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Low-cost Road Surfacing for Rural Development

In developing countries much of the poverty and low standard of living takes place in rural communities. Governments and international agencies are committed to alleviating poverty in these countries but typically with limited financial resources. However, a recent and appealing approach to alleviate poverty is to improve rural transport infrastructure through Low-cost Road Surfacing.

Important Role of Roads

Maintained roads provide rural communities with sustainable year-round access to basic social and economic requirements; however, due to season-caused damages and subsequent unsustainability, many rural communities have a limited, often season-dependent access to outside resources. Roads are especially important for agriculture; damaged or unpaved roads may significantly inhibit market opportunities, where crops are unsold and revenue is reduced. Because the influence agriculture has on the economy is at its highest during the rainy season, it is important to have a maintainable road system.

Roads also promote access to health care. Because many rural communities lack drinkable water, they are susceptible to water-borne diseases. Roads also encourage education and job opportunities. Roads promote inter-community networking that can lead to an improved overall social standard of living.

Development of Bitumen

Road Surfacing is the construction of roadways using a material that is laid out on the surface of land to sustain vehicular or foot traffic. Bituminous surface treatment is a method for road : a spread of crushed-rock is cooered by a sprayed bitumen, a substance which binds the crushed-rock together. Currently, bitumen is the main substance used for paving roads; it acts as the 'adhesive' to the crushed-rock aggregate. Natural or crude bitumen found in oil reservoirs is often too viscous for use in practice, but chemical engineering has made possible large bitumen production of various grades or viscosities. Bitumen grades are usually measured by a penetration test, in which a needle is used to pierce the bitumen; the extent of penetration determines the specific grade of the bitumen. A grade of 70/100 means that the bitumen has a penetration value at 25°C ranging from 70-100 in units 1/10 mm. Common commercial bitumen grades, often used for road surfacing, include hard (40/50) and soft (180/200) Bitumen. Soft-grade bitumen generally differs from harder grades because soft bitumen consists of more asphaltenes and fewer aromatic hydrocarbons. In production, soft grade bitumen can be manufactured by fractional distillation of crude oil.

As shown in Figure 1, crude oil enters the system and is (**2**) heated in several furnaces (350°C) before it undergoes (**3**) an atmospheric distillation process. Streams of hydrocarbon mixtures (such as Kerosene and Naptha), resins, Asphaltenes, and Maltenes are then (→) separated from the crude oil. (**4**) After further heating (350–425 °C) and a (**5**) subsequent vacuum distillation, the resulting residue is soft bitumen, ready to be graded by the penetration test. (**6**) Further processes include heating, mixing (polymers are added to produce modified

Bitumen), acid modification where polymers are oxidized to reduce sulfur and nitrogen content and to raise oxygen content to produce oxidized Bitumen, and further distillation of the Bitumen depends on the initial crude source and on the specific grade desired.

Figure 1 is taken from Lesueur, Didier. "The Colloidal Structure of Bitumen"

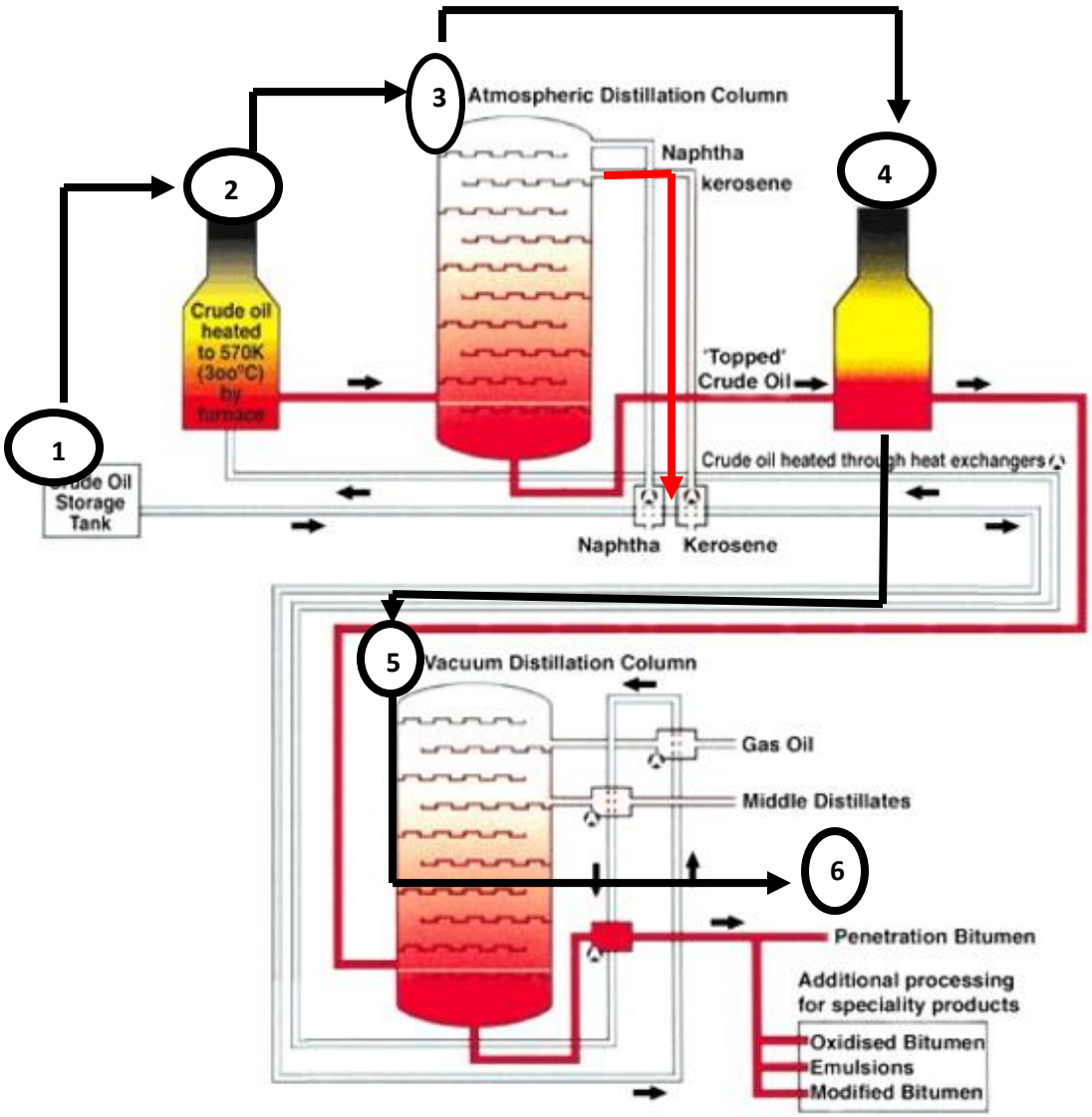

Figure 1: Bitumen Production

Bituminous surface treatment is widely used to rejuvenate current gravel and concrete road networks, but more importantly, it is also an innovative method to surface unpaved or earth-road networks, which are roads that contain any crushed aggregate, and that often have bare earth surfaces. Various types of bituminous surface treatments exist, with the suitability of each depending on traffic rates, how steep or dry the roads are, local resources, and the environment. Examples include the bamboo-reinforced-concrete surface which may be suitable in rural areas in East Asian countries, where traffic is not heavy and bamboo is abundant. Another example is the clay brick surface, which applies local sand and clay bricks by hand to cement surfaces.

Advantages of Low-cost Road Surfacing

Natural gravel consists of irregular stones mixed with varying amounts of crushed rock, silt, and clay, usually extracted from borrow pits near rivers, mountain streams, quarries and valleys, 2mm-19mm in particle size. Gravel surfacing (usually 200mm in thickness) provided the traditional approach to road construction for roads with low to medium traffic (about 50-200 vehicles per day). However, gravel proved to be wasteful, as much of the material is lost annually from traffic, rain, and sun radiation damages that result in chemical degradation by oxidation. Often, gravel roads eventually revert back to bare, earth roads. Routine maintenance would require periodic access to front loaders, dump trucks, graders (which are used to flatten), and other heavy equipment not available to many rural areas. Gravel roads also generate much dust under heavy traffic, and deteriorate during the heavy-rain season. Moreover, suitable specified-sized gravel may require extensive excavations from deep pits and long-distance

hauling from rivers, quarries, or streams. Ultimately, these factors render gravel too expensive and impractical for many developing countries in the long run. However, with current improvements in production of bitumen more appropriate methods are now available for transport infrastructure.

For alleviating poverty in rural communities that have unpaved roads and limited funding, the Otta Seal provides a promising, suitable, and flexible bitumen surface treatment that can (and did) improve transport infrastructure at low-cost.

The Otta seal is a road surface (usually 16-32mm thick) that uses soft grade bitumen for binding an aggregate spread of curshed rock or other material with particle sizes that range from 16-19mm. The Otta seal is low-cost due to its inexpensive initial construction and because of its durability relative to other road types. A rough cost for the Otta seal is about $20-$35/meter of road including supply and construction, whereas a typical gravel road costs about $500- $2,000/meter. Workable construction of Otta-seal surfacing allows the use of fairly inferior crushed, uncrushed, or mixed aggregates extracted from local granite found in rivers or lakes, or from local resources such as sand or bamboo, materials which are overall less expensive than excavated or specific graded crushed rock or industrial material such as silica sand. Otta seals do not require unpaved or earth roads to be prepared by a prime coat that smoothes the road (usually sprayed cement) before construction, nor any additional surfacing layers after construction; however both are optional choices to further improve sustainability. Road surfacing that binds sand aggregates (Sand Seals) is often used as a secondary layer in many rural areas, because sand is abundant, accessible, and easy to transport. Although these

local natural resources may not necessarily satisfy conventional standards, for developing countries, and especially for rural communities, use of these materials for an Otta seal can still provide, at minimum, an acceptable and sustainable road at an affordable cost.

Low-cost road surfaces like the Otta seal are especially cost-effective and economically viable for construction. Various types of surface treatments provide flexible applications depending on situation factors. For example, because road conditions can significantly vary due to large longitudinal gradients on hills and in villages of rural areas, construction that requires heavy vehicles such as truck loaders or dump trucks may be difficult and impractical to mobilize. These conditions can only permit construction that requires local materials, local labor, and simple technology/light equipment. For the Otta seal, the bitumen and aggregate spreads may be applied by hand or by simple equipment such as chip spreaders and spray bars, which may not need to be mounted on trucks. Access to heavier equipment such as pneumatic rollers may be limited; however, infrequent usage minimizes their use.

Figure 2 shows the different types of road surfacing treatments available and a short description which may be used to indicate each type's suitability.

Figure 2 is taken from Petts, Robert. "Low-cost Road Surfacing (LCS) Project"

Figure 2: Road Surfacing Treatment List

	Road Surface Improvement Options	Description *(A roadbase option may need to be used in combination with the selected surface improvement)*
C1	Dragging Road Surface	Smoothing out minor defects on an earth or gravel road surface and redistributing loose material on the surface, using tyre or blade drag.
C2	Light Grading/Reshaping of Surface	Minor reshaping of an earth or gravel surface to restore correct camber using labour or light/heavy grading equipment.
C3	Construct Natural Gravel Surface	A layer of compacted natural gravel wearing course (typically 15 – 20cm thick)
C4	Lime Stabilization of Existing Surface	Addition of and mixing of quicklime or hydrated lime to a soil or surface material, watering and compaction to increase its strength and reduce its susceptibility to the weakening effect of increasing moisture content. This is achieved by chemical reaction of the lime with the clay particles. Mixing and compaction by light or heavy equipment.
C5	Stone Chippings Surface	A layer of single sized (typically 20mm) crushed stone chippings.
C6	Construct Hand Packed Stone Surface	A layer (typically 20 – 30cm thick) of large broken stone pieces, tightly packed and wedged in place with stone chips rammed by hand into joints, with remaining voids filled with sand. The Hand Packed Stone is normally bedded on a thin layer of sand/gravel.
C7	Construct Dressed Stone Surface	A layer (typically 15 – 20cm thick) of stone blocks cut (dressed) to a cubic shape by hand, laid by hand. Joints mortared/sealed or tightly packed and wedged with stone chips rammed into place with remaining voids filled with sand. The Dressed Stone is normally bedded on a thin layer of sand/gravel.
C8	Construct Stone Sett Surface (Pavé)	As dressed stone, however stone blocks are smaller; typically about 10cm x 10cm x 10cm with mortared joints.
C9	Construct Concrete Block Surface	A layer of concrete blocks (typically each 10cm x 20cm and 7 – 10cm thick) laid by hand on a thin (3 – 5cm) sand bed with joints also filled with sand and lightly compacted.
C10	Construct Clay Brick Surface	A layer of high quality clay bricks (typically each 10cm x 20cm and 7 – 10cm thick) laid by hand on a thin sand bed with joints also filled with sand and lightly compacted, or bedded & jointed with cement mortar.
C11	Construct Bamboo Reinforced Concrete Surface	Jointed slabs of structural quality concrete reinforced with a split bamboo rod grid. Joints with steel weight transfer dowels and bitumen seal.
C12	Construct Steel Reinforced Concrete Surface	Jointed slabs of structural quality concrete reinforced with a mild steel rod grid. Joints with steel weight transfer dowels and bitumen seal.
C13	Construct Bituminous/Tar Sand Seal Surface	A seal consisting of a hand or machine applied film of bitumen (straight run, cutback or emulsion) or road tar followed by the application of excess angular sand or fine crushed stone, lightly rolled into the bitumen/tar.
C14	Construct Ottaseal Surface	A layer consisting of a hand or machine applied film of relatively soft bitumen (usually straight run or cutback) followed by the application of graded natural gravel or crushed stone aggregate (typically 16mm downwards), rolled into the bitumen using heavy pneumatic tyred rollers.
C15	Construct Bitumen/Tar Surface Dressing Surface	A seal consisting of a hand or machine applied film of bitumen (straight run, cutback or emulsion) or road tar followed by the application of a single layer of single sized (6 – 20mm) stone chippings, lightly rolled into the bitumen/tar.
C16	Construct Bitumen Slurry Seal Surface (and "Cape" Seals)	A seal consisting of fine graded aggregates (typically 10mm downwards), water, bitumen emulsion, cement, and sometimes an additive, mixed in a concrete mixer or other machine and spread on the road surface by hand or machine. Cape seals are combinations of Surface Dressing and Slurry Seal.
C17	Construct Bituminous Premix Macadam Surface	Graded crushed stone material (typically 28mm downwards) usually derived from fresh sound quarried rock, boulders or granular material and mixed with a bituminous binder (straight run, cutback or emulsion) and laid and compacted. Material may be hand or machine mixed and laid. Compaction by light or heavy equipment.
C18	Construct Penetration Macadam Surface	Two or three layers of single size crushed stone (of decreasing nominal aggregate size, e.g. 63 mm downwards) each compacted and with bitumen (straight run, cutback or emulsion) or road tar sprayed between each stone application.
C19	Construct Water Bound Macadam Roadbase	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with well graded fine aggregate which is watered into the voids and compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid.
C20	Construct Dry Bound Macadam Roadbase	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with angular sand or fine crushed stone material which is then vibro-compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or

C20	Construct Dry Bound Macadam Roadbase	A layer of nominal single sized (typically up to 50mm) crushed stone compacted and fully blinded with angular sand or fine crushed stone material which is then vibro-compacted to produce a dense stable material. Layer thickness up to twice the nominal stone size. Material may be hand or machine crushed and laid. Suitable in areas short of water.
C21	Construct Slurry Bound Macadam Roadbase	A layer (about 7cm thick) of single size aggregate (typically 50mm) blinded with smaller aggregate (typically 25mm), plate compacted and grouted with bitumen emulsion slurry before final compaction.
C22	Construct Crushed Stone Roadbase	A layer (usually up to 20cm thick) of graded crushed stone material (typically 50mm downwards) usually derived from fresh sound quarried rock, boulders or granular material. The angular material derives its strength primarily from mechanical interlock. Material may be hand or machine crushed.
C23	Construct Mechanically Stabilised Roadbase	Addition and mixing of granular material such as crushed stone or sand to a material to increase its strength and achieve the properties required of a roadbase.
C24	• Construct Chemical or Emulsion Stabilized Roadbase	Addition and mixing of a stabilizer such as lime, cement, or ion exchange chemicals, to a material to increase its strength and achieve the properties required of a roadbase. Mixing and compaction by light or heavy equipment.
C25	• Improvement using Recycled Materials	Use of recycled road pavement materials, brick kiln waste, broken brick, demolition materials, industrial slags, etc.

Affordability is bolstered not only by the low cost of construction but also through sustainability. Functions of low-cost seals include: ability to withstand solar radiation that tends to degrade surfaces, reduced temperature sensitivity, longevity (about 6-11 years depending on the number of layers and type of material), and lasting sustainability. As shown in Figure 3, the Otta Seal applies a soft Bitumen binding to aggregate interstices (**1**), so the mixture has more of a dense particle interlocking mechanism to the aggregate (**2**) than a glued effect. As such, the seal acts as a stress-dispersing mat, and is less susceptible to traffic ware and chemical degradations from sunlight radiation.

Figure 3 is taken from Overby, Charles. "A guide to the Use of Otta Seals."

Figure 3: Otta Seal

Affordable costs can promote investment and establishment of enterprises. Because surface treatments include labor-based methods, job opportunities are created for local communities when the project is financed by government or private organizations.

Case study: Botswana

In the 1970s in Southern Africa, much of Botswana's road network was composed of gravel roads, as gravel was then thought to be the most suitable road type. However, many desert regions in Botswana were left unpaved and unusable. Extensive heat made gravel roads

difficult to maintain. Limited water accessibility and harsh environmental conditions made construction difficult. Extraction of groundwater and gravel materials as well as frequent use of heavy equipment and numerous vehicles proved to be too costly and too damaging to the environment. As a result, local government sought an alternative approach, and eventually introduced the Otta seal, with private contractors appearing shortly after. Local labor was used, and government-private contractor regulations were established. Uncrushed decomposed granite (or granite rocks that have been eroded) and lake sediments of about 16mm were used as the aggregate and were applied by hand to the bitumen. The Otta seal surfacing's subsequent economic and social success eventually led to implementation in other African and Asian countries. By 2007, 2300 km or about one-third of Botswana's entire road network was surfaced with a cost of about $2.7 million.

Future Policies and Long-term Effects on Poverty

As developing countries begin to experience problems with gravel and traditional road construction, many will start to adopt and initiate policies for low-cost road surfacing in rural communities. Notable social, economic, and environmental improvements in Africa and Cambodia have significantly affected rural communities. Establishment of new enterprises and road networks have created job opportunities and encouraged inter-communal interactions. Year-round access to resources has important implications for markets, health care, and an overall higher standard of living. Experience with past case studies has improved potential policies for future implementation. With its great success, low-cost road provides a suitable step toward alleviating poverty on a large scale.

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