SYNTHESIS OF APPROPRIATE TECHNOLOGIES TO UPGRADE GRAVEL STREETS TO PAVED STREETS.

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1. INTRODUCTION

In the new township areas in South Africa (SA) paved streets are considered visible proof of service delivery of the new local governments. The new local authorities (post-1994) inherited vast backlogs of maintenance on existing streets as well as new street construction. It is particularly the previously disadvantaged, which lived in conditions where streets were not only unpaved, but formed the bulk of the vast length of unofficial street and road network (SABITA, 1993b) which were previously largely ignored. The vast majority of streets in need of upgrading are access streets or basic access streets in the street hierarchy with low to very low traffic volumes. There is an opportunity to upgrade these access and basic access streets cost effectively if a managed risk approach is followed in the use of appropriate and innovative technologies.

Even though design standards, like the Guidelines for Human Settlement Planning and Design, also known as the Red Book (1998), accommodate more realistic and affordable standards, the demand for appropriate standards and technologies have grown. The philosophy to embrace appropriate technologies is covered in the Red Book, but the Red Book was compiled prior to the development and proof of performance of a number of new appropriate technologies. These technologies have now developed credible performance records and can be included in design catalogues which are in line with the initial philosophy of the Red Book.

The socio-political pressure on decision makers in such township areas are not only to upgrade roads as economically as possible, but also to help create jobs in a sustainable empowerment fashion without sacrificing quality and performance. One of the main objectives of the initial Reconstruction and Development Programme (RDP) and the subsequent Growth, Employment and Redistribution (GEAR) macro-economic plan of the government is sustained job creation. The road construction industry has been identified even pre-1994 as an ideal area where job creation can be achieved via the increase of the labour-intensive content of projects (NEF, 1994). The aim of the paper is therefore to critically review a number of appropriate road construction technologies which enhances empowerment and performed well in the field.

The paper elaborates on the concept of Level of Service (LOS), as explained in the Red Book (1998), but which has severe practical short-comings. Additional decision making concepts like Community Benefit Index (CBI), Gravel Road Index (GRI) and

Upgrading Priority Index (UPI) are introduced as a method to guide street upgrading prioritisation and technology selection via transparent community involvement.

This paper demonstrates that the correct selection of technologies can enhance sustained job creation and lower the entry barriers for new entrepreneurs whilst ensuring that there is a progression path of improvement of skill level and associated empowerment. The discussion and description of the technologies are deliberately rather philosophical in an effort to explain the rationale behind the successes of such technologies, to learn from history and because the additional objective is to determine to what extent technologies are empowerment friendly for previously disadvantaged individuals (PDIs). The ultimate criteria is however proven performance of these technologies as communities do not want lower quality merely because it was done labour intensively with social upliftment intent only. A conceptual framework is used to combine the technical, socio-political and sustainability aspects on a relative scale to help making informed decisions.

2. COMMUNITY BENEFIT AND UPGRADING PRIORITY

In the Red Book (1998) Level of Service (LOS) is described as being dependant on stormwater drainage provision, topography, layout and street hierarchy. It is however true that the community affected is not always familiar with such technical issues determining the upgrading potential of their streets. For that reason it is necessary to include Community Benefit Index (CBI) as a community involvement indicator to add socio-political context in a structured manner in the total decision making process. CBI should be calibrated and based on aspects such as:

- Land use (residential, industrial, agricultural, educational, religious, recreation, health care, police and security)
- Functional class of streets as per the layout or community use.
- Community involvement in planning structures and forums (Have objectives been set and prioritised via ward committees? Have forums participated in Integrated Development Plans (IDPs) or Local Development Objectives (LDOs)?)
- Unemployment rate and social indicators (Is there a labour desk or are there community liaison persons to provide skills profiles and determine unemployment figures?)

These are not supposed to represent an exhaustive list of factors for consideration for the development of a CBI, but an indicator of type of factors to be taken into consideration. Over and above this the involvement and political pressure of the local ward councillor also needs to be factored in. The CBI developed for each local authority would be specific to that local authority, road authority or consulting engineer and a generalised calibrated CBI would therefore not be possible. However, the conceptual relationship between LOS and CBI to determine classes of Upgrading Priority Index (UPI) can be demonstrated via Figure 1. In Figure 1 the LOS and CBI criteria are shown versus each other on a relative scale to provide for UPI contour bands of high, medium and low priority. It can be seen that it is possible for a street to have a medium rating on LOS , but a low CBI rating which puts it in the low UPI contour band. On the other hand it is also possible to have a low to medium LOS, but a high CBI rating which puts it into a high to medium UPI contour band. This can be used in a transparent way to include and use community input in determining UPI values.

As indicated above, the greatest needs are for upgrading gravel and dirt streets or catching up on the street maintenance backlogs in township areas. If a proper Gravel Street Maintenance System (GSMS) is in place, it is possible to generate a Gravel Road Index (GRI) with relative ease to help guide decision making. GRI would in most cases be influenced strongly by network characteristics. This would include traffic class, functional class, public transport class (bus or taxi) and gravel base and surface condition, etc. If the gravel street is considered for possible upgrading additional criteria such as whether it forms a logical link with the existing surfaced street network also needs to be included in the adjudication. All these aspects are normally incorporated in an algorithm which is developed for final decision making and overall prioritisation. It must be stressed though that such algorithms are peculiar to a specific local authority even though the basic principles may be the same. In some local authorities there would not be a GSMS in place and a simplified procedure based on the basic principles would then have to be used to support the transparency and consistency in decision making.

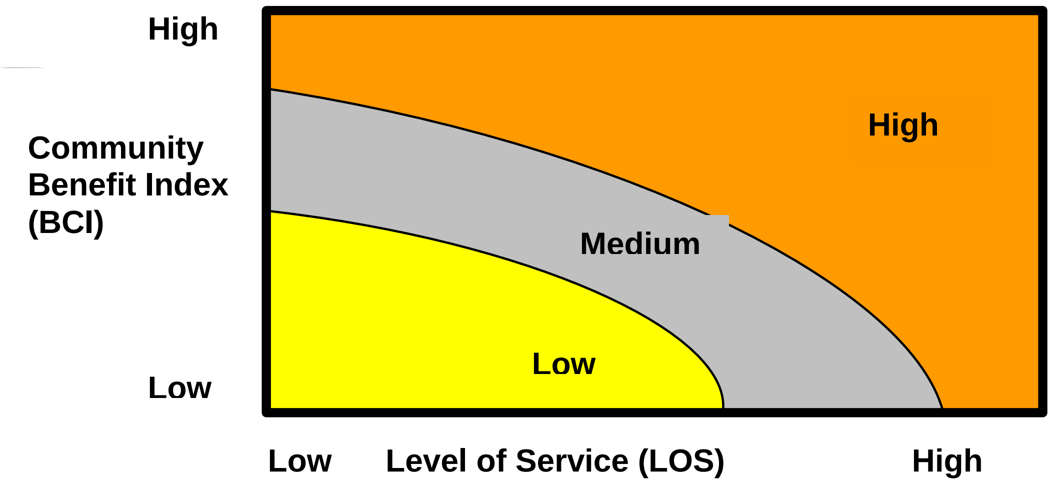

Figure 1. Street Upgrading Prioritisation Chart

3. BALANCING PLANT AND LABOUR IN PURSUIT OF EMPOWERMENT

Direct labour can be seen as the entry point en route to community and previously disadvantaged individual (PDI) empowerment. Labour-intensive work must be coupled with access to material, plant and equipment and appropriate construction technologies in order to facilitate empowerment development. The key to this empowerment lies in the use of small plant and appropriate technology as stepping stones. In analysing known labour-intensive construction techniques and simulating the old construction technologies small plant like a plate vibrator, wheel barrows, rakes, ballast forks and spades could be used very effectively to produce quality end products and empower budding entrepreneurs.*(Potgieter & Pieters, 1995; Horak et al, 1996)*.

An “intelligent mix” of heavy machine intensive road building techniques with labour intensive and small plant intensive techniques is needed which will ensure that maximum empowerment within levels of affordability and required skills levels and specified end products will be the outcome *(Horak et al, 1995).* This “intelligent mix” concept of labour and machine came about due to the socio-political realities in an urbanised township environment (*Horak et al, 1996*) where mechanised equipment is readily available and communities are reluctant to be used merely as “sweat machines” when equipment are parked close by which can do the job more efficiently. It is suggested that the labour and small plant intensive content are concentrated on the construction of appropriate technology road bases and surfacings. These structural layers are invariably the highest value in terms of cost and therefore indirectly enable higher portions of fees retained in the community involved. It is however also important to negotiate the proportions of the mix of plant and labour with the community beforehand to ensure that there is buy-in and commitment to the process.

In the townships and urban environments accessibility to stands needs to be interrupted for as short periods as possible. Machine intensive construction of the subgrade and subbase layers can be done in shorter periods than pure labour intensive construction and is less costly, too. Proper compaction of subgrades and subbases are not to be compromised in street construction. Man and small plant cannot compete with heavy compaction machinery when it comes to compaction (*McCutcheon,1994 and Horak et al 1996).* Heavy and large road compaction rollers are needed for such required compaction levels.

4. INNOVATIONS IN SUBGRADE AND SUBBASE LAYER PREPARATION

4.1 Bearing Capacity Classification

Normally a conservative approach is followed in preparing the in situ subgrade and subbase layers for street construction. This approach is reflected in Table I to follow, as used in the Red Book (1998). Subgrade is classified in 5 categories of bearing capacity measured by means of California bearing ratio (CBR). Based on this classification selected layers and subbase layers are then suggested to be added to ensure adequate structural strength of the road layered system. It is significant that when the CBR is 25 or more (typically a G6 quality material) that no additional layers need to be used. This is the shaded box in Table 1 and will be used as benchmark later in the proposed structural designs

This Table 1 from the Red Book (1998) is practically the same as used in the UTG 3 for urban street design (1988) and both these urban street design guidelines are based on the original design philosophy of the TRH4 (CSRA, 1996) which goes back to even the original TRH4 in 1985. The latter was developed for the rural road environment with different stormwater drainage management principles involved than what is used in the urban environment. As is known, the vast majority of street length in an urban environment are access and basic access streets with very low traffic volumes. Access and basic access streets fail in most cases not due to traffic loading, but due to erosion and other environmental effects. Such failures are a direct consequence of bad layout planning and stormwater management. If the stormwater problems are addressed properly by these means, there is considerable scope to save on pavement structural layers by using the subgrade more effectively as the main contributor to structural strength.

Table 1: Preparation of the subgrade and required selected layers for the different subgrade design CBRs					
DESIGN CBR OF THE SUBGRADE (Material class)	<3 (G10)	3-7 (G9)	7-15 (G8)	15-25 (G7)	>25 (G6)
Add selected layers: Upper Lower	Not applicable	150mm G7 150mm G9	150mm G7		
Treatment of in situ subgrade	Special treatment required	Rip and recompact to 150mm G10	Rip and Recompact to 150mm G9	Rip and Recompact to 150mm G7	Use subbase or base layer*

* Compacted to appropriate density

4.2 Using the Dynamic Cone Penetrometer (DCP)

Bearing capacity of a street or road foundation is strongly influenced by the presence of moisture. There is strong recognition, in the TRH 4 (CSRA, 1996) that large regions of SA are classified as dry and arid and a smaller portion as moderate with the smallest portion as wet areas. Therefore more leniency can be exercised in evaluating bearing capacity as measured in terms of California bearing ratio (CBR). There has long been an advocacy to use values closer to the in situ or field moisture conditions when evaluating CBR of a subgrade instead of the conservative soaked CBR values (Emery, 1987 and 1992). The Dynamic Cone Penetrometer (DCP) (Kleyn, 1982) is an ideal instrument to be used extensively in measuring CBR values of the subgrade at field moisture conditions. What has been lacking though is a further breakdown and "unpacking" of the risk associated with design and classification when using the DCP as the evaluation tool of the subgrade at field moisture condition for classification purposes, though. Research done by Sampson (1984) and de Beer (1991) have made great strides towards this risk description when using the DCP. Table 2 shows the approximate relationship between soaked CBR and field (DCP determined) CBR values. This is an extract of work done for rural gravel roads (SARB, 1992) based on work done by Emery (1992) as applicable to subgrades.

Table 2: Subgrade material classification based on DCP determined CBR

TRH 14 Material Classification	Soaked CBR (Minimum)	Approximate Field DCP determined CBR values	
		Subgrade	
		Wet Climate	Dry Climate
G4	80	Not appropriate	
G5	45		
G6	25	59	65
G7	15	45	50
G8	10	38	43
G9	7	33	37
G10	3	20	24

The climatic regions mentioned above should be used to make an initial classification as a dry or wet area. The ratio between field moisture content and Mod AASHTO optimum moisture contents can be used to do the final classify of areas as wet or dry. If the ratio is below 0.5 it can be seen as dry and if the ratio is above 0.75 it must be seen as a wet area. (Emery,1992).

4.3 Using Dynamic Compaction

It is advocated that in situ subgrades should be selectively compacted to increase bearing strength as monitored by means of extensive DCP soundings. Effective compaction of these layers cannot be compromised by using light pedestrian type rollers. The innovative use of impact compaction with the three, four or five sided rollers is proving to be a very effective way to compact sandy or granular subgrades to a depth of 1.5m without having to work in thinner lifts or layers as with normal compaction equipment (Pinard et al, 1999). This unique SA designed compaction equipment can be used depending on material type and presence of underground services, to achieve deep compaction providing structural strength in depth and achieving deep balanced pavement structures. The DCP is used extensively with dynamic compaction to monitor bearing strength improvement effectively. This is more effective than to measure density which is an indirect measure of bearing capacity. It is therefore possible, depending on material type , etc, to improve an in situ subgrade from a marginal G7 material to that of a G6 or even G5 material by impact rolling and monitoring with the DCP.

Subgrade preparation, using impact rollers, have additional advantages. The earthwork and additional layerworks can be reduced, requiring less material from borrow pits. The additional crushing effect of oversize material in the “blanket” top layer during compaction is an added bonus. This “blanket” layer is often discarded due to the disturbance (de-compacted state) in the top layer. The “blanket” layer can however be used by further densification by means of conventional rollers or even be stabilised. Stabilisation of the subbase with lime or cement will ensure that a good work platform is provided for the base and surfacing to follow. The uniform mixing and compaction with machinery make cement and lime stabilisation a preferred machine intensive construction method.

4.3 Compaction Lubrication Aid

Non-standard road material additives, like sulphonated petroleum products (SPP) can be used as an innovative compaction lubrication aid. SPPs in particular have a proven lubrication effect during compaction of marginal materials without destroying the marginal crushing strength of the granular structure of the material. If the application of the SPP dosage is correctly dosed, and proper compaction done, it is possible to improve the “G” classification according to TRH 14 (CSRA, 1985) of the subgrade material with two grades of the “G” classification (Bennet et al, 2002 and Bennett and Paige-Green, 1993). It has also been shown that such marginal materials improve the bearing capacity of base materials and it is often promoted as unconventional road stabilisers. The use of SPPs are however only advocated in improving the quality of the subgrades in this case as part of an innovative methodology to eliminate costly and unnecessary pavement layers for access and basic access street pavement structures. Old “padmakers” (road construction experts) will also testify that Teepol, a soap, in compaction water also enhances lubrication of the material particles and greatly reduces compactive effort required.

5. LAYERWORKS

Labour intensive and small plant work are mostly reserved for people friendly base and surfacing construction work as described earlier in the philosophy of an intelligent mix of labour and machinery in street construction. Some ancillary work such as kerbing and storm water facilities are also person and small plant friendly. The construction techniques reported here as preferred labour and small plant friendly construction techniques also have good structural performance records. Lately there has been an evolutionary development in these construction technologies by increasing innovative materials and small plant equipment usage which is not captured in the present Red Book (1998). In some cases these technologies are not even mentioned in the Red Book. These technologies will be discussed briefly in the sections to follow.

5.1 Telford road construction

Large sized rock, the size that one man can handle with relative ease, has been used with great success to construct road layers through the centuries. Thomas Telford (1757 - 1834), a Scottish road engineer pioneer, improved on the construction technique which Pierre-Marie Tresaguet (1757 - 1796), a great French engineer, adapted from the original Roman road construction. Telford construction is most probably the best known in SA as these bases are still found in roads in the older cities in South Africa (*Horak, 1983*). Telford used dump rock, about 75 mm by 125mm by 175 mm, to pack on a prepared level subbase by hand. Smaller stones (keying stones) were placed in the openings between these hand placed dump rock and rammed in with hammers. Protruding sharp edges were broken off by hammer in levelling the surface. (*Horak et al, 1996).*

Telford construction, using dumprock, has been used in a labour enhanced manner with success in road construction in the Doornkop and Lusaka township area of Greater Johannesburg, Krugersdorp and Kwa Thema near Springs in 1995 to 1997 and subsequently elsewhere. Dumprock lower layers have been found to provide excellent load carrying layers in ultra heavy loading conditions where 240 ton axle loads are used (Thompson and Visser, 2000). Even though manually taxing, Telford construction proved that strong quality road subgrades and subbases can be constructed with the minimum of initial skill required. However, due to void content within the dumprock layer, care need to be taken to drain the subgrade properly to avoid water being trapped inside the subgrade.

The construction of Telford type dump rock layers must be considered against the bigger picture of a whole pavement layered system with different needs of types of crushed stone materials. Dumprock construction uses a specific size of stone very effectively which under other circumstances would need further crushing. If crushing is done on site only a primary type crushing operation would be needed to produce such an aggregate. The finer crusher run also produced in the primary crushing operation can be used in the upper layers (base and subbase) cost effectively.

5.2. Single sized crushed stone layer work

5.2.1 Waterbound Macadam

It is well known that single sized large crushed stone (aggregate) type base construction has a track record of high quality bases with good performance (Burrow, 1975) records in SA. The construction technique is derived from John Louden Macadam, a Scottish road building pioneer which replaced the large stones of Telford with smaller single sized stone (maximum size 75 to 63mm), very much like the present day railway ballast. The construction process has historically been labour-intensive, although efforts were made in the late 1950s and early 1960s for it to become more machine-intensive. Waterbound macadams experienced a revival as an excellent labour-intensive construction technique in the early 1990's in South Africa (Phillips et al, 1991 and Hefer, 1997).

Waterbound Macadam is basically a single sized aggregate of 63 or 53 mm with a maximum size of 75 mm with a typical gap grading and virtually no aggregate below 19 mm size. Gradings and material qualities are specified in TRH14 (CSRA, 1985). Macadam bases get their structural strength from the large single size aggregates which interlock, ensuring a high internal angle of friction. Traditionally the large aggregates were hand-laid with ballast forks on a prepared subbase or directly on a subgrade .

After initial levelling and orientation of the large aggregate layer, it is sometimes compacted, prior to the voids being filled with fines. Fines with a prescribed grading (TRH14), (CSRA, 1985) are spread on this layer to flow into the voids to provide stability for the large aggregate matrix. More recently vibratory rollers are used for this initial compaction/orientation and fines filling of voids phase (Horak, 1983). Traditionally, the fines had high plasticity indices. A clay soil, for instance, was used in the technology transfer project on the Xavier Street project in Johannesburg (Calitz et al, 1995) from the same source that was used in Johannesburg in the 1940s. This type of material and associated construction technique with thin layer applications of the fines (dried in the sun and then vibrated in with typically Bomag 90 compactors until all voids were filled) was done as close to the way the old “padmakers” remembered doing it. The waterbound action is then performed by wetting the layer, compacting it and brooming off the excess fines. Today it is referred to as “slushing”. After sun drying the pavement is primed and surfaced. A number of waterbound macadam streets have subsequently been built in similar fashion in various areas of SA with success. Structural design of waterbound macadams are well documented (Hefer, 1997) and included in the latest Red Book (1998) in the catalogue of designs.

5.2.2. Drybound Macadam

Macadam bases can also be constructed with low plasticity fines. Windblown sands on the Cape Flats and the Berea red sands in Kwa-Zulu Natal have been used with great success as fines for macadam construction (Horak, 1983). Such fines are normally spread in a thin layer on top of the coarse aggregate layer and dried by the sun before it “flows” into the voids during vibration compaction. This operation is repeated until the voids are filled to the top. Mine dump and slimes sand have the same cohesionless nature and have been used in this drybound fashion on macadam road construction in Johannesburg more recently (Calitz et al, 1995). In essence, a Macadam base with its voids filled with low plasticity sand does not need to be moistened and slushed (waterbound).. The fines primarily enhance the internal matrix stability. A practical test to determine the level of void filling is to open a test hole and observe the void filling or to do a volumetric check of the voids and the filler material sampled.

However, drybound macadam does leave a surface which can easily be disturbed by construction traffic. Experimental work done on the south coast of Kwa-Zulu Natal (McCall et al, 1990) led to the development of a bitumen emulsion slurry which fills the top 10 to 25 mm of the exposed large aggregate voids as a type of working carpet. This can also serve as an interim riding surface and is labour friendly in its application. Drybound macadam construction enhances low water needs in road construction and is suitable for use in the vast arid regions of Southern Africa (Visser and Hattingh, 1999). The design standards would be the same as for waterbound macadams as described before

5.2.3. Penetration Macadam

Penetration macadam developed from waterbound macadam construction as a means to waterproof macadam layers. Previously the high clay content (High Plasticity Index) fines provided some form of water proofing with the help of prominent road crowns in the age of horse drawn carts. This surface was however not resistant to the faster and abrasive motion of the increasing numbers of motor vehicles appearing on the scene since 1900. Penetration macadams are in essence a water proofing and surfacing layer and in general tended to be relatively thin. Layers as thin as 75mm performed well in the old Johannesburg. (Potgieter et al, 1995)

Traffic loading was much lower in those days and pavement structures were often very simple and thin or light structured. Subgrade quality is generally good on the old Reef area and often no subbase was provided with the penetration macadam applied directly on top of such quality subgrades. These pavement structures were further compacted and consolidated over years with increased traffic and good maintenance and are still functional on existing high traffic volume roads after 40 to 50 years of service (Potgieter et al, 1995 and 1996 and Burrows, 1975).

The hot bitumen or tar binder was initially sprayed on top of the prepared coarse aggregate base by hand and later by mechanised spray bars. The hot bitumen and tar binder flowed into the voids and took the place of the aggregate and soil fines. The voids were never fully filled by the hot tar or bitumen binder as it only needed to provide the "glue" to the matrix of coarse aggregate. The relatively high cost of the bitumen and tar binder lead to thinner layers being constructed. The coarse aggregate was also gradually reduced in maximum size to become an exclusive weather proofing surfacing layer. This led to the term "Macadamised roads", meaning that a water proofed surfacing was provided. This was the beginning of hot mix asphalt layers. The hot mix process was patented initially and mechanised in the 1950s. The original large sized aggregate penetration macadam can however still be constructed as it is in essence highly labour intensive

5.2.4 Slurrybound Macadam

The development and use of cold bitumen processes such as emulsions did open a new opportunity to redesign the original penetration macadams. Slurry mixes made from bitumen emulsion and fine aggregate are labour friendly and replace the costly hot tar and bitumen binder of the original penetration macadam. Potgieter et al (1995) experimented with this redesigned people friendly penetration macadam construction technique in the early 1990s in Johannesburg to emulate the successful penetration macadam layers described before. It was called slurrybound macadam (SBM) to differentiate it from the penetration macadams.

Slurrybound macadam is in essence a thin base and weather proof surfacing combined. Layer thicknesses are mostly restricted to 75 mm maximum. In essence the large aggregate is spread and oriented to achieve optimum packing and relative orientation with the help of light vibratory rollers or plate vibrators. he optimum packing pattern is achieved through aggregate relative orientation and interlocking and not due to compaction principles. It is in essence hard aggregate on hard aggregate in a thin layer which is just more than the maximum aggregate dimension. Voids are minimised in such a tight interlocked and relatively thin layer. Lately even thinner bases/surfacings have been constructed successfully with a smaller maximum aggregate of 37mm and even 19mm on top of high quality subbases. Layer thicknesses may therefore vary between 20mm and 50mm. Only a very light vibratory plate compactor is needed for this compaction/orientation. (Potgieter et al, 1995). This thin base and surfacing combination can be used in light traffic situations such as for access and basic access streets Slurry- bound macadams (SBMs) have lately also been used successfully as an overlay and rehabilitation measure.

5.2.4. Composite Macadam

Oglesby (1975) indicates that the hardness specification for waterbound macadam base material was originally less than that for a waterbound macadam surfacings. The need to optimise the use of available natural gravel material, reduce the cost and enhance labour intensive potential of construction techniques led to the development of composite macadam on projects in Doornkop, Johannesburg (Horak et al, 1996). Composite macadam is a waterbound macadam or drybound macadam base constructed with good quality single sized natural gravel in the lower base. The top layer is then constructed of smaller and harder coarse freshly crushed aggregate (maximum stone size 37mm) as a thin slurrybound macadam. This layer acts as a durable “key-in” or surface layer and thereby reduce the asphalt binder demand and cost.

This type of construction was used experimentally on access and basic access roads in the urban street hierarchy to manage associated risk of structural failure. Considerable lengths of footpaths and sidewalks have subsequently been constructed successfully in this way in some of the Johannesburg townships (Visser and Hattingh, 1999). In some cases natural gravel was hand selected to sort hard large aggregate which met the required single size dimensions. Roux (1991) developed a procedure and simple tests to measure the durability, hardness and strength of marginal aggregate more accurately. This approach was used to select natural gravel with the required strength and hardness with success. Over and above the construction aspect, the sieving action and separation of the course aggregate offers additional opportunity for labour enhancement in the total construction process. Roux (1991) also advocates the use of marginal aggregate of slightly larger dimension than the normal large aggregate size. This means as example that a 90mm in stead of the normal 75mm could be specified for such composite macadam bases. It is accepted that this larger marginal aggregate will have limited break down under normal compaction activity. The majority of aggregate will however still be single sized and provide the necessary interlock ensuring structural strength. Voids are filled with soil fines to provide the matrix stability.

This improved understanding of the hardness requirements for the lower layer of composite macadam construction have also led to the use of recycled bricks and building rubble material in this layer on an experimental basis on street construction in Soweto, Johannesburg. A mobile single stage crusher was used to crush builder rubble at Doornkop, Soweto (Horak et al, 1996). This obviously opens other opportunities for labour enhancement in the whole process of selection and separation, crushing and sieving of such materials. It is interesting to note that after World War II much or the rebuilding of roads in Britain were done labour-intensively by the returned service men using broken bricks and building rubble. Specifications for the use of broken baked clay brick aggregates and clinker still form part of Indian road material specifications for macadam base roads constructed labour-intensively (Horak, 1983).

5.3 Innovations with natural gravels

5.3.1 Gravel Emulsified Mixes (GEMs)

GEMs is the modification of medium to marginal quality natural gravels with the addition of 2 to 3 percent emulsified bitumen and 1 to 2% of cement or lime. GEMs design specifications were developed from research funded by SABITA and tested under the Heavy Vehicle Simulator (HVS) (Grobler et al, 1994 and De Beer and Grobler, 1995). Guideline documents on the mix design, specifications and material tests were also provided via SABITA funded technology transfer projects (SABITA,1993).

The CSIR proved that such a quality end product was well suited for labour-intensive friendly construction (Hendriks, 1995) on a pilot project in Phutaditjaba in Qwa Qwa in the Free State Province and subsequently on a number of other projects elsewhere. This type of base construction does not need a surfacing to be applied immediately as it is able to carry traffic virtually immediately. Even though HVS tests proved that it can carry considerable traffic (2 to 3 million standard 80 kN axles on 150mm bases), (Liebenberg and Visser, 2002) it is believed that GEMs would be best suited for local streets (access streets) and not major streets (major collectors) or bus routes when applied in thinner bases. This type of base construction is also small plant intensive (SPI) friendly.

The natural gravel is mixed on site in batches and constructed in layers of 75 mm with manual labour. It is also ideal for appropriate surfacing types ranging from slurry surfacing to sand seals to chip and spray done labour-intensively. The mixing process is done by hand or with small concrete mixers. The large and oversized aggregates are often re-used as a hand-packed layer on the prepared subbase prior to being covered with the mixed GEM mixture and being compacted.

5.3.2 Foamed Bitumen and Tar

Bitumen binder, when heated to 165°C and with 2% water added in a small chamber, just prior to its being sprayed through a nozzle, foams and increases its volume more than tenfold. In this foamed state, it is sprayed through a special nozzle. At this stage it also has low viscosity which enhances good mixing with aggregates. It keeps this foamed state for a period of, on average, 40 seconds before it reverts back to its original volume. The mixing in with the aggregate can be achieved in a pugmill within the predetermined half life of the foamed state (about 20 seconds). Once the foamed bitumen is mixed in with the aggregate it cools off and can be placed immediately or stock piled for up to 2 or 3 months before being constructed in a layer (Lewis et al, 1995 and Hotte, 1995).

Considerable research work was done on this technology to stabilise cohesionless sands in Namibia, Botswana and recently on the Makhatini Flats sands in KwaZulu-Natal (Lewis et al, 1995). The potential for this material to be used labour-intensively with natural gravel, was proved on a number of community based construction projects in KwaZulu-Natal (Lewis et al, 1995). The stock piled material is constructed like any natural gravel by compacting a moistened mixture with small Bomag type compactors in layer lifts of 75 to 100 mm. This process was used with success on a number of roads in the Soweto area in Johannesburg in 1995 and subsequently elsewhere with success (Horak et al, 1996).

More fundamental work on foamed bitumen was done by Jenkins (2000) to help develop design procedures and better characterisation (Jenkins et al, 1999). Gasifier low temperature tars can also be foamed successfully on a variety of granular materials. The historic perceived health hazards are largely overcome by the confined mixing of tar in a drum or pug-mill with limited or no exposure of the hot gases to people where after it can be used in a cold mixed or stock-piled fashion in a labour friendly manner (Morton et al, 2002). The end result is however a bituminous product which has much better adhesion and anti-stripping characteristics than foamed asphalt mixes.

5.4. Concrete blocks and bricks

Block and brick paving is a well known labour-intensive construction technique (Kelly, 1995). Traditionally block paving had been associated with footways, parking areas, pedestrian areas and loading areas. Considerable work was done in the early 1980’s by the CSIR on various types of block paving as a proper road construction material. The Heavy Vehicle Simulator (HVS) was used to do accelerated road tests on these types of pavements and it resulted in dedicated design procedures such as the UTG2 design guideline (CUTA, 1987).

This technology, must be seen as an alternative surfacing type as it requires road structures equivalent to other road construction types (Kelly,1995). It means that the inherent structural value of block paving is not optimally utilised and tends to make it more expensive than other types of base and surfacing if initial construction costs are used as the only criteria. In an analysis of the total life cycle cost of roads though this surfacing type may prove to be more cost effective than other flexible base types.

Cement brick making on site has obvious cost saving implications and entrepreneurial development opportunities, but quality should be carefully controlled. The link with other construction activities like house building has added empowerment potential. Recently recycling of bricks from building rubble to be used on footways and sidewalk construction have also been done with success in Soweto, Johannesburg (Horak et al, 1996). The broader job creation and community self-help aspects of rubble sorting and recycling in itself also have good merits.

5.5. Geo-cells

Geo-cells are made of strands of durable material, like plastic, which when stretched horizontally on a prepared subbase or selected layer creates openings and pockets in which soil is poured to form a layer. Due to the confinement of the surrounded geo-cells, the vertical bearing strength is dramatically improved. Geo-cells have originally been developed to stabilise sands and cohesionless material *(Horak et al, 1996*), but have developed into erosion protection mats, in situ moulds for concrete blocks and other labour-intensive applications. (*Visser and Hall, 1994*). The cell dimensions can vary in height and size, but generally resemble a standard paving block size. This type of construction is included in the Red Book (1998) in a catalogue format.

These geocells have been used with great success though as in situ paving blocks when filled with concrete. Such applications have been used in hard standing areas on quay walls and container stacking areas with success. Geo-cells concrete blocks are relatively expensive as the plastic and its setting up is often perceived as an extra cost versus normal concrete blocks.. It is however ideal to be used in cohesionless sand and arid regions to form a strong structural work platform. By adding treated material (cemented or bituminous) to the cells, additional cost is added compared to filling it with just soil or sand.

5.6 Roller Compacted Concrete (Rollcrete)

Rollcrete is a dry-mix concrete produced from a continuously graded crushed stone product. It was originally used for dam construction. Rollcrete is normally placed by means of graders or pavers and compacted with vibratory compactors. Work done in Spain since the 1970's on lightly trafficked roads led to the use of Rollcrete in heavy duty pavements for the US Corps of Engineers and led to further use in various countries as a mechanised road construction method (Gill, 1988).

Subsequently work done in SA to develop appropriate design standards led to accelerated road testing with the Heavy Vehicle Simulator (HVS) on pilot sections in Kwa-Zulu Natal. (Wright et al, 1990). The application of this road construction technology was also tested with in the construction of access roads in townships in Kwa-Zulu Natal and subsequently elsewhere. These applications in townships were on steep gradients where concrete normally does have better application and where the drainage channels were incorporated as shallow V-shaped roads as suggested in the Red Book (1998). This application was done with hand operated vibratory compaction devices with great success. This is clearly a road building technology with great potential for Small Plant Intensive (SPI) applications. Transportek, the University of Pretoria and the Cement and Concrete Institute (C&CI) have recently done a number of pilot demonstration projects with this technology in various townships with relatively thin concrete pavements (90 to 75mm thick) and with mesh reinforcement with apparent success. Fibre-reinforced thin concrete layers have also recently been experimented with in this joint project in the Roodepoort area, where performance records are being monitored.

6. STRUCTURAL DESIGNS

A simplified catalogue of designs is presented in Table 3 for various quality subgrades for access and basic access street construction. The departure point is to use quality in situ subgrades directly as base or subbase layers as described in section 4 with the DCP determined CBR values and dynamic compaction. The designs are strictly to be used only in the dry regions of SA. Moisture influence is managed via proper stormwater facility designs and management as described in the Red Book (1998). All these provisions and considerations make this not merely a higher risk approach than the traditional designs in the Red Book, but a cost saving risk managed approach as well as an extension of innovative technologies provided for initially.

Table 3 Catalogue designs for DCP classified subgrades for access streets

Base and surfacing technology	**Subgrade classification based on DCP determined CBR**		
	G4 (Field CBR>110)	**G5 (Field CBR >80)**	**G6 (Field CBR >65)**
Waterbound macadam (WBM)	Direct on subgrade 100mm thick plus a single seal	Direct on subgrade 125mm thick plus a single seal	Direct on subgrade 150mm thick plus a single seal
Penetration Macadam (PM)	Direct on subgrade 50mm thick	Direct on subgrade 75mm thick	Direct on subgrade 100mm thick
Slurrybound macadam (SBM)	Direct on subgrade 20mm thick	Direct on subgrade 50mm thick	Direct on subgrade 75mm thick
Composite Macadam (CM)	Direct on subgrade 100mm thick	Direct on subgrade 125mm thick	Direct on subgrade 150mm thick
Dumprock (DR)	Not applicable	Not applicable	Direct on subgrade 200mm thick plus 20mm SBM
Emulsion treated gravel base (ETB)	Direct on subgrade 75mm thick	Direct on subgrade 100mm thick	Direct on subgrade 125mm thick
Foamed bitumen gravel base (FB)	Direct on subgrade 75mm thick	Direct on subgrade 100mm thick	Direct on subgrade 125mm thick
Block paving (CB)	50mm with 20mm sand layer	60mm with 20mm sand layer	80mm with 20mm sand layer
Rollcrete (RC)	75mm directly on subgrade	100mm directly on subgrade	125mm directly on subgrade
Geocells (GC)	50mm/20MPa cell slab directly on subgrade	75mm/20MPa cell slab directly on subgrade	75mm/30 MPa cell slab directly on subgrade
Recycled clay bricks (RCB)	Directly on subgrade with 20mm sand layer	Directly on subgrade with 20mm sand layer	Directly on subgrade with 20mm sand layer

A risk management approach is followed by using the shaded block of Table 1 (See Section4) from the Red Book, with a G6 quality subgrade, as the departure point.For this quality subgrade no additional subbase and base are needed. The risk is further managed by adding two higher quality subgrades classified with the DCP in situ (a G5 and G4 equivalent subgrade). The appropriate base and surfacing technologies listed in the Table 3 also increase in layer thickness as lower quality subgrades are used in this fashion as in situ bases and subbases. Table 3 can be seen as a logical extension of the design catalogues provided in the Red Book for some of these technologies and an addition for those not included yet.

7. RELATIVE COMPARISONS

A primary objective of street construction in townships is effective service delivery with optimum job creation. Technologies selected must however not only meet these socio-political criteria, but also technical quality and cost to construct. There are a number of other factors which are normally considered in such evaluation and choice, such as availability of material, transport cost, reigning soil conditions, topography, access to support services, availability of plant, skill level of prospective entrepreneurs, etc.

In pursuance of job creation and entrepreneurial development of SMMEs and PDI development, the aspect of level of mechanisation plays a determining role. Normally the mechanisation parameter is measured on a relative scale from the low level of direct labour only to increased use of small plant and machinery to the highest level of heavy machine intensive (Horak et al, 1996). Entrepreneurial development is often linked with skill level required and person friendliness of the technology selected to indicate to what extent the technology opens up opportunity for previously disadvantaged individuals (PDIs) to progress from labour only to higher levels of empowerment through access and use of small plant and associated skill improvement. To combine all these aspects, the collective concept of PDI friendliness will be used on a relative scale in this comparison.

Cost will always be an important criterion. It is however always problematic to try to compare direct cost only as it inevitably leads to an “apple and pear” type comparison. The wider cost to a community is often not included in such narrow cost comparisons and therefore a relative cost comparison which factor these aspects in are suggested over and above the normal straight forward comparisons. The cost expressed as Rand/m^2 in this comparison demonstration therefore include these broader cost aspects even though normalised in relative terms.

In Figure 2, a comparative analysis of the various technologies are given for the parameters, PDI friendliness, and cost per m^2. A zone which is deemed unacceptable in terms of both parameters is indicated. It is significant that even though the various technologies show a spread over the relative scale of cost, the technologies are bunched on the medium to high PDI friendliness. This indicates that the selected technologies will offer value for money in terms of ability to involve and develop PDIs at reasonable cost. In order to calibrate these technologies a150mm G1 crushed stone base, which is a highly mechanised construction technique, is also shown. This technology is the only one which lands up in the unacceptable zone for both parameters. Thickness of layers may have a significant effect on some of these technologies on the cost axis and for that reason this relative comparison should be treated as an example only and not as a rule.

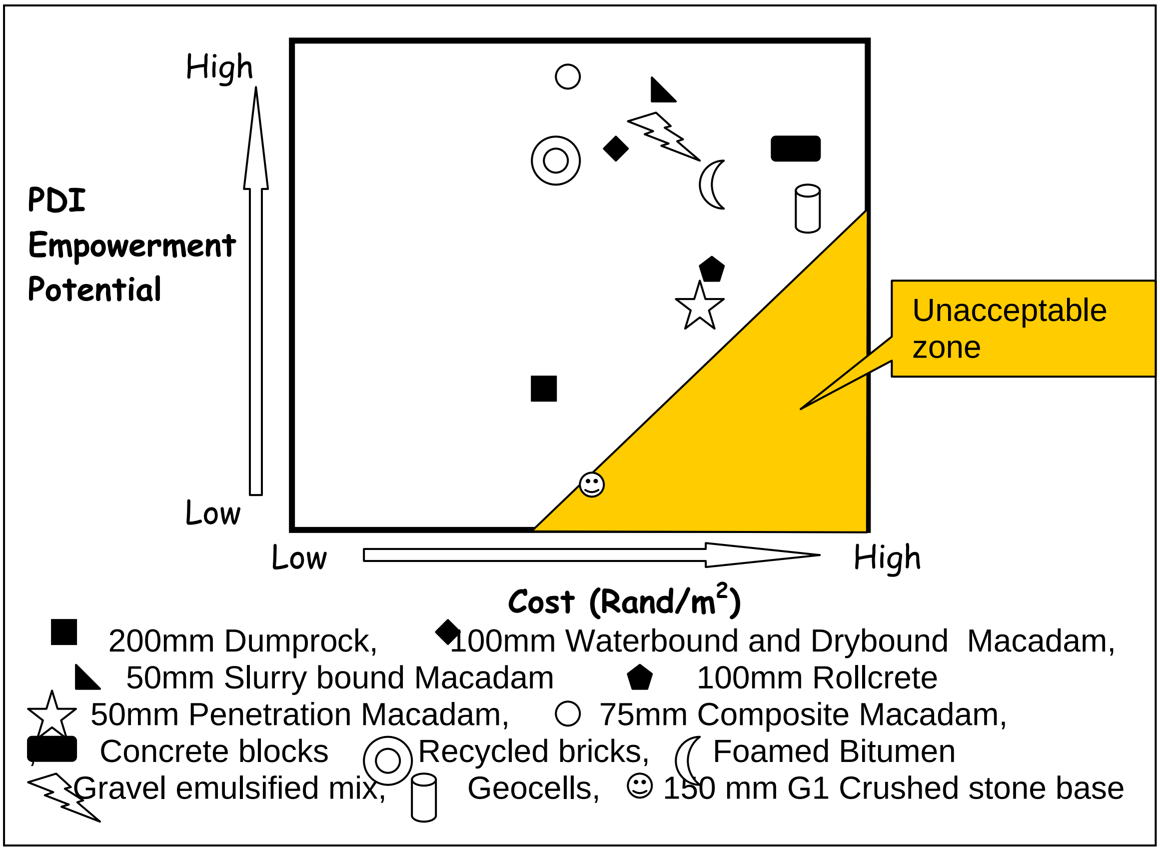

Figure 2: Relative comparison of construction techniques

8. CONCLUSIONS

A number of road construction technologies which are human friendly, labour-intensive (LI) as well as being small plant intensive (SPI) friendly were discussed in a philosophical fashion to explain the rationale behind their structural strength and their good performance. The significance of these construction techniques lie in their skills transfer potential and associated empowerment of Small, Medium and Micro Enterprises (SMME's) and previously disadvantaged individuals (PDIs). These technologies discussed are by no means an exhaustive list of such empowerment friendly techniques, but has the distinction that they have a proven record of constructability, quality, durability and good performance end products.

These technologies are applied to the design of access and basic access streets only. These streets make up the bulk of the backlog of street construction and maintenance needs in the urban township areas. The upgrading and construction of these streets are very visible measures of service delivery in the mind of township communities. The aspect of community involvement in decision making was also facilitated in the expansion of the well known concept of Level of Service (LOS) to include a Community Benefit Index (CBI) to derive a community participated street Upgrading Priority Index (UPI). If these innovative street construction technologies are combined with this transparent decision making processes and prioritisation, empowerment of the communities and job creation will be the end result in a sustainable fashion.

As SA is largely a dry region, a more realistic evaluation of bearing strength of subgrades are suggested. This is achieved by using the Dynamic Cone Penetrometer (DCP) to evaluate subgrades at field moisture conditions and thereby enable the elimination of additional structural layers. Structural designs are suggested for these innovative base and surfacing construction for access and basic access streets which extends the catalogue presented in the Red Book. This is a managed risk approach if the rationale behind it is clearly understood and adhered to. The innovative base and surfacing construction technologies meet the requirement of structural quality and performance, but it also distinguishes itself in terms of its empowerment friendliness towards Previously Disadvantaged Individuals (PDIs) as well as realistic total cost factors.

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