Full Depth Remediation of Roads Using Portland Cement

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Abstract

Full depth reclamation (FDR) utilizing Portland cement has been utilized successfully for over 25 years worldwide for the rehabilitation of severely failed pavements. The process involves the mixing of Portland cement into the pulverized existing road in order to achieve certain strength requirements, and offers a sustainable alternative to traditional rehabilitation processes. Historically, the process has met with mixed success, primarily due to the opinion that the more cement the better. This has led to over-cementing and subsequent shrinkage cracking of the recycled material, ultimately resulting in reflective cracking in the asphalt wearing course.

Modern practices consider significantly reduced Portland cement additions that produce a less brittle material. Furthermore, pre-cracking of the cement stabilized material allows for a matrix of small micro cracks on the surface that eliminate the risk of shrinkage cracks occurring.

This paper gives an overview of the FDR process together with a description of the pre-cracking process utilized in Nova Scotia. It is also demonstrated that greenhouse gas emissions are significantly reduced when FDR with Portland cement is used compared to a traditional maintenance strategy.

1. Introduction

Pavement rehabilitation requires significant resources and is placing ever-increasing demands on non-renewable aggregate resources (aggregate quarries and pits), fuels and binders (asphalt cements). The need for non-renewable resources and the constant increases in oil prices render traditional pavement rehabilitation techniques, costly with a significant environmental footprint. Additionally, there is also pressure from a waste management perspective in order to minimize construction waste taking up valuable space in ever scarce landfills, particularly when a large proportion of this waste can be reused. Therefore, there is a general acceptance that a much more sustainable approach to pavement maintenance is required to reduce greenhouse gas emissions, whilst still maintaining a strong, durable material suitable for the construction and maintenance of the highway network.

An alternative to using non-renewable resources for highway maintenance is to recycle the material from the failed section of road that requires maintenance. Thus the road itself becomes the quarry for the supply of the required aggregates. Recycling of the road has been a widely accepted practice around the world since the petroleum crisis in the early 1970s and can either be performed as an in-situ or an ex-situ operation. Due to inflated oil prices and the development of milling and reclaiming equipment a favorable and emerging market was created for recycling/reclaiming technologies for highway pavements.

Typically, the failed section of road is pulverized to a certain depth and stabilizing agents are blended with the crushed material. The treated material is then compacted, and is used to form a stabilized base course to which a single or double layer of hot mix asphalt is applied.

Depending upon the type of road and the nature of deterioration several recycling/reclamation options are available to the pavement engineer. For surface based distresses (not resulting from subgrade or sub-base failure) partial depth or hot in-place recycling strategies are most applicable. Where deeper seated failures occur, FDR offers the ability to address sub-base failures. This process has been widely utilized across Europe and the USA for many years. Although not commonly utilized in Canada, the province of Nova Scotia has recently adopted FDR rehabilitation strategies utilizing Portland cement as the stabilizing agent.

2 FDR with Portland Cement

FDR with Portland cement, as the name suggests, involves the rehabilitation of the full thickness of asphalt pavement, and a predetermined portion of the underlying material (base, sub base and/or subgrade) using Portland cement as the stabilizing agent. The depth of treatment typically varies from 200-300mm, depending upon the thickness of the existing pavement, traffic volume and condition of the existing road. Processing depths greater than 300mm are not common as compaction requirements are difficult achieve.

The Portland Cement Association (PCA), together with the Asphalt Recycling and Reclaiming Association (ARRA) suggest that FDR is appropriate under the following conditions:

- Where the pavement has inadequate structural capacity for current and future traffic.
- Where the existing condition of the pavement requires full depth patching over more than 15-20% of the surface area.
- Where the existing pavement distress indicates that the problem is a function of a base or subgrade failure.
- Where the condition of the pavement is so seriously damaged that re-surfacing or “mill and fill” operations will not address the level of deterioration.

The above conditions can result as a function of the following types of pavement distresses:

- Severe fatigue, slippage, block, longitudinal and reflection cracking.
- Severe rutting, corrugations and shoving.
- Severe loss of surface integrity due to raveling, potholes and bleeding.

Figure 1 depicts typical candidates where FDR with Portland cement is applicable.

Figure 1 Appropriate candidates for FDR with Portland Cement.

Once an appropriate candidate for FDR has been identified a field investigation should, be performed, if possible, to determine the nature of the materials in the existing pavement structure. The purpose of the field investigation is twofold. Firstly, the thickness of the pavement layers can be determined. Secondly, materials from each of the pavement's layers to be recycled can be retrieved in order for a laboratory mix design to be performed.

Field investigations typically comprise cores and/or small trial pits. Regardless of the methodology utilized the depth of intrusion should not exceed 300-400mm (i.e., no deeper than the depth of proposed treatment).

Cores are a good way of determining the depth of asphalt layers and the nature of the underlying material. Larger cores (250-300mm) are required so that enough material can be retrieved to perform the necessary laboratory mix designs (see Figure 2).

Figure 2 Large diameter coring and retrieval of underlying material.

Ideally, the material retrieved from either coring or trial pit activities should be kept separate. This allows for easier blending during mix design procedures when undertaking the laboratory mix design.

The number of sample locations is a function of the size of the contract. Smaller contracts clearly require fewer exploratory holes than larger contracts. The Transportation Research Laboratories (TRL) recommends that the sample frequency should not be less than 1 every 500m^2. However, for large projects significant samples locations would be required if this sampling frequency were to be utilized.

During field investigations it is also advisable to note any significant issues relating to drainage and/or road geometry as FDR operations offer a good opportunity to remedy such problems.

Furthermore, during field investigations some agencies also perform non-destructive testing to assess the structural capacity of the underlying subgrade. This is primarily undertaken to ensure the strength of the subgrade is sufficient to offer enough resistance to allow for the FDR layer to be adequately compacted. Non-destructive testing undertaken typically comprises Falling Weight Deflectometer (FWD) testing or Dynamic Cone Penetrometer (DCP) testing.

3 FDR Mix Design

Material retrieved from the field investigation is used to perform the FDR mix design. The purpose of the mix design is to determine the appropriate addition of cement that meets the engineering requirements and that is also cost effective. Laboratory tests are performed on the untreated material (i.e., as retrieved material from the field) and the material treated with Portland cement. The tests typically performed are as follows:

- Gradation of the pulverized reclaimed asphalt pavement (RAP) and granular base material (pre-treatment).
- Unconfined compressive strength of the blended RAP and granular base material at varying cement concentrations (typically 3-6%).
- Compaction characteristics of the blended RAP and granular base material with the mix design concentration of Portland cement.

Pulverization of the RAP material is an important aspect of the mix design process and should replicate, as closely as possible, anticipated field conditions. Although no specific crushing systems/processes are specified, care should be taken so that the resultant material is not too coarse or too fine as this can affect the cement requirements of the mix. Typically, a coarser gradation of material will require more cement than a finer gradation. In some cases the crushing and sieving of the material may be an iterative process until the desired gradation is achieved. If required, it may be necessary to mix additional fines to the material to increase the fines concentration of the mix in order to replicate field conditions more closely. The fines material can comprise of any inert (non-reactive) material, including flyash, crusher fines, etc.

Another important aspect of the mix design is determining the optimum moisture content (OMC) of the treated mix. The cement-treated material should be compacted as close to the OMC as possible. This increases the densification of the material and results in greater strengths being achieved. Compaction at, or near the OMC also reduces the concentration of air voids and ensures the material is not sensitive to water ingress. It is not advisable to compact the cement treated material at moisture contents above the OMC as too much water can result in excess drying. This will result in significant shrinkage cracks occurring, which may compromise the durability and integrity of the treated layer.

Unconfined compressive strength (UCS) tests are performed to determine the concentration of Portland cement required to achieve the desired engineering properties. The PCA recommend that a 7-day moist cure strength of between 2.1 to 2.8 MPa is desirable for FDR applications. This strength prevents the treated material from becoming too brittle, which may result in cracking of the layer under traffic loading. UCS tests are performed at varying cement concentrations on materials prepared at, or near the OMC. Generally, cement concentrations varying from 3-7% are investigated. The design concentration is typically the lowest cement concentration achieving the desired strength.

4 FDR Construction Process

The FDR construction process is relatively simple once the mix design has been developed. The process comprises the following phases.

- Pulverization of existing pavement to the desired depth.
- Spreading and mixing of the cement.
- Compaction of the treated material.
- Placement of the final surface course.

Figure 3 schematically represents the process described above. It should be noted that it may sometimes be necessary to mill part of the pavement prior to FDR operations.

This is necessary for two reasons. Firstly, it may not be possible to increase the elevation of the roadway due to overhead obstructions. Secondly, the thickness of the existing asphalt surface may have to be reduced to allow pulverization and incorporation of part of the underlying granular base.

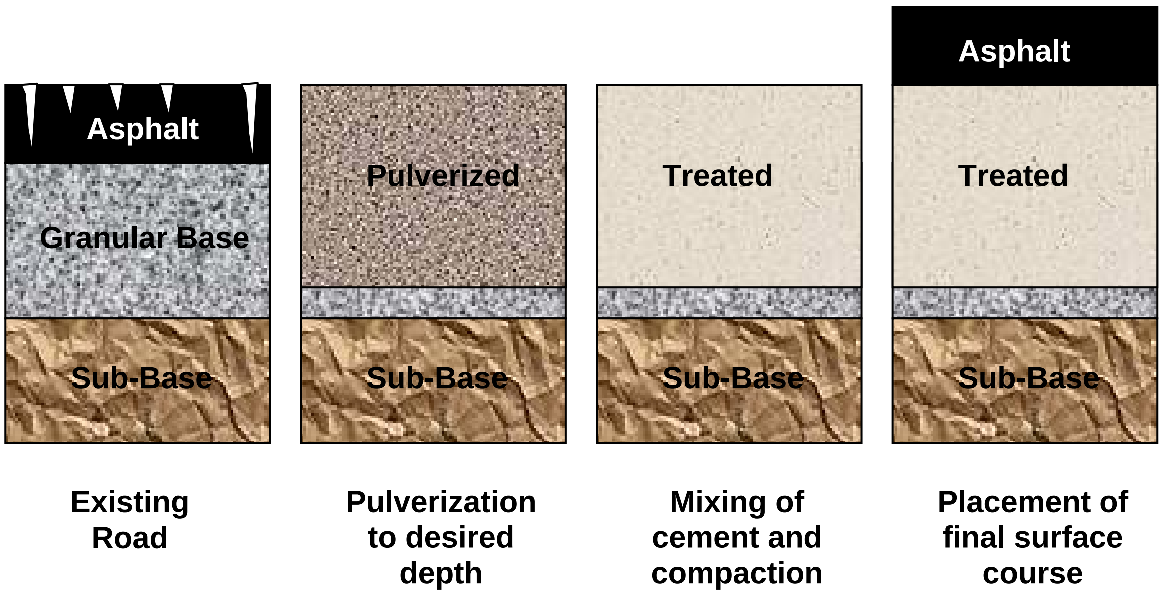


Figure 3 Schematic of the FDR process.

4.1 Pulverization Operations

Typically pulverization operations exceed the depth of the asphaltic surface course. This ensures incorporation of the underlying granular base material. Modern equipment can pulverize up to depths of 450mm; however, 200-300mm is the preferred depth as compaction of the material in lifts greater than 300mm is not practical. Where pulverization operations are being performed in urban areas care must be taken to accommodate for ironworks and curbs. Figure 4 illustrates typical pulverizing equipment utilized.

After pulverization operations, and if required, grading of the pulverized material can be performed. The pulverized material is easy to re-grade and offers a good opportunity to re-shape the road prior to treatment. Grade corrections typically include improvement to the road crown, super elevation and drainage.

Figure 4 Pulverizing equipment used for FDR operations.

4.2 Cement Addition and Mixing

Cement is typically spread on the surface of the pulverized material in a controlled manner. Cement is primarily spread as a dry powder (see Figure 5); however, in urban areas cement can be distributed in a slurry form to eliminate the potential for dust generation. The cement is added as a percentage of the weight of material being treated. Spread rates are typically calculated on a weight being distributed per square metre.

Once spread the same equipment utilized for pulverization operations is used to mix and blend the cement into the pulverized material. This is typically achieved in one pass. During mixing water is introduced into the milling drum via a water truck (see Figure XX). This is necessary to ensure that the correct amount of water is added to the cement treated material to ensure compaction at the desired OMC.

Figure 5 Dry cement application and mixing operations.

4.3 Compaction and Final Grading

After mixing operations are complete compaction to the desired specification is required. Initially, the material should be compacted utilizing a pad foot roller (see Figure 6). This ensures adequate compaction of the bottom of the treated layer. Once the initial compaction has occurred re-grading may be required to maintain grade and elevation. Once graded, final compaction can take place. This is typically achieved using a smooth wheel roller (see Figure 6).

Figure 6 Pad foot (initial compaction) and final compaction operations.

5 Cracking and Minimization of Cracking in FDR Cement Treated Bases

Cracking occurs in cement treated materials as a result of volume change. This can occur for a number of reasons, such as cement hydration, water evaporation from the treated material and temperature change. Shrinking, and subsequent cracking, occurs in the early life of the treated layer. As the treated layer shrinks, its movement is resisted by friction by the underlying granular layer. This results in tensile forces in the treated layer. The build up of these tensile forces can generate cracks in the treated material. These cracks only become deleterious to the durability of the pavement if they are typically greater than 2.5mm.

Excessive shrinkage can be prevented by proper design and control of the proportioned cement and water content in the treated material.

One of the most common causes of excessive shrinkage is by providing more water than is needed to achieve the desired maximum density. This creates two problems. Firstly, the compacted material contains higher amounts of moisture filled pore space, reducing its resistance to shrinkage cracking. Secondly, the excess moisture is available for evaporation, making the material more susceptible to drying shrinkage.

Excessive cement content increases the amount of shrinkage which occurs as higher amounts of moisture are consumed during the hydration process. The strength and stiffness of the treated material are also increased, resulting in larger crack spacing and wider cracks that subsequently develop in the material.

Failure to meet maximum density in compaction creates an abundance of pore space in the material, reducing its volumetric stability (resistance to shrinkage cracking) and increasing the hydraulic conductivity of the material, allowing it to dry at a faster rate.

Proper curing is needed to ensure adequate moisture is available to prevent excessive drying shrinkage. Generally, water is sprayed from supply trucks onto the material as soon as the final grading and compaction have been completed in order to replace surface moisture that has evaporated, and to replenish internal moisture that has been consumed during the hydration process. Curing water should be applied to the surface of the treated material for at least seven days following construction to sufficiently hydrate the Portland cement, and to develop resistance to further shrinkage stresses. Alternatively, a curing membrane can be applied to the surface of the treated material as soon as final compaction is completed. The curing membrane typically comprises an asphaltic tack coat.

A method which is gaining popularity in helping to prevent reflective cracking from the stabilized material to an asphalt overlay is micro-cracking. Micro-cracking involves the application of several passes from a vibratory steel drum roller onto the treated material (see Figure 7). Micro cracking typically occurs 24-48 hours after final compaction. The same vibratory roller used for final compaction is preferred, in order to avoid overloading the material whilst minimizing the number of passes required. This secondary rolling introduces a network of closely spaced hairline cracks throughout the surface of the stabilized layer. These cracks help to relieve the shrinkage stress during the early life of the treated layer which will minimize the development of wide shrinkage cracks. Micro-cracking does not impact the pavements overall structural capacity as the material is self healing in its early life. Nevertheless, the introduced “flaws” assist in relieving shrinkage stresses in the long-term.

Figure 7 Inducing micro cracks and the treated material before and after rolling

Micro-cracking is typically conducted after a 24-48 hour period after final compaction. Sufficient passes of the vibratory roller are applied to reduce the modulus (stiffness) by at least 40%. This encourages the development of a sufficiently distributed network of micro-cracks. Micro-cracking tends to produce a smoother surface finish on the treated material (see Figure 7) and when properly conducted, does not tend to create large visible surface opening cracks.

The modulus of the treated material is typically measured in-situ using one of several techniques, which may include the Humboldt Geogauge, a Slab Impulse-Response System (Slab IR), or a portable/lightweight Falling Weight Deflectometer (FWD). Results obtained in Nova Scotia to date, utilizing the above method, have been very encouraging.

6 Environmental Benefits of FDR with Portland Cement

The demand for non-renewable resources and the constant increase in oil prices is making traditional pavement rehabilitation techniques, costly and less environmentally sustainable. Therefore, there is a general acceptance that a much more sustainable approach to pavement maintenance is required to reduce greenhouse gas emissions whilst still maintaining a strong, durable material suitable for the construction and maintenance of the highway network. FDR with Portland cement offers such an alternative. The environmental advantages of utilizing FDR with Portland cement include:

- Re-use of a failed section of pavement reduces the demand on non-renewable aggregates.

- Less quarrying, processing and production required.
- Hauling of materials to and from site is minimized.

The result of the above is a significant reduction in greenhouse gases as a result of recycling of pavements utilizing FDR with Portland cement.

6.1 Environmental Benefits of Using FDR with Portland Cement in Nova Scotia

AMEC Earth and Environmental, Nova Scotia, has recently developed software that analyses greenhouse gas emissions as a result of highway maintenance processes. The software performs a cradle-to-cradle approach analysis to determine environmental benefits from alternate approaches to maintenance (i.e., comparing traditional maintenance processes to recycling maintenance processes). The software considers all greenhouse gas production from material extraction to completion of the project. Three main greenhouse gas generating phases are considered in the analysis.

- **Material Production** (including extraction, transportation, processing, refining, storage and associated upstream greenhouse gas generation)
- **Material Processing** (including blending and production of pavement materials, transportation of processed material and associated upstream greenhouse gas generation).
- **Material Handling/Placement** (including transportation of material, placement of material at the project site and associated upstream greenhouse gas generation).

Since 2007, Nova Scotia Transportation and Infrastructure Renewal (NSTIR) has successfully rehabilitated approximately 35km of its highway network utilizing FDR with Portland cement. The sections of road selected for FDR with Portland cement were ideal candidates due to the major structural distress (see Figure 8). Traditionally, these roads would have been reconstructed using a “gravel sandwich” approach. This typically comprises the milling of a portion of the pavement section (50-75mm) and the placement of approximately 150mm of Type 1 gravel on the milled surface; a surface course (50mm deep) is then placed. However, this solution is not always possible as the elevation of the road is raised significantly. FDR offers a cost-effective and environmentally sustainable alternative that does not alter the elevation of the road significantly.

Figure 8 Pavement distresses at Main-a-Dieu and Point Michaud before FDR

In order to assess potential greenhouse gas reductions resulting from utilizing the FDR process a comparative analysis was performed, using the AMEC's proprietary software, between the completed FDR sections and the traditional gravel sandwich approach.

Table 1 presents the geometrical data of all FDR project sections. Table 2 and Table 3 present material quantities for the FDR and gravel sandwich option respectively, based on geometric data presented in Table 1 and actual quantities of material utilized.

Table 1 Geometry of the project sections of roadway

Project	Length (km)	Area (m^2)	Surface course (tonnes)
Point Michaud Rd.	6.8	60,000	5,600
Main-a-Dieu Rd.	4.7	41,500	8,800
Glenelg Church Rd.	5.0	44,200	4,200
Mt. William Rd.	5.3	31,750	4,550
Scotch Lake Rd.	7.9	52,000	6,650
Big Baddeck Rd.	5.5	38,600	4,690

Table 2 Quantities of material required for FDR

Project	Volume of FDR (m^3)	Cement (tonnes)	Surface course (tonnes)
Point Michaud Rd.	9,000	864	5,600
Main-a-Dieu Rd.	6,225	598	8,800
Glenelg Church Rd.	6,630	636	4,200
Mt. William Rd.	4,760	457	4,550
Scotch Lake Rd.	7,800	749	6,650
Big Baddeck Rd.	5,790	556	4,690

Table 3 Quantities of material required for alternate gravel sandwich approach

Project	Milling Area (m^2)	Type 1 for gravel sandwich (tonnes)	Surface course (tonnes)
Point Michaud Rd.	60,000	21,600	5,600
Main-a-Dieu Rd.	41,500	14,900	8,800
Glenelg Church Rd.	44,200	15,900	4,200
Mt. William Rd.	31,750	11,400	4,550
Scotch Lake Rd.	52,000	18,700	6,650
Big Baddeck Rd.	38,600	13,900	4,690

In addition to the above, the following assumptions were made for the analysis:

- All milled material was transported via truck to the closest NSTIR depot. The distance from the project site to the depot was kept constant at 30km.
- A distance of 30km from the aggregate quarry to the project site (gravel sandwich option only) was utilized for all project sections.
- A 0km haul distance was used for the aggregate to the HMA production facility (i.e., all HMA production facilities were located in the quarry).
- The haulage distance for cement was assumed to be 100km for all project sections.
- The haulage distance for asphalt cement (both maintenance options) was assumed to be 100km for all project sections.

Using the data presented in Tables 1 through 3 and the assumptions listed above, the environmental analyses were performed utilizing AMEC's proprietary software. The results of the analyses have been summated for all 6 project sections and are presented in Tables 4 and 5. Figure 9 graphically represents the summated greenhouse gas production, in terms of CO_2, for all 6 project sections and has been broken down into each of the three generating phases, i.e. material production, processing and handling/placement.

The software utilized to analyse the environmental impact of highway maintenance strategies considers five major emission parameters; CO_2, NO_2, PM_{10}, SO_2 and CO. Results from the environmental analysis demonstrate that significant reductions in all emission parameters were realized when utilizing the FDR with Portland cement strategy compared to the traditional gravel sandwich maintenance strategy.

Table 4 Emissions produced per generating phase for all six projects

Parameter	FDR with Portland cement option	Gravel sandwich traditional option
Material Production		
CO_2 (kg)	2,041,000	2,407,000
NO_2 (kg)	20,454	12,466
PM_{10} (kg)	6,650	20,797
SO_2 (kg)	393,929	403,247
CO (kg)	8,512	5,688 8,512
Material Transportation		
CO_2 (kg)	53,000	460,000
NO_2 (kg)	2,813	24,533
PM_{10} (kg)	571	4,804
SO_2 (kg)	1,472	169
CO (kg)	234	2,044 234
Material Handling and/or placement		
CO_2 (kg)	72,000	74,000
NO_2 (kg)	1,652	1,515
PM_{10} (kg)	118	108
SO_2 (kg)	10	110
CO (kg)	326	358

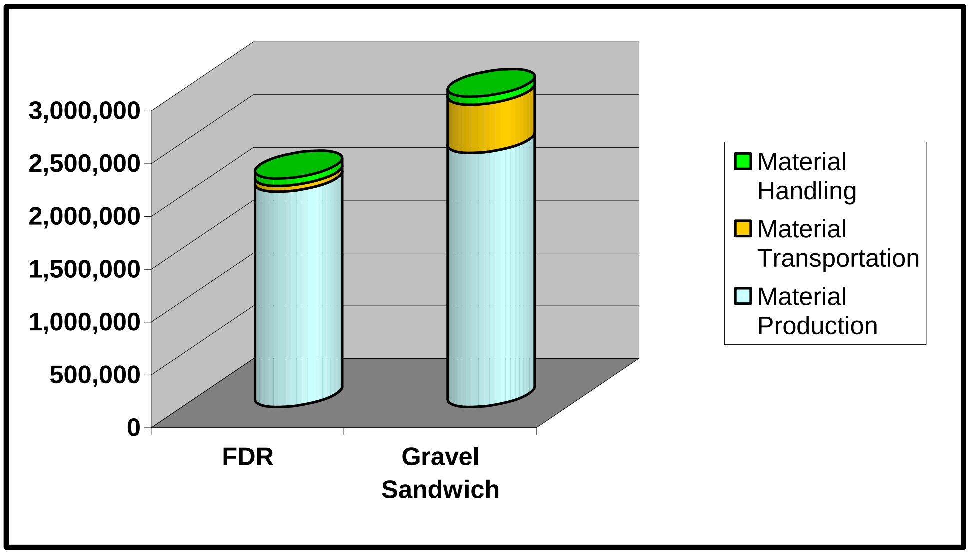
The most significant reduction is that of CO_2. CO_2 is a greenhouse gas and is responsible for global warming. Reducing CO_2 emissions can assist in reducing the effect of global warming. When comparing the FDR strategy with the tradition gravel sandwich strategy a reduction of nearly 27% was achieved. This equates to 775,000kg of CO_2.

Detailed analysis of the results indicates that the majority of the CO_2 savings are accrued during the material production and material transportation phases of the project (see tables 4 and 5 and Figure 9). The reason for this is twofold. Firstly, fewer non-renewable resources are being extracted and processed when the pavement is recycled. Secondly, due to the recycling process and the utilization of the in-situ material, fewer haulage trucks are used.

Table 5 Total emissions generated for the FDR and gravel sandwich option

Parameter	FDR with Portland cement option	Gravel sandwich traditional option
CO_2 (kg)	2,166,000	2,941,000
NO_2 (kg)	24,919	38,514
PM_{10} (kg)	7,339	25,709
SO_2 (kg)	395,501	403,526
CO (kg)	8,058	9,104

Figure 9 Total CO_2 greenhouse gas emissions (kg) for the FDR and gravel sandwich option during material production, processing and handling



The analysis has demonstrated that significant environmental benefits can be achieved when adopting an FDR with Portland cement strategy when compared to the traditional gravel sandwich strategy. The reduction in environmental impact can be quantified in terms of emission reductions per km of road maintained for each of the emission parameters. For the FDR projects analysed these results are presented in Table 6

Table 6 Reductions in emissions per km resulting from FDR

Reduction in emissions (kg/km) per Parameter				
CO_2	NO_2	PM_{10}	SO_2	CO
22,143	388	525	229	30

7 Conclusions

FDR with Portland cement offers the pavement engineer a rehabilitation strategy that replaces the need for major road rehabilitation strategies, particularly where sub-base failures are prevalent. Not only does the process offer the ability for the structural capacity of a failing road to be enhanced, but also offers the pavement engineer a more sustainable approach to pavement rehabilitation.

Appropriate field investigations, material retrieval and laboratory mix design procedures are essential in ensuring the success of the process. These preliminary investigations help in providing important information for quality control during construction operations.

All FDR sections constructed in Nova Scotia to date have utilized pre-cracking methodologies. This has help to control and mitigate shrinkage cracking of the treated layer.

When compared to the traditional gravel sandwich maintenance strategy, 27% less CO_2 emissions were generated when a FDR with Portland cement strategy was adopted. The greatest reduction in CO_2 was realized during the material production and material transportation phases due to reduced extraction, processing and hauling of materials.

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