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Rehabilitation of Faulted Joints In Rigid Pavements

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TRANSPORTATION RESEARCH AND DEVELOPMENT BUREAU
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REHABILITATION OF FAULTED JOINTS IN RIGID PAVEMENTS

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ABSTRACT

Faulting at transverse joints and cracks in rigid pavements is a common problem not only in New York but across the United States and Canada. This report summarizes New York State current practices and past research, as well as results of a survey of methods of other transportation agencies in dealing with this problem. Many techniques are being used, both short- and long-term. Among the former are slab grinding, thin flexible overlays, and slab shimming (either with asphalt cement concrete or through microsurfacing with a latex-modified asphalt emulsion). Among long-term solutions are slab grinding, thicker flexible overlays (either alone or in conjunction with cracking/breaking-and-seating, rubblizing, or undersealing), rigid overlays, retrofitting load-transfer devices, slab lifting, and joint replacement. Each method has its advantages and disadvantages, and should be evaluated according to each agency's experience and preferences.

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Figure 1. Survey form sent to other transportation agencies.

NYS QUESTIONNAIRE

Project R223-01.881 "Low Cost Solutions to Rigid Pavement Joint Faulting"

PROBLEM: Many miles of PCC pavements have faulted in NYS and in the past different methods have been tried to correct or arrest this problem including ashalt cement overlays, slab grinding, slab lifting, and retrofitting load-transfer devices. What is needed is a repair method that will provide low-cost, practical solution(s) to this widespread distress.

1) Is faulting at joints on PCC pavements a problem in your jurisdiction?
Yes ____ *Please continue* No ____ *Thank you*

2) If so, approximately what percentage of the total PCC pavements lane miles are affected?
______ Total lane miles of PCC pavement ______ Percent faulted

3) On what types of PCC pavement does this problem occur?
a. Jointed Reinforced ____ b. Jointed Unreinforced ____

4) Which of the following rehabilitation methods do you use as a short-term solution to correct or retard this problem? Please provide approximate cost, stating whether it is per lane mile or per joint and indicate expected service life (in years) of each method used.

	Cost	Life
a. Asphalt shims	______	______
b. Concrete shims	______	______
c. Thin asphalt overlay (<3")	______	______
d. Slab grinding	______	______

e. Other *Please describe, including details of cost and service life:*

____

____

____

____

5) Which of the following rehabilitation methods do you use as a long-term solution to correct or retard this problem? Please provide approximate cost (designating whether it is per lane mile or joint) and expected service life (in years) of each method used:

	Cost	Life
a. Replace LTDs	______	______
b. Slab lifting	______	______
c. Slab jacking	______	______
d. Asphalt overlay (>3")	______	______
e. Concrete Overlay	______	______
f. Slab Grinding	______	______
g. Replace joints	______	______
h. Breaking & seating w/ACC OL	______	______
i. Rubblizing w/ACC OL	______	______

j. Other, including combinations of above methods
Please describe with respect to cost and service life:

____

____

____

____

____

6) Are you currently researching rehabilitation methods (or have you done so in the past) to correct or retard this problem? Yes ____ No ____

7) Is there a written report available concerning this research? Yes ____ No ____

How may we obtain a copy? ________________

____

8) Please provide the name and address of a person we may contact for further information:

Name ________________ Title ________________

Organization ________________________________

Address ________________________________

Telephone Number (______) ______ – ______ Fax Number (______) ______ – ______

Thank you for your assistance.

08/93

I. INTRODUCTION

A. Background

In New York many rigid pavements fail from joint-related distress. This is a gradual process, beginning with water infiltration, pumping, and loss of foundation support, and progressing to subsequent faulting and slab cracking. Loss of load-transfer capacity at joints and weakening of subbase support are accelerated by repeated applications of heavy wheel loads. Many techniques have been tested in New York through the years to alleviate the discomfort that faulting causes the driving public, and also to retard the rate of faulting (1,2,3). Among these have been asphalt shims, microsurfacing with asphalt emulsions, undersealing, asphalt overlays, slab grinding, retrofitting of load-transfer-devices (LTDs), and slab lifting with grout placed beneath the pavement. These methods have not proved to be completely successful or practical.

The Department's Technical Services Division and Transportation Maintenance Division were interested in re-examining the cost and practicality of these methods, as well as those used by other highway agencies.

B. Objectives and Methodology

This study's objectives were three-fold:

1. To investigate techniques used in the United States and Canada to repair or retard rigid-pavement faulting,

2. To list these techniques with approximate costs and possible advantages and/or disadvantages, and

3. To recommend cost-effective techniques for New York State.

To meet these objectives, state transportation agencies in the United States and provincial agencies in Canada were surveyed to determine their experiences and practices in dealing with this problem. The form sent to them is shown in Figure 1. A list has also been compiled of procedures now recommended and/or used by NYSDOT, along with brief summaries of past research.

Table 1. States and provinces responding to survey.

Positive Responses		Agencies Having No Rigid Pavements or No Faulting Problems
Alabama	Nevada	Connecticut
Arkansas	New Hampshire	Indiana
California	North Dakota	Kentucky
Colorado [a]	Ohio	Maryland
Georgia	Ontario	Michigan
Idaho	Pennsylvania	New Mexico
Illinois	South Carolina [c]	Oregon
Iowa	South Dakota [a]	Quebec
Kansas	Tennessee	Saskatchewan
Louisiana	Utah [d]	Texas
Manitoba [b]	Virginia	Vermont
Minnesota [a]	Washington	
Missouri	Wisconsin	
Nebraska	Wyoming	

[a] Uses no short-term solutions.
[b] Uses no short-term solutions but has some roads that could be candidates for grinding in the near future.
[c] Uses grinding short-term but their other option is to do nothing.
[d] Faulting is a minor problem; uses joint resealing to retard continued faulting.

Table 2. Short-term solutions.

Agency	Treatment*	Cost, $/m[2]	Expected Service Life
ALABAMA [a]	SLAB GRINDING	2.39	7 to 10 yr
ARKANSAS [a]	ACC OL <75 mm	10.18	8 yr
	SLAB GRINDING	2.38	8 yr
CALIFORNIA [a]	SLAB GRINDING	5.08	8 yr
GEORGIA [a]	SLAB GRINDING	2.99	7 to 10 yr
IDAHO [a]	SLAB GRINDING	4.24	5 to 7 yr
ILLINOIS [a]	SLAB GRINDING	3.39	3 to 5 yr
IOWA [a]	ACC OL < 75 mm	8.91	3 to 10 yr
	SLAB GRINDING	5.94	5 to 8 yr
KANSAS [a]	ACC OL <75 mm	9.33	5 to 7 yr
	SLAB GRINDING	4.24	4 to 6 yr
LOUISIANA USES ACC OL BUT GAVE NEITHER COST NOR LIFE			
MISSOURI	SLAB GRINDING	4.24	3+ yr
NEBRASKA [a]	SLAB GRINDING	11.03	14 yr
NEVADA	SLAB GRINDING	2.99	5 to 10 yr
NEW HAMPSHIRE [b]	ACC OL <75 mm	1.27	5 to 6 yr
NORTH DAKOTA	SLAB GRINDING	2.99	10 yr
OHIO [a]	SLAB GRINDING	3.59	6 to 12 yr
ONTARIO [a]	ACC OL <75 mm	12.00	12 yr
	SLAB GRINDING	5.00	8 to 10 yr
PENNSYLVANIA [a]	SLAB GRINDING	2.69	4 TO 6 yr
SOUTH CAROLINA [a,c]	SLAB GRINDING	2.51	8 yr
TENNESSEE USES ACC SHIMS AND OL BUT GAVE NEITHER COST NOR LIFE			
UTAH RESEALS JOINTS TO RETARD FAULTING, CONSIDERED A MINOR PROBLEM			
VIRGINIA [a]	ACC OL <75 mm	6.36	2 to 8 yr
	SLAB GRINDING	4.24	2 to 4 yr
WASHINGTON [a]	SLAB GRINDING	3.71	8 to 10 yr

* OL = overlay
[a] Also uses slab grinding as long-term solution, with same costs and expected service life.
[b] Uses ACC shims but gave neither cost nor life.
[c] Prefers no short-term action, but grinds slabs when necessary.

II. RESULTS AND DISCUSSION

A. Survey of Other Transportation Agencies

Survey forms were sent to 54 agencies across the U.S. and Canada resulting in 39 responses (Table 1); 11 said they had no rigid pavements or that faulting was not a problem. Costs and expected service lives for the several methods varied greatly -- some agencies apparently reported costs not only for the treatments but also included traffic control, pavement preparation, and numerous other expenses. Also, costs were estimated by square meter or lane-kilometer; for easier comparison the latter were converted to square meters, assuming a lane width of 3.6 m. The following discussion summarizes these short- and long-term solutions, various combinations of these methods, and their advantages and disadvantages.

1. Short-Term Solutions

Of the remaining 28 agencies, 22 said they had some experience with short-term solutions (Table 2). Slab grinding was the most frequent remedy (18 agencies). Eight had used thin flexible overlays (<75 mm), two had used asphalt shims to improve ride, and one had used rigid-pavement joint resealing to retard further faulting.

a. Slab Grinding

Costs for slab grinding vary from $2.38 to $11.03/m^2, with an average of $4.09/m^2 and a majority in a range of $3.40 to $6.80/m^2. Expected service life of slab grinding was 2 to 12 yr with an average of 7.3 yr.

b. Thin (<75 mm) Flexible Overlay

Costs ranged from $1.27 to $12.00/m^2 with an average of $8.01/m^2. Expected service life was 2 to 10 yr with an average of 7 yr.

c. Other Methods

The two agencies using asphalt shims and one using joint resealing gave neither costs nor expected service life for those treatments.

Table 3. Long-term solutions.

Agency	Treatment*	Cost, $/m^2	Expected Service Life
ALABAMA [a,b]	SLAB UNDERSEAL	2.39	7 to 10 yr
ARKANSAS [a]	ACC OL >75 mm	25.46	20 yr
	PCC OL	59.40	20 yr
	BREAK & SEAT W/ACC OL	33.94	8 yr
CALIFORNIA [a]			
COLORADO	ACC OL >75 mm	25.46	20 yr
	PCC OL	33.94	30 yr
GEORGIA [a]	ACC OL >75 mm	11.03	7 yr
IDAHO [a]	REPLACES JOINTS WHEN NEEDED DURING GRINDING, NO COSTS,		5-7 yr
ILLINOIS [a]	SLAB LIFTING	0.21	2 to 4 yr
	ACC OL >75 mm	5.13	8 to 10 yr
	REPLACE JOINTS	1.74	NONE GIVEN
IOWA [c]	ACC OL >75 mm	12.73	15 yr
	SLAB GRINDING	7.64	5 TO 8 yr
KANSAS [a,d]	ACC OL >75 mm	12.73	7 to 10 yr
	SLAB UNDERSEAL	2.92	4 to 6 yr
	RUBBLIZE W/ AC OL	23.76	10 yr
MANITOBA	ACC OL >75 mm	6.79	15 yr
MINNESOTA	ACC OL >75 mm	13.58	12 yr
	SLAB UNDERSEAL	4.78	12 yr
	PCC OL	46.67	30 yr
MISSOURI [a,e]	ACC OL >75 mm	33.94	10+ yr
	SLAB UNDERSEAL	0.85	1+ yr
NEBRASKA	ACC OL >75 mm	42.43	14 yr
NEVADA	BREAK & SEAT W/ AC OL	59.40	10 to 15 yr
	RUBBLIZE W/ AC OL	67.89	10 to 15 yr
NORTH DAKOTA	REPLACE JOINTS	13.16	10 to 20 yr
	CRACK & SEAT W/AC OL	0.24+ACC	20 yr
OHIO [a]	ACC OL >75 mm	52.63	NONE GIVEN
	REPLACE JOINTS	800/JT	NONE GIVEN
	PCC OL	29.90	20 yr
	RUBBLIZE W/ AC OL	55.02	10 to 15 yr
ONTARIO [a]	ACC OL >75 mm	18.00	12 to 15 yr
	SLAB UNDERSEAL	150/JT	6 to 10 yr
	PCC OL	30.00	20+ yr
	REPLACE JOINTS	1000/JT	20 yr
PENNSYLVANIA [a]	RETROFIT LTDs	NONE GIVEN	10+ yr
	SLAB UNDERSEAL	NONE GIVEN	4 to 8 yr
	ACC OL >75 mm	7.78	6 to 8 yr
	PCC OL	29.90	20 yr
	REPLACE JOINTS	65.79	5 to 10 yr
	BREAK & SEAT W/ AC OL	16.75	6 to 8 yr
	RUBBLIZE W/ AC OL	14.35	20 yr
SOUTH CAROLINA [a]	REPLACE JOINTS	49.70	8 yr
SOUTH DAKOTA	SLAB GRINDING	2.87	10 to 15 yr
	SLAB UNDERSEAL	85.00/JT	10 to 15 yr
	ACC OL >75 mm	16.97	15 yr
	BREAK & SEAT W/ AC OL	16.97	15 yr
VIRGINIA [a]	ACC OL <75 mm	12.73	6 to 12 yr
	SLAB GRINDING	6.36	4 to 8 yr
	REPLACE JOINTS	800/JT	10 to 20 yr
	BREAK & SEAT W/ AC OL	41.43	30 yr
	RUBBLIZE W/ AC OL	42.43	30 yr
WASHINGTON	RETROFIT LTDs	34.00/BAR	10+ yr
	SLAB UNDERSEAL	20.93	NONE GIVEN
	ACC OL <75 mm	10.52	12 to 15 yr
WISCONSIN	SLAB GRINDING	3.59	12 to 15 yr

* OL = overlay

[a] Slab grinding used as long-term solution.

[b] Uses slab replacement, joint repair, slablifting, ACC OL(no cost or life), also use rubblizing w/ACC OL as second-time method (no cost or life).

[c] Uses slab undersealing only when necessary and with their other methods, tried retrofitting LTD's, but too costly (not given) for < 5 yr service life.

[d] Uses these methods in combination.

2. Long-Term Solutions

Of the 28 agencies, 23 stated that they performed some type of long-term rehabilitation for their faulted pavements. Slab grinding (18 agencies) and flexible overlays of 75 mm or more (17 agencies) were most widely used. Other methods included joint replacement (10 agencies), subsealing (9 agencies), cracking/ breaking-and-seating with a flexible overlay (6 agencies), rigid overlays (6 agencies), LTD retrofitting (2 agencies), and slab lifting (1 agency). Some said they often used various combinations of these methods. Responses are summarized in Table 3.

a. Slab Grinding

Of 18 agencies stating that they used grinding as a long-term solution, 13 gave the same costs and life expectancies as when using it as a short-term remedy. One uses grinding for both long- and short-term improvement, but cost for the former is $\$6.36/m^2$ as compared to $\$4.24/m^2$ for the latter. Life expectancy also increased for the long-term -- 4 to 8 yr compared to 2 to 4 yr. Two other agencies use grinding only as a long-term solution. Costs for grinding as a long-term solution generally showed the same range as for short-term ($\$2.38$ to $\$11.03/m^2$) but the average increased slightly to $\$4.37/m^2$. The majority of per-lane costs were again in the range of $3.40 to $\$6.80/m^2$. Expected service life ranged from 3 to 15 yr with an average just under 8 yr.

b. Thicker Flexible Overlay (>75 mm)

Cost ranged from $5.13 to $\$52.63/m^2$ with an average of $\$19.24/m^2$. Expected service life ranged from 6 to 20 yr with an average of 12.6 yr.

c. Undersealing

Costs were given per square meter or per joint, and ranged from 85¢ to $\$20.93/m^2$ with an average of $5.31; two agencies reported per-joint costs of $85 and $150. Service life expectancy ranged from 4 to 15 yr with an average of 7.6 yr.

d. Joint Replacement

Costs were also reported per square meter and per joint, ranging from $1.74 to $\$65.79/m^2$ with an average of $\$32.60/m^2$, and $700, $800, and $1000 per joint with an average of $833. Expected life ranged from 5 to 20 yr with the average just over 12 yr.

e. Cracking/Breaking-and-Seating with Flexible Overlay

Costs ranged from $16.75 to $\$59.40/m^2$ with an average of $\$33.63/m^2$. Expected service life ranged from 6 to 30 yr with an average of 15.4 yr. One agency reported cracking and seating at a cost of 24¢/m^2 (excluding cost of the asphalt overlay) with an expected service life of 20 yr.

f. Rigid Pavement Overlay

Costs ranged from \$29.90 to \$59.40/m^2 with an average of \$38.30/m^2. Expected service life was 20 to 30 yr with an average of 24 yr.

g. Rubblizing with Flexible Overlay

Average costs were \$40.69/m^2 with a range from \$14.35 to \$67.89/m^2. This treatment was expected to give an average service life of 18.1 yr with a range from 10 to 30 yr.

h. Retrofitted LTDs

Only one of the two agencies using retrofitting gave costs (\$34 per LTD), and both said they expected about 10 yr from this procedure. Puerto Rico has been using this method successfully for the past 10 yr, and expects a service life of 10 to 15 yr at a cost of \$20 per retrofitted dowel (4).

i. Slab Lifting

Cost for the one agency reporting was 21¢/m^2 with an expected service life of 2 to 4 yr.

3. Combinations

Several agencies reported using various combinations of these methods:

1. Undersealing voided areas, slab-jacking settled areas, slab grinding with cleaning and sealing of joints and/or cracks, replacing severely broken slabs, installing pavement edge drains, and repairing spalls (one agency).

2. Cleaning and resealing joints, replacing severely broken slabs, and grinding faults (one agency).

3. Undersealing when voids were found, before flexible overlay or slab grinding (two agencies).

4. Undersealing and replacing badly deteriorated joints before slab grinding (one agency).

5. Repairing joints before grinding (one agency).

6. Replacing severely distressed joints before flexible or rigid overlay (one agency).

7. Five agencies said that they install pavement edge drains before overlaying, cracking/ breaking-and-seating, or rubblizing.

4. Advantages and Disadvantages

The following successes and problems were described:

a. Slab Grinding

This is most effective when pavement slabs are structurally sound with only minor slab cracking and/or spalling. If there are subbase problems, pumping, and/or voids, faulting returns quickly unless other methods (such as undersealing or slab lifting) are used in conjunction with the grinding. Grinding may create an uneven ride if the longitudinal distance ground is small. Full slab grinding provides the best ride and a short-term increase in pavement friction numbers, but is also more expensive.

b. Thin Flexible Overlays (<75 mm) and Flexible Shims

These provide short-term improvement of ride, but do nothing to address the actual cause of faulting. Shims give the same short-term benefit as thin flexible overlays but share their short life expectancy.

c. Undersealing

This works best when pumps used are operated at a slow rate (14 to 28 kPa), ensuring that grout flows into all the voids without overfilling and/or missing any voids that can cause slabs to rock. When done properly, it also is effective in extending the performance of such other methods as grinding, retrofitting joints, or overlaying, because it eliminates voids underlying slabs and thus reduces pumping of fines. Determining when the underseal has set is also critical for success of this method, because allowing traffic on the slabs prematurely will pump the underseal grout into the shoulders or joints. One agency said that they found undersealing to be expensive with a short service life and that it also contributed to accelerated slab breakup, probably because some voids were improperly filled, causing slabs to rock. This is a difficult technique, and even with high quality control its success is not guaranteed.

d. Retrofitted LTDs

For successful LTD retrofitting the following steps (4) must be taken:

1. Retrofit before major deterioration occurs, both at joints and within slabs.

2. Slot preparation is critical to assure good bonding of the repair material, and slots should be as narrow as possible.

3. Patching material must be thermally compatible with the existing concrete. Use the same materials and the same preparation and installation procedures that work for partial-depth repairs. Ensure that repair material does not infiltrate adjacent joints and/or cracks.

4. Two to four epoxy-coated dowels per wheelpath should be used, the number determined by the dowel size used, volume of heavy truck traffic, and condition of the existing pavement. Alignment of dowels is critical to prevent failure of repair material or slab cracking through the slot. Expansion caps or compressible material must be used on dowel joints unless the joint or cracks are tightly closed at the time of reconstruction.

5. Duration of lane closure will depend mainly on curing time for the repair material. Equipment has been developed to cut the required multiple slots in a single pass, thus reducing duration of lane closure.

6. Joint resealing is required.

B. New York State Practice and Past Research

New York has researched and used a variety of methods to resolve this problem, including slab lifting, subsealing, slab grinding, retrofitting LTDs, cracking-and-seating, rubblizing, flexible overlays of various thicknesses, and slab shimming (asphalt concrete or microsurfacing with latex-modified asphalt emulsion).

1. Slab Lifting

This was tested on I-84 as part of Research Project 176 in the 1980s (1), and entailed physically lifting the slab and then filling underlying voids between the slab and base with grout. This procedure, however, was determined to be impractical for several reasons. It was time-consuming -- 2 to 3 hours per joint. Many slabs required full-depth sawcuts, thus destroying any remaining load-transfer capabilities. Some slabs could not be lifted even with these full-depth sawcuts. Even when it was possible, lifting proved difficult -- either it could not be done evenly or when the slab was released it settled below the desired level, forcing grout out the sides or into the joints. Slab lifting currently is not a recommended rehabilitation technique in New York.

2. Undersealing

This was attempted in the same study, using both limestone and fly ash grouts. Angularity of the limestone increased the mixture's viscosity, thus reducing its ability to flow freely beneath the slabs. This caused uneven support under the slabs and resulted in poor performance. The fly ash grout flowed more freely and thus performed better.

Undersealing is meant to eliminate voids between slabs and subbase, and thus pumping of fines from beneath the slabs. Careful attention to construction practice is important because insufficient grout may not reduce slab deflections, and too much grout could easily result in more broken slabs by providing uneven support. Excessive grout can also fill the transverse joints and cause blowups (2). Undersealing is not currently recommended as a rehabilitation technique in New York.

3. Slab Grinding

This also was tested in the same research project. Although grinding does level off whatever faulting is present, it does not address its cause. If there are other problems (such as voids between the slab and base and/or pumping of fines), the faulting problem will thus return to at least the same degree as before treatment. Also, if the slab surface is ground for part of its length instead of its full length, this often produces a wavy ride that can be as objectionable as the original faulted pavement, and may even be worse if the faulting returns. Cost for grinding in New York is \$2.04/m^2 for partial-length grinding, and \$3 to \$4.80/m^2 for full-length, each with an expected service life of 6 yr. Grinding has the following advantages: 1) the highway can be opened to traffic immediately, 2) one lane can be ground at a time, and 3) it is a common construction technique (1,6). It is now recommended in New York only for bridge-approach slabs.

4. Retrofitting LTDs

This was also tested in Research Project 176. Two types were studied, each having a different placement pattern: 1) University of Illinois epoxy-coated retrofit LTDs (UIEs) placed three or four per joint, and 2) epoxy-coated I-beams placed four or eight per joint.

The UIEs were placed in 150 mm diam core holes that spanned the transverse joint and were refilled with polymer concrete, using fiberboard and a sawcut to form a joint through the polymer concrete. The first test installation using UIEs failed when the polymer concrete broke away from the edge of the core hole during cold weather contraction. They were placed a second time using precompressed UIEs to allow for this contraction. The I-beams were placed using the same method as for the UIEs, but in a 75 by 450 mm longitudinal slot spanning the transverse joint.

Both methods were found to be more effective when the slabs had no structural problems. Also, quality construction and material control were important, although more critical when installing UIEs. Costs for experimental installation were $6.95 (three/joint) to $8.75 (four/joint) per square meter for the UIEs, and $11.70 (four/joint) to $23.40 (eight/joint) per square meter for the I-beams (2). Retrofitting is not currently a recommended procedure in New York.

5. Breaking/Cracking-and-Seating

This is recommended in New York for use with 125 mm flexible overlay on pavements having one or more of the following conditions: 1) failed joint seals, 2) medium-to-high severity slab cracking, 3) infrequent joint separation, 4) high-severity spalling, 5) infrequent settlements, heaves, and/or blowups, and/or 6) high-severity joint faulting and/or wheelpath rutting. Estimated cost of this procedure with the overlay is about $17.30/m^2, not including such additional necessary work as a shim course, cleaning and filling joints, shoulder repair, etc. (5).

Advantages include: 1) it can be done one lane at a time, 2) overnight lane closures are not required, 3) traffic can be maintained on the cracked-and-seated rigid pavement, and 4) it is a common rehabilitation method. Disadvantages include: 1) it may create additional spalls, 2) it has potential to disrupt culverts and underground utilities, and 3) the 125 mm overlay may be a problem for vertical clearances and appurtenances (5).

6. Rubblizing

With a 150 mm flexible overlay, this is recommended for the same conditions just listed for breaking/cracking-and-seating (except Condition 3 -- infrequent joint separation), and if underground utilities and/or separated joints are present, or widening is contemplated. Estimated cost of this procedure with a 150 mm flexible overlay is about $27.65/m^2, also not including any necessary additional work (5).

Advantages for this procedure are as follows: 1) it can be done one-lane-at-a-time, 2) it does not damage underground utilities, 3) the needed compaction and overlay are standard procedures, 4) spall repair and full-depth replacement are not necessary, and 5) crushed stone can be used in pavement widening, shoulder replacement, and filling depressions. Disadvantages are 1) traffic cannot return to the pavement until the first overlay layer is placed, 2) positive drainage is required, 3) a 150 mm overlay may cause problems for vertical clearances and appurtenances, 4) most roadway features will require adjustment, and 5) rubblizing equipment cannot get closer than 1 m to curbs (5).

Expected overlay service life above both cracking-and-seating and rubblizing is 15 yr, provided required maintenance is performed (5).

7. Thin (<75 mm) Flexible Overlays

These overlays are used in New York by maintenance forces to improve ride on faulted pavements until proper rehabilitation methods can be implemented. This is a short-term solution, with expected service life of only 4+ years. Costs range from \$4.25 to \$9.85/m^2.

Advantages for this method are 1) it can be done one lane-at-a-time without overnight lane closures, and 2) it is a common rehabilitation method. It disadvantages are 1) it does nothing to address causes of faulting problems, 2) life expectancy is short, and 3) when long-term rehabilitation finally takes place the overlay must be milled off if the pavement is to be ground, broken-and-seated, or rubblized (3,5).

8. Thicker (>75 mm) Flexible Overlays

With sawed-and-sealed joints, these are recommended in New York for the following conditions: 1) when joint seals have failed, 2) when joints have not separated, 3) with low-severity cracking, 4) with infrequent settlements, heaves, and/or blowups, 5) with medium joint faulting and/or high-severity spalling, and 6) after severe wheelpath rutting. Cost (overlay only) ranges from \$10.20 to \$17/m^2 depending on thickness and not including any other required work. Cost of the saw-and-seal joints is about \$3.40/m^2. Overlay life expectancy is 15 yr, with crack sealing at 5-yr intervals.

Advantages are the same as for thin overlays. In addition, as Research Project 188 proved, rate of fault return on the overlay is directly affected by its thickness: the thicker the overlay, the slower the rate of fault return. This is because the overlay both seals the old rigid pavement joints (thus stopping infiltration of water) and distributes the weight of heavy trucks over a greater area instead of directly onto the old joints (3). Disadvantages include: 1) location of sawcuts over the underlying joints is critical, 2) sealers must be properly installed and maintained, and 3) thickness of the overlay may create problems with overhead clearance and appurtenances (3,5).

9. Slab Shimming

In New York, this involves either Type 5 asphalt cement concrete or microsurfacing with a proprietary latex-modified asphalt-emulsion slurry. The Type 5 shim mix is hand-placed, raked, and flattened with a steel-wheel roller. The slurry is placed using a specially designed hopper and paver. An asphalt-emulsion tack coat is applied to the concrete pavement before either treatment. Both can be placed at widths of 1, 1.3, or 2 m but the 2 m treatment seems to restore a smoother ride.

Cost are 55¢/m² (1.3 m wide) and 80¢/m² (2 m wide) for asphalt concrete shims, and 35¢/m² (1.3 m) and 50¢/m² (2 m) for microsurfacing. These figures include tack coat and taping of joints to prevent intrusion of the slurry with the microsurfacing. There is an added cost for the microsurfacing's special hopper and paver (6). Anticipated service life for both methods is 4+ years. Advantages and disadvantages for these methods are the same as for thin overlays. Both slab shimming techniques result in significantly better ride than partial grinding. They restore the original road profile, and the wavy surface resulting from grinding is essentially eliminated. Microsurfacing using the latex-modified asphalt emulsion may be re-applied in subsequent years for short-term repairs, if long-term repair is delayed beyond the original, expected short-term period and/or if faulting returns.

III. CONCLUSIONS AND RECOMMENDATIONS

This study's objective was to document experiences in rehabilitating faulted rigid pavements:

1. Faulted rigid pavements are a common problem across the United States and Canada, and many rehabilitation methods have been tried or are in use.

2. Many methods address only the problem of poor riding quality and do nothing to treat the actual cause of the faulting.

3. The most common short-term solutions are slab grinding or thin (<75 mm) flexible overlays.

4. The most common long-term solutions are slab grinding or flexible overlays, either alone or in conjunction with cracking/breaking-and-seating, rubblizing, or undersealing.

5. Among the other solutions are slab undersealing, slab shimming, rigid overlays, retrofitting the LTDs, slab lifting, and replacing joints.

6. All methods have advantages and disadvantages.

These techniques did not undergo life-cycle cost analysis because it could not be determined whether costs reported in responses from other agencies included such associated expenses as traffic control, drainage work, etc. Based on these observations, however, the following recommendations are proposed:

1. The following short-term solutions are recommended: microsurfacing with a latex-modified asphalt emulsion, slab shimming with ACC Type 5, and thin (<75 mm) flexible overlays.

2. Slab grinding is an appropriate alternative short-term solution, especially if long-term rehabilitation plans entail a treatment that requires milling off the shims or overlay, such as cracking/breaking-and-seating or rubblizing.

3. Slab grinding is an appropriate long-term solution where slabs are structurally sound, or when using other methods that address the cause of faulting.

Figure 2. Short-term rehabilitation methods for faulted joints (5,6).

PAVEMENT CONDITIONS	RECOMMENDED REHABILITATION	WORK PROCESS	OTHER CONSIDERATIONS
1.INFREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 2.LOW-MEDIUM JOINT SPALLING 3.LOW-MEDIUM SCALING/ NON-JOINT SPALLING 4.MEDIUM SEVERITY RUTTING IN WHEELPATHS 5.MEDIUM-HIGH JOINT AND/OR CRACK FAULTING	ACC TYPE 5 SHIMS OR MICROSURFACING W/ LATEX-MODIFIED ASPHALT EMULSION	SHIMS 1.APPLY TACK COAT 2.HAND PLACE SHIM MIX 3.RAKE SHIM MIX 4.ROLL W/ STEEL-WHEEL ROLLER MICROSURFACING 1.APPLY TACK COAT 2.TAPE JOINT/CRACK TO PREVENT INTRUSION BY EMULSION 3.PLACE LATEX-MODIFIED ASPHALT EMULSION	1.SPECIAL DESIGN HOPPER IS REQUIRED TO PLACE LATEX MODIFIED ASPHALT EMULSION FOR MICROSURFACING 2.THESE BOTH CAN BE PLACED AT WIDTHS OF 1, 1.3, AND 2 m 3.THE 2 m WIDTHS SEEM TO PROVIDE A SMOOTHEST RIDE 4.MICROSURFACING CAN BE RE-APPLIED IF LONG-TERM REHABILITATION REHABILITATION OCCURS
1.FREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 2.MEDIUM-HIGH JT SPALLING 3.MEDIUM-HIGH SCALING/ NON-JOINT SPALLING 4.MEDIUM-HIGH SEVERITY WHEELPATH RUTTING 5.MEDIUM-HIGH JOINT AND/OR CRACK FAULTING 6.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 7.OTHER DISTRESSES AT NONE-LOW SEVERITY LEVELS	ACC OVERLAY (Less than 75 mm)	1.CLEAN PAVEMENT 2.SHIM FAULTS & WHEEL RUTS 3.APPLY TACK COAT 4.ACC T&L COURSE 5.ACC TOP @ DESIRED THICKNESS	IF OVERLAY IS > 50 mm, APPLY TWO COURSES OF ACC (ONE 37.5 mm TOP AND ONE BINDER OF REMAINING THICKNESS)
1.FREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 2.LOW-MEDIUM SEVERITY WHEELPATH RUTTING 3.MEDIUM-HIGH JOINT AND/OR CRACK FAULTING 4.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 5.OTHER DISTRESSES AT NONE-LOW SEVERITY LEVELS	SLAB GRINDING	1.DIAMOND GRIND PCC SURFACE 2.CLEAN GRINDING SLURRY & RESIDUE FROM PAVEMENT 3.POWER-SWEEP SURFACE BEFORE OPENING TO TRAFFIC	1.FULL SLAB LENGTH GRINDING IS PREFERRED TO PARTIAL LENGTH BUT IS MORE EXPENSIVE 2.PROCEDURE SHOULD BE CONSIDERED IF LONG-TERM TREATMENT REQUIRES MILLING ACC OVERLAYS AND SHIMS

4. Flexible overlays with either saw-and-seal joints, cracking/breaking-and-seating, or rubblizing are appropriate long-term solutions.

5. Use of retrofit LTDs should be more closely examined, in view of recent improvements in installation procedures, greater life expectancy, and reduced costs (as compared to earlier experiments on I-84 in Research Project 176).

6. As various methods are used more frequently and construction techniques are refined, their inclusion as possible solutions should be considered.

To determine which rehabilitation method should be used, pavement deficiencies should be examined thoroughly and their causes identified. The method finally selected must be appropriate to the situation. Its selection should be based on consideration of construction feasibility, performance period desired, and available funding (7). Figures 2 and 3 are matrices to aid in selecting short- and long-term rehabilitation method, based on existing pavement conditions and other considerations as indicated.

Figure 3. Long-term rehabilitation methods for faulted joints (4,5,6).

PAVEMENT CONDITIONS	RECOMMENDED REHABILITATION (EXPECTED SERVICE LIFE)	WORK PROCESS	OTHER CONSIDERATIONS
1.FAILED JOINT SEALS 2.INFREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 3.INFREQUENT TRANS. AND/OR LONG. JOINT SEPARATIONS 4.MEDIUM-HIGH JOINT SPALLING 5.MEDIUM-HIGH SCALING / NON-JOINT SPALLING 6.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 7.MEDIUM-HIGH SEVERITY WHEELPATH RUTTING 8.LOW SEVERITY JOINT FAULTING 9.OTHER DISTRESSES AT NONE-LOW SEVERITY LEVEL	BONDED PCC OVERLAYS (20 yr)	1.FULL-DEPTH REPAIR OF 2nd, 3rd, & 6th PAV'T COND. W/RAPID-SET PCC 2.MILL OUT SPALLS 3.SCARIFY 6 mm OF SURFACE 4.SANDBLAST & CLEAN SURFACE 5.PLACE 75 mm BONDED OVERLAY 6.SAW & SEAL OVER EXISTING JTS	1.OVERNIGHT LANE CLOSURES ARE REQUIRED 2.ACHIEVING BOND IS CRITICAL 3.75 mm THICKNESS MAY CAUSE PROBLEMS W/ VERTICAL CLEARANCE & APPURTENANCES 4.UNDERLYING UNREPAIRED CRACKS MAY REFLECT 5.DUST CONTROL DIFFICULT FOR SANDBLASTING 6.LESS SUSCEPTIBLE TO RUTTING THAN ACC OVERLAY 7.RAPID-STRENGTH-GAINING PCC NOW AVAILABLE
1.FAILED JOINT SEALS 2.INFREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 3.INFREQUENT TRANS. AND/OR LONG. JOINT SEPARATIONS 4.MEDIUM JOINT SPALLING 5.MEDIUM SCALING/NON-JOINT SPALLING 6.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 7.MEDIUM-HIGH SEVERITY WHEELPATH RUTTING 8.LOW-MEDIUM SEVERITY JOINT FAULTING 9.OTHER DISTRESSES AT NONE-LOW SEVERITY LEVEL	SAWED & SEALED ACC OVERLAY (75mm) (15 yr)	1.FULL-DEPTH REPAIR OF 2nd, 3rd, & 6th PAV'T COND. W/RAPID-SET PCC or ACC 2.MILL & PATCH SPALLS W/PCC or ACC 3.CLEAN & FILL ALL JTS & CRACKS 4.SHIM FAULTS & WHEEL RUTS 5.CLEAN PAVEMENT 6.APPLY TACK COAT 7.ACC T&L COURSE 8.ACC BINDER 37.5 mm 9.ACC TOP 37.5 mm 10.SAW & SEAL OVER EXISTING JTS	1.OVERNIGHT LANE CLOSURES ARE NOT REQUIRED 2.SAWCUTS MUST BE PROPERLY LOCATED OVER EXISTING JTS 3.SEALERS MUST BE PROPERLY INSTALLED 4.75 mm THICKNESS MAY CAUSE PROBLEMS W/ VERTICAL CLEARANCE & APPURTENANCES 5.SAW & SEAL CONTROLS REFLECTIVE CRACKING 6.SEALS PREVENT WATER INTRUSION, AVOIDING FURTHER JOINT DISTRESS 7.SEALS MUST BE MAINTAINED TO AVOID MULTIPLE CRACKS & POTHOLES AT JTS
1.FAILED JOINT SEALS 2.INFREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 3.INFREQUENT TRANS. AND/OR LONG. JOINT SEPARATIONS 4.HIGH JOINT SPALLING 5.HIGH SCALING/NON-JOINT SPALLING 6.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 7.HIGH SEVERITY WHEELPATH RUTTING 8.MEDIUM SEVERITY JOINT FAULTING	SAWED & SEALED ACC OVERLAY (100mm) (15 yr)	1.FULL-DEPTH REPAIR OF 2nd, 3rd, & 6th PAV'T COND. W/RAPID-SET PCC or ACC 2.MILL & PATCH SPALLS W/PCC or ACC 3.CLEAN & FILL ALL JTS & CRACKS 4.SHIM FAULTS & WHEEL RUTS 5.CLEAN PAVEMENT 6.APPLY TACK COAT 7.ACC T&L COURSE 8.INITIAL ACC COURSE, TOP 25 mm 9.ACC BINDER 37.5 mm 10.ACC TOP 37.5 mm 11.SAW & SEAL OVER EXISTING JTS	1.OVERNIGHT LANE CLOSURES ARE NOT REQUIRED 2.SAWCUTS MUST BE PROPERLY LOCATED OVER EXISTING JTS 3.SEALERS MUST BE PROPERLY INSTALLED 4.100 mm THICKNESS MAY CAUSE PROBLEMS W/ VERTICAL CLEARANCE & APPURTENANCES 5.SAW & SEAL CONTROLS REFLECTIVE CRACKING 6.SEALS PREVENT WATER INTRUSION, PREVENTING FURTHER JT DISTRESS 7.SEALS MUST BE MAINTAINED TO AVOID MULTIPLE CRACKS & POTHOLES AT JTS
1.FAILED JOINT SEALS 2.MEDIUM-HIGH SEVERITY SLAB CRACKS 3.INFREQUENT TRANS. AND/OR LONG. JOINT SEPARATIONS 4.HIGH JOINT SPALLING 5.HIGH SCALING/NON-JOINT SPALLING 6.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 7.HIGH SEVERITY WHEELPATH RUTTING 8.MEDIUM-HIGH SEVERITY JOINT FAULTING	CRACK & SEAT W/ ACC OVERLAY (125mm) (15 yr)	1.FULL-DEPTH REPAIR OF 3rd, & 6th PAV'T COND. W/ ACC 2.CRACK & SEAT EXISTING PAVEMENT 3.MILL & PATCH SPALLS W/ ACC 4.CLEAN & FILL ALL JTS & CRACKS 5.SHIM FAULTS & WHEEL RUTS 6.CLEAN PAVEMENT 7.APPLY TACK COAT 8.ACC T&L COURSE 9.INITIAL ACC COURSE, BINDER 50 mm 10.ACC BINDER 37.5 mm 11.ACC TOP 37.5 mm	1.OVERNIGHT LANE CLOSURES ARE NOT REQUIRED 2.TRAFFIC CAN BE MAINTAINED ON CRACK & SEAT PCC PAVEMENT 3.CRACK & SEAT MAY CREATE MORE SPALLS 4.CRACK & SEAT MAY DISRUPT CULVERTS & UNDERGROUND UTILITIES 5.125 mm THICKNESS MAY CAUSE PROBLEMS W/ VERTICAL CLEARANCE & APPURTENANCES 6.MULTIPLE CRACKS & POTHOLES MAY APPEAR OVER EXISTING PCC JOINTS 7.ACC REPAIRED AREAS ARE LIKELY TO RUT, SHOVE, AND/OR HEAVE CAUSING BUMPS
1.FAILED JOINT SEALS 2.MEDIUM-HIGH SEVERITY SLAB CRACKS 3.SEPARATED TRANS. AND/OR LONG. JOINT 4.HIGH JOINT SPALLING 5.HIGH SCALING/NON-JOINT SPALLING 6.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 7.HIGH SEVERITY WHEELPATH RUTTING 8.MEDIUM-HIGH SEVERITY JOINT FAULTING	RUBBLIZE W/ ACC OVERLAY (150 mm) (15 yr)	1.INSTALL EDGE DRAINS 2.REMOVE ANY ACC ON PCC SURFACE 3.RUBBLIZE & COMPACT EXISTING PCC 4.PATCH DEPRESSIONS W/ CRUSHED STONE 5.ACC BASE 75 mm 6.ACC BINDER 37.5 mm 7.ACC TOP 37.5 mm	1.PAVEMENT MAY BE WIDENED W/ CRUSHED STONE MATCHING THICKNESS OF RUBBLIZED PCC 2.TRAFFIC CAN NOT BE MAINTAINED ON RUBBLIZED PCC PAVEMENT 3.RUBBLIZING EQUIPMENT CANNOT GET CLOSER THAN 1 m TO CURBS 4.RUBBLIZING DOES NOT DISRUPT CULVERTS & UNDERGROUND UTILITIES 5.150 mm THICKNESS MAY CAUSE PROBLEMS W/ VERTICAL CLEARANCE & APPURTENANCES 6.MOST ROADWAY FEATURES WILL REQUIRE ADJUSTMENT 7.POSITIVE DRAINAGE REQUIRED
1.INFREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 2.INFREQUENT TRANS. AND/OR LONG. JOINT SEPARATIONS 3.LOW JOINT SPALLING 4.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 5.LOW-MEDIUM SEVERITY WHEELPATH RUTTING 6.LOW SEVERITY JT FAULTING 7.OTHER DISTRESSES AT NONE-LOW SEVERITY LEVEL	RETROFIT LTD's (20 yr)	1.CUT SLOTS TO DESIRED DEPTH & WIDTH 2.CLEAN DEBRIS ON PAV'T & IN SLOTS 3.BLOW OUT SLOTS W/ COMPRESSED AIR 4.CAULK TRANS. JT IN SLOTS TO PREVENT BACKFILL FROM ENTERING 5.PLACE LTD's IN SLOT AT PROPER POSITION 6.MOISTEN BOTTOM & SIDES OF SLOTS TO INSURE BETTER ADHESION 7.PLACE BACKFILL MATERIAL	1.BACKFILL MATERIAL MUST BE THERMALLY COMPATIBLE W/ EXISTING PCC 2.USE LIGHTWEIGHT TOOLS FOR ALL WORK 3.EQUIPMENT IS AVAILABLE TO CUT MULTIPLE SLOTS 4.PROPER POSITIONING OF LTD's IS CRITICAL 5.USE OF END CAPS ON LTD's TO ALLOW FOR EXPANSION & CONTRACTION IS RECOMMENDED 6.PREVENTION OF BACKFILL ENTRY INTO JOINT IS ESSENTIAL 7.MINIMUM OF 2 LTD's/WHEELPATH RECOMMENDED AS MORE ESALs EITHER INCREASE LTD DIAMETER OR NUMBER/WHEELPATH
1.INFREQUENT MEDIUM-HIGH SEVERITY SLAB CRACKS 2.INFREQUENT TRANS. AND/OR LONG. JOINT SEPARATIONS 3.LOW JOINT SPALLING 4.INFREQUENT SETTLEMENTS, HEAVES, AND/OR BLOWUPS 5.MEDIUM-HIGH SEVERITY WHEELPATH RUTTING 6.MEDIUM-HIGH SEVERITY JT FAULTING 7.OTHER DISTRESSES AT NONE-LOW SEVERITY LEVEL	RETROFIT LTD's W/ FULL-LENGTH SLAB GRINDING (20 yr)	STEPS 1-7 SAME AS ABOVE 8.DIAMOND GRIND TO REMOVE FAULTS 9.CLEAN PAVEMENT SURFACE	SAME AS 1-7 ABOVE 8.FULL-LENGTH GRINDING IS PREFERRED BECAUSE PARTIAL-LENGTH GRINDING CAN CREATE A WAVY RIDE THAT IS OFTEN MORE OBJECTIONABLE TO THE PUBLIC THAN THE FAULTING

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