# THE REHABILITATION OF A CONCRETE PAVEMENT USING IN-PLACE RUBBLIZATION AND COLD RECYCLING TECHNOLOGIES

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## ABSTRACT

In 1998, a 19 km portion of Highway 2 located between Woodstock and Thamesford was transferred from the provincial jurisdiction to the County of Oxford, Ontario. County Road 2 was a concrete pavement with 75 mm of hot mix asphalt surfacing. The pavement serviceability was considered poor mainly due to the multiple active joints and rocking of the concrete slabs. In 1999, the County of Oxford made the decision to restore the serviceability of the new County Road 2 using a rehabilitation method that would provide smooth ride, mitigate cracking and eliminate the rocking effect of the concrete slabs. The retained rehabilitation strategy included rubblization of the concrete pavement, cold recycling of the old hot mix asphalt surfacing and placement of new hot mix asphalt surfacing. The rehabilitation of County Road 2 was carried out in three phases and the last phase was completed in the summer of 2001. The experience acquired with every phase of work contributed to define and optimized a construction method that minimizes both, the rehabilitation costs and the construction risks associated with the break up of the concrete pavement structure. This paper presents an overview of the approach undertaken by the County of Oxford to establish a pavement rehabilitation strategy and the step taken to optimize the usage of rubblization and cold recycling of the old hot mix asphalt surfacing.

## 1.0 INTRODUCTION

The rehabilitation of a composite pavement is always a challenge for road engineers. In 1998, a composite pavement located between Woodstock and Thamesford was transferred from the provincial jurisdiction to the County of Oxford. Former Highway 2, now Oxford County Road 2 was a concrete pavement with 75 mm of hot mix asphalt surfacing. The pavement serviceability was considered poor mainly due to the multiple active joints and rocking of the concrete slabs. In 1999, the County of Oxford began to rehabilitate County Road 2 using an original method, which included cold milling, rubblization of the in-place concrete slabs, cold recycle of the existing hot mix asphalt, and hot mix asphalt surfacing. This paper presents an overview of the rehabilitation program of County Road 2 as well as the steps taken by the County of Oxford to develop a cost-effective method for the rehabilitation of composite pavements.

## 2.0 BACKGROUND

The County of Oxford originally built the 19 km section of County Road 2, located between Woodstock and Thamesford, in the 50's. It was built as a concrete road and it was known as the Governor's Road. The concrete remained exposed until the road was transferred to the provincial government in 1978. In 1978, the pavement was widened with HMA and a HMA surfacing was placed over the full width of the new widen roadway. In 1998, the 19 km portion of Highway 2 was transferred back from the provincial jurisdiction to the County of Oxford.

## 3.0 PAVEMENT CONDITION

The original concrete pavement was 225 mm thick by 6.1 m wide. An HMA lane widening of 0.6 m as well as 75 mm of HMA surfacing were placed in 1978. The concrete pavement with the exception of a few areas was placed directly onto the subgrade which consist of a sandy loam type soil. Granular materials was also placed between the subgrade and the concrete pavement in some areas. The Average Annual Daily Traffic on the 19 km section between Woodstock and Thamesford is approximately 10,000 with approximately ten percent commercial traffic. Two cement plants are located on County Road 2 and the two cement manufacturers use it as a haul road.

The Pavement Condition Index (PCI) in 1995, just before the highway was transferred, was about 50. The condition of the existing pavement was considered to be poor. The surface exhibited severe cracking. Blown up joints were relatively frequent. Milling was often necessary to restore the longitudinal profile of the road at the joint. Load transfer from one slab to another was very poor. As a result rocking of the slab was frequent and in many cases the movement of the slabs could be observed with the naked eye. Consequently the riding condition of the road was considered very poor. Photograph 1 shows the typical condition of the County Road 2 pavement prior to rehabilitation.

## 4.0 REHABILITATION PROGRAM

In the late 90's County Road 2 had reached the end of its service life and pavement rehabilitation became imperative. The County's objective was to restore the serviceability of County Road 2, using a rehabilitation method that would provide a smooth ride, an effective mitigation of cracking, and a total elimination of the movement of the slabs. The rehabilitation of County Road 2 was broken down into a three-phase program. An initial 1.25 km testing phase to demonstrate and validate the selected rehabilitation method and two subsequent ≈9.0 km phases to complete the rehabilitation of the 19 km section of County Road 2.

**Photograph 1: Typical condition of County Road 2 prior to rehabilitation**

## 5.0 PHASE 1

The cost of reconstruction, which usually requires removal and replacement, is high and the disturbance to traffic associated with such an operation is significant and in some cases unacceptable. Total reconstruction of County Road 2 was therefore not considered. Nevertheless, rehabilitation of a composite pavement also presents many challenges in terms of cost, effectiveness and possible disturbance to traffic. Furthermore, there is no well-known, well-established cost effective rehabilitation method used in Ontario to rehabilitate composite pavements.

The purpose of phase 1 was to investigate and validate a rehabilitation method that would be used to restore the serviceability of the complete 19 km section of County Road 2. A request for proposal (RFP) was called by the County of Oxford with the idea of generating innovative and cost-effective solutions for the rehabilitation of County Road 2.

### 5.1 Rehabilitation Proposals

The road construction industry responded very well to the County' RFP. Numerous proposals were submitted. The proposals were as follows:

- conventional hot mix asphalt (HMA) surfacing
- cold milling, concrete joint repairs and HMA surfacing
- cold milling, in-place pulverizing of concrete and HMA surfacing,
- complete removal of in-place material, off site crushing, haulage and placement of crushed concrete/old HMA as base material and HMA surfacing,
- cold in-place recycling and HMA surfacing,
- cold milling, in-place rubblizing, placement of reclaimed pavement on top of rubblized surface and HMA surfacing.

## 5.2 Retained Solution

The County of Oxford retained the proposal that included the rubblization of the existing concrete. Cayuga Materials & Construction Co. Limited submitted the retained solution. The detailed proposal consisted of the following operations:

- cold milling the existing surface and placement of reclaimed bituminous material in windrows on shoulder,
- in-place rubblization of concrete slab using resonance breakers,
- placement of windrowed bituminous material back onto rubblized concrete surface,
- placement of 100 mm of HMA surfacing in two lifts,
- placement of shoulder material.

The work was completed in the fall in1999.

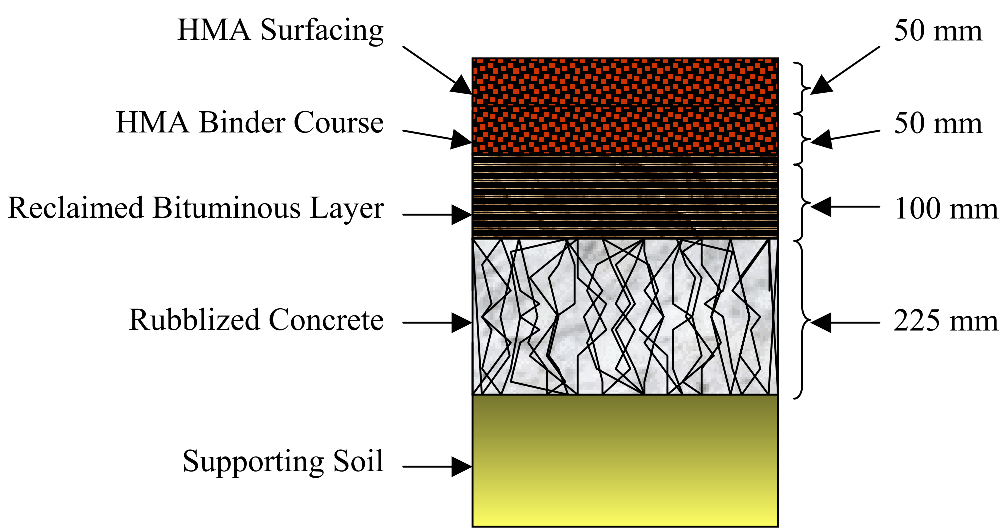


**Figure 1: Pavement design Phase 1**

## 5.3 Difficulties

The difficulties associated with the retained proposal were related to the placement of the reclaimed bituminous material back onto the rubblized concrete surface and the resulting nuisance to the travelling public. The reclaimed material was variable in size and the presence of large chunks (150 mm in size) was frequent. The lack of homogeneity in the reclaimed material impeded the grading operation. As a result, frequent segregated areas were present in the finished surface. Compaction was difficult to control and it appeared to be variable due to the occurrence of segregation.

The surface of the reclaimed material raveled and maintenance was required to ensure the surface remained suitable for the travelling public. The dynamic action of the traffic had an unexpected effect on the rubblized concrete. The reinforced steel mesh, released from the concrete during the rubblization operation, worked its way up through reclaimed bituminous material in a few areas. The disturbance to traffic was considered limited, but not minimal.

Phase 1 was considered a success and as of September 2002 there is no evidence of any distresses or defect over the 1.25 km section.

## 6.0 PHASE 2

With the success and experience acquired during Phase 1, it was decided to carry on with Phase 2 of the project the following year. Phase 2 presented a different challenge with respect to traffic. The section of road to be rehabilitated was substantially longer than Phase 1. It was essential to eliminate the difficulties associated with the placement of an untreated reclaimed material on top of the rubblized concrete.

The County of Oxford has used in-place cold recycling processes successfully for many years in very in many locations throughout the County. To provide a better riding surface for the travelling public during the rehabilitation operations it became evident the reclaimed material needed to be treated and the cold recycling process offered that possibility. The cold recycling process would offer many advantages over the previous solution:

- the existing old surfacing hot mix asphalt would be reused in its entirety
- the cold recycled material would provided a much improved driving surface thereafter eliminating the traffic nuisance issues
- the gain in pavement structural strength provided by the cold recycled material offered the possibility of reducing the thickness of the surfacing layer

The scope of work for Phase 2 of the project included the rehabilitation of an 8.5 km section of County Road 2.

### 6.1 Retained Solution

The County of Oxford retained solution consisted of the following operations:

- cold milling the existing HMA and haulage of reclaimed HMA to a central site
- crush reclaimed HMA to a minus 37 mm material
- in-place rubblization of concrete slab using resonance breakers,
- proof roll rubblized concrete
- cold recycle reclaimed HMA using a cold mix plant (HF-150(M))
- placement of recycled material using conventional paving equipment
- placement of 50 mm of HMA surfacing,
- placement of shoulder material.

### 6.2 Difficulties

The difficulties associated with the work carried out during Phase 2 were related to mechanical breakdowns, placement/gradation of the cold recycled material and development of unstable areas that may have been related to wet weather conditions during construction.

During rubblization the concrete is broken into large interlocking particles of up to 150mm in size. If disturbed, the interlocking effect of the rubblization is lost. It is therefore not recommended to allow traffic to drive the roadway while the rubblized concrete is exposed. The rubblized surface must be covered before traffic can use the roadway again. Once the rubblization starts the chain of production needs to be reliable. Mechanical breakdowns have to be avoided in order to be able to cover the exposed rubblized concrete. Unfortunately, mechanical breakdowns were frequent with the production of the cold recycled material, which created a lack of continuity with the rubblizing operation and delays.

Segregation of the cold recycled material created significant difficulties. The cold recycled material was placed using a standard paver. Standard pavers are sometimes the source of systematic segregation. They are designed to place HMA that are finer than the cold recycled material specified for County Road 2. The cold recycled mixture specified for County Road 2 was coarse and its workability was difficult. Segregation turned out to be very difficult to control and it became a major concern. Segregation was frequent and the mixture was particularly prone to raveling in segregated areas. In some cases, surface raveling became so severe that the recycled mat potholed as well (Photograph 2).

**Photograph 2: Raveling of recycled mat leading to potholing**

After rubblization, proof rolling was performed to seat the rubblized concrete and also to identify potential soft zones or unstable areas. Proof rolling was not totally effective to identify these areas. In many cases the unstable areas would develop with the dynamic action of the traffic riding on the freshly placed cold recycled mat. As a result, sporadic areas of the cold recycled mat would breakup. In some cases the subgrade became sufficiently unstable to cause the protrusion of rubblized concrete chunks through the recycled mat. Photograph 3 shows a localized breakup area of the recycled mat with the appearance of concrete chunks.

The frequent development of unstable areas may have been amplified by wet weather conditions that prevailed in May 2000. The spring of 2000 was exceptionally wet. The complete removal of the HMA cover exposing the concrete may have allowed the rain to penetrate the sub-grade at the slab joints reducing the bearing capacity of the subgrade. In addition, it was found during construction that some of the drains installed in 1978 were plugged, resulting again in a lack of drainage of the subgrade.

**Photograph 3: Localized rapid breakup of recycled mat**

### 6.3 Corrective Measures

Several corrective measures were taken to ensure the success of Phase 2. The frequent mechanical breakdowns of the equipment were mainly related to an unreliable cold mix plant. The subcontractor responsible for the production and placement of the cold recycled material (Miller Paving Ltd.) abandoned the usage of the cold mix plant and brought on site a more reliable mix-paver. The usage of the mix-paver virtually eliminated the ongoing delays in the rubblizing operation and the placement of the recycled mix.

The mix-paver also provided the solution to the segregation problem. The pugmill system of the mix-paver and the outboard driven auger system that distributes the recycled material in front of the paver screed in essence eliminated the occurrence of segregation. No repairs related to segregation were necessary in the section of County Road 2 where the recycled mix was placed using the mix-paver.

At first the unstable areas were repaired using the remove-and-replace method. The remove-and-replace method was still not considered adequate because it created discontinuities in the pavement structure. Furthermore, the dynamic action of the traffic was always creating more unstable areas that would eventually breakup. Not only was a measure needed to be taken to correct the areas that were broken up, but it was also necessary to find a solution to stop the appearance of new unstable areas due to the dynamic action of the traffic.

On a Friday afternoon, because of the weekend and the lack of time to correct a broken up area using the remove-and-replace method, it was decided to place a 50 mm temporary intermediate layer of HMA on top of the broken up area. The intent was to hold the surface for the weekend and on Monday the area would be repaired using the remove-and-replace method. On the following Monday, not only the temporary intermediate HMA layer held the surface, but it appeared to have helped the recycled cold mix to build up strength. The area was no longer moving or showing any signs of deterioration. The remaining unstable areas were corrected using this method.

To stop the appearance of new unstable areas due to the dynamic action of the traffic, it was decided to use this 50 mm HMA intermediate layer method over the entire length of the 8.5 km section. In order to make sure that the appearance of new unstable areas was definitely under control, the placement of the final HMA surfacing was delayed two months. The intermediate layer held up well and no other repairs were required in the two-month period before the placement of the surfacing layer.

Although as of September 2002 there is no evidence of any distresses or defects over the 8.5 km section, Phase 2 was not considered a complete success. The operational difficulties were significant and the phase 2 was not completed on budget as a result of the placement of the intermediate HMA layer.

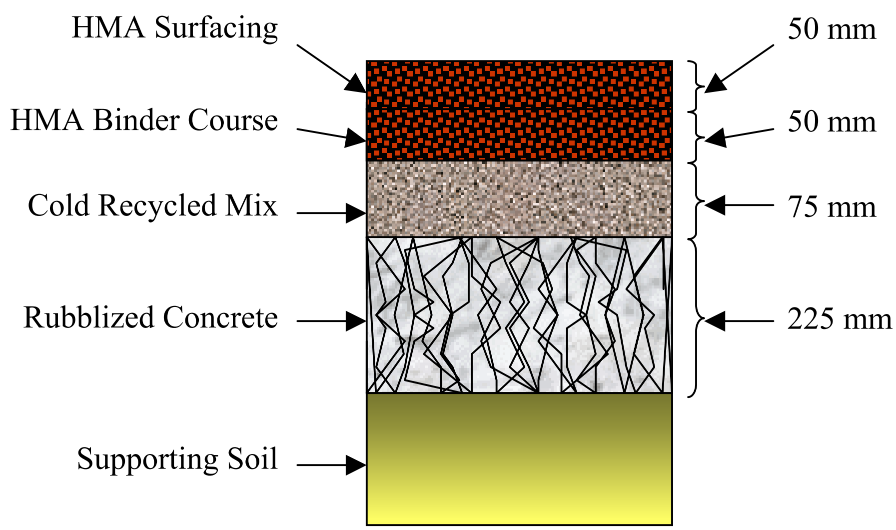


**Figure 2: Final pavement design Phase 2**

## 7.0 PHASE 3

The approach to Phase 3 was different than the previous phases. Phase 2 was not considered a success and it was decided to reengineer the process, to make sure that some of the problems that were encountered in Phase 2 would be avoided or at least controlled during Phase 3. The reengineering of the process needed to address the issues related to:

- the reliability of the chain of production,
- the segregation of the recycled material,
- the early localization and repair of the soft areas,
- the tolerance of the cold recycled material to movement of rubblized concrete.

The County of Oxford worked with Miller Paving Ltd. and McAsphalt Engineering Services to engineer a rehabilitation strategy that would optimize the benefits of recycling along with minimizing operational risks.

The scope of work for Phase 3 of the project included the rehabilitation of the last 8.25 km section of County Road 2 between Woodstock and Thamesford..

### 7.1 Start-up Parameters for Phase 3

The engineering start-up parameters for Phase 3 were as follows:

- removal of existing HMA,
- rubblization of existing concrete and immediate placement of covering material,
- reuse of the reclaimed HMA,
- placement of a HMA surfacing course.

Variable parameters were related to the type, the thickness and the method of production of the paving material to be placed between the rubblized concrete and the HMA surfacing.

### 7.2 Objectives of Phase 3

The first objective of Phase 3 was to minimize the interdependence of the various operations associated with the rubblization of the concrete. The two previous phases clearly indicated that the reliability of the operations of production and placement of the material that covers the rubblized concrete are extremely important. As a result, it was decided to use a process where the production and the placement of the paving material are not linked and the shelf life of the paving material was relatively long. The elimination of the production of the paving material as an operation associated with the rubblization would greatly reduce the risk of not having the proper paving material necessary to cover the rubblized concrete.

The second objective of the 2001 work was to eliminate segregation. The two previous phases clearly demonstrated the necessity to control segregation in order to avoid raveling and breakup of the recycled layer. In previous phases, repair work of the recycled layer was necessary before the placement of the HMA surfacing. The coarseness of the recycled material was identified as the main cause of segregation. Consequently, it was decided to utilize a paving material that would be comparable to a base HMA type material with a maximum size particle of no more than 25 mm. The control of the segregation would reduce the raveling and potential breakup.

The third objective was to use a process that would allow for identification and correction of soft areas before the placement of the HMA surfacing. The two-lift system between the rubblized concrete and the HMA surfacing used in previous phases permitted the identification of all soft areas before the placement of the final surfacing layer. Thus, it was decided to place a two-lift system again to help to identify soft areas early. It was also decided to schedule the work in July to reduce the detrimental effect of associated with wet weather and the final surfacing operation was scheduled six weeks after the placement of the second lift of the two-lift system.

Furthermore, some movement/settlement of the rubblized concrete was observed in the previous phases. It was determined that the selection of a paving material that behaves like a membrane and that could tolerate some movement/settlement of the rubblized concrete without breaking up would be preferable.

### 7.3 Identified Options

Five different options were identified for the rehabilitation of the last section of County Road 2. The two-lift system between the rubblized concrete and the HMA surfacing was used in all cases. The paving materials used to develop these options were conventional HMA, various types of recycled cold mix and conventional granular material. The details of the five options are as follows:

- Option 1: rubblized concrete, conventional cold recycled mix, HMA scratch course and HMA surfacing
- Option 2: rubblized concrete, stockpiled cold recycled mix, conventional cold recycled mix and HMA surfacing
- Option 3: rubblized concrete, stockpiled foam recycled mix, conventional cold recycled mix and HMA surfacing
- Option 4: rubblized concrete, granular material, conventional cold recycled mix and HMA surfacing
- Option 5: rubblized concrete, granular material, foam recycled mix and HMA surfacing.

Pavement designs were established using the AASHTO Guide for Pavement Design (1993). A layer coefficient of 0.30 was used for the recycled cold mix. The estimated Average Annual Daily Traffic (AADT) was estimated at 10,000 and the commercial traffic was assumed to be 10 %. The soil sub-grade was considered soft; a resilient modulus of 31 MPa was assumed. The selected design life was 15 years and the reliability of the proposed design was established at 95 %. Finally, the reliability of each individual strategy was assessed as well as the cost, initial and life cycle cost.

The maintenance associated with the temporary granular material surfacing included with Option 4 and 5 was considered unsatisfactory and therefore those two options were rejected. Option 3, even though it was considered an excellent option, it was also rejected because the foam technology for a cold mix plant was not available in Ontario at that time. Finally, Option 2 was considered the best option because it was less expensive, initial cost and life cycle cost, than Option 1. Furthermore, all the existing HMA would be recycled which was not the case with Option 1. Finally, Option 2 was also favoured over option 1 because of the possibility of stockpiling the recycled cold mix. The stockpiling capability of the recycled cold mix offered the possibility of separating the production and the placement of the mix to cover the rubblized concrete. In phase 2 of the project, the simultaneous production and placement of recycled cold mix on top of the rubblizing concrete was a constant source of difficulties.

### 7.4 Retained Solution

The pavement design for option two consisted of 75 mm of stockpiled cold recycled mix over the rubblized concrete, 60 mm of a conventional cold recycled mix and 50 mm of HMA surfacing (Figure 3). To avoid segregation, it was required that the cold recycled mixture be crushed to a minus 25 mm maximum size. This thickness of the independent layers resulted in a calculated Structural Number ($SN_{Calculated}$) of 5.26, where the required Structural Number ($SN_{Req}$) was 5.25 In addition, the selected structural design was re-evaluated to calculate reliability for an 18 year service life and was determined to be at a reasonable level of 90%.

The amount of existing HMA to be extracted from the roadway was not sufficient for the production and placement of the total amount of recycled mix needed for the new pavement design. To supplement the reclaimed HMA a granular material was added to the crushed reclaimed HMA. The split between the two materials was 80 % reclaimed HMA and 20 % granular material. Because of the presence of virgin aggregate in the cold recycled mixtures cationic emulsions were specified. Standard Ontario Specifications were used except for the rubblizing operation and the emulsion used to produce the stockpile cold recycled mixture.

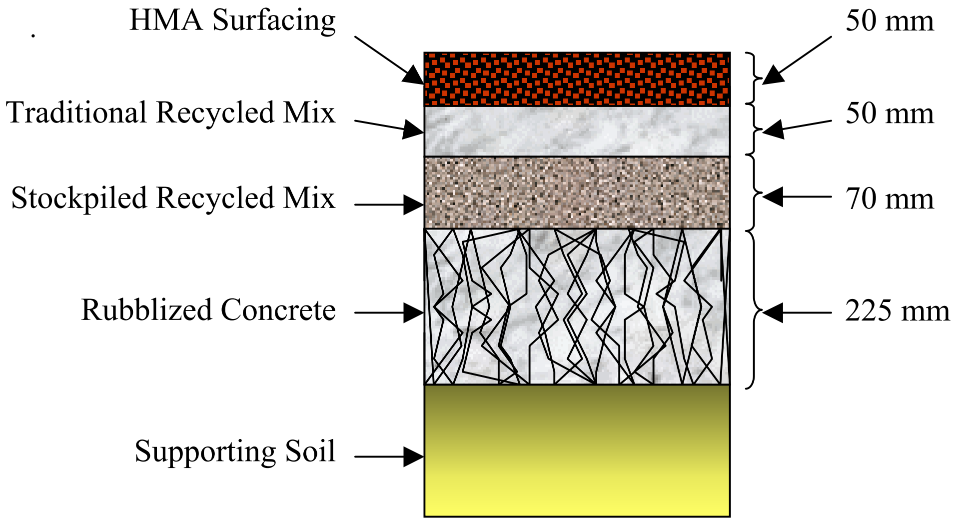


**Figure 3: Retained pavement design Phase 3**

The retained solution for phase 3 of the project consisted of the following operations:

- cold milling the existing HMA and haulage of reclaimed HMA to a central site
- crush reclaimed HMA to a minus 25 mm material
- production of a cold recycled mixture (stockpile mixture)
    - blend of reclaimed HMA & granular material
    - conventional cold mix plant operation
- rubblize concrete slab using resonance breakers,
- proof roll rubblized concrete
- place stockpiled material onto rubblized concrete
    - conventional placement operation
- produce & place a second layer of cold recycle mixture
    - blend of reclaimed HMA & granular material
    - conventional cold mix plant & placement operation
- place HMA surfacing,
- place of shoulder material.

The milling operation was carried out using a standard 2-m milling machine. The full depth of the existing HMA was removed as well as the underlying surface of the concrete leaving a bear concrete surface (Photograph 4) which is required for the rubblizing operation. Three resonance breaker machines working in echelon were used to rubblize the concrete (Photograph 5 & 6). A 12-tonnes single drum roller was used to proof roll the rubblized concrete.

The stockpiled cold recycled mixture was produced using a two-bin cold mix plant (Photograph 7). A stockpile of cold recycled mixture was produced every day. The stockpiled mixture was placed onto the rubblized concrete approximately 24 hrs after being produced (Photograph 8). The rubblizing operation would start only when sufficient recycled cold mix was already produced to cover the daily area rubblized. The placement of the cold recycled mix was carried out using conventional paving equipment.

The first layer of cold recycled material cured for about five to seven days (Photograph 9) before the second layer of conventional cold recycled mixture was placed. The total curing time for the two layers of recycled material was approximately four weeks before the HMA surfacing was placed. Phase 3 of the project was completed at the end of August 2001 (Photograph 10).

**Photograph 4: Milled surface of concrete slab before rubblization**


**Photograph 5: Resonance breaker working in echelon**

**Photograph 6: Resonance breaker shoe**

**Photograph 7: Two-bin cold mix plant**

**Photograph 8: Stockpiled recycled cold mixture**

### 7.5 Difficulties

No difficulties were encountered in phase 3. The rubblizing and the recycling work was carried out in July and the weather was particularly warm and dry. The rubblizing work and the recycling work were performed in less time than anticipated. The rubblizing operation was never slowed down or stopped because of a breakdown in the chain of production. Using a minus 25 mm recycled mixture eliminated segregation. The occurrence of soft areas was greatly reduced by performing the work in warm and dry weather but also because the stockpile recycled mixture did tolerate movement/settlement of the rubblized concrete. Phase 3 was considered a success and the work was performed well within budget. As of September 2002 there is no evidence of any distresses or defects over the 8.25 km section.

## 8.0 CONCLUSIONS

The County's objective was to restore the serviceability of County Road 2, using a rehabilitation method that would provide a smooth ride, an effective mitigation of cracking, and a total elimination the movement of the slabs. Even though there were construction difficulties in phase one and two, the County of Oxford still achieved that objective by using rehabilitation methods that combined the rubblization of concrete with cold recycling of existing HMA. The current restored roadway is free of cracking and potential slab movement, and the resulting ride meets the County's expectation. The rehabilitation method using rubblization and cold recycling turned out to be 30 to 40% more economical when compared to a traditional reconstruction alternative.

Innovation in this project was a very important component of its success. The road building industry responded very well to the County's request for proposals. The selected rehabilitation method was certainly not considered a text book solution. All parties involved assumed risks and fully cooperated in this project. Difficulties were encountered during the first two phases of the project. The method of construction was refined with every phase of rehabilitation and phase 3 was considered a full success with no significant difficulties encountered by any parties involved.

**Photograph 9: Cured stockpiled recycled cold mix**

**Photograph 10: Completed project**