CONTROLLING REFLECTION CRACKING
IN BITUMINOUS SURFACINGS

by

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SUMMARY

Laboratory and field studies on control of reflection cracks in bituminous concrete overlays in Massachusetts have so far led to the following conclusions:

1) All joints, cracks, and other discontinuities in the original pavement are undesirable because:

a) They decrease the load carrying capacity of the pavement.

b) They are often a source of deterioration of pavement due to elements.

c) They require constant maintenance.

d) They are not always pleasing to the eye.

2) If a bituminous concrete overlay (say three inches [illegible]) is placed on top of the old (original) pavement covering its joints and cracks, many of the discontinuities of the [illegible] invariably show up in the new surface in a form [illegible] cracks within a year or so. This is caused by [illegible] joint and crack movements due to changes in [illegible] temperature, moisture) and loading resulting in [illegible] and flexural forces in the resurfacing.

3) [illegible] year laboratory and field tests in preventing reflection cracks in a surfacing over jointed and cracked [illegible] concrete have indicated:

a) Appropriate continuous welded wire reinforcement in a resurfacing can reduce cracking to a negligible amount (eight times less than in the non-reinforced control).

b) Dummy grove sawing in the resurfacing above joints will also prevent reflective crack appearance in the surface.

CAUSES OF RESURFACING CRACKING

Although a three inch resurfacing will strengthen the old support on which it is laid, it cannot always withstand the stresses borne out of physical movements at various discontinuities beneath. In the case of resurfacings over worn portland cement concrete surfaces the primary causes of cracking are strains induced by the horizontal and vertical movements at joints in the covered slabs. The amount of maximum joint opening depends upon the length of the slabs, their condition, temperature and moisture, and other factors. In Massachusetts with 60 x 10 feet slabs 80 percent of the transverse joints open 0.05 inches or more during a one year cycle with maximum variation in width as much as 0.2 inches.

Vertical slab deflections are primarily activated by traffic. The maximum measured relative slab movement at transverse joints in uncovered concrete slabs was found to be 0.06 inches.

In general, the longer the slabs, the greater is the horizontal movement at the slab ends; the shorter the slabs, the higher is the relative vertical deflection at joints. Due to these movements of slabs, reflection cracking is found in practically all types of plain bituminous overlays.

The causes for reflection cracks in resurfacings over old and cracked bituminous concrete pavements are not much different except that the vertical deflection at cracks seems to be the most damaging.

MECHANISM OF CRACKING

Cracks in bituminous overlays usually appear in winter. This tends to lead to the conclusion that the most destructive combinations of stresses occur in cold weather. Laboratory data and field observations show that due to the low tensile strength of bituminous concrete at elevated temperatures the weakening of the overlay right above a joint (or crack) can start in summer. For instance, a tensional reflection crack above a transverse joint can develop as follows:

a) An old portland cement concrete roadway is resurfaced with bituminous concrete overlay (three inches) during warm weather.

b) The joints are at or above their minimum size and varying slightly in width due to daily temperature cycles.

c) The tensile strength of the overlay at warm temperatures is very low and the resurfacing cannot overcome the friction with the underlying slabs as they move with rise and fall of daily and monthly temperatures.

d) High strains are imposed in the resurfacing right above the joint.

e) Although extension is followed by a compression cycle, and the overlay is kneaded constantly by traffic, the strain recovery apparently is never complete.

f) As the cold season approaches and the temperatures decline, joints open up reaching maximum width. The tensile strength of the bituminous overlay also reaches its maximum and if the resurfacing had not been weakened above the joint while it possessed a low tensile strength (warm weather), it probably would be able to overcome the friction with the support and would not crack.

g) In cases where yearly joint opening is large (say, 0.1 to 0.2 inches) a crack can "open up" above the joint already during the first winter.

h) More often visible cracking appears during the second year (winter) after the pavement has gone through one complete yearly extension-compression cycle.

In summary, present evidence indicates that the resurfacing is weakened above a discontinuity (joint) during summer and a crack opens up in winter when plastic flow and traffic kneading action do not help to "keep the crack closed."

In cases where the main cause of cracking is vertical deflection, a similar explanation holds true, because during warm temperature exposures bituminous concrete is also weak in shear and flexure.

Finally it must be remembered that stress-strain characteristics of bituminous concrete can change with time (aging). These changes are super-imposed on the temperature effects.

WAYS OF CONTROLLING REFLECTION CRACKS

One choice is to accept reflection cracks as inevitable and try to maintain them. The main arguments against this procedure are:

a) Due to the highly irregular nature of a reflection crack and the fact that it has been adulterated by foreign matter (silt, clay, organic matter), it is nearly impossible to seal it tightly.

b) Even if the crack could be sealed, the continuity of the pavement is not restored. This, from the point of view of strength (and beauty), is undesirable.

Another choice is to try to prevent reflection cracks. Although there might be various ways of doing this, the discussion will be concentrated on two methods which have been studied in Massachusetts and where actual field performance data are available. These two methods are:

a) Reinforcing the overlays with welded wire fabric.

b) Sawing and sealing dummy joints in the resurfacing coinciding with the old portland cement concrete joints. (This method would not be practical in case of resurfacings over old bituminous roads or areas where crack geometry is variable).

PURPOSE OF REINFORCEMENT IN RESURFACING

The main purpose of reinforcement for the control of reflection cracking is to strengthen the resurfacing and to distribute strains so that they do not exceed the strain limit of bituminous concrete. Because the physical properties of a bituminous mix change greatly with temperature and time of loading, mathematical analysis of welded wire fabric interaction with bituminous concrete is difficult. Consequently, both full scale field installations and laboratory tests were made first to determine the relative merits of different types and placement of reinforcing. The field tests served to measure the performance in a natural environment. The laboratory tests were aimed at determining the interaction of wire and bituminous mix under controlled conditions of temperature and applied load.

FIELD EXPERIMENT - STRIP REINFORCEMENT

Various types and dimensions of welded wire fabric strip reinforcement were installed in resurfacing over old portland cement concrete joints in the so-called Raynham (Mass) Test Road. The underlying slabs were about 60 x 10 feet, placed on a 12-inch gravel base about 30 years ago. The reinforcement fabric strips were 5 to 10 feet wide (2.5 to 5 feet on each side of the joint) placed directly on top of the old surface and covered with a 1 3/4 inch binder course, and 1 1/4 inch top, both Massachusetts Type I mixes. Altogether 12 different tests were installed with appropriate control sections for comparison.*

*For details see reference 10 in bibliography.

The principal findings after five years under medium to heavy traffic follows:

a) The strips of reinforcement were easy to place in the three-inch bituminous concrete overlay when the fabric was placed directly on the surface of the old concrete pavement.

b) All types and styles of fabric used reduced the amount of reflection cracking.

c) Where cracks did appear at reinforced transverse joints, they were of smaller average width than those in the comparable control sections.

d) In the strip reinforcement for transverse joints, a strip of 6 x 6, 8/8 welded wire fabric 7.5 feet wide proved the best. Total cracking was one-third (33 percent) of that in the control. Another test using 3 x 6, 10/10 fabric showed the lowest percentage of wide cracks; i.e., about one-seventh of the control.

e) Strip reinforcement over longitudinal joints was also most successful with the 6 x 6, 8/8 welded wire fabric in five feet wide strips. The next most successful was 6 x 3, 10/10 (with the three inch spacing across the joint).

f) Field sampling shows that gauge 12 welded wire fabric reinforcement tends to fail across the joint and is too fine. Gauges 10 and 8 did not fail.

FIELD EXPERIMENT - CONTINUOUS REINFORCEMENT

A similar test road was chosen in Walpole, Massachusetts. Here also 12 different test sections were installed, but the reinforcement was placed continuously covering the whole roadway and extending into the shoulder widening.

The results after five years under medium to heavy traffic can be summarized as follows:*

a) The amount of transverse joint cracking was lower in all reinforced sections when compared to that in the controls. The average amount of cracking was also lower than in the strip reinforced (Raynham) test.

b) Continuous reinforçement in rolls was more successful in controlling cracks than that placed in a series of sheets.

c) Welded wire fabric, 3 x 6, 10/10 showed the best performance by the following measures of crack occurence:

1. Only nine percent of the total length of potential transverse reflection cracks appeared. This was about one-eighth of that found in the comparable control sections.

2. Only four percent of the cracks are wide (over 1/8 inch), which was about one-fifteenth of the percentage of wide cracks in the control section.

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*For details see reference 10 in bibliography.

3. Only about two percent of potential longitudinal cracking along slab edges (shoulders) occurred, and that consisted only of narrow cracks.

d) The amount of longitudinal cracking along slab edges (shoulders) was small in the Walpole Test Road in all reinforced sections.

e) However, where settlement of the resurfacing over a shoulder was more than about 1/4 inch, longitudinal cracks were observed above the slab edge at the shoulder with or without reinforcement.

f) Unreinforced resurfacing 3 3/4 inch thick cost about the same to place as three-inch, reinforced surfacing. However, the thicker non-reinforced surface developed a crack incidence five times greater than the three-inch section reinforced with 3 x 6, 10/10 welded wire fabric.

g) Field observations show that 7/8 inch maximum size aggregate appears to be the upper size limit for a bituminous mix reinforced with a fabric having openings of 2 x 2 inches.

LABORATORY TENSION TESTING RESULTS AT 70F

A series of laboratory tests (using primarily 3 x 6, 10/10 welded wire fabric in five feet wide strips) were performed to obtain stress-strain data. The specimens for these tests were taken from actual road installation (Walpole) and tested in a tension machine built to simulate road joint movements. The following few findings are cited:*

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*For details see reference 9 in the bibliography.

a) The resistance of the welded wire fabric to horizontal movement through the mix was directly proportional to the number of transverse wires per unit length of longitudinal wires; wire diameter appeared to be of secondary importance.

b) By pulling the welded wire fabric through the mix at speeds comparable to the slow movement of concrete slabs in a road (about 0.01 inch per hour), relatively low stresses were developed in the welded wire fabric. These stresses increased very little with time, indicating that the transverse wires slowly shear through the mix without increased resistance.

c) When the welded wire fabric was pulled through the mix more rapidly (about 12 times faster than in b) the stresses in the longitudinal wires increased with time , showing an actual "yield point" of the bituminous concrete as the transverse wires shear through the mix.

d) In spite of the relatively easy shear displacement of the wire fabric in a mix when stresses were applied, the tensile strength of reinforced bituminous concrete at room temperatures was considerably higher than that of plain bituminous concrete. In the case of 3 x 6, 10/10 welded wire fabric, five feet wide simulated strip reinforced specimens showed strains in the resurfacing beyond the edge of the reinforcement. This indicates that the fabric-mix combination was strong enough to overcome frictional forces between the slab and the overlay.

LABORATORY TENSION TESTING RESULTS AT 27F

Some conclusions:

a) Pulling the wire fabric through the mix at a slow rate (about 0.01 inch per hour) the resistance to pull was several times (up to 10 times) higher than at room temperature for a similar specimen.

b) During the test the resistance to pull increased with time indicating "consolidation" of the mix around the transverse wires.

c) In a tension test, simulating a joint and a five feet wide strip reinforcement (3 x 6, 10/10) the stresses in the horizontal wires over the joint were highest, decreasing with the distance away from a joint.

LABORATORY TESTS IN SHEAR UNDER A MOVING WHEEL LOAD

These tests were performed on a laboratory test track where samples of reinforced and unreinforced bituminous surfacing were submitted to repeated applications of a rubber-tired wheel load passing over a simulated joint. The resurfacing placed in the track was three inches thick and simulated five-foot wide strip reinforcing. Most of the test specimens were reinforced with 3 x 6, 10/10 welded wire fabric.

At a test temperature of 40F, the following significant findings were obtained.

a) The reinforcement added beam strength to the resurfacing.

b) Welded wire fabric, style 3 x 6, 10/10 showed marked resistance to cracking in a test where the relative vertical slab joint movement was about 0.12 inches. At high joint movements (about 0.2 inches) both the reinforced and plain specimens cracked at about the same number of load repetitions.

c) Cracks which developed on the reinforced specimens were narrow and did not widen with time. This was not the case with unreinforced specimens.

d) The decrease in stiffness of the specimens under test is approximately proportional to the logarithm of load applications. The stiffness was measured in terms of deflections at the joint as the wheel passed over it.

GENERAL COMMENTS ON PERFORMANCE OF REINFORCED OVERLAYS

It was learned that the behavior of the reinforcement in bituminous concrete depends greatly upon the temperature of the compacted bituminous concrete mix and the rate at which the load is applied. Because bituminous concrete is very weak in tension and shear when warm (say, temperatures of 60° and above), the greatest benefits of welded wire fabric reinforcement against reflective cracking are obtained while the overlay is at elevated temperatures.

Whenever large horizontal joint movements occur (0.1 inch or more) strip reinforcement requires a carefully "balanced" design, taking into account factors such as mix characteristics, temperature and loading, and friction between the old slabs and the surfacing. This friction is not uniform for all slab ends and therefore a balanced design is very difficult.

Strip reinforcement has a definite place in reinforcing above longitudinal joints and edges of the road where reinforcement resists mainly shear and some tensional forces.

Continuous reinforcement makes the whole surfacing more "homogeneous" by holding it together and helping to resist excessive strains at local spots. Continuous reinforcement can be designed as strong as economically feasible and balanced design is not mandatory.

PRACTICAL SUGGESTIONS FOR USE OF REINFORCEMENT

On the basis of laboratory and field data obtained on Massachusetts Type I Mix, three inches thick, 0-5 years old, the following numerical results are presented. They are subject to modifications as additional information is developed:

a) The approximate limits of wire spacing in any direction appear to be 2 to 6 inches.

b) The minimum effective wire size is about Gauge 12. The maximum size has not been established.

c) The minimum wire spacing in any direction should be at least three times the maximum dimension of mix aggregate.

d) While the choice of width of welded wire fabric reinforcement strips is a function of several factors, under the conditions tested six to eight foot width of reinforcement (centered over joint) appears satisfactory for transverse joints and about five foot width for longitudinal and edge joints.

e) If the horizontal joint opening is less than 0.04 inches and vertical relative joint movements of unsurfaced slabs are low (below 0.06 inches) reflection cracking is unlikely with or without reinforcing. If the horizontal joint movement is between 0.04 and 0.1 inch (with vertical relative movement of 0.06 inch or less), cracking may occur but it can be prevented or effectively reduced by a 3 x 6, 10/10 or 6 x 6, 8/8 strip reinforcement (six to eight feet wide). If the maximum yearly joint expansion horizontally is over 0.1 inch, a continuous wire fabric reinforcement such as 3 x 6, 10/10 in rolls is preferable.

f) If the maximum vertical relative joint movement of unsurfaced slabs is below 0.06 inches and the horizontal joint opening is small (below 0.04 inches) reflection cracking will probably not occur. If the vertical movement is between 0.06 and 0.12 inches, 3 x 6, 10/10 wire fabric strip reinforcement will delay the cracking considerably, but cannot always prevent it. For such conditions larger size wire fabric may be more effective. When the vertical wire fabric gives little promise of increasing crack resistance over that of non-reinforced surfacing. However, the presence of the fabric does keep the cracks narrow. Again, a larger size wire fabric than used in these tests would be more effective.

JOINT SAWING - ANOTHER METHOD TO LIMIT REFLECTION CRACKING

The idea of sawing dummy joints to predetermine cracking in pavements is not new. The application to resurfacings for prevention of crack reflection above joints was an adaptation of the technique in another area. Usually the three-inch overlay is cut one inch deep above the joints and then filled with a sealer. The high stress concentrations in the overlay at the cut cause a failure along the weakened plane and the crack never shows up in the surface.

FIELD EXPERIMENTS AND RESULTS*

In order to determine the feasibility of joint sawing-sealing as a cure to reflection cracking, a test section in Walpole (near the reinforced Test Road) was installed in 1955. Again, the old portland cement concrete slabs were 60 x 10 feet, placed on a 12-inch gravel base, about 30 years ago. The bituminous concrete resurfacing laid on top was three inches thick.

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*For details see reference 15 in the bibliography.

Only transverse joints were sawed in this experiment. They were marked by stakes before the resurfacing was placed in order to get the sawed dummy grooves right above the underlying joint. (This is very important). The grooves were cut with a wet diamond saw, about 1/4 inch wide and one inch deept. They were dried and sealed afterwards.

A test section similar to the Walpole was also installed in Bridgewater, Route 28.

After five years under medium to heavy traffic the following conclusions can be drawn:

a) Transverse groove sawing and sealing (if done right) prevents the weakening of the resurfacing in the area over the joints of the underlying concrete and stops the appearance of reflection cracks.

b) Sawed grooves 1/4 inch wide and one inch deep can be kept water-tight by rubber-asphalt sealers.

c) Even if the joint sealer fails (or is not used) the unsealed groove will have a better appearance and the adjoining surface will be stronger than is the case at a natural reflection crack.

d) The locations of joints in concrete should be carefully marked before the resurfacing is placed so that the sawed groove is directly over the underlying joint.

COMPARISON OF THE TWO TREATMENTS

From an engineering standpoint there is a difference between the two types of treatments which can be summarized as follows:

a) Continuous wire reinforcement is used to prevent any cracking and to preserve the continuity of the overlay. If grooves are cut, the pavement is subdivided into slabs and continuity is destroyed.

b) In spite of the neatness of the sawed grooves, they are still noticeable by the travelling public.

c) Sawed-sealed surfacings might require some sealing maintenance. Proper continuous wire reinforced overlay should require minimum maintaining except for random cracks.

d) The sawing-sealing method does not take care of random cracks in the underlying slabs. Continuous reinforcement does.

e) Reinforcement increases the stability of the overlay.

f) The additional initial cost of the resurfacing under Massachusetts conditions using either of the methods is approximately the same.

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