design of Flexible Pavements for Roads, Streets, Walks, and Open Storage Areas

TM 5-825-2/AFM 88-6
Flexible Pavement Design for Airfields

c. Corps of Engineers Guide Specification.

CEGS-02548
Resin Modified Pavement

d. American Society for Testing and Materials.

ASTM C 127
Test Method for Specific Gravity and Absorption of Coarse Aggregate

ASTM C 128
Test Method for Specific Gravity and Absorption of Fine Aggregate

ASTM C 136
Method for Sieve Analysis of Fine and Coarse Aggregates

ASTM D 70
Test Method for Specific Gravity and Density of Semi-Solid Bituminous Materials

ASTM D 75
Practice for Sampling Aggregates

ASTM D 140
Practice for Sampling Bituminous Materials

A-2. Related References.

TM 5-822-2/AFM 88-7
General Provisions and Geometric Design for Roads, Streets, Walks, and Open Storage Areas

TM 5-825-1/AFMAN 32-8008
General Provisions for Airfield/Heliport Pavement Design

Ahlrich and Anderton 1991
Ahlrich, R. C. and Anderton, G. L. 1991 "Construction and Evaluation of Resin Modified Pavement," Technical Report GL)91)13, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS 39180-6199

Anderton and Ahlrich 1994
Anderton, G. L. and Ahlrich. R. C. 1994 "Design, Construction, and Performance of Resin Modified Pavement at Fort Campbell Army Airfield, Kentucky," Technical Report GL-94-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS 39180-6199

Anderton 1996
Anderton, G. L. 1996 "User's Guide: Resin Modified Pavement," FEAP-UG-96/01, U.S. Army Center for Public Works, Alexandria, VA 22315-3862

APPENDIX B: RESIN MODIFIED PAVEMENT (RMP) MIX DESIGN METHOD

B-1. Open-Graded Asphalt Concrete.

a. Preliminary.

(1) Gather representative samples of aggregates and asphalt cement. Sample aggregates according to American Society for Testing and Materials (ASTM) D 75 and asphalt cement according to ASTM D 140. An open-graded asphalt concrete mix design requires a minimum of 45 kg of each aggregate stockpile and 15 L of asphalt cement.

(2) Oven dry aggregate stockpile samples and conducts a sieve analysis (ASTM C 136) on each sample. Determine the combination of aggregate stockpiles that results in a gradation closest to the center of the limiting gradation band specified in CEGS-02548. This stockpile combination will become the blending formula for the open-graded asphalt concrete.

(3) Ensure that the aggregates representing the selected stockpiles and the asphalt cement meet the quality requirements as detailed in CEGS-02548. Measure apparent specific gravity of aggregates (ASTM C 127 and C 128) from each stockpile used in the final gradation. Calculate apparent specific gravity of combined aggregates using the blending formula percentages. Measure specific gravity of asphalt cement (ASTM D 70).

(4) Estimate the optimum asphalt content using the following equation:

$$\text{Optimum asphalt content} = 3.25(\text{"})E^{0.2}$$

where

" = 2.65/SG

SG = apparent specific gravity of the combined aggregates

E = conventional specific surface area
 = 0.21G + 5.4S + 7.2 s + 135f

G = percentage of material retained on 4.75-mm sieve

S = percentage of material passing 4.75-mm sieve and retained on 600-µm sieve

s = percentage of material passing 600-µm sieve and retained on 75-µm sieve

f = percentage of material passing 75-µm sieve

(5) Round the calculated optimum asphalt content value to the nearest tenth of a percent. Use this asphalt content value along with two asphalt contents above this amount and two asphalt contents below this amount in the production of mix design samples. Use 0.5 percent above and below the optimum and 1.0 percent above and below the optimum as the four additional asphalt contents. Calculate maximum theoretical specific gravities for each of these five asphalt cement contents.

b. Specimen production.

Using the five mix design asphalt contents, produce three 100-mm-diameter Marshall specimens at each asphalt content. Use approximately 800 grams of combined aggregates following the previously determined aggregate blending formula for each specimen. Just before mixing, the temperature of the aggregates should be 145 $\pm$ 5 ^{o}C and the asphalt cement should be 135 $\pm$ 5 ^{o}C. With normal mixing procedures, the temperature of the asphalt mixture during compaction is 120 $\pm$ 5 ^{o}C. Compact the open-graded asphalt concrete specimens with 25 blows from a 4.5-kg Marshall hand hammer on one side of each specimen. Allow the specimens to air cool for a minimum of 4 hours before carefully removing from molds.

c. Measuring voids total mix (VTM).

(1) Measure the VTM of each open-graded specimen using the following formula:

$$VTM = (1 - WT_{air}/Volume * 1/SG_T) * 100$$

where

Wt_{air} = dry weight of specimen

Volume = $B/4\ D^2H$

D = diameter   H = height

SG_T = maximum theoretical specific gravity

(2) Calculate the average VTM for each of the five asphalt cement contents. Select the optimum asphalt content as that

which resulted in a VTM value closest to 30.0 percent. If no VTM averages are in the 30.0 percent range, then slight adjustments to the aggregate gradation may need to be made to achieve the proper void content. Optimum asphalt contents resulting in average VTM values in the 25 to 35 percent range are acceptable, but due to normal production and construction variations, a mix design that provides a 30-percent VTM value is most desirable. (Typical optimum asphalt contents are between 3.5 and 4.5 percent.)

d. Job-mix formula.

(1) The open-graded asphalt concrete job-mix formula will consist of the following information:

(a) Percentage of each aggregate stockpile.

(b) Percentage passing each sieve size for the blended aggregate.

(c) Percentage of bitumen.

(d) Temperature of discharged asphalt mixture.

(e) Voids total mix percentage.

(2) The target temperature of the asphalt mixture when it is discharged from the mixing plant should be 125 ± 5°C. Select 120°C when ambient temperatures are relatively high and the haul distance from the asphalt plant to the job site is short. Select 125°C when either the haul distance is relatively long or the ambient temperatures are relatively cool. Select 130°C when ambient temperatures are expected to be cool and the haul distance is relatively long. Persistent high winds during construction may also require mix production temperatures to be in the 125°C to 130°C range.

B-2. Resin Modified Portland Cement Grout.

a. Preliminary.

(1) Gather representative samples of portland cement, silica sand, Class F fly ash, and resin additive. Minimum sample sizes are 23 kg each of cement, sand, and fly ash, and 4 L of resin additive. Ensure that all materials meet the quality requirements as detailed in CEGS-02548.

(2) Using the grout material proportions specified in CEGS-02548 and shown below, develop a matrix of initial job-mix formulas for laboratory viscosity testing. The goal of the grout mix design is to produce a material formulation which results in a Marsh Flow Cone viscosity of 8.0 to 10.0 seconds. The initial formulations should ensure that a grout formulation can be produced with a Marsh viscosity no greater than the 10.0 seconds maximum. This is accomplished by testing grout formulations with relatively high w/c ratios and the maximum allowable amount of resin additive. Typical initial grout formulations tested in a mix design evaluation are shown below.

	Batch Percentage by Weight			
Material	CEGS-02548 Limits	Trial 1	Trial 2	Trial 3
Portland Cement	34-40	37.0	36.0	35.0
Silica Sand	16-20	18.0	17.8	17.7
Fly Ash	16-20	18.0	17.9	17.8
Water	22-26	24.0	25.0	26.0
Resin Additive	2.5-3.5	3.0	3.3	3.5

(3) Although the grout's w/c ratio is unspecified, the desirable w/c range is 0.65 to 0.75. Lower w/c values are more desirable to reduce the risk of shrinkage cracking and for higher grout strengths. Higher w/c ratios are sometimes necessary to produce grouts with Marsh Flow viscosities less than the 10.0-second maximum value. Therefore, the focus of the initial grout viscosity tests is to determine the minimum W/C ratio that will produce a grout viscosity less than or equal to 10.0 seconds. It is important to remember that the resin additive serves as a plasticizer which reduces grout viscosity while reducing the amount of water required.

(4) The standard laboratory grout batch size should be in the 4,000- to 5,000-g range. Calculate the material batch weights based on the desired proportions. Multiple grout viscosity tests are facilitated by first blending the dry ingredients (cement, sand, fly ash) for each test sample and then adding the appropriate amount of water and resin additive during the mixing process. These dry- ingredient batches should be kept in air-tight containers to prevent loss of material or contamination before mixing. Two replicate samples per blend are appropriate for grout viscosity testing.

b. Mixing.

(1) The equipment needed to effectively mix the resin modified pavement grout includes a laboratory mixer equipped with a wire whip mixing attachment and approximately 10-L-capacity mixing bowl, a calibrated set of weight scales, and various small containers to weigh and transfer mix water and resin additive.

(2) Place dry ingredients into mixing bowl and adjust the bowl height so that the wire whip is just off of or touching the bottom and sides of the bowl. Begin mixing the dry ingredients at a slow speed and immediately add the appropriate amount of water. Once all of the water is added, speed up the mixer to a point where the grout is being thrown onto the sides of the mixing bowl. Mix the grout at this high speed for 5 minutes, then add the appropriate amount of resin additive. Mix the grout again at a high mixing speed for an additional 3 minutes before testing for Marsh Flow viscosity.

c. Viscosity testing.

(1) The equipment needed to measure grout viscosity includes a Marsh Flow Cone (Figure 1), a 1,000 mL glass or clear plastic graduated cylinder beaker, a 1,500 mL (approximately) empty beaker or bucket, and a stopwatch. Have this equipment set up near the mixing bowl before the end of the 8-minute grout mixing time.

(2) Immediately after mixing the grout, transfer the grout from the mixing bowl to the empty beaker or bucket. Take note of any lumps of material or excess sand in the bottom of the mixing bowl. (Excess lumps indicate inadequate mixing and render the grout useless for viscosity testing.) Immediately fill the Marsh Flow Cone with about 1,100 mL of grout. (A consistent head of grout in the flow cone is achieved for all viscosity tests by marking an 1,100 mL fill line inside the flow cone.) The flow cone outlet is plugged by simply placing one's finger over the outlet opening. Immediately after the flow cone is filled to te 1,100 mL fill line, position the cone over the 1,000 mL graduated beaker. Release the grout opening and start the stopwatch timer simultaneously. Measure the time of flow for 1 L of grout from the flow cone to the nearest tenth of a second.

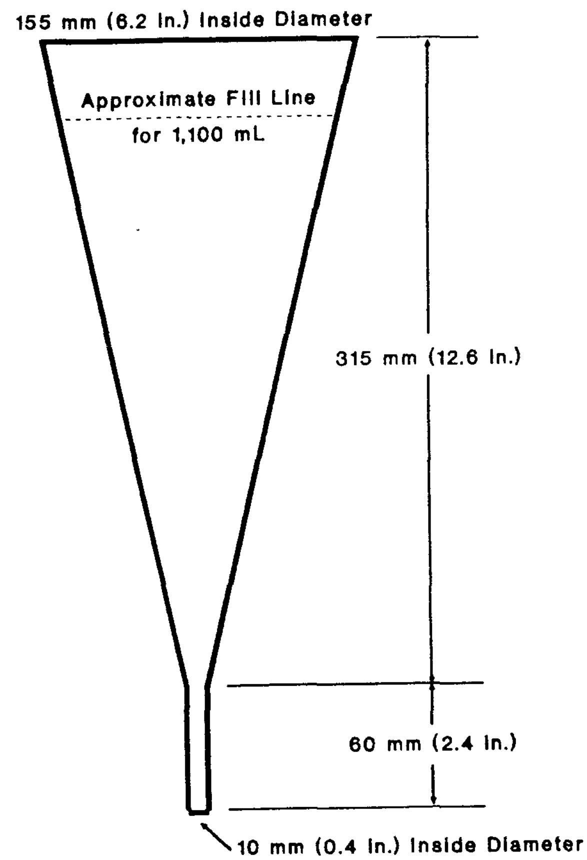

Figure 1. Cross-section of Marsh Flow Cone

(3) Record each test sample's viscosity, averaging the two replicates for each blend. Adjust the grout mix proportions as needed with the following considerations:

(a) Any grout viscosity between 8.0 and 10.0 seconds is acceptable. It should be noted, however, that when field construction temperatures are expected to be comparatively high (greater than 32°C) and/or the open-graded asphalt concrete voids are expected to be considerably low (less than 30 percent), then lower viscosity grouts will help to ensure easy grout application and full grout penetration. In most cases, these variables are unknown; therefore, it is prudent to select the grout formulation which has the lowest viscosity.

(b) It is best to develop a grout job-mix formula with water and resin additive contents below the maximum allowable limits to allow for small additions of these ingredients in the field if necessary to meet viscosity requirements.

(c) Lower w/c ratios are more desirable for a number of reasons: they tend to produce grouts of higher strengths; they reduce the chances for drying shrinkage cracking; they produce grouts which are more consistent and better able to keep the sand in suspension during mixing and placement.

(d) When the sand is noted to settle out of solution during or immediately after mixing, it can be expected that similar problems would occur in the field during construction. This problem can be remedied by reducing the amount of sand and increasing the amount of fly ash (both within the specified tolerances) to produce a slightly creamier grout.

(e) When it becomes impossible to meet the viscosity requirements within the specified limits for material quantities, there usually is a problem with a particular ingredient. Some of these deficiencies are detectable, while others are not. These material deficiencies may include one or more of the following: grout sand which is too coarse, portland cement which is highly reactive during the early stages of the hydration process, fly ash with excess cementitious nature. When it is possible to isolate the problem material in these instances, the only recourse is to substitute another material from another source whose physical or chemical difference will likely solve the problem.

d. Job-mix formula. The grout job-mix formula will consist of the following information:

(1) Percentage (by weight) of each mixture ingredient rounded to the nearest tenth of a percent.

(2) Type and source of portland cement.

(3) Source of fly ash, silica sand, and resin additive.

(4) Marsh Flow Cone viscosity of job-mix-formula grout.