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Stabilized Full Depth Reclamation (SFDR)

Evaluation of Two Products:

Base One®
Engineered Emulsion

March 2022

Report 2022-06

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In previous Local Road Research Board (LRRB) studies there has been discussion but no empirical data regarding proprietary stabilizers. The LRRB leveraged an existing rehabilitation project on the border of Beltrami and Hubbard Counties to gather data and report on two stabilizers: engineered emulsion (used on the Beltrami County portion) and BASE ONE® (used on the Hubbard County portion). The county projects were Beltrami County: CSAH 4 and Hubbard County: CSAH 46.

The purpose of this study was to document as-builts/road history; collect and report pavement condition; document stabilized full depth reclamation (SFDR) rehabilitations (and mix designs); interview contractor(s) and stakeholders; conduct sampling/testing (dynamic cone penetrometer, coring, and falling weight reflectometer testing); conduct performance analysis; and write a summary report.

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Stabilized Full Depth Reclamation (SFDR) – Evaluation of Two Stabilization Products: Base One® And Engineered Emulsion

FINAL REPORT

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EXECUTIVE SUMMARY

In previous Local Road Research Board (LRRB) studies, there has been discussion but no empirical data on proprietary stabilizers. The LRRB leveraged an existing project on the border of Beltrami and Hubbard counties to gather data and report on two stabilizers: engineered emulsion (Beltrami CSAH 4) and BASE ONE® (Hubbard CSAH 46).

The purpose of this study was to document the as-builts, history and pavement condition; document the stabilized full depth reclamation (SFDR) rehabilitations; conduct sampling/testing; interview the engineers; and write a report.

Summary of Findings

Since this was only one site, the sample size was not statistically significant; however, this project provided an opportunity to gather and report some pertinent data. Both roadways were in similar condition prior to receiving SFDR and overlaid with 3.5 inches of hot mix asphalt (HMA). Field and lab testing were performed on both roadways in 2020 and 2021. A summary of the findings follows:

	Beltrami County engineered emulsion		**Hubbard County Base One®**	
Original Structure (reported)	2.75” Bituminous 10.00” Class 3		2.75” Bituminous 4.25” Class 5 12.00” Select Granular	
Initial PQI (prior to rehabilitation)	2.4		2.7	
ADT (reported)	770		370	
SFDR Stabilizer	engineered emulsion		BASE ONE®	
SFDR Pavement Design (10-ton)	3.5” HMA 5.0” SFDR w/EE 7.8” Class 3		3.5” HMA 6.0” SFDR w/BASE ONE® 1.0” Class 5 12.0” Select Granular	
Stabilizer Application Rate	2.9 gallons/sq yd (approximately 30% water)		0.03 gallons/sq yd (Concentrate)	
Cost – Construction, per mile	$360,000		$259,000	
Cost – Stabilizer, per mile	$ 88,391		$ 10,625	
Tests Results				
CBR, average (calculated from DCP testing)	Before 29-31 After 33-34		Before 28-31 After 17-25	
Core Results (Tensile Strength)	**2020**	**2021**	**2020**	**2021**
Dry Indirect	38	39	unbound, no test	
Conditioned Indirect	20	25	unbound, no test	
FWD Results (capacity, tons/axle)	**2020**	**2021**	**2020**	**2021**
Effective Capacity (15th percentile)	14.2	15.1	12.1	11.9
FWD Results (R-value)	25.8		24.2	
Pavement Condition L-severity transverse cracks per mile	8.3		45	

Both products met their design criteria and yielded a 10-ton roadway. While the Base One® material was cheaper (by a factor of 8), the engineered emulsion sections had a higher effective capacity, less cracking, and provided a bound base.

CHAPTER 1: PROJECT INFORMATION

In previous Local Road Research Board (LRRB) studies, there has been discussion but no empirical data regarding proprietary stabilizers. The LRRB leveraged an existing rehabilitation project on the border of Beltrami and Hubbard counties to gather data and report on two stabilizers: engineered emulsion (used on the Beltrami County portion) and BASE ONE® (used on the Hubbard County portion). The county projects were:

- Beltrami County: CSAH 4 (S.A.P. 004-604-006)
- Hubbard County: CSAH 46 (S.A.P. 029-646-004)

Beltrami CSAH 4 starts at Station 47+52 at the county border, goes around Grace Lake and ends at the Beltrami County border at Station 228+80. This section is approximately 3.5 miles in length.

Hubbard CSAH 46 starts where Beltrami CSAH 4 ends at Station 228+80 and goes south with an ending Station of 295+84. This section is approximately 1.3 miles in length.

Figure 1-1 is a screenshot of a 2020 construction plan that illustrates these two sections.

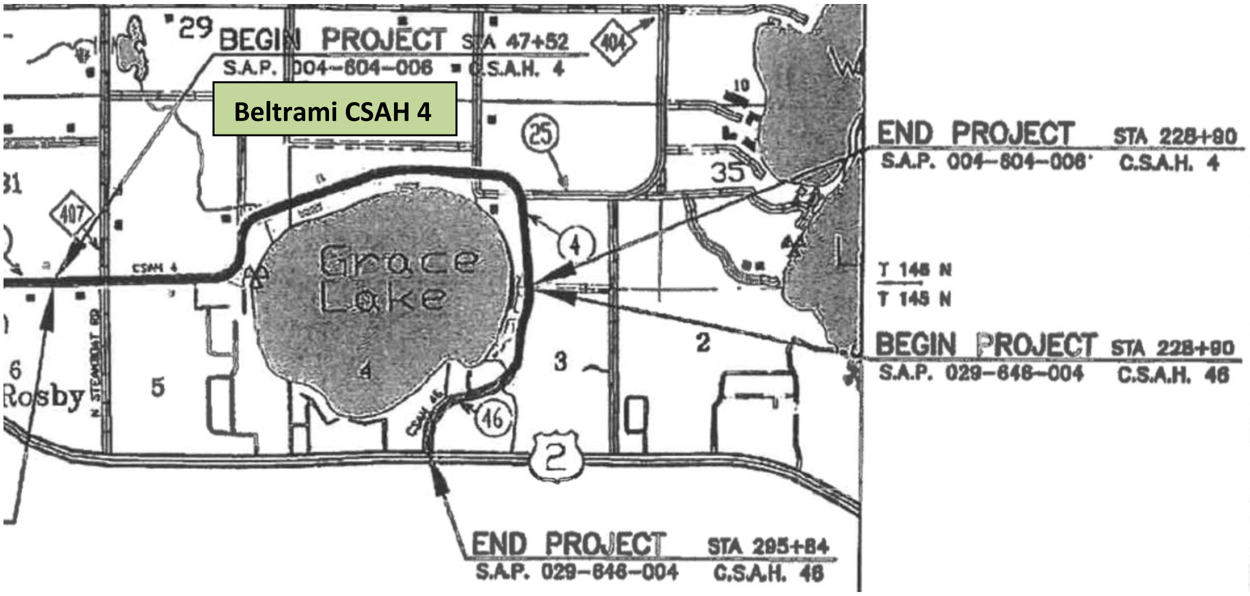

Figure 1-1 Beltrami CSAH 4 and Hubbard CSAH 46 from 2020 Construction Plan

1.1 ROADWAYS CONDITIONS BEFORE REHABILITATION

Pathway data were reviewed through the PathWeb application. PathWeb is one of MnDOT's tools to easily access road network data that has been collected using a digital inspection vehicle (DIV). DIV captures pavement photos at every 0.005-mile increment documenting pavement distresses. The DIV also captures and graphically presents the international roughness Iindex (IRI) and rutting of the tested roadway. A table of results is provided following the actual data.

Data on both study sections had been collected and was available on the PathWeb application. Beltrami CSAH 4 was surveyed on 6-25-2018 and Hubbard CSAH 46 was surveyed on 6-19-2019 as follows:

- Beltrami CSAH 4: from mile post (MP) 0.000 to MP 3.305 (west to east)
- Hubbard CSAH 46: from MP 0.000 to MP 1.421 (south to north)

From a rough, qualitative, visual survey of the condition of the bituminous pavement surfaces using the pavement photos available in the PathWeb application, both roadways seemed to be in poor condition with failing/breaking up of edges, wide linear cracking that was often too wide to be sealed, frequent patches, and loss of bituminous material integrity.

Table 1.1 summarizes the pavement condition indices including the ride quality index (RQI), surface rating (SR), and pavement quality index (PQI) along with the international roughness index (IRI) and average rutting for both the left and right wheel-paths for both directions of the roadways. As Table 1.1 shows, both the roadways fall under the “Fair” condition category based on their RQI values (RQI between 2 and 3).

Table 1.1 Roadways Condition Data

Roadway (year)	Mile Post	Direction	RQI	SR	PQI	IRI LWP(1) (in/mi)	IRI RWP(2) (in/mi)	Avg. Rut LWP (in)	Avg. Rut RWP (in)
Beltrami CSAH 4 (2018)	0.000 to 3.305	WB	2.5	2.2	2.4	143	184	0.17	0.32
		EB	2.6	2.2	2.4	132	178	0.18	0.28
Hubbard CSAH 46 (2019)	0.000 to 1.421	WB	2.2	2.8	2.7	169	197	0.16	0.16
		EB	2.7	2.8	2.7	122	142	0.16	0.14

(1) LWP= left wheel-path

(2) RWP= right wheel-path

1.2 PAVEMENT DESIGNS

The details of the pavement designs were provided to the project team by the counties.

Table 1.2 summarizes the roadway information for Beltrami CSAH 4 and Hubbard CSAH 46. As this table suggests, the two sections are similar in terms of design speed, design load, and lane configuration.

Table 1.2 Roadways Information for Beltrami CSAH 4 and Hubbard CSAH 46

Roadway	Design Speed (mph)	Design Load (tons)	#Lanes per direction	Two-way or One-way
Beltrami CSAH 4	55	10	1	Two-way
Hubbard CSAH 46	55	10	1	Two-way

Table 1.3 summarizes the pavement design inputs for the study roadways. Hubbard CSAH 46 has a relatively stronger subgrade compared with Beltrami CSAH 4. In terms of traffic counts, Beltrami CSAH 4 carries a higher traffic load and receives approximately 80% more equivalent single axle load (ESAL) compared with Hubbard CSAH 46 over the design period of 20 years. The percentage of heavy vehicles for the two roadways is almost the same.

Table 1.3 Pavement Design Inputs for Beltrami CSAH 4 and Hubbard CSAH 46

Roadway	R-Value	Traffic Projection Factor	ADT(1) (year)	Projected 2040 ADT	20-year ESAL(2)	HCADT(3) (%)
Beltrami CSAH 4	15	1.1	770 (2018)	855	248,795	9.00
Hubbard CSAH 46	20	1.3	370 (2016)	507	138,411	9.08

(1) Average Daily Traffic

(2) Equivalent Single Axle Load

(3) Heavy Commercial Average Daily Traffic

Table 1.4 presents the pavement designs of the study sections. As this table shows, the Beltrami CSAH 4 SFDR layer is one inch thinner than the Hubbard CSAH 46 SFDR layer. Also, the stabilizing agent for Beltrami CSAH 4 is engineered emulsion while BASE ONE® is used on Hubbard CSAH 46. It should be noted that a granular equivalence (GE) of 1.5 is assigned per inch of SFDR with emulsion and a GE of 1.25 is assigned per inch of SFDR with BASE ONE® in the design process.

Beltrami CSAH 4 SFDR will be supported by an average of 7.7 inches of the remaining in-place aggregate base, while Hubbard CSAH 46 SFDR will be constructed on the remaining 1 inch in-place aggregate over 12 inches of select granular materials. Both roadways received 3.5 inches of bituminous overlay.

As shown in Table 1.4 both sections had relatively similar design GEs.

Table 1.4 Pavement Designs for Beltrami CSAH 4 and Hubbard CSAH 46

	Previous Typical Section		**SFDR Design**		
Roadway	**Layer**	**Thickness (inches)**	**Layer**	**Thickness (inches)**	**GE (inches)**
Beltrami CSAH 4	Bituminous	2.75	HMA overlay	3.5	21.2
	Aggregate Base – Cl 3	10.0	SFDR w/engineered emulsion	5.0	
			Aggregate Base – Cl 3	7.8	
Hubbard CSAH 46	Bituminous	2.75	HMA overlay	3.5	22.4
	Aggregate Base – Cl 5 Select Granular	4.25 12.0	SFDR w/BASE ONE®	6.0	
			Aggregate Base – Cl 5 Select Granular	1.0 12.0	

1.3 TYPICAL SECTIONS

Figure 1-2 and Figure 1-3 present Beltrami CSAH 4 existing and proposed typical sections, respectively. Figure 1-4 and Figure 1-5 present Hubbard CSAH 46 existing and proposed typical sections, respectively. As these figures show, the width of the SFDR layer is 29 feet for Beltrami CSAH 4 and 28 feet for Hubbard CSAH 46.

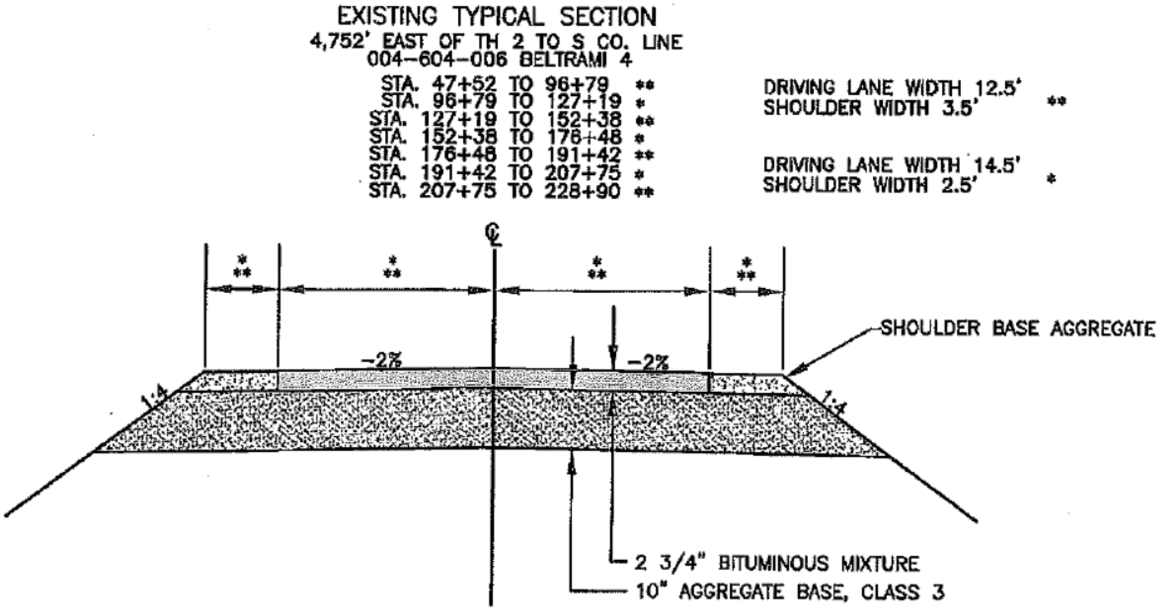

Figure 1-2 Beltrami CSAH 4 Existing Typical Section

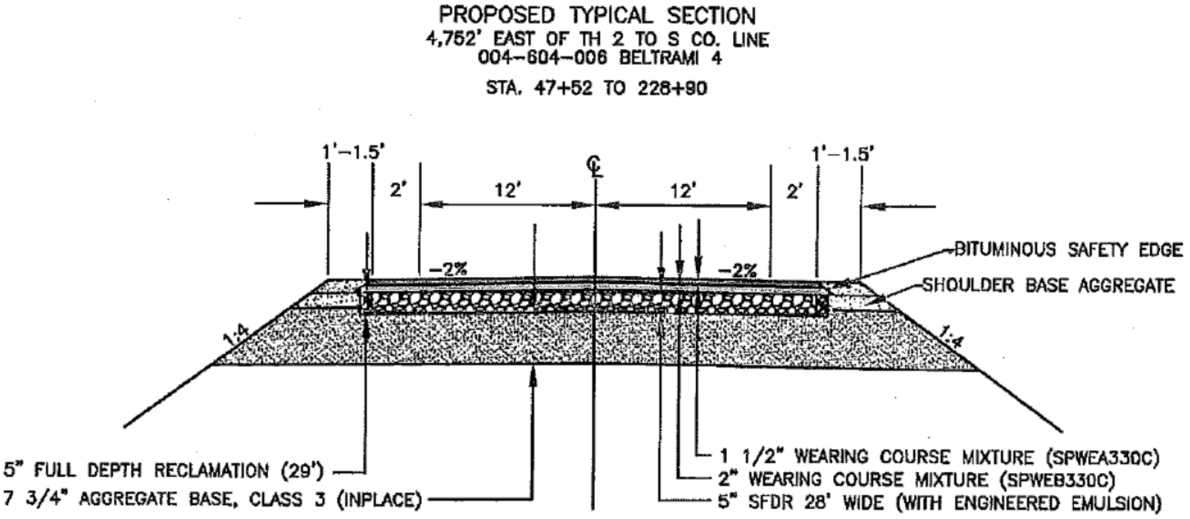

Figure 1-3 Beltrami CSAH 4 Proposed Typical Section

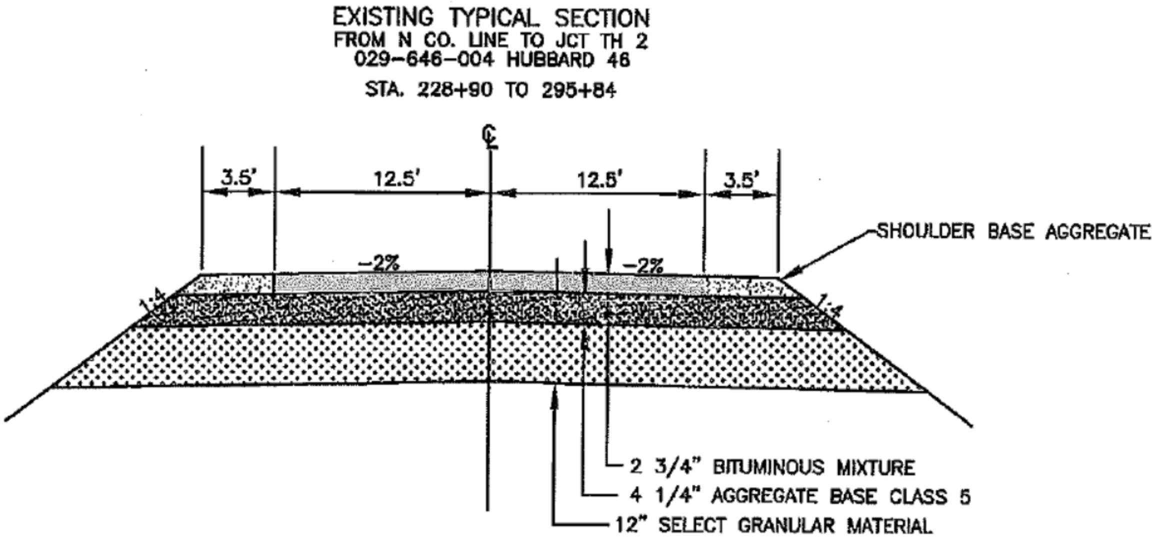

Figure 1-4 Hubbard CSAH 46 Existing Typical Section

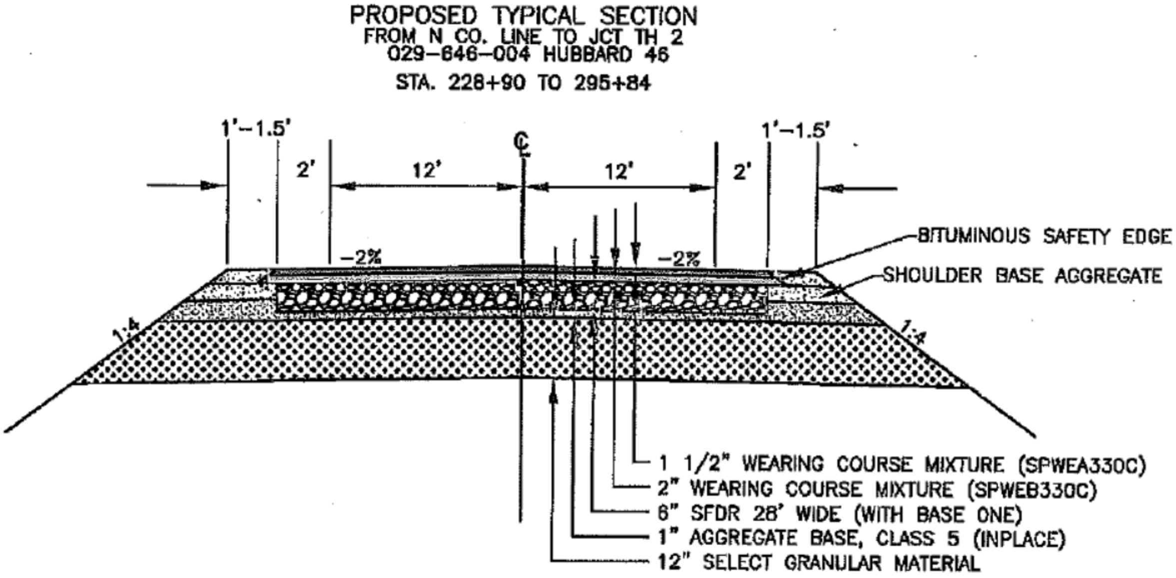

Figure 1-5 Hubbard CSAH 46 Proposed Typical Section

1.4 SFDR MIX DESIGNS

Beltrami CSAH 4 SFDR mix design was performed by Braun Intertec Corp. prior to LRRB funding this project. The average in-place bituminous thickness was 2.8 inches. At a reclamation depth of 5 inches, the reclaimed asphalt pavement (RAP) to aggregate base ratio in the reclaimed materials was 56% RAP to 44% aggregate base. Figure 1-6 presents the gradation used in the mix design.

Figure 1-6 Beltrami CSAH 4 SFDR Gradation

Table 1.5 summarizes the SFDR mix design for Beltrami CSAH 4. The design emulsion application rate is 2.9 gallons per square yard.

No prior testing or mix design was performed on Hubbard County CSAH 46. The recommended application rate for BASE ONE® was 0.005 gallons per square yard per inch of SFDR, which equates to 0.03 gallons per square yard for 6 inches of the SFDR layer. According to Hubbard County, the actual application rate of BASE ONE® was equal to 0.0332 gallons per square yard.

As noted above and illustrated in Figure 1-13, there is a difference in the application rates of the two products. One thing to note is that the engineered emulsion contains about 30% water whereas the BASE ONE® is a concentrate and mixed with water onsite.

Table 1.5 Beltrami CSAH 4 SFDR Mix Design

Emulsion Type	SFDR-EE (PG 58-28 base binder)	Specification Requirement (MnDOT Grading & Base Manual)
Emulsion (%)	5.5	--
Added Water (%)	2.5	--
Density (pcf)	136.2	--
Maximum Specific Gravity (G_{mm}) - ASTM D 2041	2.440	--
Bulk Specific Gravity (G_{mb}) - ASTM D 6752	2.183	--
Voids (%)	10.5	--
Short-Term Strength g/25mm - ASTM D 1560	181	175 g/25mm, minimum
Indirect Tensile Strength (ITS), psi, 25°C - ASTM D 4867	41	40 psi, minimum
Vacuum Saturated (%)	59	55%, minimum
Conditioned ITS, psi, 25°C - ASTM D 4867	28	25 psi, minimum
Resilient Modulus, ksi, 25°C - ASTM D 7369	212	150 ksi, minimum
Thermal Cracking (IDT), °C - AASHTO T-322	-22	Report

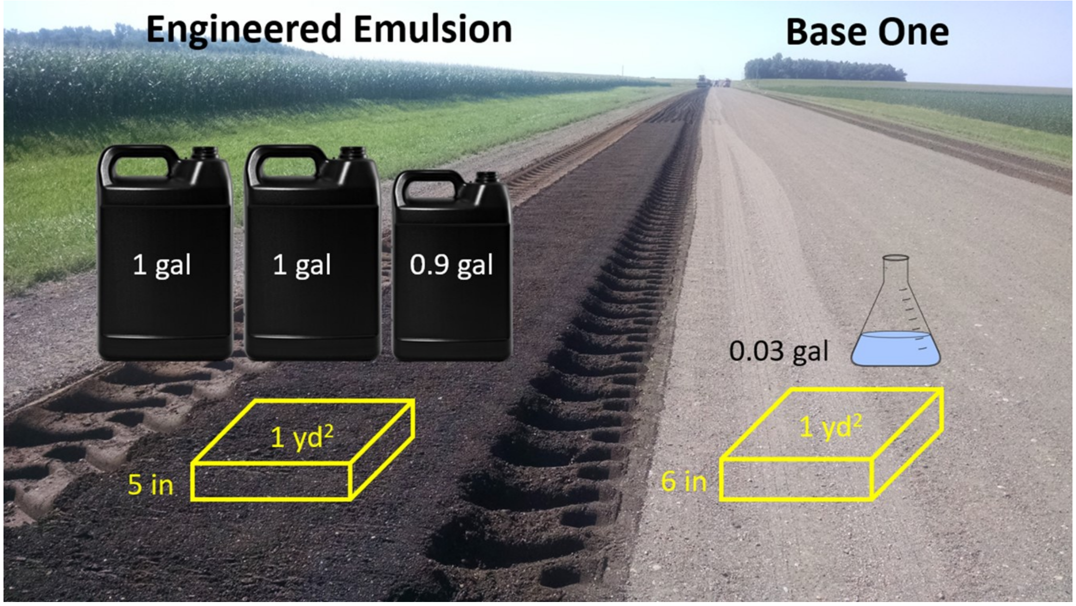

Figure 1-7 Engineered emulsion vs. BASE ONE® Application Rates Comparison

1.5 ESTIMATED QUANTITIES AND COST

Table 1.7 and Table 1.8 show the estimated quantities and cost for Beltrami CSAH 4 and Hubbard CSAH 46, respectively. To better compare the construction costs of these two sections, cost per mile is calculated:

- Beltrami CSAH 4: $\frac{\$1{,}255{,}252}{3.5} \approx \$360{,}000$ per mile
- Hubbard CSAH 46: $\frac{\$336{,}221}{1.3} \approx \$259{,}000$ per mile

Beltrami CSAH 4 is about 39% more expensive than Hubbard CSAH 46.

To compare the cost difference of the stabilization processes only, engineered emulsion and BASE ONE® costs need to be compared directly.

- Bituminous emulsion (from Table 1.7): $309,370
- BASE ONE® (from Table 1.8): $13,812.50

Table 1.6 shows the approximate product cost both on a per mile and per square-foot basis for each roadway.

Table 1.6 Product Cost Comparison

Roadway	Cost per mile	Cost per sq. ft.
Beltrami CSAH 4 (engineered emulsion)	$88,391	$0.58
Hubbard CSAH 46 (BASE ONE®)	$10,625	$0.07

Based on this project, Table 1.6 shows that the cost of engineered emulsion is 8 times the cost of BASE ONE®.

Table 1.7 Beltrami CSAH 4 Estimated Quantities and Cost

Item Number	Item	Unit	Estimated Quantities	Unit Price	Cost ($)
2021.501	MOBILIZATION	LUMP SUM	0.7	$22,310.00	$15,617.00
2051.501	MAINT & RESTORATION OF HAUL ROADS	LUMP SUM	0.7	$1.00	$0.70
2105.609	SALVAGED AGGREGATE FROM STOCKPILE	TON	6,690.0	$3.75	$25,087.50
2105.609	HAUL FROM STOCKPILE	TON	4,400.0	$8.65	$38,060.00
2105.609	HAUL & STOCKPILE BITUMINOUS MATERIAL	TON	6,690.0	$4.15	$27,763.50
2112.519	SUBGRADE PREPARATION (P)	RDST	181.0	$125.00	$22,625.00
2211.509	AGGREGATE BASE CLASS 5	TON	3,365.0	$11.85	$39,875.25
2215.504	STABILIZED FULL DEPTH RECLAMATION (P)	SQ YD	56,430.0	$1.65	$93,109.50
2221.509	SHOULDER BASE AGGREGATE CLASS 1	TON	200.0	$19.90	$3,980.00
2232.603	MILLED SINUSOIDAL RUMBLE STRIPS-INTERM	LIN FT	27,280.0	$0.15	$4,092.00
2331.606	BITUMINOUS EMULSION	GAL	163,650.0	$1.80	$294,570.00
2355.502	BITUMINOUS MATERIAL FOR FOG SEAL	GALLON	7,400.0	$2.00	$14,800.00
2357.606	BITUMINOUS MATERIAL FOR SHOULDER TACK	GALLON	3,910.0	$2.00	$7,820.00
2360.509	TYPE SP 9.5 WEARING COURSE MIXTURE (3,C)	TON	5,300.0	$52.40	$277,720.00
2360.509	TYPE SP 12.5 WEARING COURSE MIX (3,C)	TON	7,000.0	$52.40	$366,800.00
2540.602	MAILBOX SUPPORT	EACH	50.0	$105.00	$5,250.00
2563.601	TRAFFIC CONTROL	LUMP SUM	0.7	$2,400.00	$1,680.00
2574.507	COMMON TOPSOIL BORROW	CU YD	90.0	$64.00	$5,760.00
2575.501	TURF ESTABLISHMENT	LUMP SUM	0.9	$3,950.00	$3,555.00
2580.503	INTERIM PAVEMENT MARKING (P)	LIN FT	5,445.0	$0.33	$1,796.85
2582.503	6" SOLID LINE PAINT (P)	LIN FT	36,280.0	$0.09	$3,265.20
2582.503	6" SOLID LINE PAINT	LIN FT	20,278.0	$0.09	$1,825.02
2582.503	6" BROKEN LINE PAINT	LIN FT	2220	$0.09	$199.80
				Total Cost	**$1,255,252.32**

Table 1.8 Hubbard CSAH 46 Estimated Quantities and Cost

Item Number	Item	Unit	Estimated Quantities	Unit Price	Cost ($)
2021.501	MOBILIZATION	LUMP SUM	0.18	$22,310.00	$4,015.80
2051.501	MAINT & RESTORATION OF HAUL ROADS	LUMP SUM	0.2	$1.00	$0.18
2105.609	SALVAGED AGGREGATE FROM STOCKPILE	TON	1,700.0	$3.75	$6,375.00
2105.609	HAUL FROM STOCKPILE	TON	850.0	$8.65	$7,352.50
2105.609	HAUL & STOCKPILE BITUMINOUS MATERIAL	TON	1,700.0	$4.15	$7,055.00
2112.519	SUBGRADE PREPARATION (P)	RDST	67.0	$125.00	$8,375.00
2211.509	AGGREGATE BASE CLASS 5	TON	450.0	$11.85	$5,332.50
2215.504	STABILIZED FULL DEPTH RECLAMATION (P)	SQ YD	20,830.0	$1.65	$34,369.50
2221.509	SHOULDER BASE AGGREGATE CLASS 1	TON	200.0	$19.90	$3,980.00
2232.603	MILLED SINUSOIDAL RUMBLE STRIPS-INTERM	LIN FT	10,690.0	$0.15	$1,603.50
2357.606	BITUMINOUS MATERIAL FOR SHOULDER TACK	GALLON	1,310.0	$2.00	$2,620.00
2360.509	TYPE SP 9.5 WEARING COURSE MIXTURE (3,C)	TON	1,900.0	$52.40	$99,560.00
2360.509	TYPE SP 12.5 WEARING COURSE MIX (3,C)	TON	2,500.0	$52.40	$131,000.00
2540.602	MAILBOX SUPPORT	EACH	54.0	$105.00	$5,670.00
2563.601	TRAFFIC CONTROL	LUMP SUM	0.2	$2,400.00	$432.00
2574.507	COMMON TOPSOIL BORROW	CU YD	10.0	$64.00	$640.00
2575.501	TURF ESTABLISHMENT	LUMP SUM	0.1	$3,950.00	$395.00
2580.503	INTERIM PAVEMENT MARKING (P)	LIN FT	1,340.0	$0.33	$442.20
2582.503	6" SOLID LINE PAINT (P)	LIN FT	13,390.0	$0.09	$1,205.10
2582.503	6" SOLID LINE PAINT	LIN FT	15,930.0	$0.09	$1,433.70
2582.503	24" SOLID LINE PAINT	LIN FT	14.0	$6.00	$84.00
2582.503	6" BROKEN LINE PAINT	LIN FT	290.0	$0.09	$26.10
2582.518	PAVEMENT MESSAGE PAINT (P)	SQ FT	49	$9.00	$441.00
--	BASE ONE®	--	--	--	$ 13,812.50
				Total Cost	**$336,220.58**

CHAPTER 2: SFDR CONSTRUCTION

The SFDR rehabilitation of Beltrami CSAH 4 and Hubbard CSAH 46 were constructed along with some other roadways in Beltrami and Hubbard Counties by Allstates Pavement Recycling and Stabilization Company. Beltrami CSAH 4 was injected with engineered emulsion on June 28, 2020, through June 30, 2020. CSAH 46 was injected with BASE ONE® on July 3, 2020. The application rates are discussed in Section 1.4 .

A pavement engineer from Braun Intertec Corporation visited the project on June 28, 2020. Figure 2-1 documents the SFDR construction on Beltrami CSAH 4.

Figure 2-1 SFDR Construction on Beltrami CSAH 4.

2.1 QUALITY CONTROL DATA SUMMARY

Allstates Pavement Recycling and Stabilization Inc. hired a testing company to perform quality control testing during construction. Beltrami County administered the entire project and provided all the QC data. The QC testing that was performed was as follows:

- Modified Proctor testing
- Moisture content testing before the addition of stabilizing agent
- Simple and entire gradations
- Depth checks
- Control strip using a nuclear density gauge
- Compaction testing using a nuclear density gauge
- Emulsion/BASE ONE® yields
- DCP testing prior to stabilization (Beltrami CSAH 4 only)

2.1.1 Beltrami CSAH 4

According to the QC data that was provided by Beltrami County, the following testing results were reported for Beltrami CSAH 4:

- Three control strips were performed (one per day) with 3 to 4 passes of a steel drum roller to reach a maximum wet density between 137.4 to 143.3 pcf.
- A modified proctor test was carried out on the reclaimed materials resulting in a maximum dry density of 131.3 pcf and an optimum moisture content of 6.3 percent.
- Four entire and four simple gradations were performed all with 100 percent passing a 2-inch sieve and 94.3 to 100 percent passing a 1.5-inch sieve.
- Four moisture tests were carried out before injecting the engineered emulsion resulting in a moisture content in the range of 2.4 to 4.9 percent.
- Seven DCP tests were performed on the un-stabilized materials with number of blows between 23 and 29 and DPI's ranging between 3 to 10 mm per blow (all passed).
- SFDR layer thickness was measured at 76 locations and ranged between 5.0 to 5.75 inches.
- 29 yield checks were done ranging between 1.63 to 3.58 gallons per square yard (the mix design application rate was 2.9 gallons per square yard)
- Density was measured at 78 locations using a nuclear density gauge resulting in compactions between 97 to 104 percent.

2.1.2 Hubbard CSAH 46

The following testing results were reported for Hubbard CSAH 46:

- A modified proctor test was carried out on the reclaimed materials resulting in a maximum dry density of 131.1 pcf and an optimum moisture content of 6.8 percent.
- One entire and two simple gradations were performed all with 100 percent passing a 2-inch sieve and 100 percent passing a 1.5-inch sieve.
- Four moisture tests were carried out before injecting BASE ONE® resulting in a moisture content in the range of 2.6 to 8.0 percent.
- SFDR layer thickness was measured at 28 locations and ranged between 6.0 to 6.375 inches.
- One yield check was done with an application rate of 0.11 gallons per square yard (the target application rate was 0.03 gallons per square yard)
- Density was measured at 27 locations using a nuclear density gauge resulting in compactions between 98 to 105 percent.

Table 2.1 provides a summary of the QC data which was done on the study roadways.

Table 2.1 QC Data Summary

QC Testing/Roadway	Beltrami CSAH 4		Hubbard CSAH 46	
	# of Tests	Results	# of Tests	Results
Control Strips (Passes of roller and maximum wet density)	3	3 to 4 passes 137.4 to 143.3 pcf	--	--
Modified Proctor (Density and OMC)	1	131.3 pcf 6.3% OMC	1	131.1 pcf 6.8% OMC
Gradation (Percent passing)	8	100% 2-inch, 94.3 to 100% 1.5-inch sieves	3	100% 2-inch 100% 1.5-inch sieves
Moisture Content (%)	4	2.4 to 4.9	4	2.6 to 8.0
DCP (Blow number and DPI)	7	23 to 29 blows 3 to 10 mm per blow	--	--
Layer Thickness (inches)	76	5 to 5 ¾	28	6 to 6 3/8
Yield Check (Gallons per square yard)	29	1.63 to 3.58	--	--
Density (%)	78	97 to 104	27	98 to 105

2.2 INTERVIEW WITH THE COUNTY ENGINEERS

2.2.1 Interview with the County Engineers

As part of this research project, Braun Intertec Corporation and SRF interviewed the two county engineers, Bruce Hasbargen with Beltrami County and Jed Nordin with Hubbard County, to discuss the project background, selection process, construction, lesson learned, and recommendation to others. Table 2.2 summarizes the highlights of this interview.

Table 2.2 Interview with the County Engineers

Q1: What were the predominate distresses of the road prior to SFDR rehab?
Both counties reported: rutting, longitudinal and transverse cracking, alligator cracking, patching.
Q2: What alternatives were you considering?
None, SFDR was the only alternative considered.
Q3: Why did you select SFDR?
Worked well in the past, good fix for road.
Q4: Why stabilize?
Beltrami: always stabilize when doing SFDR Hubbard: needed benefit of stabilizing agent to achieve 10-ton design
Q5: Past experience with stabilizers?
Beltrami: in past have used cement, BASE ONE® and engineered emulsion. Contracted with Braun Intertec Corporation who obtained in-situ samples, evaluated options, and recommended engineered emulsion. They then conducted mix design to determine application rate. Hubbard: only experience using stabilization of SFDR was a few projects with BASE ONE®. Have been satisfied with the results.
Q6: How was decision made to use two different stabilizers?
Beltrami: engineered emulsion was selected because of past performance, producing a solid base and providing the desired GE. Hubbard: Considered using engineered emulsion; based on estimated pricing selected BASE ONE®.
Q7: Was any pavement prep done?
None
Q8: Any issues with the contractor?
One of the roads (Hubbard CSAH 46) did not have compaction done by sheep's foot roller; contractor stated they could not get the rollers onsite. The section did meet density; will want to look at long term performance.
Q9: General observations/comments?
engineered emulsion: east sections looked better than west. Due to traffic, some raveling did occur. Worst areas were patched prior to overlay. BASE ONE®: looked good
Q10: Lessons learned/suggestions to others?
Highly recommend sampling the in-situ materials and have a mix design done.

CHAPTER 3: 2020 TESTING

In summer of 2020, three sets of tests were carried out on the study roadways:

1) Dynamic cone penetrometer (DCP) testing before injection of the stabilizing agent and after compaction of the SFDR layer,
2) Coring through the SFDR layer along; the cores were then evaluated by performing dry and conditioned strength tests, and
3) Falling weight reflectometer (FWD) testing which was performed by MnDOT.

The test results are discussed in the following sections.

3.1 DCP TESTING

As it was mentioned above, two sets of DCP were performed: before injection of the stabilizing agent and after compaction of the SFDR layer. Before injection DCP’s were done on June 28 and July 2, 2020. DCP tests were then done after compaction on July 5, 2020. Figure 3-1 shows the DCP testing set up in the field. DCP testing was performed at 5 locations along the test sections (A through E). At each location, three DCP tests were done; one at the centerline (CL), one right of centerline (ROC), and one left of centerline (LOC) for a total of 15 DCP’s. After compaction DCP’s were performed at approximately the same locations bringing the total number of DCP’s to 30. Figure 3-1 shows the approximate location of the DCP sets.

Table 3.1 presents the DCP testing stationing, offset and results prior to injection (stabilization). This table includes the DCP Penetration Index (DPI) which is the DCP cone penetration in millimeters per hammer blow. California Bearing Ratio (CBR) was also estimated using the equation developed by the US Army Corps of Engineers.

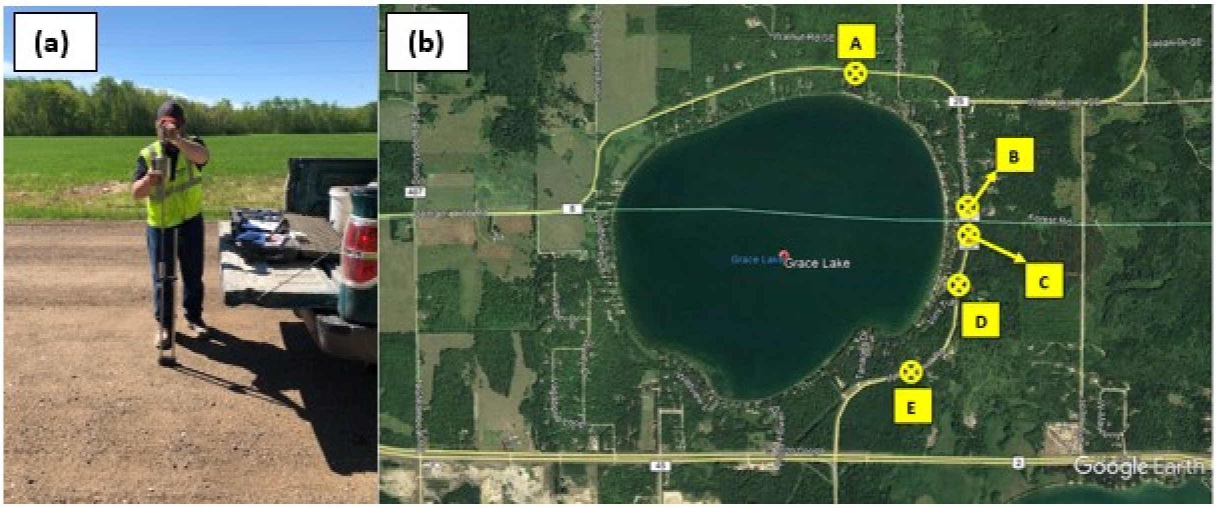

Figure 3-1 (a) DCP Testing Setup, and (b) Approximate DCP Locations.

Table 3.1 DCP Location, Offset and Results prior to Stabilization

Roadway	Set	#	Station	Offset [(1)]	Cone Penetration (mm)	Blow Number	DPI (mm/blow)	CBR	Average
Beltrami CSAH 4	A	1	176+00	6 ft ROC	172	24	7.2	32	**31**
		2	176+00	CL	170	25	6.8	34	**31**
		3	176+00	8 ft LOC	175	21	8.3	27	**31**
	B	4	226+40	11 ft ROC	182	17	10.7	21	**29**
		5	226+50	CL	181	30	6.0	39	**29**
		6	226+52	9 ft LOC	181	21	8.6	26	**29**
Hubbard CSAH 46	C	7	230+97	9 ft ROC	182	25	7.3	32	**29**
		8	231+00	CL	181	30	6.0	39	**29**
		9	230+90	11 ft LOC	178	14	12.7	17	**29**
	D	10	247+00	6 ft ROC	206	19	10.8	20	**28**
		11	247+12	CL	197	23	8.6	26	**28**
		12	247+21	10 ft LOC	173	28	6.2	38	**28**
	E	13	272+35	6 ft ROC	196	23	8.5	27	**31**
		14	272+40	CL	187	30	6.2	38	**31**
		15	272+52	14 ft LOC	196	24	8.2	28	**31**

(1) ROC: right of centerline, CL: centerline, LOC: left of centerline.

As the above table illustrated, CBR is generally higher at the centerline compared with the left and right offsets which indicates higher strength of underlying soils at the center of the roadway. The last column shows the average CBR for each testing location which is in the range of 28 to 31. The average CBR's are comparable between the two roadways.

Table 3.2 presents both DCP results prior to stabilization and after stabilization and compaction. Regarding the after-compaction results, as this table suggests, CBR is generally higher at the centerline compared with the left and right offsets. The average DCP results are consistent on Beltrami CSAH 4 with a CBR value in the range of 33 to 34. The average DCP results are relatively more variable on Hubbard CSAH 46 and in the range of 17 to 25.

Table 3.2 After Compaction DCP Results Before Stabilization and After Compaction

			Before Stabilization					**After Stabilization and Compaction**				
Roadway	**Set**	**#**	**Cone Penetration (mm)**	**Blow Number**	**DPI (mm/ blow)**	**CBR**	**Avg**	**Cone Penetration (mm)**	**Blow Number**	**DPI (mm/ blow)**	**CBR**	**Avg**
Beltrami CSAH 4	A	1	172	24	7.2	32	**31**	170	17	10.0	22	**33**
		2	170	25	6.8	34	**31**	176	33	5.3	45	**33**
		3	175	21	8.3	27	**31**	181	26	7.0	33	**33**
	B	4	182	17	10.7	21	**29**	178	22	8.1	28	**34**
		5	181	30	6.0	39	**29**	178	34	5.2	46	**34**
		6	181	21	8.6	26	**29**	173	22	7.9	29	**34**
Hubbard CSAH 46	C	7	182	25	7.3	32	**29**	174	21	8.3	27	**25**
		8	181	30	6.0	39	**29**	169	17	9.9	22	**25**
		9	178	14	12.7	17	**29**	174	20	8.7	26	**25**
	D	10	206	19	10.8	20	**28**	171	15	11.4	19	**22**
		11	197	23	8.6	26	**28**	182	23	7.9	29	**22**
		12	173	28	6.2	38	**28**	179	14	12.8	17	**22**
	E	13	196	23	8.5	27	31	176	10	17.6	12	17
		14	187	30	6.2	38	31	178	17	10.5	21	17
		15	196	24	8.2	28	31	169	14	12.1	18	17

Figure 3-2 compares before injection and after compaction DCP results. As this graph shows, after compaction CBR slightly increases on Beltrami CSAH 4 by 8% and 20% which could be related to the short-term stiffening effect of the engineered emulsion. On the contrary, Hubbard CSAH 46 CBR shows a decrease in CBR value which was unexpected and not consistent with another LRRB report: MN/RC 2018-33 [1]. Without additional testing/analysis, there is no way to know why the values decreased; one possible explanation is that the DCP tests were done within 2-days of the injection which may have added additional moisture to the pavement leaving little time for the additional moisture to dissipate.

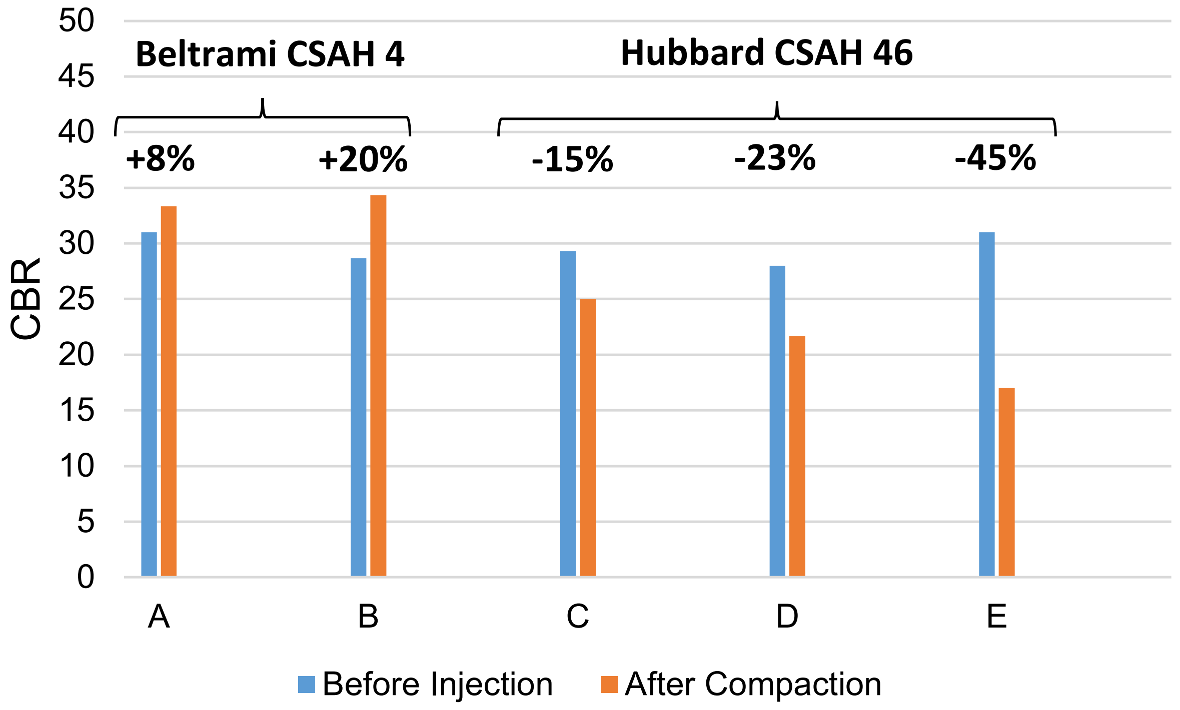

Figure 3-2 CBR Values for Beltrami CSAH 4 and Hubbard CSAH 46

3.2 CORING AND LAB TESTING

3.2.1 Coring and Lab Testing

Coring was performed on September 23, 2020. A total of 12 core locations were selected: three on Hubbard CSAH 8 (C-1 through C-3), five on Beltrami CSAH 4 (C-5 through C-8), and four on Hubbard CSAH 46 (C-9 through C-12). Figure 3-3 shows the approximate coring locations.

Hubbard CSAH 8 is located on the west of Beltrami CSAH 4 which was also injected with BASE ONE® like Hubbard CSAH 46. Hubbard CSAH 46 did not have compaction done by pad-foot roller as the contactor could not get the rollers onsite while CSAH 8 compaction was done using a pad-foot roller. As such, it was requested by the Counties that a few cores be extracted form CSAH 8 to further evaluate the effect of different construction procedures on the BASE ONE® performance. Additional analysis was conducted on CSAH 46 (see below) to investigate the impact of the pad-foot roller.

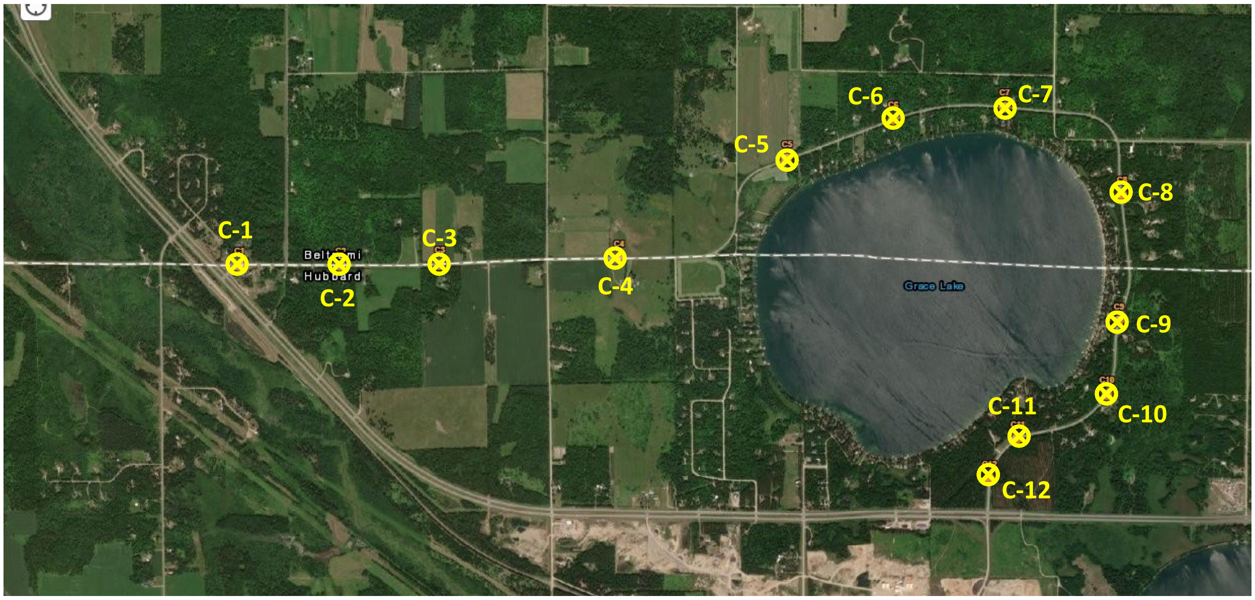

Figure 3-3 Approximate Coring Locations on CSAH 8, Beltrami CSAH 4, and Hubbard CSAH 46

On both Hubbard CSAH 8 and Hubbard CSAH 46 which were injected with BASE ONE®, no intact core could be recovered from the SFDR layer; the material below the HMA overlay was not a bound layer. Figure 3-4 shows C-4 coring location from the BASE ONE® section along with the material retrieved from the core hole.

Figure 3-4 Core Hole and Material Obtained from BASE ONE® Section (Hubbard CSAH 46) at C-4.

Figure 3-5 illustrates Core C-7 which was extracted from Beltrami CSAH 4.

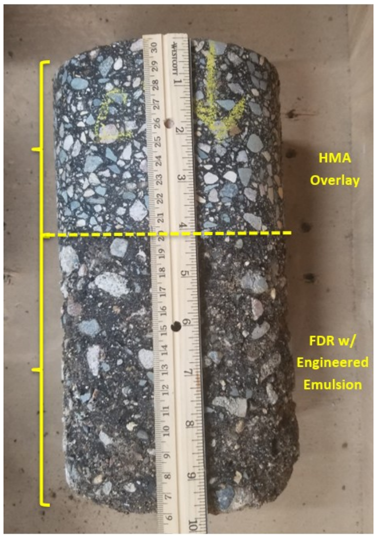

Figure 3-5 Core C-7 Obtained from the engineered emulsion Section (Beltrami CSAH 4).

Table 3.3 summarizes the laboratory testing results along with comparison with the mix design. As this table shows, the dry indirect tensile strength of the field cores was very close to its projected value from the mix design, but the conditioned set yielded a lower strength compared to the mix design value.

Table 3.3 Laboratory Testing Results on Cores Obtained from Beltrami CSAH 4

Test	Field Cores	Mix Design
Dry Indirect Tensile Strength Test	38 psi	41 psi
Conditioned Indirect Tensile Strength Test	20 psi	28 psi

3.2.2 Benefits of Bound Base

As noted above, the sections with engineered emulsion were able to extract “intact” or “bound” cores while this was not possible with the BaseOne® sections. As part of the research done by MnDOT at MnROAD, in a study done by Johanneck and Dai [1], strains were measured under both the HMA overlay and the bound base (stabilized base with emulsion) on Test Cells 2 through 4. Similar instrumentation was installed in a control section with an unbound granular base layer. It was found that strain magnitude at the bottom of HMA overlay over the bound base was significantly lower than those at the bottom of HMA overlay over the unbound granular base. Also, the strain measured at the bottom of the bound base layer was greater than that at the bottom of HMA overlay indicating the bound layer was able to transfer the strains deeper into the pavement structure. This strain transfer decreases the potential for distresses initiating at the bottom of the HMA overlay and results in higher fatigue life of the pavement. Figure 3-6 shows the transferred tensile strain at the bottom of the bound layer [2]. A similar concept is used in designing Perpetual Pavements. The characteristics of Perpetual Pavements can be found elsewhere [3].

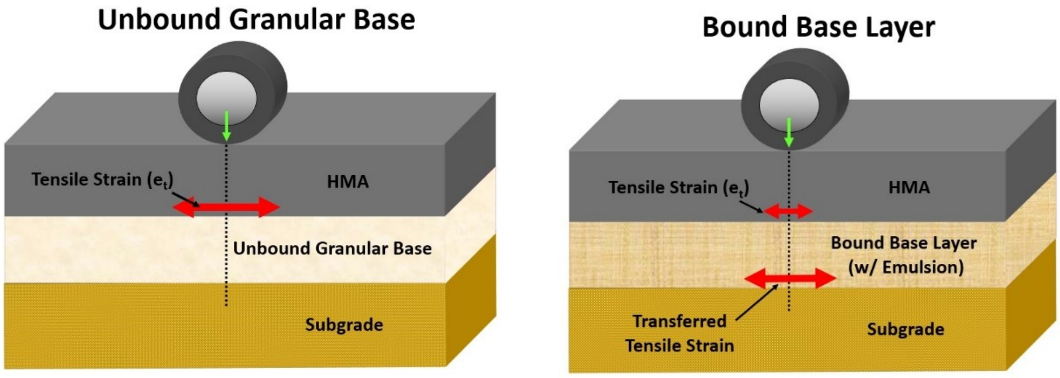

Figure 3-6 Tensile strains in unbound and bound layers [2]

Given only one of year of service for the Beltrami-Hubbard roadways, the observed cracks on both Beltrami CSAH 4 and Hubbard CSAH 46 seem to be mainly related to low temperature cracking. Nevertheless, the thicker bound structure in the case of Beltrami CSAH 4 (3.5 inches of HMA plus 5 inches of bound base layer) could resist the thermal stresses better resulting in a less frequent thermal cracking compared with Hubbard CSAH 46 with only 3.5 inches of HMA overlay as the bound structure. Figure 3-7 shows the difference between thermal stress gradient in unbound and bound base layers. Also, according to the previous discussion, a better fatigue performance of Beltrami CSAH 4 is expected.

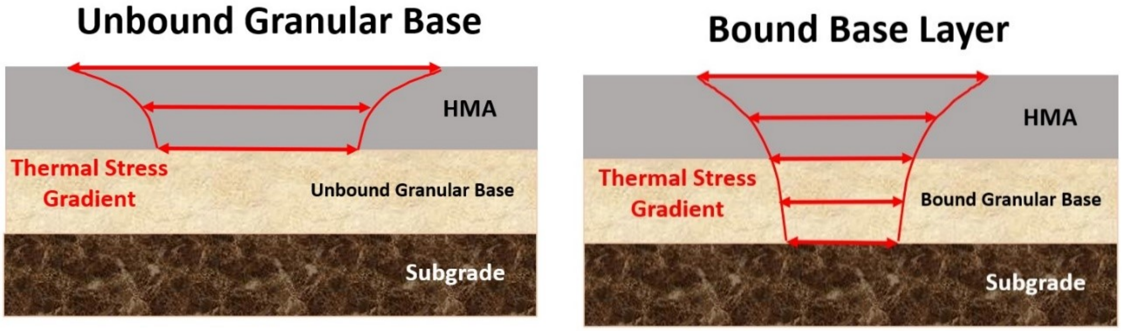

Figure 3-7 Thermal stress gradient in unbound and bound layers

[1] Johanneck L. and Dai S. (2013), “Responses and Performance of Stabilized Full-Depth Reclaimed Pavements at the Minnesota Road Research Facility,” Transportation Research Record: Journal of Transportation Research Board, pp. 114-125.

[2] Daniel Wegman, Sabouri M., Korzilius J., and Kuehl R. (2017), “Base Stabilization Guidance and Additive Selection for Pavement Design and Rehabilitation,” Minnesota Department of Transportation, MN/RC -2017RIC02.

[3] Daniel Wegman and Sabouri M. (2016), “Minnesota Perpetual Pavements Analysis and Review,” Minnesota Department of Transportation, MN/RC 2016-33.

3.3 2020 FWD DATA ANALYSIS

Falling weight deflectometer (FWD) testing was performed by MnDOT on both Beltrami CSAH 4 and Hubbard CSAH 46 at 500-foot intervals. Field testing was conducted on September 18, 2020. Data collected by the FWD during testing include the measured surface deflections, applied impulse load levels, pavement surface temperature, and the ambient air temperature.

FWD data analysis was done by Braun Intertec using the TONN2010 program; for more detailed explanation of TONN2010 see Appendix A of this report. The TONN2010 capacity (tons/axle) was calculated at each testing location. Figure 3-8 presents the roadways capacities for Beltrami CSAH 4 and Hubbard CSAH 46. The 15th percentile (or “effective”) values are also compared in Table 3.4. Using the 15th percentile value is on the conservative side, as only 15 percent of the data points have lower R-values than this value.

As shows, the effective capacities exceeded the design capacity of 10-ton for both roadways. Beltrami CSAH 4 has a higher effective capacity than Hubbard CSAH 46.

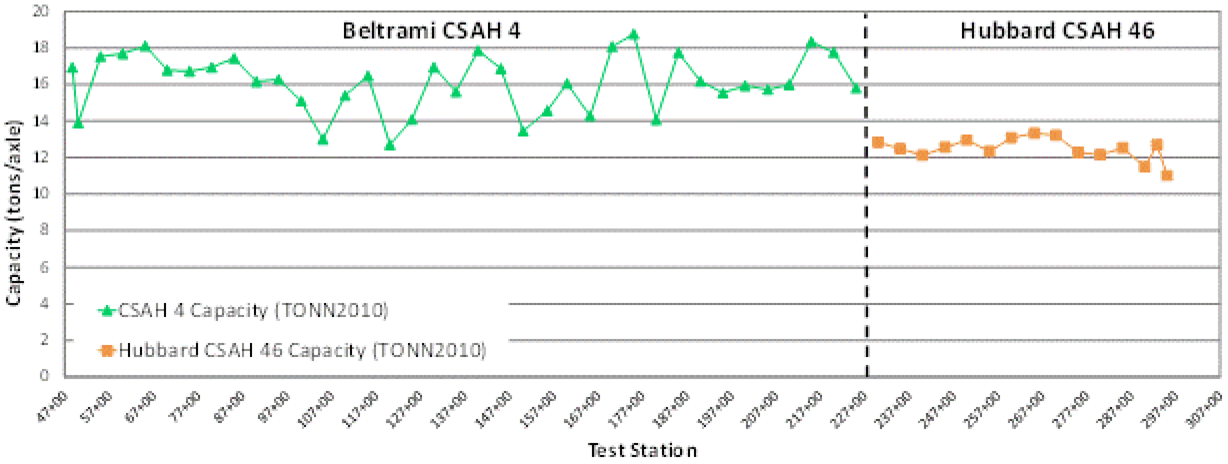

Figure 3-8 Beltrami CSAH 4 and Hubbard CSAH 46 Capacities (2020)

Table 3.4 Roadway Capacity Comparison

Roadway	Effective Capacity (tons/axle)
Beltrami CSAH 4	14.2
Hubbard CSAH 46	12.1

The subgrade R-values were also calculated for both roadways which Figure 3-9 shows the results. The 15th percentile R-values are 25.8 and 33.3 for Beltrami CSAH 4 and Hubbard CSAH 46, respectively. The assumed R-value for Beltrami CSAH 4 and Hubbard CSAH 46 pavement design were 15 and 20, respectively (Table 1.3).

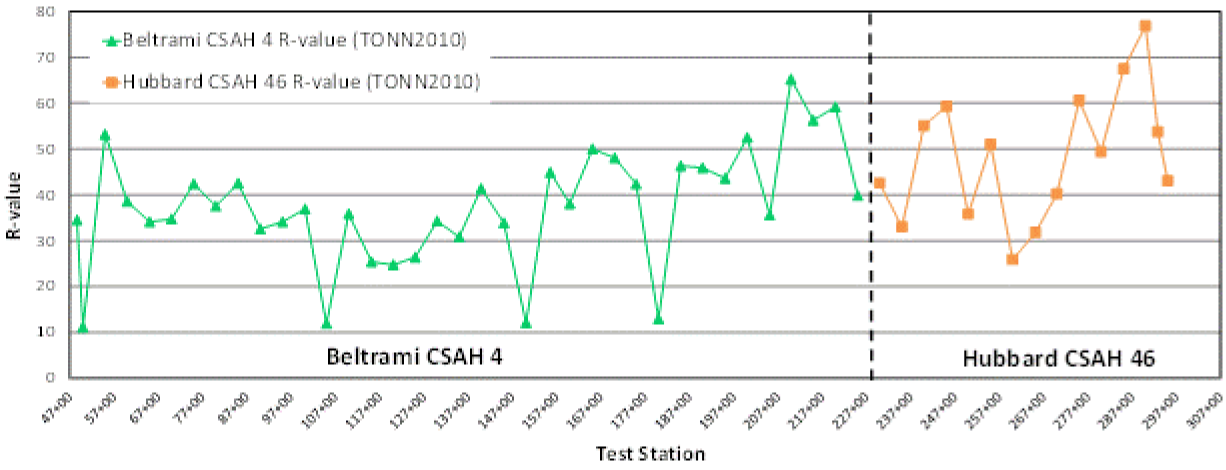

Figure 3-9 Beltrami CSAH 4 and Hubbard CSAH 46 R-value (2020)

As it was mentioned before, during the construction, the contractor was not able to provide pad-foot rollers on Hubbard CSAH 46 while they were used on Hubbard CSAH 8. To assess the effect of using pad-foot rollers on the capacity of the roadways, FWD testing was also performed on Hubbard CSAH 8 similar to the study roadways which Table 3.5 shows the results. As this table shows, the effective capacities are very close and the effect of using pad-foot rollers seems to have little to no effect on roadway capacities.

Table 3.5 Hubbard CSAH 46 vs. Hubbard CSAH 8 Capacity Comparison

Roadway	Effective Capacity (tons/axle)
Hubbard CSAH 46	12.1
Hubbard CSAH 8	10.2

CHAPTER 4: 2021 TESTING

In 2021, a pavement condition survey was performed to assess the pavement condition after 1 year of service. Also, similar to 2020 testing, coring and FWD testing was performed on both Beltrami CSAH 4 and Hubbard CSAH 46.

4.1 PAVEMENT CONDITION SURVEY

Pavement engineers from Braun Intertec visited the project on April 14, 2021. From a visual survey of the condition of the bituminous pavement surfaces, both roadways were in good condition with some low-severity transverse cracking (linear thermal cracking). Beltrami CSAH 4 transverse cracks were mostly sealed. Figure 4-1 shows typical transverse cracking on Beltrami CSAH 4 and Hubbard CSAH 46.

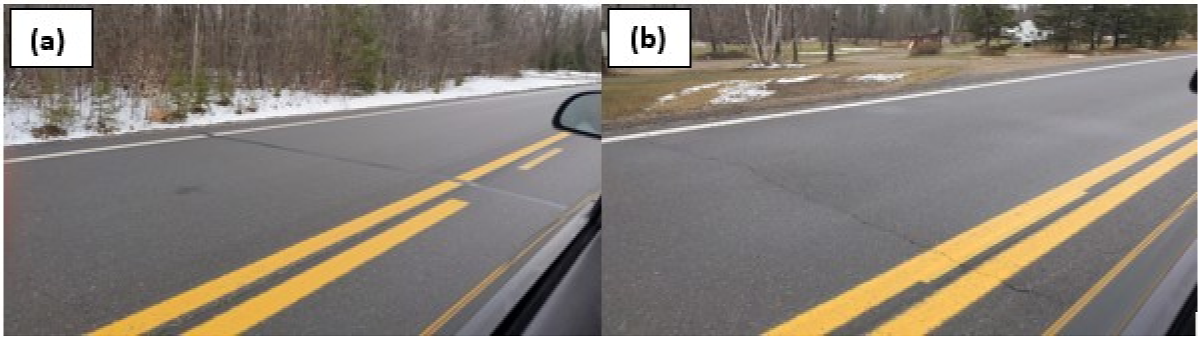

Figure 4-1 Typical Transvers Cracking on: (a) Beltrami CSAH 4 (Sealed), and (b) Hubbard CSAH 46

The number of the transverse cracks were counted along both segments; Table 4.1 compares the number of cracks per mile. As this table shows, Hubbard CSAH 46 has more than five times the number of low severity cracks as compared with Beltrami CSAH 4. The lower crack count of Beltrami CSAH 4 may be attributed to the existence of the bound layer below the bituminous overlay which provides a higher low-temperature strength which can better resist the low-temperature stresses that are developed in the pavement structure at very low temperatures. According to Weather Underground the minimum air temperature recorded in the 2020 winter season in Bemidji was -37°F. With only 3.5 inches of bound material, Hubbard CSAH 46 theoretically could not resist the low-temperature stresses as much.

Table 4.1 Number of the Transverse Cracks Counted

Roadway	**Number of transverse cracks** (low severity)	**Length of the roadway (mile)**	**Number of transverse cracks per mile**
Beltrami CSAH 4	29	3.5	8.3
Hubbard CSAH 46	57	1.3	45

4.2 CORING AND LAB TESTING

Coring was performed on April 14, 2021. A total of 6 coring locations were selected: four on Beltrami CSAH 4 (C-1 through C-4), and two on Hubbard CSAH 46 (C-5 and C-6). Figure 4-2 shows the approximate coring locations.

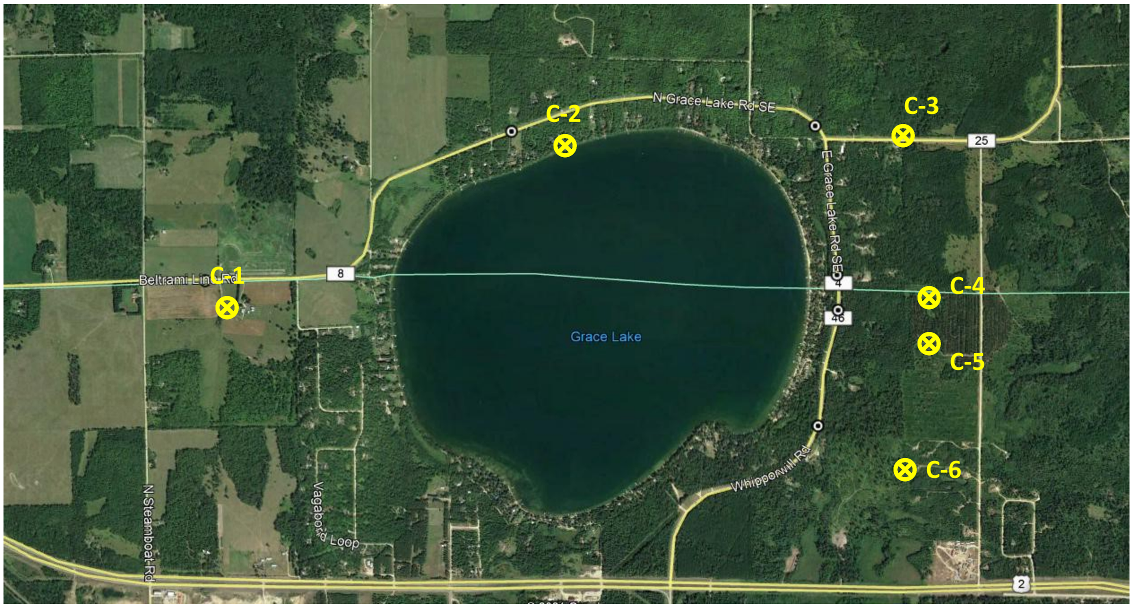

Figure 4-2 Approximate Coring Locations on Beltrami CSAH 4 and Hubbard CSAH 46

Similar to the 2020 coring, no cores could be recovered from the SFDR layer on Hubbard CSAH 46 (BASE ONE®), as a bound layer did not exist below the HMA overlay. Field cores were obtained from Beltrami CSAH 4 SFDR layer which was injected with engineered emulsion indicating the existence of a bound layer below the HMA overlay. Figure 4-3 illustrates Core C-2 which was extracted from Beltrami CSAH 4.

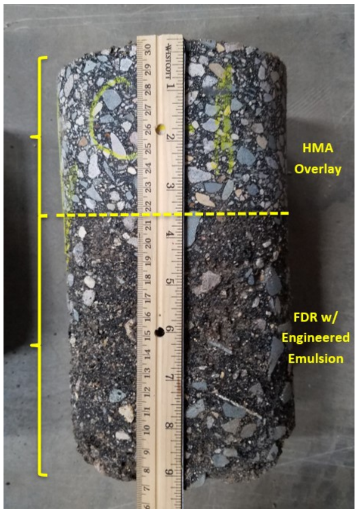

Figure 4-3 Core C-2 Obtained from the engineered emulsion Section (Beltrami CSAH 4).

Similar to 2020 laboratory testing plan, dry and conditioned indirect tensile strength tests were performed on the cores obtained from the engineered emulsion section (Beltrami CSAH 4) in accordance with ASTM D 4867.

Table 4.2 summarizes the laboratory testing results along with a comparison of the mix design and 2020 testing results. As this table shows, the dry indirect tensile strength of the field cores is close to its value from the mix design, but the conditioned set has yielded a slightly lower strength compared to the mix design. This may be expected, as the dry and conditioned strength samples go through an oven-curing process during the mix design procedure which expedites curing. This is while the field samples cure in-place and are expected to continue gain strength in a gradual manner.

As Table 4.2 suggests, the dry strength has remained about the same, but the conditioned strength has shown an increase in 2021 compared to its value in 2020 which may indicate that engineered emulsion has continued gaining strength (i.e., curing) over the past year.

Table 4.2 Laboratory Testing Results on Cores Obtained from Beltrami CSAH 4

Test	Field Cores 2020	Field Cores 2021	Mix Design
Dry Indirect Tensile Strength Test	38 psi	39 psi	41 psi
Conditioned Indirect Tensile Strength Test	20 psi	25 psi	28 psi

4.3 2021 FWD DATA ANALYSIS

Similar to 2020, the FWD testing was performed by MnDOT in 2021 on both Beltrami CSAH 4 and Hubbard CSAH 46. Field testing was conducted on May 26, 2021. FWD data analysis was performed by Braun Intertec Corporation using the TONN2010 program. Figure 4-4 presents the roadways capacities for both roadways.

The 15th percentile (or “effective”) capacities are compared in Table 4.3 for both the 2020 and 2021 testing. The effective capacity had a slight increase for Beltrami CSAH 4 (6% increase); and a slight decrease for Hubbard CSAH 46 (2% reduction).

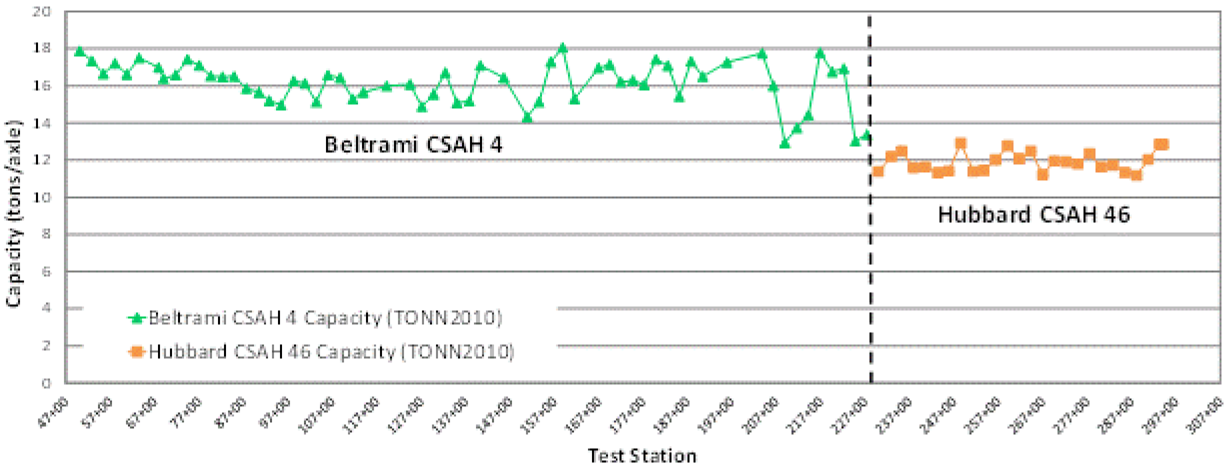

Figure 4-4 Beltrami CSAH 4 Capacity (2021)

Table 4.3 Roadway Capacity Comparison

Roadway	Effective Capacity (tons/axle)		
	2020	2021	% Change
Beltrami CSAH 4	14.2	15.1	+6%
Hubbard CSAH 46	12.1	11.9	-2%
Hubbard CSAH 8	10.2	9.5	-7%

Similar to 2020, FWD testing was also performed on Hubbard CSAH 8 to assess the effect of using pad-foot rollers on the capacity of the roadways. As the table shows, it appears that the absence of pad-foot rollers in CSAH 46 construction has not adversely affected its effective capacity.

CHAPTER 5: SUMMARY AND CONCLUSIONS

In this study, Beltrami CSAH 4 and Hubbard CSAH 46, which border Beltrami and Hubbard Counties, were investigated. Both roadways were in similar condition prior to receiving SFDR and overlaid with 3.5 inches of HMA. Each county used a different stabilizing agent; engineered emulsion was used on Beltrami CSAH 4, while Hubbard CSAH 46 was stabilized with BASE ONE®. Field and lab testing, including coring, DCP, FWD, and dry and wet strength testing, were performed on both roadways in 2020 and 2021 and the results were compared.

A summary is included in the table below along with a few concluding statements.

- Both products yielded pavements that exceed their 10-ton design. The engineered emulsion, using a GE factor of 1.5 produced a higher capacity pavement; the BASE ONE® GE factor was 1.25.
- Engineered emulsion requires a mix design, has a higher application rate, and costs more per mile.
- The engineered emulsion sections were able to be cored and tested (tensile strength); the BASE ONE® sections did not yield a bound layer that could be tested in the laboratory.
- After one year, low-severity transverse cracking occurred in both sections; the engineered emulsion section had fewer cracks per mile.

Table 5.1: Summary table.

	Beltrami County engineered emulsion		**Hubbard County Base One®**	
Original Structure (reported)	2.75” Bituminous 10.00” Class 3		2.75” Bituminous 4.25” Class 5 12.00” Select Granular	
Initial PQI (prior to rehabilitation)	2.4		2.7	
ADT (reported)	770		370	
SFDR Stabilizer	engineered emulsion		BASE ONE®	
SFDR Pavement Design (10-ton)	3.5” HMA 5.0” SFDR w/EE 7.8” Class 3		3.5” HMA 6.0” SFDR w/BASE ONE® 1.0” Class 5 12.0” Select Granular	
Stabilizer Application Rate	2.9 gallons/sq yd (approximately 30% water)		0.03 gallons/sq yd (Concentrate)	
Cost – Construction, per mile	$360,000		$259,000	
Cost – Stabilizer, per mile	$ 88,391		$ 10,625	
Tests Results				
CBR, average (calculated from DCP testing)	Before 29-31 After 33-34		Before 28-31 After 17-25	
Core Results (Tensile Strength)	**2020**	**2021**	**2020**	**2021**
Dry Indirect	38	39	unbound, no test	
Conditioned Indirect	20	25	unbound, no test	
FWD Results (capacity, tons/axle)	**2020**	**2021**	**2020**	**2021**
Effective Capacity (15th percentile)	14.2	15.1	12.1	11.9
FWD Results (R-value)	25.8		24.2	
Pavement Condition L-severity transverse cracks per mile	8.3		45	

APPENDIX A: FWD DATA ANALYSIS

INPUT DATA

The following data are required inputs into the analysis program used to generate the spring axle-load capacities and structural information from the deflection data:

- Traffic loadings (Beltrami and Hubbard Counties)
- Pavement layer thicknesses (Beltrami and Hubbard Counties)
- Subgrade soil type (Beltrami and Hubbard Counties)
- Pavement temperatures (Minnesota Department of Transportation)
- Previous day temperature (Weather Underground website: www.weatherunderground.com)
- Pavement deflection data (Minnesota Department of Transportation)

ANALYSES

The MnDOT TONN2010 spreadsheet program was developed by the MnDOT Office of Materials and is recommended by MnDOT State Aid. It is based on the TONN2010 analysis method, which was developed at the University of Minnesota and further refined at Minnesota State University, Mankato. Section 200 in Chapter 2 of MnDOT Pavement Design Manual explains the analysis tool and describes step-by-step how to run the MnDOT TONN2010 program. The following defines the parameters presented in this report:

TONN2010 Spring Axle-Load Capacity – The TONN2010 analysis method back calculates layer moduli using a four-layer elastic method (HMA layer, base layer, subgrade layer, and semi-infinite very stiff layer). The critical pavement responses for each season are computed using adjusted moduli values and the embedded layered elastic program called MnLAYER, which was developed at the University of Minnesota.

Damage analysis is performed using a mechanistic-empirical approach and the 20-year design ESALs. The damage analysis is very similar to the MnPAVE method, which uses failure criteria models for HMA fatigue cracking, subgrade rutting, base shear failure, and base deformation and five distinct seasons. The TONN2010 spring axle-load capacity at each test location is based on the lowest rating of the four failure models. The segment axle load capacity (ton rating) is represented by the 15th percentile of all the results and labeled Effective Capacity.

Effective R-value – Effective R-value is the stiffness of the subgrade soil. The back calculation routine in TONN2010 calculates subgrade modulus values at each test location, which are converted to R-value by the method described in MnDOT Investigation 201. The effective R-value for each segment is represented by the 15th percentile value.

Limitations – The MnDOT TONN2010 program includes the following limitations:

- The HMA layer must be between 2 and 12 inches thick.
- The aggregate base layer must be between 3 and 48 inches thick. Sand subbase thickness (if applicable) is included in this value.
- The subgrade is between 12 and 240 inches thick.
- Aggregate base modulus is always 1 to 100 times the subgrade modulus.
- The HMA modulus is between 1/10 and 400 times the aggregate base modulus.