MAINSTREAMING THE USE OF GREEN CONSTRUCTION MATERIALS IN RURAL ROADS IN INDIA

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ABSTRACT

There is an increasing scarcity of traditional road construction material in India. In addition are the high costs of transporting construction materials, rampant environmental degradation, as well as climate change impacts. There is a need to explore the increased use and mainstreaming of more sustainable road construction materials and technologies in rural roads in India. This would help focus on climate change mitigation and adaptation aspects, and generate significant positive economic benefits.

The Central Government and several State Governments in India have already started taking initiatives in this direction. The Ministry of Rural Development has issued Guidelines for a mandatory use of innovative and green construction material and technology for 15% of the roads in the PMGSY programme. Active discussions are also on for increasing this to 30% in the next phases. Several other states are mandating similar targets.

Many of the local/marginal materials require additional research before they can be used on a wider scale in India, which should be done through full-scale trial sections. Techniques for monitoring and evaluating the results from such trials would be critical to their sustained long-term use. The success of such a framework would, at its core, require developing a programme of research and a new approach to training of engineers that would involve creation of national and state-level "champions" through specific and sustained training. This paper aims to elaborate on such a framework. It is relevant to theme 7: "Sustainable and Green Transport Infrastructure" and sub-theme "Impact of Using Local/Marginal Materials".

KEYWORDS

"green", "sustainable", "local", "marginal", "PMGSY", "climate change", "mitigation", "adaptation".

1 CONTEXT

The increased use of more sustainable road construction materials and technologies in rural roads in India is a critical requirement in view of the increasing scarcity of traditionally used road construction material, high costs of transporting construction materials over distances as high as 400 km, and rampant environmental degradation, as well as other impacts caused by the mining of sand and aggregates (with climate change impacts) – all of which are unsustainable practices. This is also necessary in order to address the increasingly felt need to make investments "climate-smart" by addressing both climate change mitigation and adaptation aspects of the rural roads constructed. In doing so, it has potential to actually create opportunities for local employment ("green growth").

2 USE OF LOCAL NATURAL AND RECYCLED IN-SITU MATERIALS

Local natural materials consist of those materials that are naturally in their current form (state) and position as a result of geological and geomorphological processes. These make up the bulk of materials currently used in road construction. Such materials would normally be classified into one of the following groups:

- Fresh/unweathered rock
- Residual soils
- Transported material
- Pedogenic materials

The use of natural gravels in road construction is not a sustainable option in the long-term, thus other material options should be pursued in the interest of sustainability.

Although the majority of low volume roads in India are being developed from old tracks and paths, the need to rehabilitate or reconstruct older and failed roads (preferably with minimal traffic disruption) is increasing rapidly. Relatively new technologies involving cold in situ recycling of such roads are highly cost-effective options. The technology to carry this out rapidly and effectively has developed in leaps and bounds over the past 10 or 15 years and the equipment, although expensive, is now relatively common among larger construction companies in most parts of the world, including India.

There are, however, problems and limitations with the technology that need careful design and supervision on any project. These include the variability of the existing materials in the road resulting from prior road repairs in the past, variable layer thicknesses, etc. and the usual procedure of widening lanes during recycling and the associated material properties (i.e. incorporating shoulders and new material over previously un-trafficked areas). These can be overcome with careful design, the correct choice of stabilizing agent and good supervision during construction. The understanding in this regard is increasing day by day around the world.

3 USE OF BY-PRODUCT MATERIALS

In order to promote “greenness” in road construction, the use of non-natural materials should be increased as far as possible. These include by-products from most industrial enterprises (e.g. mining, manufacturing, industrial, power generation, etc.) as well as wastes produced in the urban environment (small industrial, construction and demolition wastes and even domestic wastes).

These materials have mostly been through a severe comminution and often a heating process; they thus generally incorporate a significant quantity of “embodied energy” due to their primary processing (as opposed to using a lot of additional energy in their production for use in roads). Their use also involves considerably less emissions than the processing of an equivalent quantity of natural material.

A summary of the potential waste materials, classified by their locations and including highlights regarding their potential uses and problems is shown in Table 1. The need for additional research is probably common to most of these products and is not identified individually in the Table.

TABLE 1 Classification and Summary of uses and Properties of By-Product Materials

Classification of by-product material	Possible uses	Potential problems	Special requirements
Urban by-products			
Crushed concrete	• Base • Sub-base • Concrete aggregate	• Can lead to over-stabilization	• Requires careful sorting at collection point • Requires crushing and screening
Aluminum industry wastes	• Below sub-base • Stabilizer	• Very fine material • Often mixed with other wastes	• Unknown at this stage
Construction and demolition waste	• Base • Sub-base • Concrete aggregate	• Requires careful processing/sorting • May contain a lot of deleterious materials	• None – should behave as a normal aggregate
Tires	• Below sub-base • Bitumen modifier • Concrete aggregate	• Variability of rubber types in tires (natural and synthetic)	• Requires innovative research (e.g. highly flexible pavements) • Collection, sorting and processing must be formalized
Foundry sand	• Sub-base • Below sub-base • Mechanical stabilizer	• Fine grained • May contain unusual chemicals (release agents`)	• Unknown at this stage
Cement kiln dust	• Stabilizer	• Very fine dusty material • Pozzolanicity lost with storage	• More rapid construction (quicker reaction rates due to fineness) • Difficult to place and mix
Glass	• Surfacing aggregate • Mechanical stabilizer	• Difficult to work with • Fractures into flaky particles	• Special processing/ crushing technique needs to be developed
Rural by-products			
Pulverized fuel ash (PFA or fly ash)	• Cemented layer • Stabilizer	• Very fine/dusty • Monopolies often control supply	• New innovative uses need to be assessed
Blast-furnace slag	• Surfacing aggregate • Base • Sub-base • Concrete aggregate	• Contains unhydrated oxides • Can be variable • Possible deleterious components • Variable density (voids)	• Must be conditioned before use to eliminate oxide

Classification of by-product material	Possible uses	Potential problems	Special requirements
Steel slag	• Surfacing aggregate • Base • Sub-base • Concrete aggregate	• Contains unhydrated oxides • Can be variable • Possible deleterious components • Variable density (voids)	• Must be conditioned before use to eliminate oxides • Otherwise similar to a conventional aggregate
Other metallurgical slags	• Base • Sub-base	• Contains unhydrated oxides • Can be variable • Possible deleterious components • Variable density (voids)	• Must be conditioned before use to eliminate oxides
Colliery spoil	• Sub-base • Below sub-base	• Highly variable materials • May contain sulphates • Abrasive on crushing plant	• Needs good sorting and processing • Otherwise similar to a conventional aggregate
Mine and stone processing waste	• Surfacing aggregate • Base • Sub-base • Concrete aggregate	• May contain deleterious materials	• Need to be assessed individually
Crushed waste brick	• Sub-base • Mechanical stabilizer	• Variable physical properties • Small individual deposits	• Needs investigation for each use
Furnace bottom ash	• Base • Sub-base • Below sub-base	• Soft particles • Contains unburnt coal • May contain sulfates	• Needs careful processing
Spent oil shale	• Sub-base • Below sub-base	• Variable hardness and composition	• Little known
By-products from both rural and urban environments			
Reclaimed bituminous material (RA)	• Asphalt • Base • Sub-base	• Variable materials	• Each source needs evaluation and investigation for each project
Phosphogypsum	• Cemented layer	• Very fine powder • Changes moisture condition readily	• Needs additional research for bulk use
China clay sand	• Mechanical stabilizer • Below sub-base	• Fine grained	• Little research done

Classification of by-product material	Possible uses	Potential problems	Special requirements
Used rail ballast	• Base • Sub-base • Concrete aggregate	• Collection of sufficient quantities	• New disposal strategy from railway authority required

4 GAPS IN INDIAN PRACTICE AND SWOT ANALYSIS

The Indian manual for low volume roads (Indian Road Congress - IRC SP 72: 2015) is a significant improvement over the 2002 IRC SP 20 document, and contains many innovative and creative philosophies. Unfortunately, however, these are currently not implemented to the fullest extent possible. This may in some cases be due to a number of gaps in the document, but also to the conservative nature of many engineers who fear moving away from the norm.

The use of material strength testing in the un-soaked condition is permitted in IRC SP 72. While it is acknowledged that the use of un-soaked strengths would not be appropriate in many parts of India (e.g. Bihar and Assam), this procedure could result in significant savings in pavement material quantities, for instance in large parts of Rajasthan and other areas (normally receiving less than about 600 or 700 mm of rain per annum), and where flooding is unlikely.

IRC SP 72 specifies almost entirely the use of densities related to the light compaction effort (Proctor), although heavy compaction effort (modified Proctor) testing is included in the Indian Standard Test methods. Compaction is the least costly way of improving material quality, and the use of higher compaction requirements alone could save significant volumes of material and provide better pavements.

IRC SP 72 permits (and in fact even encourages) the use of local and waste materials. Very few examples of such usage have been observed in India. Where waste materials have been used, insufficient controls have been taken to optimally monitor their cost-effectiveness and performance. Concerted effort is required to identify the properties and performance of the common by-product materials widely available. Much work has been done and can be found in the Indian literature, but little of this is taken to a successful conclusion that will allow the material to be confidently used in construction [(*1*), (*2*), (*3*)]. The use of such materials often requires careful production and processing as well as modified construction processes. These are, however, not complex, and only require minor adjustments to normal construction processes.

India has an excellent three-tier quality assurance process developed for use on Pradhan Mantri Gram Sadak Yojana (PMGSY) projects. Observations in the field, however, indicate that it may not always be fully implemented. Many examples have been observed where simple problems, which should be picked up during the quality testing and inspections, are overlooked, resulting in premature problems.

The maintenance contracts implemented on PMGSY roads are laudable and extremely innovative. However, although regular inspections of any problem on the road are made, discussions with a number of maintenance contractors indicate that the problems appear to be attended to less frequently. Issues such as the build-up of material on the shoulders, resulting in the shoulder sloping in towards the paved carriageway have been noted regularly on PMGSY roads.

A summary of the gap analysis on Construction Materials and Specifications and the use of by-product materials is as follows:

- Little detailed information on use of "wastes" (better termed as "by-products")
- Nothing currently on mechanical stabilization/blending of by-products even though IRC:SP:72-2015 allows for this
- No detailed guidelines for using by-product materials
- Some pavement layer strength requirements unnecessarily conservative for very light traffic
- Exclusive use of water bound macadam (WBM) for base even though alternative material types now allowed in IRC:SP:72-2015
- Generally insufficient consideration for the use of locally available materials, even though IRC:SP:72-2015 now promotes this
- Insufficient information on stabilization design procedures
- Aggregate specifications not always appropriate for low volume roads, e.g. PSV of more than 55 required

A simple SWOT analysis has indicated the following issues related to low-volume road construction in India:

TABLE 2 SWOT Analysis of Issues Related to Low-Volume Road Construction in India

Strengths • Competent engineers • Good manuals • Long-term commitment to PMGSY roads – contractors can thus justify obtaining new and modern equipment • Medium-term maintenance contracts • Effective accelerated testing facilities available in India • Need for innovative materials	**Opportunities** • National policies (PMGSY) • Creation of new SMMEs and industries • NRRDA policies (15% innovation) • Upgradation of the construction industry • Job creation at low levels • Development of by-product "champions"/experts • Environmental and sustainability benefits
Weaknesses • Lack of suitable materials • Old and inappropriate construction equipment • Lack of overloading control norms • Ineffective implementation of maintenance contracts • Apparent shortage of engineers knowledgeable in by-product materials	**Threats** • Conservative engineers (fear of failure) • Ineffective quality assurance implementation • Depletion of good construction materials • Climate change • Monopolies take control of sources (increased prices) • Parts of some manuals and specifications outdated

In general, the strengths and opportunities far outweigh the weaknesses and threats, and the potential for the greater use and implementation of by-product materials in India looks very promising.

5 IMPLEMENTATION STRATEGY

The implementation of new and innovative technologies is always difficult to initiate. New technologies bring the fear of premature failures and/or claims to many consulting engineers, who can design roads based on standard procedures ("recipe designs") with no fear of any problems occurring. If failures do occur, they are normally attributed to poor construction, excessive overloading or extraordinary climatic conditions. An enabling environment to assist with implementation thus needs to be created.

5.1 Early Implementation

A number of technologies described in this paper have been developed to a significant degree internationally, and can be implemented with little additional research or development in India. These include such technologies as:

- The use of slag materials
- Chemical stabilization
- Mechanical stabilization
- "Recycling" of mine wastes
- The use of products such as fly ash, phosphor-gypsum, granulated blast-furnace slag, etc.
- The use of recycled asphalt (RA)

Significant international research has been carried out on these techniques and products, and their use in road construction has been "tried and tested" in many countries. Additional research in India is probably unnecessary [(*4*), (*5*), (*6*), (*7*)]. Only the implementation of international experience, initially in the form of demonstration sections, needs to be carried out in order to confirm that such experience is applicable, valid and cost-effective under Indian conditions.

Such implementation should follow international best practice, with appropriate testing, monitoring and evaluation. It is important, however, that similar test methods and construction procedures to those used internationally are followed to ensure that the fundamental principles are retained. Other less-established technologies using unusual by-product materials will need to follow the traditional research process (desk study, laboratory study, pilot-scale trials, full-scale trials, road authority specification trials).

5.2 Creating an Enabling Environment

An appropriate institutional and support environment is essential to promote and establish new/innovative technologies. It is already required that 15% of the length of all NRRDA roads shall include some innovative technology. However, field observations indicate that many of these initiatives make use of "safe" technologies that are unlikely to result in any visible problems if they are not successful, e.g. the use of recycled plastic bags in asphalt. In many other cases, more than one technology has been included in the same "experimental section", which results in difficulties in attributing changes in performance to any one cause.

Government initiatives such as these are almost essential in ensuring the uptake of new technologies. This is particularly the case with the use of alternative/by-product materials, where economic opportunities need to be instituted early in the production stream. This may range from initial sorting and processing of the products to the provision of incentives to small entrepreneurs to actually collect, process, stockpile and deliver such materials.

It is important, however, that once a material reaches such a stage, its value does not become artificially distorted so as to make it uneconomic for use in low volume roads in rural areas as compared to traditional materials.

At the same time, it is essential that a number of "champions" of the by-product industry are identified and nurtured. These must be open-minded engineers or material specialists, who have both a deep understanding of the behavior and properties of road construction materials, as well as conviction regarding the beneficial attributes and advantages of increasing the use of non-traditional materials in road construction.

The main objective of all of the research and development will be to produce comprehensive guidelines, user manuals and specifications for each of the viable by-product materials. This will then need to be adopted and promoted by the Indian Road Congress as official documents. Once this is in place, it is the responsibility of the client bodies to ensure that local non-traditional materials are at least assessed as alternatives for every proposed project. If these are found to be economically attractive options, they should be included in the tender documentation.

In order to increase the competitiveness of such interventions, it will also be important to develop a programme of research that will determine financial values for issues such as the use of non-renewable natural resources (e.g. a realistic, aggregate tax), environmental benefits (e.g. release of land, reduced pollution) and other sustainability issues. These values should be included in any economic analyses.

Studies of overall costs/benefits of each potential product should be initiated in order to justify their introduction, and convince otherwise skeptical practitioners of the potential benefits. This will require individual investigations of each material, and assessment of the local cost and competitive product conditions.

During development of the inventory of potential material resources, it will be useful to identify the "zone of economic use" of each material. The materials may each have a unique basic production cost (perhaps a nominal purchase cost as well as some processing costs such as crushing, screening or sorting). The zone of economic use for each resource will depend on the typical transportation costs in the area as well as the cost of the materials normally used.

5.3 The Complete Road Package

The use of innovative materials, the "environmentally optimized design (EOD)" method and application of alternative surfacings in low volume (PMGSY) roads must be viewed as a complete package included in an overarching road delivery process. Each of the inputs must be compatible with the others, and all are subject to certain overall requirements and fundamental responses.

Where un-soaked pavement designs are employed (the basis of much of the EOD method), it is essential that precipitation is removed from the road environment as quickly and effectively as possible. This requires well-designed drainage (side and cross drains) that are kept clean and effective in addition to being well-shaped and well-maintained shoulders that facilitate the rapid and total removal of precipitation from the road surface to the drainage systems. This requires regular de-silting, grass and bush removal and reshaping where necessary.

5.4 Incentive Structure and Institutional Issues

There are numerous approaches that could be taken to encourage risk-taking in the use of alternative materials, and each specific environment calls for a slightly different approach. It would be virtually impossible to write standards and specifications to address all the options identified in this paper. It will ultimately depend on the judgment of individual engineers within the framework of more flexible standards and specifications. However, the key will be empowering engineers to take these risks, to think about each situation separately and create an environment where innovation is rewarded. This will require a new approach to the training of engineers which should be central to the strategy. This is explained in Figure 1 below:

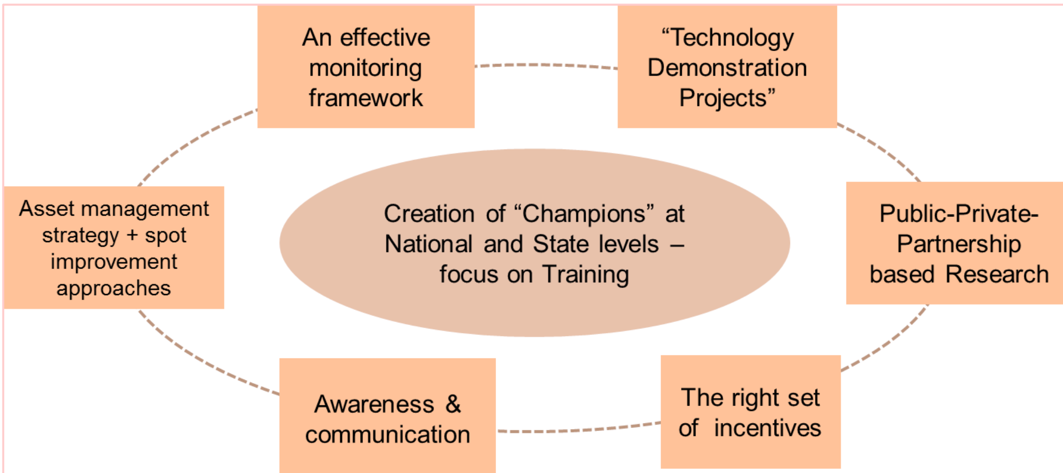

FIGURE 1 An incentive and institutional structure for adoption of sustainable materials/technology

The current institutional organization for roads in India is generally adequate for the implementation of the increased use of local and by-product materials in low volume rural roads, and no major structural changes (e.g. establishment of a Road Agency or dedicated Road Fund) are considered necessary. There is, at the same time, a need for creating "champions" both at NRRDA as well as the state level. These champions will need to be knowledgeable and believe fully in the benefits and potential of alternative materials, both in the interests of economy and sustainability. Such champions should be identified from within the existing staffing structures and singled out for specific and sustained training (technical training, as well as training to address resistance to change within their organizations) and instruction in the location, sampling, testing, use and monitoring of such materials and their performance. Champions need to be identified carefully and should have a good fundamental understanding of material properties, rock and soil chemistry and mineralogy, structural behavior of roads and materials, long-term effects (durability) of these materials and the desire to see constructive and innovative change.

The next step would be to undertake "Technology Demonstration Projects" on the use of sustainable materials/technology. These projects would involve co-opting field engineers right from the research planning phase, documenting all key technical and implementation processes, and disseminating these to more field engineers through regional workshops and other events. This would, in turn, increase their exposure and instill confidence in them for large scale adoption of these alternative materials/technologies. The successful demonstration of these projects would also showcase the cost effectiveness, potential for "green jobs" as well as conservation of natural resources and climate change impacts of these initiatives, in the long run.

It is also important that the research backbone for the use of sustainable materials be strengthened. Each of the materials identified has unique properties, which need to be investigated and researched, in order to benefit optimally from their uses. Many of the by-product materials can be used in combination with local materials (e.g. fly ash and slag). In these cases, specific investigations need to be carried out with the various combinations because of the variability in the properties of the local natural materials. This is, however, the type of research that can easily be carried out by researchers at universities and research institutions as part of post graduate qualifications (Masters and Doctorate degrees).

Another form of research that could possibly be replicated in India is public-private partnership-based research which has been used successfully in the transportation sector in South Korea. This involves research and academic institutes playing a key role in mainstreaming the use of alternative materials and technologies by inviting interested private sector agencies to be partners in their research programs, and then using a combination of their own and private sector funding to conduct the core research. Once the core idea matures, the private sector partner applies for patents and subsequent commercial application. The research institutes get a predetermined share (about 3-5%) of the revenue (profits) from commercial application.

In many cases incentives are required to initiate the implementation of new and innovative ideas. The “compulsory” inclusion of 15% of all new PMGSY construction being devoted to innovative materials and methods is certainly a good incentive for most engineers, as the risk of premature failure of the roads is mostly removed from their responsibility. However, incentives are best done on a more personal scale with the implementation of recognition criteria (prizes/awards) for individual staff members or teams who successfully implement innovative ideas or solutions, that will ultimately lead to wider understanding and adoption of such materials/technologies. It has been found that nominal monetary awards are the most effective technique for this.

In order to implement new innovations, it is also essential that they are widely communicated to potential users. It is also essential that their benefits are clearly represented, and that potential users recognize and accept that there are these benefits, either observable (lower cost and/or better performance) or intangible (more sustainable). This requires wide publication of success stories, frequent feedback at seminars and workshops and hands-on sessions with engineers. It is also important that the public is made fully aware of the presence of experimental and research work on roads, in order to justify any problems that may occur. It should be borne in mind during such trials that far more is learned from things that go wrong, than from experiments that perform extremely well. In the latter, the road is probably over-designed but it is difficult to determine by how much, while premature failure identifies the shortcomings more easily.

Key to the success of any approach, but particularly one using marginal materials, is effective maintenance. An asset management strategy particularly focused on the use of marginal materials and innovative technology would thus need to be expressly developed. Linked to asset management is also the issue of using effective spot improvement approaches where particularly vulnerable parts of the network may be improved to a higher standard for climate resiliency.

Finally, continuous monitoring of acceptance, adoption, refinement and results of use of alternative materials through an effective monitoring framework would be key to keeping up the momentum and scale of efforts.

5.5 Skill Development of Contractor Managers, Workers and Equipment Operators

Many of the suggested improvements in institutional arrangements can be related back to one common denominator – institutional capacity building (ICB), whether it be training, improvement of systems, better implementation of existing or improved methods, or purely improved supervision and management. Sustained training to field engineers and the development of a "risk-taking culture" is, however, the keystone of this strategy.

It appears clear from the observation of local practice and discussion with stakeholders in India, that the intangible capacity is mostly in order but the tangible, day-to-day institutional arrangements and capacity could be incrementally improved.

5.6 The Way Forward

The proposed way forward is as follows:

1. Develop an inventory of <u>all</u> possible by-product materials (including those that are currently considered highly unlikely to ever be used in roads). Some states have initiated this to some extent.
2. Identify appropriate and willing potential champions for by-products in the academic, research and state bodies, and establish an informal working group. This would need to be approved and supported by the supervisory bodies involved (universities, road authorities, research organizations, product suppliers, etc.), and should identify potential sources of funding, which can then be motivated.
3. Identify those materials from the inventories that have been developed, which occur in significant quantities, currently have disposal problems or high storage costs, and, based on existing knowledge (international or local experience), have the potential to be used in road construction.
4. Initiate research and development on these materials to fill in existing gaps in knowledge regarding their properties and use. This would mostly be literature and laboratory based and would be coordinated by the local champion(s).
5. Support the fundamental research using full-scale trial sections and accelerated testing where feasible.
6. Develop specifications, new test methods where appropriate, user guidelines and manuals and disseminate the findings widely.

6 CONCLUSIONS

This paper discusses the use of materials for the construction of low volume roads, with a strong emphasis on "green" issues and sustainability. The status quo in road construction using natural materials cannot continue sustainably as good materials are consumed. Further, assuming that road provision does not change dramatically, future generations will not have suitable materials for road construction.

There are many potential by-product materials in India that could effectively and economically be used as road construction materials, up to base course level for low volume roads.

International experience can be used to guide the specification and use of many of these, while local research and development may need to be carried out on others. However, new and innovative materials need to be “tested” in properly controlled full-scale experiments on normally trafficked roads with the appropriate monitoring and analysis for the material being investigated. There are also many ways (including mechanical, chemical or bitumen stabilization) of improving unsuitable materials to the point that they may be used in structural layers in roads. For any innovative material, it is also essential that life cycle benefits are determined using full life cycle cost analysis procedures.

On incentive structure and institutional issues, the paper discusses a new approach to the training of engineers, which should be central to an overall strategy that would involve at its core the creation of national and state-level “champions” through the use of specific and sustained training. This would include technical training, as well as training to address resistance to change within their organizations, and instruction in the location, sampling, testing, use and monitoring of such materials and their performance. Specific recommendations included in this paper may well have applicability beyond rural roads, and could be applied to national and state highways in certain cases, with suitable modifications, if required.

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