Title

Full-Depth Pavement Reclamation with Foamed Asphalt: FWD Backcalculation on Interstate Highway 80 Rehabilitation Sections

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Partnered Pavement Research Program (PPRC) Strategic Plan Element 4.12: Development of Improved Mix and Structural Design and Construction Guidelines for Full-Depth Reclamation with Foamed Asphalt

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Abstract:

The conclusions from the backcalculation analysis are as follows:

- The overall stiffness values of the two pavement structures indicated by the surface moduli are similar. The variation along the section is typical of that of other projects in which the pavement structure is relatively homogenous.
- The average backcalculated stiffness of the cold foam material combined with the existing asphalt concrete layer below it is 1,778 MPa, with an 80 percent confidence range of 1,210 MPa to 2,660 MPa along the section tested.
- The backcalculated stiffness of the cold foam mix is roughly 25 percent lower than that of the 37.5-mm asphalt concrete layer in the other structure. In both structures the layer in question was combined with the thin existing asphalt concrete layer below it for backcalculation.
- The backcalculated CTB stiffness values of the two sections are very similar. The subgrade stiffness of the section using cold foam is slightly higher than the other section.
- The coefficient of variation of the resilient moduli of Layer 2 (cold foam combined with existing asphalt concrete or 37.5-mm maximum size aggregate asphalt concrete) and Layer 3 (CTB) along the sections is relatively high (>30 percent) for both structures. This is likely due in part to variations in actual thickness compared to the assumed thickness, and in the case of the CTB, may indicate more damaged areas as well as variations in thickness. However, in both cases the variability is typical of structures with relatively homogenous structures. The coefficient of variation of the stiffness of the subgrade along the sections is very low (12 percent).

Keywords:
Full-depth reclamation, Full-depth recycling, FDR, Deep in situ recycling, DISR, foamed asphalt, foamed bitumen. FWD, Backcalculation.

Proposals for implementation:

Related documents:

Signatures:

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DISCLAIMER

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PROJECT OBJECTIVES

The objective of this project is to develop improved mix and structural design and construction guidelines for full-depth reclamation (FDR) of cracked asphalt concrete with foamed asphalt.

This objective will be met after completion of six tasks:

1. Undertake a literature survey, and technology and research scan.
2. Perform a mechanistic sensitivity analysis on potential pavement structures incorporating full-depth recycled layers using foamed asphalt.
3. Undertake an assessment of Caltrans projects built to date based on available data.
4. Measure properties on Caltrans full-depth reclamation with foamed asphalt projects to be built in the future.
5. Carry out laboratory testing to identify specimen preparation and test methods, and develop information for mix design, structural design and construction guidelines.
6. Prepare interim guidelines for project selection, mix design, structural design, and construction.

The work discussed in this document was undertaken as a special request by Caltrans as part of Task 4.

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CONVERSION FACTORS

SI* (MODERN METRIC) CONVERSION FACTORS				
Symbol	**Convert From**	**Convert To**	**Symbol**	**Conversion**
LENGTH				
mm	millimeters	inches	in	mm x 0.039
m	meters	feet	ft	m x 3.28
km	kilometers	mile	mile	km x 1.609
AREA				
mm^2	square millimeters	square inches	in^2	mm^2 x 0.0016
m^2	square meters	square feet	ft^2	m^2 x 10.764
VOLUME				
m^3	cubic meters	cubic feet	ft^3	m^3 x 35.314
kg/m^3	kilograms/cubic meter	pounds/cubic feet	lb/ft^3	kg/m^3 x 0.062
L	liters	gallons	gal	L x 0.264
L/m^2	liters/square meter	gallons/square yard	gal/yd^2	L/m^2 x 0.221
MASS				
kg	kilograms	pounds	lb	kg x 2.202
TEMPERATURE (exact degrees)				
C	Celsius	Fahrenheit	F	°C x 1.8 + 32
FORCE and PRESSURE or STRESS				
N	newtons	poundforce	lbf	N x 0.225
kPa	kilopascals	poundforce/square inch	lbf/in^2	kPa x 0.145
*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)				

1. TESTING AND ANALYSIS PERFORMED

This technical memorandum presents resilient moduli (also referred to as stiffness) of pavement layers backcalculated using *CalBack* for two sections on the I-80 rehabilitation projects near Auburn, California. The testing was performed by Caltrans using their Falling Weight Deflectometer (FWD). Several different structures were analyzed. 30 locations were tested for each section, and three drops with different loads were applied at each location. The length of each section was approximately 1500 m. The FWD testing was carried out between 1:00 PM and 2:00 PM on July 11, 2005. The structural profiles of the two sections provided by District 3 are shown in Table 1.1.

Table 1.1: Structural Profiles Provided by District 3 for the Two FWD Testing Sections

Layer #	Section A (Using Cold Foam)		Section B (Using Asphalt Concrete)	
	Material	Thickness (mm)	Material	Thickness (mm)
1	19 mm AC[1] AR4000	38	19 mm AC AR4000	37
2	Cold foam mix	100	37.5 mm AC AR4000	100
3	Existing AC	45	Existing AC	42
4	First lift CTB[2]	122	First lift CTB[2]	122
5	Second lift CTB[2]	150	Second lift CTB[2]	150
6	Subbase & Subgrade	-	Subbase & Subgrade	-

[1] Asphalt Concrete [2] CTB (cement treated base) lifts are separated by asphaltic bond breaker.

The data collected on July 12 have two limitations:

- Across the thirty test points for each section, one given pavement structure, i.e. the layer configuration was used. Backcalculated stiffness is sensitive to layer thickness, and better and more consistent estimates of the stiffness of each layer are obtained from backcalculation with correct cross-sections for each location. This is particularly true where thin, soft layers are located above thick, stiff layers, while most pavement layer stiffness backcalculation procedures work better for structures with stiffnesses of layers decreasing along the depth. If the actual layer thickness deviates from the assumed values, which is inevitable in real pavement structures, the backcalculated stiffness differs from the real value. A sensitivity study of the calculated results compared to assumed thickness of the cement treated base (CTB) layer is presented in the attached Appendix.
- The construction date of the tested sections was not provided. The backcalculated stiffness of a pavement layer is representative of the age of the pavement when tested.

2. SURFACE MODULUS

The surface modulus calculated at Sensor 1 is a rough indicator of the overall stiffness of the pavement structure. The surface moduli along the two sections calculated by *CalBack* are shown in Figure 2.1. Although the surface moduli along the two sections inevitably have some fluctuation, generally speaking the difference of the overall stiffness of the two structures is insignificant.

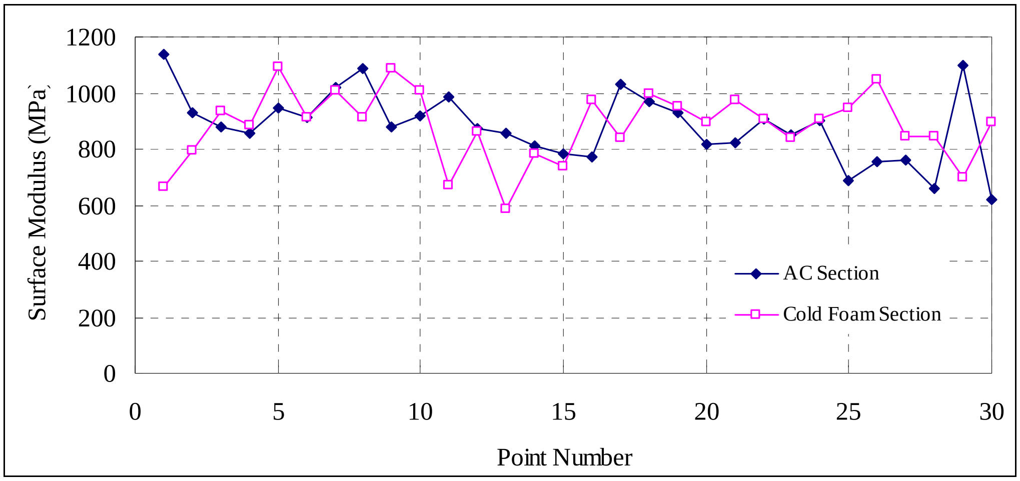

Figure 2.1: Surface moduli at Sensor 1.

3. BACKCALCULATED MODULI

3.1 Assumptions

Generally most FWD backcalculation procedures work better for structures with softer materials at deeper layers. The pavement structures analyzed are complex because of the thin softer layers located above the thick stiff CTB layer. This structure makes determining the stiffnesses of the thin softer layer from the FWD data difficult. Therefore, combining some layers with similar stiffness is necessary.

In addition, the backcalculated values are sometimes sensitive to the initial seed values. Therefore, during the entire analysis process, a step-by-step approach was employed to determine the initial seed values, and to guarantee reasonable and reliable results. The details of these preliminary investigations and sensitivity studies that lead to the final cross-sections and seed values used for the analyses are not presented in this memorandum. In the final results given below, the following assumptions were used:

- The cold foam mix or 37.5 mm asphalt concrete (AR4000 binder) is combined with the existing asphalt concrete, which is only 42 mm to 45 mm thick.
- The CTB layers with two lifts are regarded as a single layer.
- All layers beneath the CTB layer, which are not identified by the cores, are regarded as subgrade.

3.2 Results

The mean value of the resilient modulus of each layer, the coefficient of variation, and the 80 percent confidence intervals of the resilient moduli are listed in Table 3.1 and Table 3.2. The fluctuation of the resilient modulus values of each layer along the two sections is shown in Figure 3.1 through Figure 3.3.

Table 3.1: Backcalculated Results of Section A (Cold Foam)

Layer	Thickness (mm)	Resilient Modulus (MPa)		
		Mean	Coeff. of Variation (%)	80% Conf. Interval
AC overlay	38	1500*	-	-
Cold foam mix Existing AC	145	1778	33	(1,210, 2,660)
CTB	272	2491	35	(1,260, 3,740)
Subgrade	Infinite	229	12	(200, 260)

* According to the FWD data, at the time of testing, the temperature at the surface of the pavements was between 56°C and 61°C. The resilient modulus of an AR4000 mix should be within the range of 1,000 to 1,500 MPa at this temperature, according to stiffness master curves developed by the UCPRC. Because the main concern is the stiffness of the second layer, the resilient modulus of the first layer was fixed at 1,500 MPa (the upper limit value) in order to 1) reduce the number of unknown variables and to 2) obtain conservative estimates of the stiffness of the underlying layers.

Table 3.2: Backcalculated Results of Section B (Asphalt Concrete)

Layer	Thickness (mm)	Resilient Modulus (MPa)		
		Mean	Coeff. of Variation (%)	80% Conf. Interval
AC overlay	37	1,500*	-	-
37.5-mm max size aggregate AC Existing AC	142	2,449	36	(1,580, 3,580)
CTB	272	2,601	38	(1,430, 4,260)
Subgrade	Infinite	195	12	(160, 220)

* According to the FWD data, at the time of testing, the temperature at the surface of the pavements was between 56°C and 61°C. The resilient modulus of an AR4000 mix should be within the range of 1,000 to 1,500 MPa at this temperature, according to stiffness master curves developed by the UCPRC. Because the main concern is the stiffness of the second layer, the resilient modulus of the first layer was fixed at 1,500 MPa (the upper limit value) in order to 1) reduce the number of unknown variables and to 2) obtain conservative estimates of the stiffness of the underlying layers.

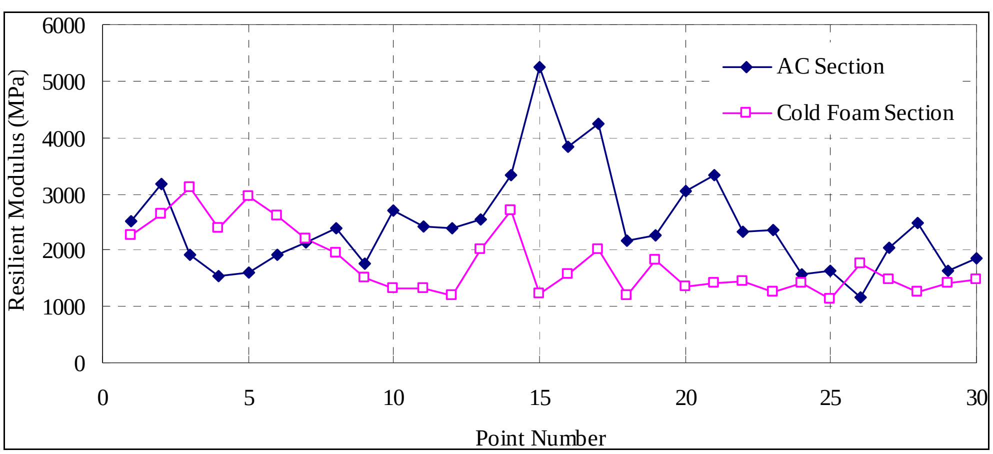

Figure 3.1: Resilient modulus of Layer 2.

(Cold foam layer and existing AC or 37.5-mm maximum size aggregate AC layer with existing AC).

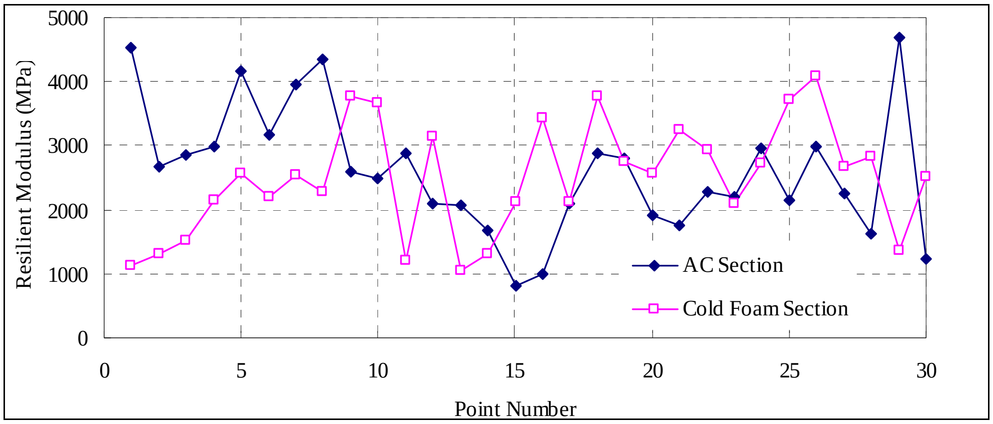

Figure 3.2: Resilient modulus of Layer 3 (CTB).

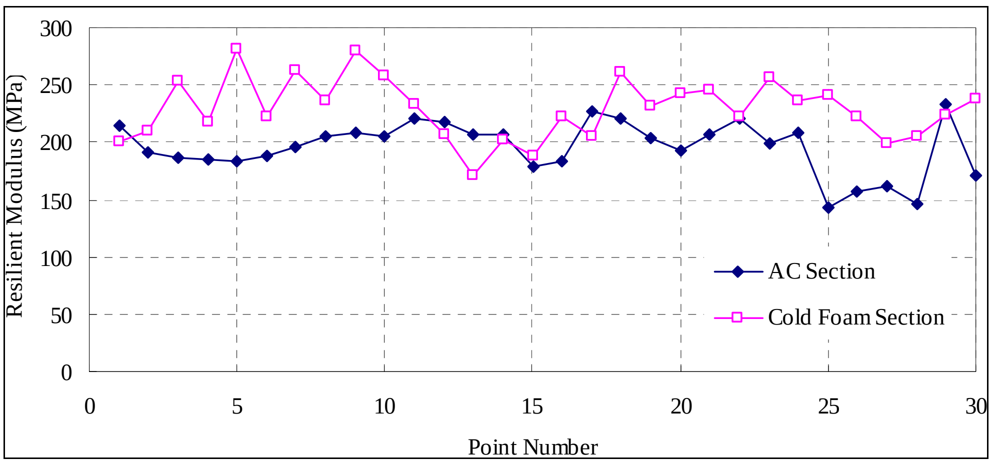

Figure 3.3: Resilient modulus of Layer 4 (subgrade).

4. CONCLUSIONS

The main difference between the two pavement sections investigated is the materials used for the second layer. The objective of this study is to provide backcalculated stiffnesses for the layers in the pavement structures, and in particular to estimate the stiffness of the cold foam mix in one structure and of the 37.5-mm asphalt concrete in the other structure. The conclusions from the backcalculations are as follows:

- The overall stiffness values of the two pavement structures indicated by the surface moduli are similar. The variation along the section is typical of that of other projects in which the pavement structure is relatively homogenous.
- The average backcalculated stiffness of the cold foam material combined with the existing asphalt concrete layer below it is 1,778 MPa, with an 80 percent confidence range of 1,210 MPa to 2,660 MPa along the section tested.

- The backcalculated stiffness of the cold foam mix is roughly 25 percent lower than that of the 37.5-mm asphalt concrete layer in the other structure. In both structures the layer in question was combined with the thin existing asphalt concrete layer below it for backcalculation.
- The backcalculated CTB stiffness values of the two sections are very similar. The subgrade stiffness of the section using cold foam is slightly higher than the other section.
- The coefficient of variation of the resilient moduli of Layer 2 (cold foam combined with existing asphalt concrete or 37.5-mm maximum size aggregate asphalt concrete) and Layer 3 (CTB) along the sections is relatively high (>30 percent) for both structures. This is likely due in part to variations in actual thickness compared to the assumed thickness, and in the case of the CTB, may indicate more damaged areas as well as variations in thickness. However, in both cases the variability is typical of structures with relatively homogenous structures. The coefficient of variation of the stiffness of the subgrade along the sections is very low (12 percent).

APPENDIX A: ANALYSIS APPROACH

A step-by-step approach was employed in the analysis process. The differences in the steps include:

1. How the layers were combined for analysis;
2. Initial seed values of the stiffness;
3. Stiffnesses for different layers set to fixed values or backcalculated.

The 10 steps can be divided into three stages according to their objectives:

- **Stage 1, Step 1–3.** A three-layer structure is used in this stage. The objective is to find reasonable initial seed values of stiffness by combining the layers to only three equivalent layers.
- **Stage 2, Step 4–7.** Use a four-layer structure to backcalculate the stiffness of each layer. The results from Step 6 were selected as the final results.
- **Stage 3, Step 8–10.** The sensitivity of the results to subgrade (SG) stiffness and cement treated base (CTB) thickness were investigated.

The configurations of the steps are listed in Table A.1. The results of each step are listed in Table A.2 and Table A.3.

Table A.1: Configurations of Each Step

Layer	Seed Value (MPa)									
	Step 1 3 Layers	Step2 3 Layers	Step3 3 Layers	Step4 4 Layers	Step5 4 Layers	Step6 4 Layers	Step7 4 Layers	Step8 3 Layers	Step9 3 Layers	Step10 3 Layers
37-38 mm AC overlay	1,000	2,000	1,500	1,000	1,000	1,500	1,500	1,000	1,000	1,000
100 mm FB or AC				2,000	2,000	2,000	2,000	2,000	2,000	2,000
42-45 mm old AC										
272 mm CTB	2,000	2,000	2,000	2,600	2,600		2,600	2600	2,600 (218 mm thickness assumed)	2,600 (218 mm thickness assumed
Granular subbase and SG	200	200	200	200	200	200	200	210	200	200
Shaded cell means fixed value										

Table A.2: Backcalculation Results of each Step for Section A (using cold foam).

Step	Mean Stiffness (MPa)					Coefficient of Variation				
	37-38 mm AC overlay	100 mm FB or AC	42-45 mm old AC	272 mm CTB	Granular subbase and SG	37-38 mm AC overlay	100 mm FB or AC	42-45 mm old AC	272 mm CTB	Granular subbase and SG
Step 1	1,000			3,541	215	0%			34%	11%
Step 2	2,000			2,105	237	0%			28%	13%
Step 3	1,460			2,600	228	18%			31%	12%
Step 4	1,000	1,816		2,600	226	0%	41%		0%	18%
Step 5	1,000	2,123		2,405	230	0%	36%		36%	11%
Step 6	1,500	1,778		2,491	229	0%	33%		35%	12%
Step 7	1,500	1,584		2,600	226	0%	35%		0%	18%
Step 8	1,000	1,909		2,594	210	0%	35%		59%	0%
Step 9	1,000	1,653		3,102	231	0%	27%		34%	12%
Step 10	1,000	2,204		2,008	225	0%	33%		31%	12%
Shaded cell means fixed value										

Table A.3: Backcalculation Results of each Step for Section B (using AC).

Step	Mean Stiffness (MPa)					Coefficient of Variation				
	37-38 mm AC overlay	100 mm FB or AC	42-45 mm old AC	272 mm CTB	Granular subbase and SG	37-38 mm AC overlay	100 mm FB or AC	42-45 mm old AC	272 mm CTB	Granular subbase and SG
Step 1	1,000			4,092	181	0%			41%	11%
Step 2	2,000			2,540	198	0%			33%	11%
Step 3	2,014			2,576	197	30%			39%	12%
Step 4	1,000	3,253		2,600	193	0%	52%		0%	16%
Step 5	1,000	3,056		2,497	196	0%	41%		39%	12%
Step 6	1,500	2,449		2,601	195	0%	36%		38%	12%
Step 7	1,500	2,406		2,600	194	0%	51%		0%	16%
Step 8	1,000	3,521		2,016	210	0%	26%		37%	0%
Step 9	1,000	2,641		3,273	198	0%	42%		40%	12%
Step 10	1,000	3,185		2,144	190	0%	25%		28%	12%
Shaded cell means fixed value										