**Full Depth Reclamation (FDR)**

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**ABSTRACT**

"Good practice dictates that pavements be maintained and preserved so that major rehabilitation is not needed. For a variety of reasons, this does not always happen. Sometimes it is not practical to fully rehabilitate a badly deteriorated asphalt pavement. Cracking or other distresses may have progressed to the point that a more aggressive approach is needed. Complete removal and replacement is not necessary; the in-place materials of the old pavement have value and can be reused. Full depth reclamation (FDR) is an efficient means of rehabilitating these pavements."

A pavement rehabilitation technique in which the full flexible pavement section and a predetermined portion of the underlying materials are uniformly crushed, pulverized or blended, resulting in a stabilized base course. In its simplest form, FDR consists of in-situ pulverization of existing pavement and underlying layers, uniform blending of pulverized material, grading, and compaction. Cement, emulsion or foamed asphalt or combinations of these materials are added to produce a strong durable base.

The benefits of FDR can be placed into three major categories:

- Economical
- Technological
- Environmental

There are several road improvement objectives that can be addressed by FDR:

1. Increase capacity
2. Increase structural strength and stability
3. Improve pavement condition
4. Improve serviceability
5. Extend service life

Before discussing the full depth reclamation a brief introduction of sub base stabilization and base stabilization is as follows:
**Soil Stabilization**

Stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil. Additive stabilization is achieved by the addition of proper percentage of cement, lime, fly ash, or combinations of these materials to the soil.

**Mechanical Stabilization** – Mechanical stabilization is a process in which materials are proportioned to obtain desired gradation and plasticity of the mix. This type of stabilization adds selected aggregate sizes or RAP to the pulverized existing materials to create a stronger sub-base. Mechanical stabilization can be used in combination with asphalt or chemical modification.

**Cement Stabilization** – Generally granular soils are suitable for cement stabilization.

**Lime Stabilization** – Clayey soils including heavy clays, moorum and other soils met with in alluvial plains can be effectively treated with lime. In case of highly plastic soils, two stage stabilization is adopted. Soil is first treated with a small quantity of lime. Later on the soil may be treated with remaining quantity of lime or with cement to achieve the desired strength.

**Subbase stabilization**

A stabilized and therefore stiffer, subbase provides greater load spreading ability and hence reduces stresses imposed on the subgrade. When stabilized the subbase provides much of the structural rigidity in the pavement, and also assists during the compaction of the upper granular layers and hence increases their ability to withstand deformation.

The material for cemented subbase may consist of -

- Soil + Cement or lime
- Soil and aggregate mixture + Cement, lime or both.
- Aggregate + Cement
- Reclaimed asphalt pavement (RAP) + Cement.

**Base stabilization**

Base course is the layer directly below the HMA layer and generally consist of aggregate (either stabilised or unstabilised). Base course distribute the loads to the foundation.

The material for cemented base may consist of -

- Soil + Cement or lime
- Aggregate + Cement.
Full Depth Reclamation (FDR) Construction

**Scarification and Pulverization**

Depending on the construction equipment available, and the thickness of existing pavement, roadway may need to be scarified (ripped) before it can be pulverized. Depth of pulverization is usually 150 to 300 mm which on some roads (MDRs/ODRs) will typically include all of the surface and base, plus some part of the subgrade. The particle distribution should have 100% smaller than 50 mm and 53% passing 6 mm sieve.

**Shaping and Grading**

The pulverized material is shaped to the desired cross section and grade. This could involve additional earthwork in order to widen the roadway. Final base/sub-base elevation requirements may necessitate a small amount of material removal or addition.

**Spreading Cement**

Cement is spread in a measured amount on the surface of the shaped roadway.

**Water Application**

Water is added to bring the aggregate-soil mixture to optimum moisture content.
Design & Construction of damaged pavement of a road in District Unnao in the State of Uttar Pradesh

Other District Road in District Unnao connecting NH-25 Lucknow – Kanpur to State Highway to Bilgram – Unnao– Allahabad Road (Commonly referred as Dostinagar Unnao Bypass Road) was in very bad and dilapidated condition as CBR of sub grade was very low ranging from 3% to 4%. The strengthening of road was taken up more than 3 times within a short span of 10 years from 2002 to 2011, but each time it failed because of poor soil of subgrade. This 4.30 kms long road was selected for rehabilitation by Full Depth Reclamation. Crust thickness of existing road was 25 cm including damaged bituminous layer.

Design Parameters:

1. Length (Ch. 0.000 – 4.300) = 3.80 km
2. CBR of existing sub grade = 3.4%
3. Effective CBR of sub grade after soil stabilization with lime = 10%
4. CV PD = 1589
5. MSA = 18
6. Carriageway width = 7.0 mtrs
7. Existing crust = 250 mm
8. Surfacing = SDBC (Damaged)
9. Design crust
   - Full Depth Reclamation with 2% OPC = 250 mm
   - Cement Treated Base (WMM + 4% OPC) = 90 mm
   - Crack Relief Layer (WMM) = 100 mm
   - BC = 50 mm

The existing sub grade to the depth of 30 cm was stabilized with 2% lime after removing existing granular base and sub base. After soil stabilization material of existing road was re-laid and mixed in addition of 10% fresh aggregate to improve the gradation of aggregates. FDR with 2% cement was executed and compacted at optimum moisture content. 90 mm fresh base layer of aggregate with 4% cement was placed over cemented sub base as per design carried out by IIT Pave. 100 mm inter layer of WMM and 50 mm of Bituminous Concrete were also placed as per design. The photographs showing the existing pavement before rehabilitation and after construction is placed below.
Significant Cost and material savings

A comparative study based on Unnao Bypass shows a significant savings of 49% & 39% respectively, in material and cost, in comparison to conventional method of rehabilitation as depicted in graph.
**Evaluation of Constructed Pavement**

Construction of road work was completed in May, 2014. Inspections of road were carried out in June 2014, January 2015, June 2015, August 2015 & October 2015 to evaluate the condition and after construction performance. Road was found in good condition. No cracks were appeared in the pavement.

During the last inspection of road in October 2017, Deflections were calculated using Falling Weight Deflectometer. Layer moduli were calculated using KGPBACK programme. Using these, moduli strains were calculated at the bottom of bituminous layer and at the top of sub grade using IIT Pave. The results are as follows.

**Field Deflection in micron mm**

<table>
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<th>S. No</th>
<th>0</th>
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<th>600</th>
<th>900</th>
<th>1080</th>
<th>1360</th>
<th>Pav. Temp</th>
<th>Season</th>
<th>Layer th in mm</th>
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Falling weight = 45 in KN
### Normalised Deflection in mm

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<th>Pav.Temp</th>
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<td>33.17</td>
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### Moduli Value (MPa)

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<th>Moduli Value after (Temp and seasonal correction)</th>
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<td>15(^{th}) Percentile moduli</td>
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### Strain as per IIT Pave

- CBR = 3
- MSA = 18
- $E_t = 10.2 \times 10^{-6}$
- $E_v = 160.0 \times 10^{-6}$

Fatigue Life = 3205516.2 msa
Rutting Life = 2283.5 msa
Overlay Required = 0.0 mm
Conclusion

Horizontal Tensile Strain at the bottom of bituminous layer is $10.2 \times 10^6$ and Vertical Compressive Strain on subgrade is $160.0 \times 10^6$, which shows that the pavement is in very good condition and remaining life of pavement is two to three times its design life.
Sustainable Transportation for Indian Cities:
Role of Intelligent Transportation Systems

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INTRODUCTION

Sustainability, as an important issue in development came into public focus with Carson's book titled "Silent Spring" [1]. Schumacher's thoughts in "Small is Beautiful" [2] brought the issues of sustainability and the then development models into sharper focus. Since then, policy makers, by and large, have been mindful of sustainability while formulating policies.

Oxford English Dictionary [3] defines "sustainable" as an adjective meaning "capable of being maintained at a certain rate or level." Merriam-Webster Dictionary [4] defines it as "of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged." One of the most often quoted definitions of sustainable development appeared in the Brundtland Report [5]; according to this definition, sustainable development is that which "meets the needs of the present without compromising the ability of future generations to meet their own needs."

From the above definitions few points about sustainability emerge. These and other thoughts on sustainability and sustainable transportation are the subject matter of the next section. The third section provides a brief description of the issues related to urban mobility that are foremost in India. The fourth section suggests how intelligent transportation system (ITS) can help India move towards a sustainable urban mobility plan. The fifth section summarizes the discussions in this paper.

SUSTAINABILITY AND SUSTAINABLE TRANSPORTATION

The definitions of the word "sustainable" indicate that the concept of sustainability includes the following features: (i) processes need to be maintained (or carried on with) over a period of time and (ii) harvesting of resources are inevitable for processes to run. It is the contention of the author that systems which remain efficient over a period of time and over space are the ones which can be maintained and hence are the only sustainable systems. Of course, the word efficient is used in a broader sense than it is generally used while describing efficiency of engineering systems. It must be accepted that engineering interventions (like infrastructure) which affect the society at large and use significant resources cannot be viewed and evaluated in isolation and must be looked at as a part of the habitat; that is, the efficiency of such systems must be defined in a more inclusive manner.

In the particular case of urban transportation one needs to define what this habitat includes, what are the resources that one is dealing with and how one should measure efficiency (in the broad sense that is envisaged here). In the rest of this section these points are expanded.