Performance of a Full-Scale Pavement Using Cold Recycled Asphalt Mixture

EHUD COHEN, ARIEH SIDESS, AND GABRIEL ZOLTAN

The performance of a full-scale pavement constructed using a cold recycled emulsified asphalt mixture is presented. The cold recycled mixture was used for the surface layer in a trial section of a public road in Israel, subjected to low-volume traffic. The modified Marshall stability method (ASTM D1559) at 60°C (140°F) was used for the mix design. Experimental field verification was performed starting immediately after construction and lasting 1 yr. The verification included strength and durability tests on cores taken from the site and nondestructive testing (NDT) in situ, based on elastic surface deflection measurements. As shown by the results, the cold recycled asphalt layer achieved high retained strength and high durability potential to the combined damaging effects of water and temperature. After 1 yr of service the pavement has been performing well without any kind of distortion. These findings emphasize the high engineering quality of cold recycled asphalt mixtures in construction and rehabilitation of pavements, as compared with the conventional alternatives.

Recycling of existing bituminous roads is not a new technology in the rehabilitation of deteriorated pavement and has been performed for more than 15 yr, mainly in the United States (*1*). Pavement recycling methods, mixture design guidelines, and construction practices are well established for hot mix recycling of asphalt concrete pavements.

In the last 5 yr, cold mix recycling with emulsified agents has been recognized as a practical alternative in the design of pavement rehabilitation (*2,3*). The equipment required for cold recycling is basically of a conventional nature, much the same as that used in conventional graded crushed stone procedures. Thus, the needed equipment is readily available. The major advantages of cold recycling pavement rehablilitation, compared with those of other technologies, include (*4,5*):

1. Cost savings of up to 25-30 percent compared with the hot asphalt concrete alternative;
2. Storage and application of the emulsified agent at low temperatures;
3. Capability of recycling up to 100 percent reclaimed mixes;
4. Reduction of air pollution, compared with cutback mixes and hot mixes;
5. Simplicity of mixing the emulsified recycling agent on site and ability to stockpile recycled mixtures;
6. Versatility of construction: mixing in a mobile plant, in situ, or in a central plant;
7. Capability of treating all types and degrees of pavement distress; and
8. High production rates.

It is the purpose of this paper to present a full-scale pavement performance of a trial section of a public road in Israel, constructed with a cold recycled emulsified asphalt mixture as the surface layer. After a short description of the site, a detailed analysis of the cold mix design is presented. Then, field experimental results as a function of time after construction are given and analyzed in order to verify the performance of the trial section. The field verification includes various strength and durability tests on cores taken from the site and nondestructive testing based on surface deflection measurements.

SITE DESCRIPTION AND CONSTRUCTION DETAILS

The experiment was conducted in July 1987 near Morasha Junction in Israel. Daytime temperatures range from 12°C to 33°C (50°F–90°F) throughout the year, with the mean annual temperature about 26°C. The section is classified as a low-volume road that was intended to serve an average daily traffic (ADT) of 500 vehicles, including approximately 10 percent commercial vehicles, most of them medium and heavy trucks. The subgrade in the site varied from clayey sand to sandy clay with an average CBR value of approximately 6 percent. The total thickness of the pavement design included 60 mm (2.4 in.) of cold recycled emulsified asphalt as a surface layer above 300 mm (12 in.) of crushed gravelly subbase layer.

The cold recycled asphalt mixture used in the section was combined from reclaimed asphalt pavement, new aggregate, and new quarry sand. The reclaimed asphalt was achieved by milling 50 mm (2 in.) of the asphalt concrete surface layer of a road lane near Morasha Junction. This road is subjected to heavy daily traffic and was rehabilitated through conventional technology. The milling was done by a WIRTGEN cold-milling machine. The reclaimed asphalt was stockpiled near the job site, side by side with the new aggregate and quarry sand. The cold recycled asphalt layer was laid down with a Barber Greene finisher and compacted with a single pass of an 80-kN (18 kips), three-wheel roller followed by passes of a 156-kN (35 kips), pneumatic roller until a dense and homogeneous surface texture was achieved.

The trial section was opened to traffic immediately after construction. This factor was taken into account in the design

E. Cohen and G. Zoltan, YARIV-Civil Engineering & Surveying, 1 Remez Street, Givataim 53242, Israel. A. Sidess, RAFAEL-Armament Development Authority, P.O. Box 2250, Haifa, 31021, Israel.

of the cold mix design of the surface layer, as described in the following paragraphs.

LABORATORY DESIGN OF THE COLD MIX RECYCLING

Prior to construction of the trial section, it was necessary to conduct a laboratory design procedure for the mixture. The design included the following items: (a) evaluation of the reclaimed asphalt layer, (b) selection of the amount and grading of untreated aggregate required, (c) estimate of the asphalt binder required, (d) selection of the type and grade of emulsified recycling agent, and (e) determination of the mix parameters required by the design criteria.

The mainframe mix design procedure, adopted for the cold recycled mix, is similar to the Illinois method (*6,7*) for cold mixtures containing emulsified asphalt agent and aggregates. The procedure was modified to satisfy the warm weather conditions in Israel; it used a modified Marshall method at 60°C (ASTM D1559) for mix design and durability tests (detailed description of test samples preparation is given in the next paragraph).

Materials and Laboratory Tests

A blend of 70 percent reclaimed asphalt pavement, 20 percent untreated aggregate, and 10 percent quarry sand with emulsified recycling agent type HFMS-1 was used to prepare laboratory samples for the testing program. The purpose of the fine aggregate and the quarry sand addition was to achieve a continuous grading and to compensate for the lack of those fractions in the reclaimed asphalt pavement. The emulsion is classified as belonging to a high floating anionic group with medium setting properties. The grading of the mixture components (reclaimed asphalt pavement, untreated aggregate, quarry sand, and the combined mixture), the properties of the recovered bitumen of the reclaimed asphalt, and the properties of the emulsified recycling agent (compared with ASTM specifications) are given in Tables 1 to 3, respectively.

Four emulsified agent contents (4, 5, 6, and 7 percent by weight of the dry mixture) were used in manufacturing the Marshall test specimens. The compaction process used contained the following steps:

1. Sufficient cold recycled mix (4,000 g) was prepared to allow manufacture of three specimens at a time, for each emulsified agent content.
2. Initial moisture of 1 percent was added to the mix for improving mixture workability and aggregate coating, and to simulate field moisture conditions (the quarry sand contained 7 percent moisture in the trial section, whereas in the laboratory an oven-dried material was used). The wet aggregate was left to stand for 10 to 15 min. at a room temperature of 22°C (72°F) to fill the surface voids of the aggregate and to obtain a uniform coating of moisture over the aggregate. It is worth mentioning that the effect of adding 1.5, 2.0, or 2.5 percent moisture, with a reduced emulsion content, was verified. The results produced were not better or even equal to those of the addition of 1 percent moisture.

TABLE 1 GRADATION OF MIXTURE COMPONENTS

Sieve Size	% Passing			
	Reclaimed Asphalt*	Untreated Aggregate	Quarry Sand	Combined Mixture
1.5"	100			100
1"	85			90
3/4"	70			79
1/2"	46			62
3/8"	34	100		53
4#	16	43	100	30
10#		4	93	11
40#			44	5
80#			31	3.5
200#			25	2.5

* Gradation of the dry material without bitumen extraction (ASTM C 117 & C 136).

TABLE 2 EXTRACTED BITUMEN PROPERTIES OF RECLAIMED ASPHALT PAVEMENT

Property	Unit	Test Value
Bitumen Content	%	5.2
Penetration at 25°C, 100g, 5sec	0.1 mm	18
Ductility at 25°C, 5cm/min.	cm	67

TABLE 3 HFMS-1 EMULSIFIED RECYCLING AGENT PROPERTIES

Property	ASTM	Unit	Test Value	ASTM Requirements
Tests on Emulsion				
Residue by distillation	D 244	%	57	55 min.
Sieve Test	D 244	%	0.03	0.10 max.
Storage Stability Test, 24h	D 244	%	0	1 max.
Tests on Residue from Distillation Test				
Penetration, 25°C, 100g, 5sec	D 5	0.1mm	120	100 - 200
Ductility, 25°C, 5cm/min.	D 113	cm	50	40 max.
Float Test at 60°C	D 139	sec	1400	1200 min.
Solubility in Trichloroethylene	D2042	%	100	97.5 min.

3. A cold emulsified recycling agent was added to the wet aggregate and mixed by hand with a spoon for 60 sec.
4. The specimens were compacted with a Marshall compaction hammer by using 75 blows on each side of the specimen.
5. The specimens were cured (in their molds) for 16 hr at 60°C (140°F) in a forced draft oven to ensure the breaking and curing of the emulsified recycling agent in the mix.
6. The specimens were then left to cure for 3 and 10 days at a room temperature of 22°C (72°F) before testing. All

specimens remained in the compaction molds until just before testing. This not only made handling the specimens easier but also provided confinement (similar to field conditions) to eliminate possible damage from unconfined swell.

The Marshall test was performed at a temperature of 60°C (140°F), after 3 and 10 days of air curing at room temperature. Modified Marshall stability, Marshall flow, and Marshall stiffness (the ratio between Marshall stability and Marshall flow) were determined. The test temperature is quite different from that of the Illinois method (*5–7*) and was chosen to satisfy weather conditions in Israel and to simulate actual field conditions as closely as possible. The optimum residual asphalt content was chosen as the percentage of emulsified recycling agent at which the mixture best satisfied all of the design criteria, such as maximum Marshall stability and density, coating, and workability.

Laboratory Results

The properties of the cold recycled mix at the optimum emulsified agent content and the properties of the extracted residual bitumen are summarized in Tables 4 and 5, respectively. These tables show the following findings:

1. All the Marshall test results (Table 4) comply with the Illinois standard requirement (*6,7*) for an emulsified asphalt mixtures.
2. The laboratory results show that high density and stability were achieved at the optimum emulsion content. The density values are similar to those of hot asphalt concrete mixtures. Stability values achieved are particularly high, considering the fact that the Marshall test was conducted at 60°C (140°F), and not at 22°C (72°F), as is usually accepted for emulsified asphalt mixtures (*2,6–8*).
3. Air curing has no significant effect on the laboratory results. This finding does not agree with the results shown in the literature (*6–8*) and indicates that the 16-hr curing time of the specimens at 60°C (as described in the previous paragraph) ensured the breaking of the emulsified recycling agent in the mix. It is worth mentioning that under field conditions, the curing and breaking would occur more slowly, as the following paragraphs describe.
4. The test results of the extracted residual bitumen show a great modification of the old bitumen properties. Penetration of 67 × 0.1 mm instead of 18 × 0.1 mm and ductility of 160 cm instead of 45 cm were achieved (Tables 5 and 2, respectively).

TABLE 4 PROPERTIES OF COLD RECYCLED MIXTURE

Property	Test Value after Air Curing at 22°C (72°F)	
	3 Days	10 Days
Optimum Emulsion content, %	5	5
Density, Kg/m**3	2230	2235
Air Voids, %	8	8
Marshall Stability at 60°C, kN	2.05	2.14
Marshall Flow at 60°C, mm	4.6	4.3
Marshall Stiffness, N/mm	445.6	497.2

TABLE 5 EXTRACTED RESIDUAL BITUMEN PROPERTIES OF THE COLD RECYCLED MIX

Property	Unit	Test Value
Bitumen Content	%	7.2
Penetration at 25°C, 100g, 5sec	0.1 mm	67
Ductility at 25°C, 5cm/min.	cm	>160

FIELD EXPERIENCE AND VERIFICATION

To follow and verify the performance and the structural capacity of the cold recycled asphalt layer, an experimental verification program lasting 1 yr was conducted. The program, which was started immediately after construction, included strength tests, durability tests, and nondestructive testing (NDT). The first two types of tests were performed in the laboratory on cores taken from the site. The NDT was based on measurements of surface deflections at the site.

Strength Testing

The Marshall stability method (ASTM D1559) at 60°C (140°F) was selected to estimate the strength development of the cold recycled asphalt layer. The relation between the field Marshall stability and the design value (see Table 4) was used to evaluate the percentage retained of Marshall stability as a function of time since construction. The retained strength versus time provides an indication of the cold recycled layer resistance to deformation, required to support anticipated traffic loads without cracking, rutting, or distortion.

Durability Testing

The durability potential of the cold recycled asphalt layer is defined as its resistance to the continuous and combined damaging effects of water and temperature. High durability potential usually implies that the layer performance will have a long service life.

Two durability tests were applied to characterize the durability potential of the cold recycled asphalt layer:

1. The immersion compression [of the U.S.C.O.E (*9,10*)] or Marshall immersion test after 24 hr of immersion in a 60°C (140°F) water bath [this test is recognized as a durability criterion for hot bituminous concrete mixtures (*10,11*)]; and
2. The capillary soaking test (ASTM C593) after a 4-day soaking period at 25°C (77°F) [this test is recognized as an indication of the potential durability of emulsified asphalt mixtures (*6,7*)].

Nondestructive Testing (NDT)

In addition to strength and durability tests on cores taken from the site, nondestructive testing (NDT) was performed 1 yr after construction. NDT was used mainly to evaluate the structural capacity of the pavement, particularly the cold recycled asphalt layer, under exact field states of stress. Such an evaluation is difficult, if not impossible, to simulate in laboratory testing. Furthermore, the NDT results were used to validate the strength and durability results obtained in the laboratory.

The surface deflection measurements were obtained by the Benkelman beam under an axial load of 130 kN (29.2 kips) every 20 m (65 ft). The mean temperature of the cold recycled layer at the time of the measurements was 30°C (86°F). The moduli were backcalculated by the MODFLD microcomputer program, which is similar to the SEARCH program, developed at the Texas Transportation Institute (*12*). It searches for the elastic moduli that fit the measured deflection basin to the calculated basin (from multilayer systems), with the least average error.

Strength Results

Table 6 summarizes the strength results on cores taken from the site. Retained Marshall stability versus time since construction is also shown in Figure 1. All the results represent an average of 15 to 18 cores, to ensure reliable values. Table 6 and Figure 1 show that:

1. High and uniform density values were achieved in the field compaction. The results comply with Illinois standard requirements (*6,7*) for emulsified asphalt mixtures (at least 95 percent of laboratory compaction is recommended as a criterion).
2. The initial retained Marshall stability is quite low (52 percent after 7 days), but it increases rapidly to 123 percent after 100 days. Thereafter the values show no change with time. The rapid increase in strength is due to the loss of water and solvent from the emulsified agent, in the cold mix. Some blending or fluxing of the recycling agent and aged bitumen in the reclaimed asphalt mix may also take place during this period. The recycled layer passed from the "breaking and fluxing" condition to the "fluxing" condition after approximately 100 days.

TABLE 6 STRENGTH RESULTS VERSUS TIME AFTER CONSTRUCTION

Time Since Construction (Days)	Relative Field Compaction (%)	Marshall Stability (kN)	Retained Marshall Stability (%)
7	98	1.07	52
12	97	1.00	50
23	98	1.25	61
50	98	1.96	95
63	98	2.13	103
100	99	2.52	123
200	99	2.56	125

Based on these results as well as on the absolute values of Marshall stability, it may be concluded that the cold recycled layer has achieved high resistance to deformation, rutting, or distortion. Moreover, on visual inspection, the cold recycled asphalt layer after 1 yr of service showed satisfactory performance, and no sign of fatigue cracking or rutting was observed.

Durability Results

Table 7 summarizes the durability results at 12 and 50 days after construction. All the results represent average values of 9 to 18 cores taken from the site. The results show that:

1. The Marshall immersion results comply with the durability criteria for hot bituminous concrete mixtures (75 percent retained strength is recommended as a criterion (*10,11*)).
2. High Marshall stability and almost no stability loss were achieved in the capillary soaking test at 25°C (77°F). These results comply with Illinois criteria (*6,7*) for an emulsified asphalt mixture (minimal Marshall stability of 1.78 to 2.25 kN or 400 to 500 lb and maximum 50 percent stability loss are acceptable).
3. The character of the results is similar at both time spans. It is therefore believed that these results are representative of the durability behavior of the cold recycled asphalt layer for long periods of time.

All these results indicate the high durability potential and high resistance of the cold recycled asphalt layer to the combined damaging effects of water and temperature.

NDT Results

The backcalculated moduli of the cold recycled asphalt layer, subbase, and subgrade are given in Table 8. The results show that the structural capacity of the cold recycled asphalt layer is satisfactory and validates the strength and durability results obtained on cores taken from the site. By using the relationship between the elastic modulus, the Marshall stability, and the temperature [Takeshita (*13*) and Uzan (*14*)], it was found that a modulus of 470 MPa (65,500 psi) means a Marshall stability at 60°C (140°F) of approximately 2.45 to 2.67 kN (550 to 600 lb). This result correlates well with the Marshall stability given in Table 6. Moreover, it shows that after the first year of field service, the behavior of the cold recycled layer has remained reasonably constant, indicating that the layer has reached equilibrium.

COST ANALYSIS

One of the major advantages of cold recycling mixture is that it saves money. The unit price presented here for the trial road section is the cost per ton (metric) of all activities required in the process of cold recycling, such as milling, mixing, laying,

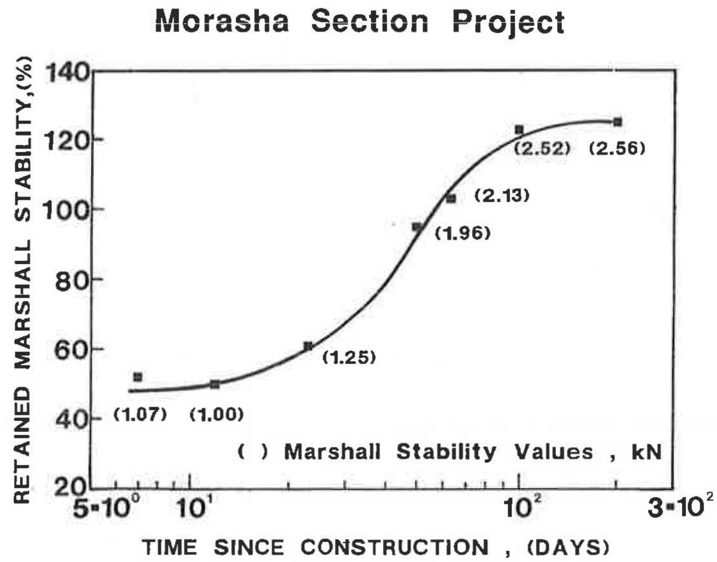

FIGURE 1 Retained Marshall stability versus time since construction.

TABLE 7 DURABILITY RESULTS VERSUS TIME AFTER CONSTRUCTION

Property	Unit	Time Since Construction	
		12 Days	50 Days
Marshall Immersion Test at 60°C			
Stability after 30 min.	kN	1.00	1.96
Stability after 24 Hours	kN	0.77	1.52
Retained Strength	%	77.0	77.6
Capillary Soaking Test at 25°C			
Stability after 2 Hours	kN	6.28	10.86
Stability after 4 Days	kN	6.13	10.61
Stability Loss	%	2.4	2.3

TABLE 8 BACKCALCULATED MODULI OF PAVEMENT LAYERS

Central Deflection (0.01mm)	Backcalculated Moduli (MPa)		
	Cold Recycled Asphalt Layer	Subbase	Subgrade
90.5	470	251	72

and compacting. (The cost is in U.S. dollars and is relevant only to Israel.)

Milling	$8.00/ton
Mixing in pug mill	$6.60/ton
5 percent of HFMS-1 emulsion	$8.60/ton
30 percent of new aggregate	$3.20/ton
Laying and compaction	$5.00/ton
Total cost	$31.40/ton

For purposes of comparison, the cost of a hot asphalt concrete alternative in the same project was U.S. $46.60/ton (not including milling). Therefore savings of 32 percent have been achieved in the trial road section construction.

SUMMARY AND CONCLUSIONS

The field performance of a trial road section with a cold recycled emulsified asphalt layer is presented. The layer properties were verified by laboratory tests on cores taken from the site and nondestructive testing in situ. The findings showed that after 1 yr of field service, the structural capacity of the cold recycled asphalt layer is satisfactory, with high durability potential and high resistance to damaging effects of water and temperature. Additional support for these conclusions is the fact that the pavement is performing well visually and no signs of fatigue-type distress or rutting are observed.

Although the trial road section has been exposed to only 1 yr of traffic service, the results shown in this paper are very promising; they emphasize the high engineering quality of cold recycled mixtures, especially considering that 32 percent of cost has been saved, compared with the asphalt concrete layer alternative.

REFERENCES

1. F. N. Finn. Seminar on Asphalt Pavement Recycling Overview of the Project Selection. In *Transportation Research Record 780*, TRB, National Research Council, Washington, D.C., 1980, pp. 5–11.
2. L. E. Santucci and M. T. Hayashida. Testing, Design and Evaluation of Cold Recycled Asphalt Mixes. *4th Conference on Asphalt Pavement for Southern Africa*, Vol. 1, 1984, pp. 561–584.
3. A. J. Lewis and J. D. Dachter. Cold Mix Recycling Trails on the N3 at Pietermaritzburg. *Annual Transportation Convention*, Vol. 4B, S 396, 1986.

4. J. A. Scherocman. Cold in-Place Recycling of Low Volume Roads. In *Transportation Research Record 898*, TRB, National Research Council, Washington, D.C., 1983.
5. J. A. Epps. State-of-Art Cold Recycling. In *Transportation Research Record 780*, TRB, National Research Council, Washington, D.C., 1980, pp. 68–100.
6. M. I. Darter, S. G. Wasill, and R. S. Ahlfield. Use of Marshall Equipment in Development of Asphalt Emulsion Mixture Design Methods and Criteria. In *Transportation Research Record 754*, TRB, National Research Council, Washington, D.C., 1980, pp. 9–17.
7. M. I. Darter, R. S. Ahlfield, P. L. Wilkey, A. J. Devois, and R. G. Wasill. Design of Emulsified Asphalt Aggregate Bases for Low-Volume Roads. In *Transportation Research Record 702*, TRB, National Research Council, Washington, D.C., 1980, pp. 164–172.
8. M. S. Mamlouk, L. E. Wood, and A. A. Gadallah. Laboratory Evaluation of Asphalt Emulsion Mixtures by Use of the Marshall and Indirect Tensile Tests. In *Transportation Research Record 754*, TRB, National Research Council, Washington, D.C., 1980, pp. 17–24.
9. *Annual Book of ASTM Standards Part 15, Road, Paving, Bituminous Materials, Skid Resistance*. American Society for Testing & Materials, 1974.
10. *Flexible Airfield Pavement, Technical Manual EM 1100-45-302*. U.S. Department of the Army, 1958.
11. J. F. Goode. Use of the Immersion Compression Test in Evaluation & Designing Bituminous Paving Mixtures. *ASTM, SPT 252*, 1959, pp. 113–125.
12. R. L. Lytton and C. H. Michalak. *Flexible Pavement Deflection Using Elastic Moduli and Field Measurements*. Research Report 207-7F. Texas Transportation Institute, Texas A&M University, College Station, 1979.
13. H. Takeshita. Considerations on Structural Number. *2nd International Conference on the Structural Design of Asphalt Pavements*, 1967, pp. 407–412.
14. J. Uzan. An Evaluation Scheme for Conventional Requirements of Design and Construction Quality for Asphalt Concrete. Association of Asphalt Paving Technologists, *Asphalt Paving Technology*, Vol. 51, 1982, pp. 129–149.

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