SARF COURSE: G1 CRUSHED STONE BASE COURSE CONSTRUCTION

CONTENT

CHAPTER OR TOPIC		PAGE
1.	INTRODUCTION	2
2.	ORIGIN AND GOAL WITH G1 CRUSHED STONE	2
3.	SPECIFICATIONS FOR G1 MATERIAL	3
	3.1. Requirements for G1 aggregate – COLTO 3602 (a)	3
	3.2. Soluble salt content – COLTO 3602 (b)	5
	3.3. Grading requirements – COLTO 3602 (c)	5
	3.4. Material from existing pavements – COLTO 3602 (d)	6
	3.5. The quality of the supporting structure	6
4.	CONSTRUCTION OF G1 CRUSHED STONE BASE	7
	4.1. Construction Equipment	7
	4.2. Sourcing G1 Material	7
	4.3. Acceptance of G1 material on site	8
	4.4. Material from existing pavements – COLTO 3602 (d)	8
	4.5. Dumping of G1 material onto the road	8
	4.6. The Construction Processes	9
5.	A WORD ON QUALITY CONTROL	16

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1. INTRODUCTION

It seems that the accumulated knowledge regarding the manufacture and construction of G1 Crushed Stone for base course work that has been carefully built up since the 1960 has largely been lost over the past 10 years - one hardly finds a site where in-spec G1 material is delivered and/or its construction is executed correctly any more.

This has a profound effect upon the efficacy and cost of such pavements. The once proud legacy of the South African road building industry, which resulted in so many international fact finding missions regarding the success of the "South African inverted pavement" seems to have been relegated to a quiet retirement from the road construction scene - it has all of a sudden become "too difficult", "time consuming", "uneconomical", etc., etc. Fortunately the technology of G1 Crushed Stone is still available – it only needs to be introduced, understood and applied again.

This manual is compiled to convey the message that the know-how has not been lost – possibly only the will to execute the once well-known process with care and pride. Visual reference is provided by the accompanying printouts of the slide show used during the presentation of the course.

2. ORIGIN AND GOAL

It is common knowledge that the strength of road building material is dependent on, amongst other parameters, the density of that material – the higher the packing density or actually the particle interlock, the higher the strength of the mass of material. This principle of particle matrix and interlock was concentrated on during the development of G1 Crushed Stone. A layer of G1 Crushed Stone actually consists of a highly interlocked matrix of continuously graded superior quality minus 37.5 mm crushed rock. The final aggregate interlock is achieved by way of a special high-water-content compaction process during which the excess fines in the aggregate matrix are expelled to achieve intimate aggregate interlocking.

Introduction to the concept that traditional crusher-run could be compacted to a much higher particle-interlocking state than known at the time, happened in the late 1950's during routine crusher-run road base compaction when, during the final stages of the process, typical Highveld summer rainstorms would occur. Wanting to complete that specific section of base course before close of day, the compaction process would then be continued during the rain. The seemingly positive effect of the additional water and the initial "worrisome" loss of fines during this final compaction process in the rain were each time noticed during the quality control process. It was also noticed that after having swept the thin layer of expelled fines off of the base course, the larger aggregate appeared to be much more tightly knit than previously. This effect was also noticed in the sand replacement/density holes. And sure enough, the measured relative density was higher than achieved before. This process was then

artificially simulated and refined to what is now known as "slush-compaction" or "water-roll" compaction.

The National Highway Materials Committee of South Africa then decided that an aggregate layer of such quality warrants being distinguished from the normally compacted aggregate (such as crusher-run) or natural gravels and assigned it the special designation "G1" (top of the range unstabilised aggregate) and the name "Crushed Stone" as an indication of its high-quality.

3. SPECIFICATIONS FOR G1 MATERIAL

The general specifications for G1 material may be found in the COLTO Standard Specifications for Road and Bridge Works for State Road Authorities. However, be aware that specific project specifications applicable to the job at hand may take preference over COLTO.

Basically the material is continuously graded according to the Fuller/Talbot best packing particle grading specification, with the intention that each particle should virtually fit into its own designated space in the finished product – just as in the solid rock from which it was crushed. This may sound like a tall order and a practical impossibility but reflects the aim with the compaction process and the developed final slush-compaction process. It stands to reason then that the manufacture and construction process needs to be executed with care and precision.

Yet, while the precision with which the material is specified may convey the message that the G1 Crushed Stone construction process is difficult and time consuming, experience has shown this not to be the case, provided that the specified material and construction procedures are adhered to. Hence the following additional comments regarding G1 material and the construction of G1 Crushed Stone should be read in conjunction with COLTO.

3.1. Requirements for G1 aggregate – COLTO 3602 (a)

No change in particle grading can be tolerated during construction (or even during its service life as result of aggregate breakdown) of a G1 Crushed Stone layer since this would result in a dramatic loss in strength and bearing capacity. Thus, the aggregate intended for G1 material must be of the highest quality, able to withstand high compaction and traffic energy input without grading and bearing capacity altering break down. It must also be chemically stable and not prone to developing moisture sensitive clayey secondary residue. Hence, if at any stage one can visually detect an area showing a colour deviation from that of the parent material, rest assured, that portion of the material has been contaminated and will test and behave out of specification.

3.1.1. Additional fines: Keep in mind that the grading specification was drawn up for material consisting of the same parent rock – same Specific Gravity (SG). Since the grading specification is based upon the particle mass of each sieve fraction, using fines with a different SG to the rest of the material will result in an incorrect volumetric quantity of that fraction. This, of course, will have a profound effect upon the slush-compaction process, even to the point of the material being unmanageable and unusable.

3.1.2. Strength: Note that the strength of the aggregate must be sufficient to withstand the compactive effort to interlock the aggregate matrix, without fracturing or breaking down the aggregate matrix (altering its particle grading characteristics) necessary to deliver the shear strength and thus bearing capacity expected from a G1 Crushed Stone layer. For this reason apparently sound material may not be suitable – the inter-particle bond may not be high enough or chemically deteriorate in itself – especially upon being introduced to the atmosphere or the abrasive nature of traffic induced deflection on the layer.

3.1.3. Flakiness Index: Flaky particles do not pack well - to the extent that such material will result in more voids and less particle interlock (density) than more cubically shaped particles. Also, flaky particles do not re-orientate readily to fit available inter-matrix spaces and thus can bridge voids in the matrix to cause low density "compaction shadows". This, results in variable particle interlock, quality control results, and layer strength characteristics.

3.1.4. Fractured faces: The more rounded and smooth the particles are the easier it will interlock (densify), however, also the easier it will de-densify and lose layer strength. Hence, some particle surface roughness (ruggosity) is necessary, even though it may require more energy during construction to interlock it; however, one then has the assistance of water and fines during the slush-compaction process.

3.1.5. Atterberg Limits: As a general note regarding the Plasticity Index (PI) of G1 one should observe that the aim of interlocking the material is to gain strength and maintain it under varying conditions, especially wet conditions. Water has a tendency to lower the shear resistance between the particles and hence the bearing capacity of the layer, especially clayey material. Hence, one does not want a water sensitive component within the material or matrix – hence, as low a PI as possible (preferably zero) – hence, no weathered material high in clay generating minerals such as smectite – hence, "fresh" high quality parent rock. So, if the parent rock consists of basic crystalline rock, such as dolerite, basalt, etc., check for traces of clay generating minerals such as smectite and treat the material (kill the PI) with lime (preferably at the crushing plant) to the extent of achieving a pH of at least 10, if not 12,4.

3.1.6. Porosity: Little mention is made of the porosity of aggregate to be used for G1 Crushed Stone. From personal experience it can be stated that, apart from the obvious reason for not wanting the finished layer to be porous, the porosity of the aggregate can complicate the construction process considerably, as well as impact on the performance of the layer. Depending on the porosity and size of the voids on the surface of the aggregate fines can inexplicably be "lost" during mixing only to be "regained" during the slush-compaction phase, adversely affecting the effective particle grading, water requirement and hence the entire slushing and interlocking process – and, hence, strength and durability of the final layer. This is particularly at stake when using highly porous crushed blast furnace slag for a G1 Crushed Stone layer. Such material tends to result in a "spongy" layer with extraordinary high deflection, adversely affecting the density attainable in any overlying layer. If this type of material has to be used it must be selected carefully to strenuously limit variability and exclude high porosity and "glassy" particles – which increases its initial cost considerably.

3.2. Soluble salt content – COLTO 3602 (b)

This limitation was found necessary because experience has shown that soluble salts and acid-soluble sulphates can cause "blistering" and disruption of the bituminous surfacing of a road. This is caused by the re-crystallisation of the salts in the upward migrating salt laden water vapour just below the highly impervious bituminous surfacing, through which only the water vapour can escape.

Sources of salt can include the natural gravel itself or even the compaction water. In such cases the salt usually was sodium chloride (NaCl). The salts in sulphidic gold and copper mine waste rock crushed for G1–G3 base have always been acidic sulphates. In the case of rocks and slags containing sulphides the salts and sulphuric acid are derived by oxidation of the sulphides – usually pyrite (FeS2) – on the dumps and/or in service in the pavement. Gypsum (CaS04.2H20) is not usually deleterious in untreated layers. (From published works by Dr Frank Netterberg)

Note that these salt fines can coat the aggregate particles in the matrix with a fine pale white to yellowish "dust" that can cling sufficiently well to the aggregate to lead to a false low registration of the fines content when dry-sieved. This then usually only become apparent during the slush-compaction process when a high volume of extracted fines/slush and an unexpectedly high energy requirement is manifested.

If the pH registers below 6 soluble salt contamination should be suspected and tested for. Such material may either be washed to get rid of the soluble salts. However, this requires copious amounts of water, which is usually easier- said than done. It may be more practical to neutralize the salt by addition of road lime (preferably at the crushing plant) until the pH is at least 10. However, this will not get rid of an excessive amount of fines, if (also) present. This will need screening out and re-introduction of the correct amount of fines thus lost. Avoid landing in this situation at all cost.

3.3. Grading requirements – COLTO 3602 (c)

Particle grading of an aggregate matrix monitors the ultimate interlock (density) achievable. In terms of G1 Crushed Stone it virtually boils down to composing the specified "picture" with randomly shaped jig-saw pieces by filling the spaces between the larger particles with other increasingly smaller particles – and discarding the excess smallest pieces during the slush-compaction process. Only, in this case the jig-saw pieces cannot be hand-picked and -placed and does not pertain only to a two dimensional picture either, but a three-dimensional aggregate structure that resembles the original intact rock mass it was crushed from, placed and interlocked by large road-building machines.

In the process the (powdery) fine particles (minus 0,075 mm) are not only used as filler for the smallest voids in the matrix but also as "lubricant" during slush-compaction to assist in maneuvering the larger aggregate particles closer together to achieve optimum packing and interlock. This is manifested by a tightly knit aggregate mosaic developing throughout the layer (and observable on the surface), with very little evidence of fines in between the larger aggregate particles (around 4% - 6% by mass). During this interlocking process the excess fines is expelled from the layer and discarded. For this reason the particle grading curve must show a small excess of fines – about 3% more than necessary for a true Fuller/Talbot particle grading (that grading which allows for best packing/interlock of the particles).

Note that the particle grading given in COLTO is the after-compaction power 0.3 and 0.5 Fuller/Talbot envelope grading. Strictly speaking that implies that the grading of the final product shall comply with Fuller/Talbot. So, what particle grading should be ordered? This should not pose a problem since only the highest quality material is specified and negligible particle breakdown under construction can be expected if the material is not over-worked and -compacted. However, since slushing of fines is applied to assist in orientating and interlocking the aggregate, a certain amount of fines (minus 0,075 mm) will be removed from the matrix. For this reason a slight excess of this fraction mentioned above should be provided to ensure that the final slush-compacted particle grading conforms to the Fuller/Talbot grading.

It has been observed that some contractors, not having acquired in-spec material may resort to "improving" the grading by deliberately breaking the material down, through use of a grid- or pad-foot roller or even a milling machine, to obtain a relatively fine gravel which, of course, compacts relatively easily and obtains the specified density more readily, without the slush-compaction process. This process may attain the specified density but certainly does not result in the required interlock and, hence, bearing capacity expected from it. Such practice cannot be condoned since it negates the objective of the design.

3.4. Material from existing pavements – COLTO 3602 (d)

Materials from existing pavements should not lightly be considered for G1 Crushed Stone layer work unless it conforms to all the requirements for such material - similar to the purchasing of G1 Crushed Stone material – otherwise it might well prove to be impossible to slush-compact to a state of interlock. This caution is intended to ensure the standard outcome specified for a G1 Crushed Stone layer and prevent heart aches and frustrations for both the Contractor and the Client – it is a matter of curbing being "penny wise and pound foolish" borne out by bitter experience.

3.5. The quality of the supporting structure

It stands to reason that the subbase of a G1 Crushed Stone pavement must have a high strength (bearing capacity) and water resistance. **Strength** - because it forms the backbone of the pavement which must ensure that the base course always operates under compressive stresses (a relatively deep pavement composition). This needs to be so since G1 Crushed Stone tends to de-interlock under tensile stresses operation, being a non-cohesive material. **Water resistance** - because it needs to deliver a very high degree of support and integrity under very wet conditions during the slush-compaction phase of the G1 material overlying it. Hence, the minimum support value is at least high C4 quality, with a low water sensitivity ensured by having a post stabilization PI below 6, even for the lightest G1 Crushed Stone pavements. (It was experimentally determined that stabilization cracks do not reflect through a G1 Crushed Stone layer of 150 mm thickness.)

4. CONSTRUCTION OF A G1 CRUSHED STONE BASE

The construction process, although very simple, has to be executed with precision. It incorporates having equipment that can effectively construct a G1 Crushed Stone layer and having a quarry that can deliver the correct G1 material correctly. This is a very important and key to achieving the correct end result with a minimum of effort – and is the responsibility of the contractor. Reference may be made to the accompanying visual extracts from the training slide show for assistance.

4.1. Construction Equipment

The following is an indication of the minimum primary pieces of equipment, in good running order, that will be necessary to successfully construct a G1 Crushed Stone layer:

- At least one construction type motor grader with an unworn blade and enough power to move a fully laden blade at an even and relatively fast pace without digging in or pulling to one side.
- Two water dispensary trucks that can apply water evenly and at a constant pace across the entire width of the material being worked, without refilling breaks.
- Sufficient 15 to 17 ton self-propelled rollers capable of adjustable amplitude and frequency vibratory, as well as static, compaction.
- At least one self-propelled heavy (24/28 ton) overlapping pneumatic-tired roller in order to cover the entire width of the material being compacted and of which the tire pressures are self adjustable.
- If available, a medium-heavy (15 ton) three-wheeled smooth drum roller will speed up and enhance the slush-compaction process because of its high rear wheel contact pressures.
- At least one light (preferably self-propelled) mechanical rotary broom of which the spindle height above the roadway is easily adjustable in relatively small increments to ensure light and even contact pressure across its width. The broom is used to distribute the extracted fines as necessary across, and finally off, the surface during the final slush-compaction phase. It is also used to sweep the surface just prior to priming/sealing.

4.2. Sourcing G1 Material

While the grading given in COLTO is the final as built grading, it may be applied as specification when ordering G1 material since it depicts the ideal Fuller/Talbot grading and does not change noticeably during construction, apart from losing the excess fines in the matrix. Hence, using it as sourcing specification may be done with the proviso that the fines content (minus 0,075 mm fraction) be increased by about 3% to allow for proper slush-compaction.

Above all, make sure that the order is placed with a crusher that can produce in-spec G1 material according to COLTO (or the specification applicable to your contract), consistently and to the volume necessary for your job, by obtaining representative laboratory test results of the material currently available and intended to be delivered to you. Do not be swayed to accept inferior materials since that will only ensure that you, the contractor, will eventually pay the extra necessary to have the correct material in terms of wasted construction effort - and possibly eventually having to discard the material and order new in-spec material out of your own pocket!

Stockpiles at crushing plants are normally highly stacked and sampling must be done correctly and with precision to avoid testing non-representative materials. The material at the toe of such a stockpile is usually badly segregated. Thus, samples should preferably be taken directly from the conveyor belt at the crusher. If one has to sample a large stockpile directly, the sample material should be taken from trenches opened up into the stockpile to a depth where the material is still un-segregated. A stockpile should be sampled at various positions to ensure obtaining a representative result. For the same reason it is important to monitor loading operations directly from a stockpile. Material loaded at the toe of a stockpile must not be used for construction as-is, but re-mixed to ensure a well graded aggregate matrix.

4.3. Acceptance of G1 material on site

It is important to ensure that you receive the G1 material that you ordered – material conforming to the test results on which you based your selection of quarry – so assess samples of the material as it is delivered so that you can report/stop delivery timely should you find out that the material delivered is out of specification. Do not accept and pay for sub-standard material – it will result in a double-pay situation when it proves to be un-constructible - rather send it back to the crusher or negotiated a lower price and use it for something else. If the material is only slightly outside the specification chances are that it can be corrected by the crusher – have a discussion with the management of the crusher to this end.

Keep in mind that the grading of the material can alter sufficiently during transport to render it problematic or even sub-standard, especially uncovered relatively dry material which is barely in spec regarding its fines content, when hauled on blustery or rainy days.

Refer to TMH 5 "Sampling methods for Road Building Materials" for more information regarding sampling.

4.4. Material from existing pavements – COLTO 3602 (d)

Materials from existing pavements should not lightly be considered for G1 Crushed Stone layer work unless it conforms to all the requirements for such material - similar to the purchasing of G1 Crushed Stone material – otherwise it might well prove to be impossible to slush-compact to a state of interlock. This caution is intended to ensure the standard outcome specified for a G1 Crushed Stone layer and prevent heart aches and frustrations for both the Contractor and the Client – it is a matter of curbing being "penny wise and pound foolish" borne out by bitter experience.

4.5. Dumping of G1 material onto the subbase

It is important that the material be dumped onto the subbase on which the G1 layer has to be built according to pre-determined volumes and intervals. This is so in order to have the correct amount of material available at that particular location with which to construct a layer of correct final dimensions and integrity, with a small amount of excess ("borrow material") in the form of a windrow along the road.

In this process allowance must be made for a compaction factor of 1,40 to 1,50. The compaction factor must be adjusted upwards if it is found that the final layer thickness is not achieved despite using all the dumped material at that location, or downwards if the excess material windrow is unacceptably large.

Normally the G1 material intended for the base layer is dumped onto a subbase that is:

- Firm and durable – usually well cemented (stabilized) to allow construction of the G1 Crushed Stone base on it.
- Clean – to prevent contamination of the G1 material to be worked on it.
- Damp – to inhibit water absorption from the G1 material and ensure sound bonding with the new base layer.
- Confined (boxed in) by specially formed, well compacted, shoulders against which the G1 layer may be shaped, worked and compacted without the danger of being contaminated by shoulder material. (In the case where boxed shoulders are not prescribed or intended, additional G1 material must be provided to form a wider layer of G1 material of which only the central or roadway part is compacted to G1 specification.)

The G1 material is dumped evenly along the middle of the entire roadway on which the G1 Crushed Stone layer is to be constructed - not in a few separate stockpiles from which the material will have to be "transported" to the specific location on the road. This is to inhibit variation in layer thickness as well as segregation of the aggregate matrix during construction. In the case where gaps in the row of dumps have to be provided for traffic crossings, the length of the gaps has to be adjusted to coordinate with the dump sizes so that it may be easily and accurately filled in later. Some contractors prefer to simply level the dumped G1 material to allow traffic to cross – but this can lead to unacceptable contamination of the G1 material and hence poor performance areas on the road.

4.6. The Construction Processes

In summary, the following main construction phases may be identified:

- **Basecourse edge constraint:** Special shoulders or edge constraints must be constructed, or allowed for in the form of additional G1 material to contain or restrict the G1 material, in order that the basecourse layer may be compacted properly right up to the edge of the layer.
- **Dumping of G1 material:** Loads of (in-spec) G1 material must be delivered and dumped onto the prepared sub-base according to a pre-determined ratio, to ensure that the specified after-compaction layer thickness is achievable.
- **Spreading, watering, mixing and shaping of G1 material:** The dumped G1 material must be spread, watered and mixed to ensure a uniform aggregate matrix and moisture content, before shaping of the layer can commence.
- **Initial compaction of the G1 material:** The mixed G1 material is compacted with a combination of heavy static and vibratory pneumatic and steel tyred rollers until a stable layer of G1 material at OMC, is obtained (usually at about 85% of ARD) to allow the final slush-compaction process to commence.
- **Slush-compaction of the G1 material:** The layer is overly watered and rolled with heavy rollers to firmly interlock the aggregate matrix whilst expelling all excess fines to the surface of the layer.

- **Final roll of the G1 basecourse:** The compacted layer must receive a final "dry" roll with a steel wheeled roller to knit the surface mosaic of the layer after it had dried out sufficiently (usually a day after completion of the slush-compaction process).

4.6.1. Edge constraint for G1 Crushed Stone

Some Clients prefer specially constructed shoulders with which to contain or "box-in the G1 material" so that the edges of the G1 layer may also be compacted to the required G1 standard. Such shoulders should consist of subbase quality material compacted to at least 95% of Mod AASHTO and constructed as subbase normally would, allowing for a small amount of excess material for final trimming. If the specified shoulder is too narrow for the construction equipment available, it can be constructed wider and the trimmed back to specification. After final compaction and finishing of the shoulder, the inner (roadway) edge must be neatly cut off vertically and all excess material removed from the road surface to prevent contamination of the G1 material to follow.

Keep in mind that water which collects in or on the basecourse during construction will have to be guided out of or off the layer, especially at the lower parts of the road. Provision has to be made for this if the shoulder material is rather impermeable. Note that crushed slag is inclined to be more permeable and rough, needing more compaction water, and hence better drainage.

If the Client prefers to use the G1 material as shoulder too, it may be done by spreading the G1 material at least 1m wider than the intended riding surface and compacting the entire layer to initial compaction stability (about 85% ARD) to act as edge restraint for the actual G1 layer against which the final G1 aggregate interlock may be attained.

4.6.2. Dumping of the G1 material

Since a G1 Crushed Stone layer is constructed to specific dimensions and density, it must be dumped according to predetermined volumes and intervals along the road, allowing only for a small amount of excess material in the form of a windrow alongside the layer being constructed. In calculating the correct amount of material to be dumped allowance must also be made for a bulking or compaction factor of 1,4 to 1,5, which should be adjusted to ensure the attainment of the correct compacted layer thickness. The degree to which this factor may need adjustment will manifest after the final compaction of the first section with the specific material. Experience has shown that a compaction factor below 1,4 is not viable.

The G1 material must be dumped as evenly as possible in the middle of the roadway on a damp and clean (well stabilized) subbase after any specified shoulder preparation has been executed. Note, once more, that to inhibit the formation of slacks and humps in the finished layer, the G1 material must be off-loaded along the entire length of road that the material is intended to cover and not in a single heap for the section.

Where traffic entrances or crossings have to be provided, the gap length must be in terms of multiples of the normal dump load sizes to facilitate correct closure of the gap. It is often better to level the G1 material as soon as it has been dumped to allow the traffic to traverse it slowly instead of providing such gaps – but only if the probability of contamination and breakdown of the material is very remote. The

material at such crossings will require very attentive mixing and re-testing to ensure that its grading will allow successful slush-compaction.

4.6.3. Spreading, watering, mixing and shaping of the G1 material

Successful construction of a G1 Crushed Stone layer depends largely on the particle size distribution and moisture content of the material. Since the material is essentially cohesion-less (non-plastic) the aggregate matrix tends to segregate easily when moved around in a dry state. This tendency is curbed by dampening the material just sufficiently for the fines to adhere to one another and to the larger particles prior to mixing the material, to ensure an even matrix – this level of care should accompany any movement of the material.

Hence, about 12 hours prior to spreading and mixing the dumped material must be inspected for moisture content. If the material needs dampening, the tops of the dumped material should be flattened slightly with a grader to allow a water distributor to drive (clamber) over it slowly, in order to dampen the material sufficiently to spread it without segregation. Do not "hose" the dumps down since this will wash the fines off/down and cause segregation - unnecessarily increasing the mixing and layer shaping time. This process must be done by an experienced operator and/or well supervised. Watering of the dumped material must be stopped immediately when water starts seeping out from under the dump or layer of material since more water will only serve to wash the fines down and out of the material.

The subbase should be dampened if dusty/dry, prior to spreading the G1 material on it. The amount of water necessary to dampen and spread the material and thereafter to bring it to optimum moisture content (OMC) for compaction, depends on the material characteristics and grading, as well as the construction equipment – and is usually correct as soon as moisture starts being visible (glistens) on the larger aggregate. It is normally in the order of 4% to 6% but must be determined experimentally to suit the compaction equipment. If the OMC of the material turns out to be lower than 4% it is an indication that the mixture probably contains too little fines and will not allow proper slushing and the attainment of the specified G1 density. Trying to "correct" this shortfall of fines by "generating" it through grid-rolling or milling, will only upset the grading and result in the specified aggregate interlock not readily being attainable, or even not at all.

On the other hand, an OMC of above 6% is an indication that the material matrix contains too much fines, which will prolong the slush-compaction process and enhance the risk of incomplete interlocking of the aggregate, resulting in lowered layer shear strength – hence not a G1. The correct way of handling is to prevent this from happening by buying in-spec material. Keep in mind that overly wet material will not compact to a firm load supportive layer that will allow slush-compaction but will start heaving under compaction equipment and consume valuable time to dry out sufficiently to allow proper compaction.

Mixing of the material should commence within 12 hours after having been dampened sufficiently. This is done by "cutting" the material from side to side across the road with the blade of a grader, starting from the middle of the road (where the material was dampened) and working out towards the edges of the road. The grader must blade only so much material as can be moved at an even pace (about 8 km/h). Under no circumstances may the grader be allowed to move at an uneven pace, dig in, pull

sideways, or slip due to a too heavy a load. Note that no material must be allowed to pass under the blade and remain behind, since that will also result in segregation of the matrix. Hence too, the bottom of the blade must not be worn irregularly. The mixing process must continue until the material is uniformly mixed across the full width of the layer to be constructed.

NB: Excessive mixing must be guarded against since it will tend to segregate the material as well as alter the grading. This process is not intended to keep the operators and machines busy or to "correct" the grading of the G1 material to suit the available equipment. It denotes a lack of understanding of the construction process and only serves to ruin the material for G1 purposes. Note that a disc harrow or milling machine cannot mix or "correct" the grading of a G1 material and so must not be used for this purpose. Rather, order, receive and use only standard G1 material!

After the evenly mixed G1 material has been placed in position, the layer must be shaped to the correct pre-compaction cross section, height, thickness and slope, taking into account of the compaction subsidence of loose material. Allowance must be made for a small windrow of excess material along the side of the G1 layer being built from which G1 material may be sourced should it become necessary.

Should level deviations occur during the construction process, one of the following remedial measures may be taken:

- Additional in-spec Crushed Stone must be dumped at such places and mixed in. If the deviation is shorter than 15m G1 material may be spread and mixed in with the existing material by way of the ripper teeth of the grader. In the case of a longer deviation all the material over at least 100m must be remixed with the correction layer material.
- An alternative remedial measure for smaller deviations is to mix G1 material and water in the correct ratio in a large concrete mixer and spreading it over the deviation area.

All deviations must be corrected during this phase of the construction since it is not effective try and do it after the initial compaction phase, let alone the final compaction phase.

4.6.4. Initial compaction of the G1 material

This phase pertains to the compaction of the G1 material as is normally done with road building gravel material. It is the compaction done prior to the slush-compaction phase and in preparation for the slush-compaction phase. It may commence after the G1 material has been thoroughly mixed and the layer shaped as described above. At this point the fines are sufficiently moist for the aggregate to be pushed together (compacted) with a minimum of effort, until it forms a stable supportive layer under the construction equipment (usually around 85% of Apparent Relative Density or 100% of Mod AASHTO).

It is important to first build a trail section to assess the most successful type and sequence of rollers to be used for the material to hand. Note that there is no place in this process for light rollers (below 14 tons). In fact too light a roller will only serve to crush the surface aggregate because of over-rolling in an effort to achieve the specified effect. Neither the trail section nor the normal compaction process should change the grading of the material or be used to change the grading of the material to "ease compaction" – it will only result in inferior shear strength.

A vibratory roller, of which the vibratory mode may also be switched off and adjusted for amplitude and frequency, may be used for all phases of the compaction process if done judiciously and with insight. Heavy static rollers of different mass are of course also used.

NB: Note has to be taken of the fact that vibratory rollers have a tendency to compact and de-compact material cyclically if used indiscriminately – and in the process changes the grading of the material, making it more difficult, if not impossible, to compact properly – hence the precaution of not more than 3 to 4 vibratory passes in any one setting of the roller on a material.

To preserve the shape of the road, rollers should always initiate compaction from the outside edge of the road towards the middle on straight sections and from the lower (inner) edge of the road towards the higher (outer) side in bends/super elevation. Always ensure that the entire width of the road is eventually covered equally by the roller.

If a vibratory roller is used, the first pass should preferably be in static mode. Thereafter two passes are applied with vibration at 3 km/h to 4 km/h at low frequency and high amplitude (for deeper reach compaction), followed by two more passes at 4 km/h to 6 km/h at high frequency and low amplitude (for shallower reach compaction). If the layer has deformed excessively during this operation it should be cut across and placed again, and compaction initiated less aggressively to ensure that the layer firms up gradually and evenly. Experience has shown that no more than two to four passes of a vibratory roller in vibration mode should be allowed because of the propensity of a vibratory roller to compact and de-compact material cyclically and changing the grading in the process!

The layer should now have the correct height and shape and the material should be in a stable condition, ready for the final cut-across action. The purpose of this final cut-across action is to ensure that the layer of G1 material to be finally compacted now has no coarse/stony patches. If such patches are evident they are rectified by distributing just enough of the relatively finer material from the windrow, across the layer to fill in coarse/stony areas and achieve an even well graded surface matrix.

The layer must now be rolled with one or more pneumatic tyred rollers in combination with other static steel wheeled rollers. Ensure that the moisture content of the material is as close to OMC as possible for the applied load (usually 4% to 6%). If difficulty in obtaining the specified density is experienced, 75mm thick layers may be attempted, using pneumatic tyred rollers. Good observation and supervision combined with timely correct/remedial action is necessary during this process.

NB: Rollers should lead with their driving wheels/drums to prevent shoving of the material by the non-driven wheels/drum – which, if not done, can account for corrugations forming on the roadway, especially with light vibratory rollers.

Rolling must be done systematically in half-wheel overlaps from the outside edge of the layer towards the centre line or highest point on the cross-section of the road and must continue until the layer displays no, or a bare minimum, of movement under the roller wheels. The density should then be around 85% ARD. This is essential for successful slush-compaction.

4.6.5. Slush-compaction of G1 material

One of two final compaction processes for G1 is normally prescribed by the Client, namely:

- The "Continuous Process (watering and slushing)" according to COLTO. This is a process during which the density of the layer is raised a further 3% to 4% of ARD above the first-phase minimum density of about 85% ARD, achieved through the initial compaction phase. It is achieved by mobilising the fines in the matrix, through use of copious amounts of water, to act as lubricant between the larger aggregate particles such that the interlock between these particles may be increased and the excess fines (slush) expelled. This slush-compaction process achieves a very high degree of aggregate interlock and shear strength - usually evident by the tightly knit aggregate mosaic on the surface.

- The "Multi-stage Process (water or slurry rolling)" according to COLTO: This is a lighter version of the Continuous Process described above which entails watering the base and subjecting it to further rolling after having been allowed to dry out to less than 50% of OMC, in order to obtain a firm, even, well-knit surface. During this process some fines are expelled from the layer (without paying particular attention to expelling all the excess fines in the matrix or achieving an aggregate mosaic) and distributed across the layer surface to achieve a uniform relatively fine textured final finish. Hence, one may say that slurry rolling is a lighter version of the continuous process.

Both the slush-compaction and the slurry rolling processes are initiated by thoroughly wetting a manageable portion (usually 40m to 60m of dual lane width per watering and compaction team, depending on the equipment available) of a suitably stable layer of G1 material (about 85% ARD) and rolling it with at least two medium-heavy (15/17 ton) steel wheeled and/or pneumatic tyred rollers and/or vibratory rollers in static mode. This phase can be executed immediately after completion of the initial compaction phase or it may be delayed for a day or too. However, the slushing process should not be delayed unnecessarily since the layer is already so dense that it may require a lot of additional time to wet it up sufficiently to initiate the slushing process. The water is required to allow the minus 0,075 mm fines to act as lubricant to achieve the high degree of aggregate interlock required from a G1 Crushed Stone layer. The action of interlocking the aggregate into a higher state of density will expel the excess fines from between the larger particles out onto the surface of the layer, from where it is swept off the surface to expose the final aggregate mosaic.

Do not attempt overly long sections because the water may drain off the road and be wasted before it can be used for the slushing process. Thus it is more effective to apply smaller amounts of water continuously than large amounts at longer intervals. Take care to apply the water to the higher parts of the road and allow it spread itself towards the lower parts. If segregated or coarser areas occur, slushing should be initiated at the areas where excess fines are obviously available, if possible, in order that the slushed out fines may be spread to the areas deficient in fines.

Once the texture of the material on the road is uniform throughout, the layer should be rolled systematically lengthwise from the outer edge in overlapping passes towards the highest part of the roadway and the excess fines swept off the layer before it dries out and hardens, without dislodging the larger aggregate. Hand brooms or lightly applied mechanical rotary brooms may be used. Note that training in the correct use of hand brooms is just as necessary as with other plant. Careless or indifferent execution of the brooming process can ruin a hard day's work in obtaining a smooth and properly interlocked riding surface!

It can happen that the outer edge (500mm to 800mm in width) of the layer becomes over-saturated or waterlogged, especially if the material is deficient in fines. In such cases small drainage ditches to the full depth of the crushed stone layer should be made through the shoulder to allow the water to drain from the G1 material. It is obvious that this situation should be avoided since, apart from being time consuming, the carefully calculated and provided fines can be washed out of the material, making it very difficult, if not impossible, to slush and interlock the matrix.

It should be obvious that the slushing process must be executed with attention and care. The following visual observations act as a guide and indicators of the progress with and the soundness of the process:

- If the layer becomes unstable under the roller (with a mass of at least 15 tons) at an attempt to slush it, it is an indication that the minimum initial bearing capacity has not been achieved (at about 85% ARD) to allow the slushing process to be initiated successfully. The layer will have to be allowed to dry out sufficiently to receive normal compaction until "slushing initiating" stability is reached. If, however, the layer does not reach sufficient stability, even after slushing it, it will have to be ripped up, re-mixed and re-compacted (provided that it contains sufficient fines), to be re-slushed – which cannot be warned against strongly enough.

- Very little, if any, movement of the layer under the roller wheels should be observable during the initiation of this compaction phase - and the stability should improve considerably during the process to eventually handle even a 27/37 ton pneumatic roller without movement. If some slight movement is still observable a remedial action could be allowing the layer to dry out for a few days, after which re-slushing may be effective in stabilising the layer.

- Provided the material is of the correct grading, the fines that are shushed out at the start of the process are very fine (minus 0,075 mm) and creamy in texture. During the process the fines slushed out may become slightly coarser and sometimes even sandy and is an indication that the slushing process has been completed and should be stopped, otherwise the layer will become unstable again. If the "fines" slushed out at the beginning of the slushing process are coarser than minus 0,075 mm material (sandy), it is an indication that the grading of the material has an excess of that fraction and that it will slush out to "pull the grading in line" before the minus 0,075 mm fines will start slushing out. That is another reason why the grading of G1 material should follow a smooth continuous line within the grading envelope without any meandering. One can expect the water expelled from the layer to become relatively clear towards the end of the slushing process – an indicator to watch out for.

- Also notable during the slushing process, is the phenomenon of air bubbles escaping from the layer as an indication that the aggregate is being interlocked. Similarly to the expelled slush, diminishing of the bubbles or cessation thereof is an indication that no further aggregate interlocking is taking place and that the process is completed for the equipment being used - even though the specified density/shear strength may not have been achieved. The same will happen if the roller is too light / ineffective. Note also that driving up and down over the layer with a roller that is too light will only

achieve the breakdown of the aggregate in the top of the layer - and so form a layer of loose coarse sand inhibiting any slush-compaction.

- **Note that** slush-compaction becomes increasingly more difficult at depth such that the bottom part of a layer much thicker than 150 mm will be found slush-compact ineffectively – and thus not conform to the specifications for G1 Crushed Stone. Equally, a very thin layer of G1 material (say less than 100 mm thick) will also not slush-compact and interlock successfully to G1 Crushed Stone standards.

- **Note that** apart from having the specified density, the swept surface of a properly slushed G1 Crushed Stone layer should be smooth and exhibit a tightly interlocked aggregate mosaic that produces a distinct high frequency or "ringing" sound when tapped with a geological hammer.

4.6.6. Final roll of G1 basecourse

After completion of the slushing process the layer must be allowed to dry out somewhat. After about 12 hours of drying out, or the next day, it should receive its final roll with a medium-heavy steel wheeled static roller (same as used for the slushing process). One pass is usually sufficient.

The final finishing roll or "dry roll" is intended to ensure a smooth well-knitted surface finish. This is necessary since the larger aggregate particles at the surface of the layer are usually ever so slightly dislodged when the free water is swept off at the end of the slushing process. With the layer still slightly damp this aggregate can be firmly re-seated. The same care executed before should be taken to preserve the cross section of the road.

Note that any traffic on the road at this stage will be severely detrimental to the interlock, final finish and long-term performance of the pavement and should not be allowed!

5. A WORD ON QUALITY CONTROL

Relying solely on the measured density of a layer of G1 Crushed Stone as the indicator of as-built quality can be very misleading because what is actually being sought for G1 Crushed Stone is the particle interlock which results in the exceptional all-weather shear resistance, well-known bearing capacity and behaviour characteristics associated with G1 Crushed Stone. It is known that some contractors regularly transform (expensive) G1 material into a "more compactable" gravelly material by breaking the larger aggregate particles down. While this ploy will surely enable the required density to be achieved with less compaction energy expenditure, it will certainly result in inferior shear resistance and performance. Some do it out of ignorance and some not – some present it as G1 Crushed Stone - and some not.

G1 Crushed Stone depends on being highly interlocked (densely packed) to deliver the impressive load bearing performance for which it is known, but because it consists of non-cohesive material this interlock can easily be upset by excessive vibration, deflection and wetting up. Hence, it must be disturbed a little as possible during quality control procedures. Apart from poor performance after it

has been disturbed, an incorrect control measurement result can be obtained – which will always be lower than what it should be.

Furthermore, since G1 Crushed Stone contains relatively coarse aggregate excavating a sand replacement hole in it with even and vertical sides is virtually impossible – unless done with great care by dislodging (by screw driver) and extracting each piece of aggregate by hand – which of course is prohibitively time consuming. Also, because of the non-cohesive nature of the material, the sides of such a test hole is inclined to move inward as it is excavated and so diminish the post excavation volume of the hole, with the result that a false higher density is registered.

Knocking a peg into the layer for a nuclear apparatus test also disturbs the layer but to a lesser degree than a sand replacement hole, and so is the preferred method of density measurement for control purposes. Strictly speaking, both methods deliver a slightly higher density reading than what the actuality is – and favours the contractor.

The density measurement must be done as soon as possible after the completion of the layer – in any case not later than the day after completion of the layer. At this stage the layer is still relatively damp and less susceptible to permanent disturbance.

Since the aggregate interlock of G1 Crushed Stone cannot easily be measured directly, one of the quality control measures prescribed for G1 is to measure the matrix density – similar to gravel layers. However, because of the fact that the material is non-cohesive and does not deliver consistent Mod AASHTO results, it was decided to use Solid Relative Density as the benchmark during the development of G1 Crushed Stone. However, Apparent Relative Density and Bulk Relative Density are also used, as follows:

- Solid Relative Density (**SRD**): Used for fresh parent rock (prescribed for G1 Crushed Stone material) without air voids or other anomalies within the rock matrix.
- Apparent Relative Density (**ARD**): Used for rock containing or suspected of containing air voids.
- Bulk Relative Density (**BRD**): Used for rock that is relatively weathered/decomposed and/or not cleanly fractured during the crushing process and hence also contains fissures.

Note that because of the allowance for voids and fissures in the rock, BRD is normally lower than ARD, which in turn is lower than SRD. Thus, it is important to inspect/test the parent rock in order to ensure using the correct density parameter relative to which the quality control is done. Thus, using BRD or ARD out of context can markedly favour a lowered final density.

Depending on the quality of G1 aimed for or specified by the Client, 86% to 88% of Solid Relative Density – which is in the order of 100% to 106% of Mod AASHTO according to inter-road authority comparative laboratory tests - is usually specified.

SERIES 3000 : EARTHWORKS AND PAVEMENT LAYERS OF GRAVEL OR CRUSHED STONE

SECTION 3600 : CRUSHED-STONE BASE

CONTENTS

3601 SCOPE
3602 MATERIALS
3603 TRIAL SECTION AND OTHER REQUIREMENTS BEFORE THE CRUSHED-STONE LAYER MAY BE CONSTRUCTED
3604 CONSTRUCTION
3605 PROTECTION AND MAINTENANCE
3606 CONSTRUCTION TOLERANCES
3607 QUALITY OF MATERIALS AND WORKMANSHIP
3608 MEASUREMENT AND PAYMENT

3601 SCOPE

This section covers the procuring, furnishing and placing of approved crushed stone on top of the completed subbase, and constructing a crushed-stone base in accordance with the requirements of these specifications.

This section also covers the replacement or the reprocessing of existing crushed-stone layers (with or without the addition of approved fresh crushed stone) over part of or over the full width of the existing layer.

3602 MATERIALS

(a) Requirements for crushed aggregate

The aggregate used for crushed-stone base shall comply with the requirements specified in tables 3602/1 and 3602/2 and in subclause 3602(b). It shall not contain any deleterious material such as weathered rock, clay, shale or mica. Argillaceous rocks may only be used if specified in the project specifications, or with the engineer's written approval.

(b) Soluble salts

(i) The percentage of soluble salts in the material shall be subject to the following provisions:

Untreated material (< 6,7 mm fraction)

Witwatersrand quartzite: Crushed stone and mine sand.

Where the pH < 6,0, it shall be treated with lime until pH ≥ 10, and then used. (The aggregate is normally treated at the crusher, and if the pH exceeds 10 at that stage, the decrease which will occur later on, shall be ignored should it remain ≥ 8,0.)

Where the pH ≥ 6,0, the material is used as it is.

Table 3602/2

10% FINES AGGREGATE CRUSHING VALUES

Rock type	Matrix	Dry min	Wet min	Wet/dry relationship min
Arenaceous rocks	Non-siliceous cementing material	140 kN		75%
	Siliceous cementing material	110 kN		75%
Diamictites (tillite)		200 kN		70%
Argillaceous rocks		180 kN	125 kN	-
Other rock types		110 kN		75%

Table 3602/3

AGGREGATE CRUSHING VALUE

Rock type	ACV, max
Arenaceous : without siliceous cementing matrix	27%
Arenaceous : with siliceous cementing matrix	29%
Diamictites (tillite)	21%
Argillaceous rocks	24%
Other rock types	29%

Table 3602/1

CRUSHED STONE BASE AND SUBBASE : MATERIAL REQUIREMENTS

MATERIAL CHARACTERISTIC		TYPE OF MATERIAL			
		G1	G2	G3	
PARENT MATERIAL		Sound rock from an approved quarry, or clean, sound mine rock from mine dumps, or clean sound boulders	Sound rock, boulders or coarse gravel	Sound rock, boulders or coarse gravel	
ADDITIONAL FINES		Only fines crushed from the same sound parent rock may be added for grading correction provided that added fines shall have a LL not exceeding 25 and PI not exceeding 4.	May contain up to 10% by mass of approved natural fines not necessarily obtained from parent rock. Added fines shall have a LL not exceeding 25 and PI not exceeding 6.	May contain up to 15% by mass of approved natural fines not obtained from parent rock. Added fines shall have a LL not exceeding 25 and PI not exceeding 6.	
STRENGTH		10% Fines Aggregate Crushing Value (10% FACT), determined in accordance with TMH1 method B2, shall be not less than the appropriate value in table 3602/2, column 3. The Aggregate Crushed value (ACV), determined in accordance with TMH1 method B1, shall not exceed the appropriate value in table 3602/3.			
DURABILITY		The material shall comply with the requirements in columns 3, 4 and 5 of table 3602/2.			
FLAKINESS INDEX		Flakiness Index, determined in accordance with TMH1 method B3, shall not exceed 35 on each of the -26,5 + 19 mm fraction and the -19 +13,2 mm fraction.			
FRACTURED FACES		All faces shall be fractured faces.	For crushed materials at least 50% by mass of the fractions retained on each standard sieve 4,75 mm and larger shall have at least one fractured face.		
ATTERBERG LIMITS	FRACTION (mm)	LL shall not exceed 25. PI shall not exceed 5. LS shall not exceed 2%. In addition the arithmetic mean of the PI's for a lot (min 6 tests) shall not exceed 4.	LL shall not exceed 25. PI shall not exceed 6. In addition the arithmetic mean of the PI's for a lot (min 6 tests) shall not exceed 4,5. LS shall not exceed 3%.	LL shall not exceed 25. PI shall not exceed 6. LS shall not exceed 3%. In the case of calcrete the PI shall not exceed 8. (% passing 0,425 mm sieve) LS ≤ 170	
	-0,425				
	-0,075	The PI shall not exceed 12. If the PI exceeds 12 the material shall be chemically modified. After chemical modification the PI of the minus 0,075 mm fraction shall not exceed 8.		If chemical modification is required, the PI of the -0,075 mm fraction after modification shall not exceed 10.	
SOLUBLE SALTS		See additional requirements.			
NOMINAL MAXIMUM SIZE		37,5 mm	37,5 mm	37,5 mm	26,5 mm
GRADING	Nominal aperture size of sieve (mm)	Percentage passing sieve, by mass	Percentage passing sieve, by mass	Percentage passing sieve, by mass	
	37,5	100	100	100	
	26,5	84 - 94	84 - 94	84 - 94	100
	19,0	71 - 84	71 - 84	71 - 84	85 - 95
	13,2	59 - 75	59 - 75	59 - 75	71 - 84
	4,75	36 - 53	36 - 53	36 - 53	42 - 60
	2,00	23 - 40	23 - 40	23 - 40	27 - 45
	0,425	11 - 24	11 - 24	11 - 24	13 - 27
	0,075	4 - 12	4 - 12	4 - 12	5 - 12
COARSE SAND RATIO (SEE DEFINITION IN SUBSUBCLAUSE 3602(c)(i)(5))		Shall not be less than 35% and shall not exceed 50% in respect of the target grading.	Shall not be less than 35% and shall not exceed 50% in respect of the target grading.	Shall not be less than 35% and shall not exceed 50% in respect of the target grading.	
COMPACTION REQUIREMENTS		Minimum of 88% of apparent relative density.	Minimum of 85% of bulk relative density.	98% or 100% of modified AASHTO density (as specified).	

Other materials such as natural gravel and other crushed stone

Where the electrical conductivity (EC) ≤ 0,15 Sm^{-1}, the material may be used.

Where the EC > 0,15 Sm^{-1}, the pH shall be determined.

Where the pH < 6,0, the material shall be treated with lime until the pH ≥ 10. The material may then be used. (Any later decrease of the pH shall be ignored should it remain ≥ 8,0.)

Where the pH ≥ 6,0, it may be used, but special attention should be given to design and construction measures.

Material being stabilized (for example with lime or cement)

Where the pH ≥ 6,0 and the EC < 0,02 Sm^{-1} and the qualitative test shows that sulphates do not pose a problem, the material may be used. If not, the material shall be further analysed by the engineer in accordance with the employer's instructions, and the proposals for its use shall be submitted to the employer for approval.

(ii) The tests conducted for determining the above judgement parameters shall include the following:

Electrical conductivity (EC) ..... method A21T of TMH1 (< 6,7 mm fraction)

Qualitative sulphate test ..... NITRR method CA21 (< 6,7 mm fraction)

pH ..... NITRR method CA 21 (< 6,7 mm fraction)

Acid-soluble sulphate content ..... BS 1377 of 1975, test No 9, made on a full sample crushed to < 2,00 mm

Water-soluble sulphate content ..... BS 1377 of 1975, test No 10

(iii) Where the salinity of the water used for compaction purposes is so high as to cause an increase in the salinity of the material, the engineer shall be entitled to determine the soluble salinity from samples taken from any section of the compacted layer within 24 hours, and also before the prime coat is applied.

(c) Grading requirements

After compaction, the individual fractions making up the grading of the material in place in the road shall conform to the proportions in table 3602/1, subject to the following requirements.

The target grading after compaction shall be as near as possible to the mean of the specified grading envelope shown in table 3602/1.

The approved target grading shall be based on test results obtained from a trial section constructed in accordance with clause 3603 and subject to complying with the following requirements unless otherwise approved, where such approval shall be based on substantive evidence relating to the crushing characteristics of the parent rock and its impact on the shear characteristics and compatibility of the structural layer:

(i) For 37,5 mm maximum size aggregate the requirements are as follows (percentage by mass):

(1) The -0,075 mm fraction shall be between 7% and 9%.

(2) The -0,425 mm fraction shall not exceed 22%.

(3) The -2,00 mm fraction shall not exceed 34%.

(4) The -4,75 mm fraction shall be between 40% and 45%. For aggregate with a flakiness index in excess of 25 and which is assessed visually to be of a needle-like shape the target value shall be 45%. With the written permission of the engineer this upper value may be exceeded if the trial section indicates that it is necessary in order to achieve the required bulk density.

(5) The -2,00 mm +0,425 mm fraction shall be not less than 35% nor more than 50% of the -2,00 mm fraction. This shall be termed the coarse sand ratio requirement.

(ii) For 26,5 mm maximum size aggregate the requirements are as follows (percentage by mass):

(1) The -0,075 mm fraction shall be between 7% and 9%.

(2) The -2,00 mm +0,425 mm fraction (ie the coarse sand ratio) shall not be less than 35% nor more than 50% of the -2,00 mm fraction

(3) The -4,75 mm fraction shall be between 45% and 50%.

(iii) The selected target values shall produce a gradual change from the coarse to the finer fractions without any marked gaps or excessive quantities at a particular size.

(iv) In order to satisfy the aforementioned requirements, the mean grading of the approved trial section may not necessarily represent the target grading finally approved for quality assessment (eg the variability actually obtained for particular fractions will dictate the setting of the target grading).

For G1, G2 and G3 base material the mean grading of each lot (minimum of 4 but preferably 6 test points per lot) determined from samples obtained in a stratified random sampling procedure shall conform to the approved target grading within the tolerances specified in table 3602/4.

(d) Material from existing pavements

Where existing crushed-stone material is to be reprocessed, the engineer will inspect the material and instruct the contractor to reprocess it as gravel subbase or base, or as crushed-stone base or subbase.

The compaction requirements specified in table 3602/1 shall apply to crushed-stone layers constructed from recovered material.

Payment for crushed-stone layers constructed from recovered material, will differentiate between the various types of material and their preparation.

Table 3602/4

TOLERANCES ON TARGET GRADING

Sieve size (mm)	Permissible deviations for mean values (% by mass)		Permissible deviations for individual values (% by mass)	
	Nominal maximum size 37,5 mm	Nominal maximum size 26,5 mm	Nominal maximum size 37,5 mm	Nominal maximum size 26,5 mm
26,5	± 5	-	± 5	-
19,0	± 5	± 5	± 7	± 7
13,2	± 5	± 5	± 7	± 7
4,75	± 4	± 4	± 7	± 7
2,00	± 4	± 4	± 5	± 5
0,425	± 3	± 3	± 5	± 5
0,075	± 2	± 2	± 3	± 3

3603 TRIAL SECTION AND OTHER REQUIREMENTS BEFORE THE CRUSHED-STONE LAYER MAY BE CONSTRUCTED

Before any crushed-stone layer is constructed, the following requirements shall be met:

(a) Approval of base material will be granted only after the successful construction of a trial section or sections complying in all respects with the specifications, including density and grading. No base material, except for the trial sections, shall be placed on the road unless the engineer has approved the base material in writing. A trial section shall be constructed from material from a proposed source (before 5 000 m³ has been produced), to prove the quality and compactibility of the material and to agree to a target grading for future construction lots where essentially the same material is used and it is processed essentially in the same manner.

The trial section shall be constructed on a layer of the specified subbase standard and shall be placed as instructed by the engineer with due regard to the approved construction programme.

The trial section shall be between 150 m and 200 m in length, or as otherwise ordered by the engineer.

The width shall be as ordered by the engineer, whilst the thickness shall be the same as the base thickness specified for the pavement structure.

The trial section shall be adequately assessed by the engineer prior to proceeding with the next one where so ordered, in order to rectify identified shortcomings.

If a trial section fails, it shall be removed as excess/unsuitable material, unless it is structurally acceptable to the engineer to be retained as subbase. Where further trial sections are required for approval, the failed sections shall be removed before further trial sections may be constructed.

Only trial sections in which the base material complies with all the requirements of the specifications shall be paid for. Payment for the construction of base will be made under the relevant items of section 3600.

No payment will be made for trial sections removed as excess/unsuitable material.

The crushing of aggregate for the base from any source, or the stockpiling of crushed stone in stockpiles, shall be restricted to 5 000 m³ until the material has been approved by the engineer. Material shall be furnished only from sources approved by the engineer, who may cancel his approval should in his opinion, the particular source, have become unsuitable. Approval of the crushed-stone material for the base will not relieve the contractor of his responsibility to produce a finished crushed-stone base constructed according to the specifications.

(b) The underlying layer shall comply with the requirements for the layer concerned.

(c) The provisions of subsubclause 3403(b)(ii) shall apply to the construction of a crushed-stone base.

(d) No crushed-stone layer shall be rolled if the underlying layer, either on account of rain or by any other cause, is so wet as to constitute a danger of the underlying layers being damaged.

3604 CONSTRUCTION

(a) Spreading and mixing

The contractor may elect to mix and spread crushed-stone material by means of a mixing plant and paver unit respectively, in which event the requirements of subclauses 3704(a) and (b) shall apply mutatis mutandis.

Crushed-stone material complying with the requirements specified above shall be dumped in quantities sufficient to ensure that the completed layer will comply with all the requirements in regard to layer thickness, level, cross-section and density. Allowance shall also be made for sufficient extra material to enable the layer to be properly formed.

The maximum compacted thickness of any layer of crushed-stone base compacted in one process shall be 150 mm, unless otherwise specified or permitted by the engineer.

The dumps of material shall be spread out to a layer with a thickness which will be suitable for mixing. The required quantity of water shall then be added and the material mixed until a homogeneous mixture is obtained.

(b) Compaction

After mixing, the crushed-stone material shall be placed to the correct thickness and level and thoroughly compacted by suitable equipment so that the specified density is obtained throughout the entire layer after slushing (except where the multi-stage process in subsubclause 3604(c)(ii) is prescribed). When required by the engineer, the density of the layer shall be tested at various prescribed depths.

The finally compacted layer shall be free from surface laminations, portions exhibiting segregation of the fine and coarse aggregate, corrugations, or other defects that may adversely affect the performance of the layer.

(c) Surface preparation of the base

(i) Continuous process (watering and slushing)

Immediately after completion of the compaction described above, short sections of the surface shall be thoroughly watered, rolled and slushed by means of steel-wheeled rollers with a mass of not less than 12 tons each, and/or with pneumatic-tyred rollers. The process shall continue until all excess fines are brought to the surface. The grout thus formed shall be uniformly broomed over the surface with stiff brooms to correct any areas still deficient in fines, whereupon the excess fines shall be broomed from the surface of the layer. This process shall continue until all excess fines in the mixture have been brought to the surface of the layer and its specified density has been reached. Excess fines and loose aggregate shall then be swept from the surface while the surface is still damp, and the layer shall then be allowed to dry out.

During slushing operations, care shall be taken not to roll the surface out of shape.

The slushing process shall be carried out on each section in one continuous process, and each section shall be completed before the next is proceeded with.

After completion of the slushing and brooming process, when the layer is wind-dried, the surface shall be finally rolled with a steel-wheeled roller.

The completed layer shall be firm and stable with a closely-knit surface of aggregate exposed in mosaic and free from nests of segregated material, laminations or corrugations.

The engineer may permit omission of the slushing process in the lower layer of a two-layer base, provided that the specified density is obtained in each of the layers.

(ii) Multi-stage process (water or slurry rolling)

After the base has been compacted to the required density at optimum moisture content and has then been allowed to dry out to less than 50% of the optimum moisture content, the final surface of the base shall be watered and subjected to additional rolling (the so-called "slurry" or "water" rolling) in order to obtain a firm, even, well-knit surface. Watering, rolling with suitable rollers, and sweeping with stiff brooms shall continue until all excess fines on the surface have been distributed over the surface of the base.

Any areas deficient in fines shall be corrected by the addition of fine aggregate from the same source of supply as the crushed aggregate, and by brooming such fine aggregate into the surface voids of the layer until a firm base with a closely knit surface is obtained, free from nests of segregated materials, loose aggregate or other irregularities. All excess fines which cannot be redistributed shall be removed by brooming whilst still wet from the slurry roll watering, and the base shall then be allowed to dry out once again to less than 50% of the optimum moisture content so as to present an exposed mosaic of regular stone faces free from fine aggregate and foreign matter before any further treatment of the surface may be carried out. When using entirely non-plastic bases, it may be necessary to remove the final portions of excess fines from the surface after the base has been allowed to dry out to a degree which will be determined only by practical trial and error in each specific case of such a non-plastic base.

The completed layer shall be firm and stable with a closely knit surface aggregate exposed in mosaic and free from nests of segregated material, laminations or corrugations. During surface preparation of the base, care shall be taken not to roll the surface out of shape.

(d) General

(i) Kerbing and channelling

Care shall be taken during rolling to ensure that concrete edging, kerbing and channelling already laid are not displaced or damaged. Any concrete edging, kerbing and channelling damaged during construction shall immediately be replaced or repaired by the contractor at his own expense.

(ii) Excess crushed-stone material

Excess crushed-stone material shall not be spread over the shoulders or side fills, but shall be loaded and removed from the road. It shall not be re-used unless it has been rescreened, retested and again approved for use. It shall not be mixed with approved material unless screened, tested and again approved for use on its own.

(iii) Junctions with existing bituminous surfaces

At junctions with existing bituminous surfaces, the new base shall not be feathered-off to obtain continuity of grade, but the existing work in the vicinity of the joint shall be cut back so as to ensure an overall compacted thickness of new base and surfacing of not less than 100 mm.

(e) Breaking down existing crushed-stone layers

The requirements of clause 3805 shall apply.

(f) In situ reconstruction of existing crushed-stone layers

Where specified in the project specifications and approved by the engineer, existing crushed-stone layers shall be reconstructed in situ in accordance with the requirements of subclause 3208(c). Where the existing layer thickness is insufficient, additional material shall be added as specified in subsubclause 3207(b)(iii). The material added shall be G1, G2 or G3 material, depending on which type has been specified. Where the grading requires adjustment by the addition of specific fractions (eg crusher dust), the contractor shall comply with the provisions of the project specifications.

(g) Work in restricted areas as defined in the first paragraph of clause 3608

The provisions of clauses 3207 and 3208 shall apply to the spreading, mixing and compacting of crushed-stone layers in restricted areas.

Where conventional rollers cannot be used for the surface preparation process, the engineer may order that other approved compaction equipment be used.

Where any compaction work is being done adjacent to existing surfacing, care shall be taken not to damage the surfacing.

(h) Joints between existing layers and new or reconstructed layers

Where the base is not replaced or reconstructed over the full width, any existing unsuitable material shall be removed until a firm, well-compacted material is reached. Where the subbase has also been replaced or reprocessed, and unless otherwise determined by the engineer, the joint in the base shall not be directly above the joint in the subbase, but staggered by at least 100 mm. The aforesaid provisions shall also apply where a pavement is being widened. Where it is widened, the excavated material shall be disposed of and not used for widening the base.

In both the above cases, the existing surfacing shall be removed to at least 100 mm outside the working area of the base.

Where the existing base consists of cemented material, the existing material at the joint shall be cut with approved sawing equipment or milled out mechanically.

Payment for sawing and milling will be in accordance with the provisions of section 3800.

Unless otherwise shown on the drawings or approved by the engineer, the joints in the bases shall not fall within a wheel track.

(i) Watering and rolling the floor of a pavement excavation

Where a crushed-stone layer is constructed on the floor of a pavement excavation, ie where the underlying layer has not been reconstructed, and where the engineer so orders, the floor of the excavation shall first be watered and rolled in accordance with the instructions of the engineer. The nominal number of roller passes shall be 5 passes with rollers specified in clause 3304. The engineer may, at his discretion, increase or decrease the number of roller passes or order the use of other rollers. Variations in the number of roller passes will be paid for under item 36.13.

Where the material in the floor of the pavement excavation consists of crushed stone, the engineer may instruct that the floor be also watered and rolled.

3605 PROTECTION AND MAINTENANCE

The contractor shall protect and maintain the completed crushed-stone layer at his own expense until the next layer or the seal or surfacing is applied. The crushed-stone base shall be primed as soon after construction as possible and as soon as the moisture content of the layer is below 50% of the optimum moisture content. Maintenance shall include the immediate repair of any damage to or defects in the layer and shall be repeated as often as is necessary. Repairs shall be so made as to ensure an even and uniform surface to be restored after completion of the repair work.

No traffic is permitted on the completed and primed layer. Only in exceptional cases may the engineer allow a limited amount of traffic on the layer.

3606 CONSTRUCTION TOLERANCES

The completed crushed-stone layer shall comply with construction tolerances specified in clause 3405.

Where a base is to be constructed in two layers, the requirements for grade, thickness, cross-section and smoothness shall not apply to the lower layer, but the lower layer shall be constructed with sufficient accuracy to enable the construction of the combined layer to be carried out to the tolerances specified.

Where a crushed-stone base is placed directly onto an existing layer without it being required that the existing layer be finished to specified levels, the requirements for layer thicknesses of subclause 3405(b) shall not apply.

3607 QUALITY OF MATERIALS AND WORKMANSHIP

Routine inspections and tests will be made by the engineer to determine whether the quality of material and workmanship complies with the requirements of this section.

Test results and measurements shall be assessed in accordance with the provisions of either section 8200 or 8300, depending on which section is indicated in the project specifications as being the appropriate section.

3608 MEASUREMENT AND PAYMENT

Items 36.09, 36.10 and 36.14 are applicable solely to work that has to be executed in a restricted area of which the width is less than 3,0 m or the length is less than 150,0 m.

Item		Unit
36.01	**Crushed-stone base:**	
(a)	Constructed from type G1 material obtained from commercial sources and compacted to 88% of apparent relative density (layer thickness indicated)	cubic metre (m^3)
(b)	Constructed from type G1 material obtained from approved borrow pits, crushed by the contractor, and compacted to 88% of apparent relative density (layer thickness indicated)	cubic metre (m^3)
(c)	Constructed from type G2 material obtained from commercial sources and	