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TITLE: Irregular[1] Cobble Stone Pavement Specification

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INTRODUCTION

Cobble stone pavement is a traditional pavement that has been applied for a very long time in China. This type of pavement is constructed using natural irregular shaped stone cobbles, which are selected and laid on a gravel layer with a fair face uppermost. They are strengthened into a road surface matrix by gravel joint filling and compaction activities.

Yun Nan province is one of the first provinces that started applying the construction technique imported from Shang Hai City in 1939. Many road sections on Dien Mien national road were built with the cobble stone pavement during the war against the Japanese and the technique has been continuously developed since then. Recently, Yun Nan province authorities have built 5,100 km of cobble stone pavement and there exists about 1,582 km of provincial and main cobble stone pavement built before these recent programmes. That will make a total number of 8,000km of cobble stone pavement length. Among these, some 20-year-old road sections are still in good condition to ensure traffic flow. At the request by Chinese Ministry of Transport, in the next few years, Yun Nan province has to build another 2,500km of cobble stone pavement and about 55% of the districts' network will have cobble stone and concrete roads.

1.0 Cobble stone pavement suitability and specification, and development reasons in Yun Nan province

Yun Nan is the most southwest province of China that has borders with the countries of Viet Nam, Lao and Burma with 26 ethnic groups and about 43 million people. Yun Nan is located in the mountainous terrain and with only about 6% of the area classified as valley terrain. Yun Nan has higher northern region (the highest point is 6,740m above the sea level) and lower southern region (the highest point is 76.4m above the sea level) and with the

[1] The term 'irregular' indicates that the individual cobble stones are not 'dressed' in any way and that the laying gang members take the selected raw broken cobbles and choose a good face to be laid uppermost. This is in contrast to some other forms of cobble stone paving where the individual stones are shaped on most faces to form a cubic shape before laying.

average height of 2,000m above the sea level. In comparison with the southeast coastal provinces of China, Yun Nan is an economically undeveloped area, especially in the rural areas with ethnic minority people located in areas close to the border that are remote and difficult to access.

Cobble stone pavement has 4 economical and technical advantages as below:

Firstly, it is a low cost pavement with low required initial investment. Based on the provincial experience, costs of different classes of cobble stone pavement vary from 80,000 to 150,000 RMB per km, equivalent to about US$10,000 to 18,000 per km respectively.

Secondly, it is a simple design and construction technique.

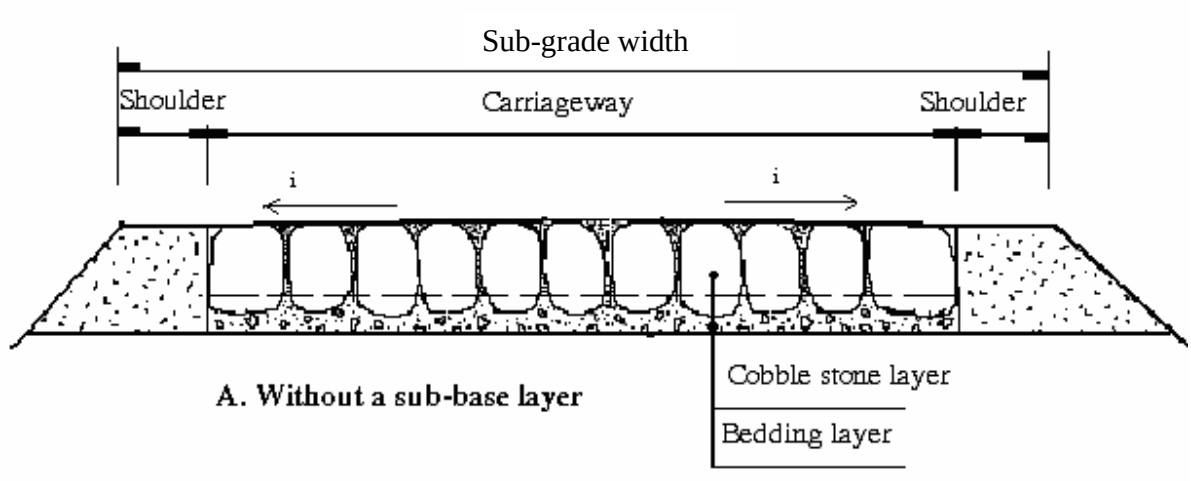
Thirdly, local materials and labour forces can be utilised efficiently.

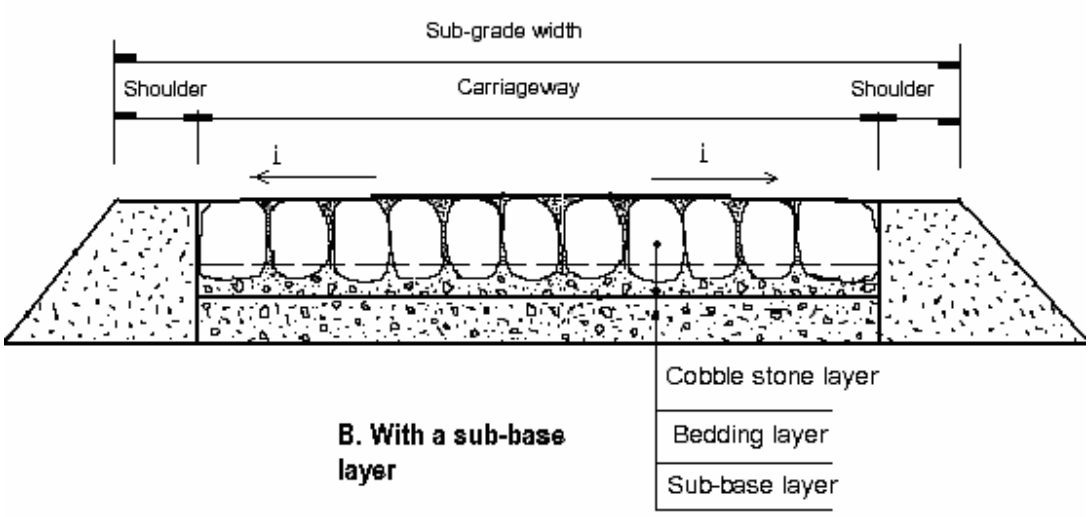
Fourthly, it is a durable pavement that creates less dust than earth or gravel, is low maintenance and is easily repaired.

Such advantages are very attractive with the demand for rural roads for remote villages which are less economically developed, experiencing severe natural conditions with the requirement for lower-classed roads (4th class) for low traffic volume flows with few motorized vehicles. The development of the cobble stone pavement in Yun Nan province is the result of the beneficial combination between the local economical and technical characteristics and the cultural and natural conditions.

2.0 Cobble stone pavement structure

Cobble stone pavement is often used with embankment profile (see the figure below). The embankment is used as the foundation for construction of carriageway. Other types of material can be used for shoulders.





Typical cross sections of cobble stone pavement (i: surfacing cross fall)

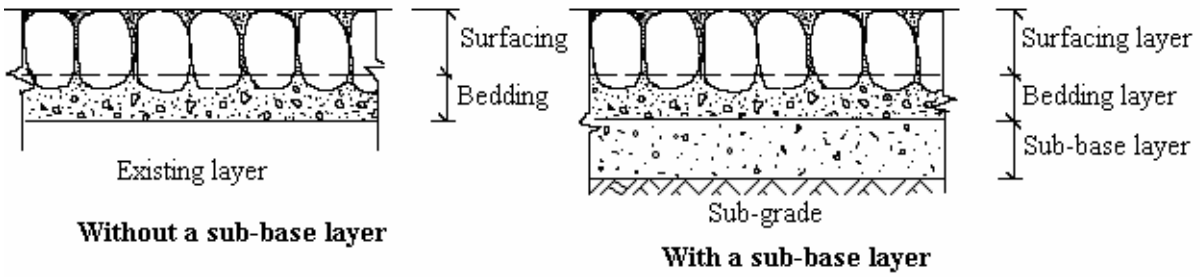
A Sub-base layer is used where deemed necessary.

Cobble stone pavement camber

In order to enable surface water to run off, the pavement should be built with the camber at the centreline (the required normal cross fall of 2-3%). In the drier regions, no camber may be built for the pavement, while one more % of cross fall should be provided for roads in higher rainfall regions.

Cobble stone pavement structure

Cobble stone pavement can be built with or without sub-base layer. The first option is built with surfacing layer on bedding layer while the second option is built with the surfacing layer on bedding and then on sub-base layer (See the figure below).



Cobble stone pavement designs

Cobble stone (surfacing) layer

The surfacing layer is directly affected by vehicle vertical and lateral loadings and wheel friction, and other natural factors such as weather, temperature and rainwater. Thus, strong and durable stone should be secured for construction.

Bedding layer

The bedding layer is built underneath the surfacing layer in order to spread the loadings, ensure the stability of the upper cobble stone layer and prevent the rainwater penetration. It is not considered a part of the structural thickness and can be built by gravel or crushed stone with typical thickness of 6 - 8cm.

Sub-base layer

Sub-base layer is a structural layer built underneath the bedding layer. It is to spread loadings caused by vehicles into the pavement. The sub-base layer is directly affected by neither vehicle wheel frictions nor environment, however, it should be sufficiently strong. The different classes of material used for sub-base layer should be appropriate for the different classes of road and estimated traffic volumes using the road.

3.0 Design method

Cobble stone pavement design thickness should be based on the analysis of the road functions, traffic types and volume, natural conditions, local materials and construction techniques. Consequently, appropriate composite cobble stone structure can be defined.

Cobble stone pavement is often appropriate for rural access roads with medium loading vehicles and with traffic volume less than 500 vehicles per day. The structural thickness of the pavement is specified mainly based on the 3-factor formula by Chinese, plus the design and construction experience as well as actual road performance data summarised over many years.

The strength of the cobble stone layer is decided by material abrasion ratio and the stability of the sub-grade. Thus, during the actual design works, special attention should be paid on material quality, strength of the sub-grade and drainage system to ensure the stability of the whole pavement.

Design of the cobble stone structure should be done through the following steps:

1. Investigate traffic volume and types of vehicle

2. Survey the existing pavement or road bed

3. Investigate the existing sub-grade and pavement strength

4. Investigate the material quality, quarrying and haulage matters

5. Define the pavement type, structure and calculate the required thickness

Calculation method

In terms of design, in order to have a consistent design standard, 100KN axle is used for calculation.

Permitted depression rate is the pavement durability design criterion. It can be calculated using the following formula:

$$l_R = 11.0/N_e^{0.2} \times A_C \times A_S$$

Among these: l_R ——Permitted depression rate (mm)
A_C——Road classification, using 1, 2
A_S——Surfacing layer type, using 1, 3

Cobble stone pavement is calculated using the following formulas:

1. Thickness calculation of one layer structure

The thickness of one layer structure to be built on a new or existing sub-grade (see the figure) can be calculated using the following formula:

$$\Psi(h/\beta) = l_R^{-0.25}(l_0/l_R - 1)^{0.35}$$

Among these: h ——Layer thickness（cm）
β——Material parameter (see figure 3.5)
l_R ——Permitted depression rate (mm)
Ψ——Loading coefficient BZZ-100 is 0.8
l_0 ——Road section depression rate（mm）

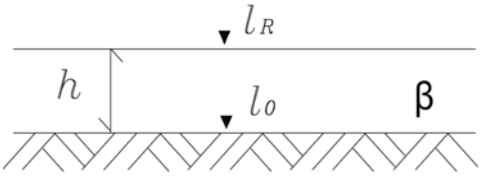


Figure 3.1 One layer

2. Thickness calculation of the two-layer structure

Construction of two-layer structure (see the figure) can be carried out using the following formula：

$$\Psi(h_1/\beta_1 + h_2/\beta_2) = l_R^{-0.25}(l_0/l_R - 1)^{0.35}$$

Among these： h_1—— First layer thickness（cm）
β_1——First layer material parameter (see figure 3.5)
h_2—— Second layer thickness（cm）
β_2——Second layer material parameter

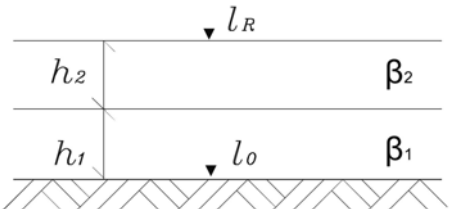


Figure 3.2 Two layer structure

4.0 Sub-grade and drainage

New and existing sub-grade requirements

The sub-grade is the supporting structure of the pavement, thus it should have high stability and durability. Cobble stone pavement should be constructed in the circumstance of dry weather and reasonable moisture content. In case, construction is carried out during wet weather, additives should be added to speed up the drying-out and hardening activities or materials that drain quickly such as gravel, crushed stone and sand etc should be used. Drainage and treatment measures should be applied for new and existing sub-grade so that the sub-grade strength should be over 30Mpa and pavement depression is less than 320 (1/100mm), making sure that the sub-grade will always be in dry condition with reasonable moisture content.

Pavement drainage

Pavement drainage is affected by camber, shoulder cross fall, bedding layer and side drainage. The pavement should have 3-4% cross fall. The road cross fall percentage should be increased for higher rainfall regions while it can be decreased for high gradient and lower rainfall regions. Shoulder cross fall should be 1% bigger than pavement cross fall, alternatively the same cross fall can be applied for both. Side drainage size will be decided based on the local rainfall with trapezium shape (0.4X0.4m) drains.

5.0 Material for the pavement

Cobble stone classification

Material used for cobble stone pavement is natural stone, class 1-3 such as granite, limestone etc. which have the required compression strengths.

Cobble stone dimensions

Cobble stones to be used for the pavement construction will be natural broken rock from the quarry operations. Stone are selected for suitability. Each final stone cobble will have the length not longer than the height; the height is not bigger than double the width and the top and bottom surfaces of each stone cobble should be flat. The top surface should be larger than the latter. The side surfaces cannot be too irregular and each stone cobble height is not over ± 2cm different from the design thickness. All the stone cobbles that do not meet the technical requirements (not processed yet) will be rejected (see the figure below).

The classification of stone cobble strength and dimension should be done pursuant to the related regulations and based on the actual traffic volume. Bigger and stronger stone cobbles will be selected for high traffic volume road sections, while smaller and less strong stone cobbles will be used for lower traffic volume road sections. In the other words, stone cobbles with different dimensions and strengths will be constructed for roads with different functions.

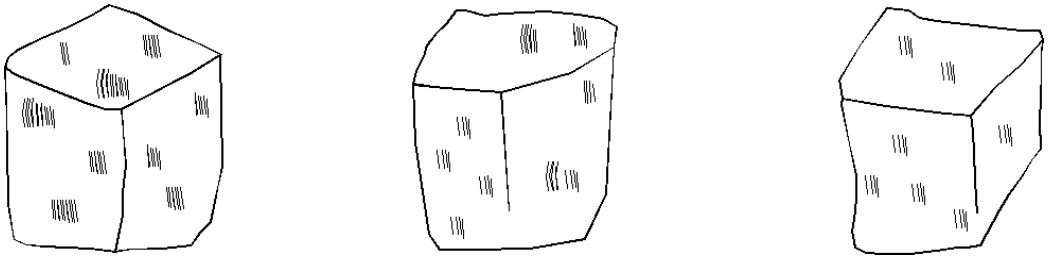


Figure 5.1 Appropriate cobble stones ready for construction

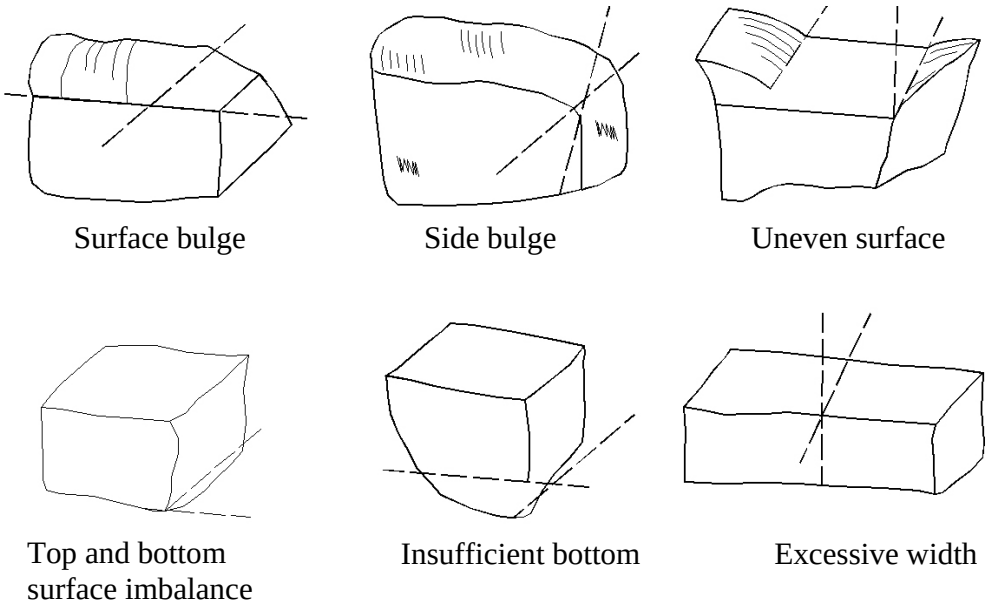


Figure 5.2 Cobble stones to be prepared before use in construction

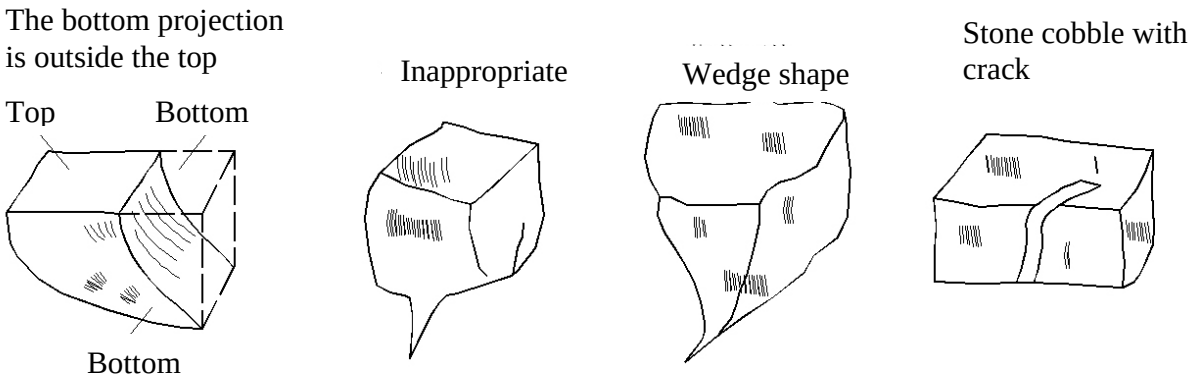


Figure 5.3 Cobble stone not to be used for construction

Bedding layer and joint filling material

Material to be used for bedding layer and joint filling will be coarse sand and crushed stone (maximum dimension 10mm and should be well graded). Inappropriate materials such as soil, weathered or too fine crushed stone, fine and weak sand, and weak stone fines will not be permitted to be used.

Sub-base layer material

Based on the various road classes and traffic volumes, economically and technically suitable and reliable sub-base structure will be selected. In general, there are two following types of sub-base for cobble stone pavement:

1. Crushed stone macadam is a mixture of different sized aggregate with very high strength and stability. The biggest particle size will have a diameter of about 37.5mm. Mixed material can be strong igneous stone with the mixture broken value ≤35% and total flakiness index is not over 20%.

2. Natural gravel is one type of material that can be found in riverbeds. Such material, which often has small soil content and adequate stability can be used for the sub-base layer of cobble stone pavement. Materials can be quarried locally and built with simple construction technique at low cost. The maximum aggregate diameter must not be over 40mm and the plasticity index should be reasonable as specified. The material broken value should be ≤35%.

6.0 Construction

Sub-base construction

Sub-base (or existing pavement) construction is one of the key cobble stone pavement construction steps. It has impacts on the quality of the whole pavement and often is carried out as below:

1. Setting out: Use string lines to define the required camber and pavement dimensions.

2. Shaping: Based on the peak point of the sub-base, layer level will be specified. Any irregular area will be replaced by appropriate material.

After construction of new sub-base or repair of the existing sub-grade accordingly to the design, the bedding layer can be constructed. Sub-base construction procedure can be carried out as below:

Sub-grade preparation - material mobilisation and spreading - shaping - compaction.

Surfacing construction

After construction of a new sub-base layer (or repair the existing pavement), cobble stone surfacing can be built accordingly the following steps:

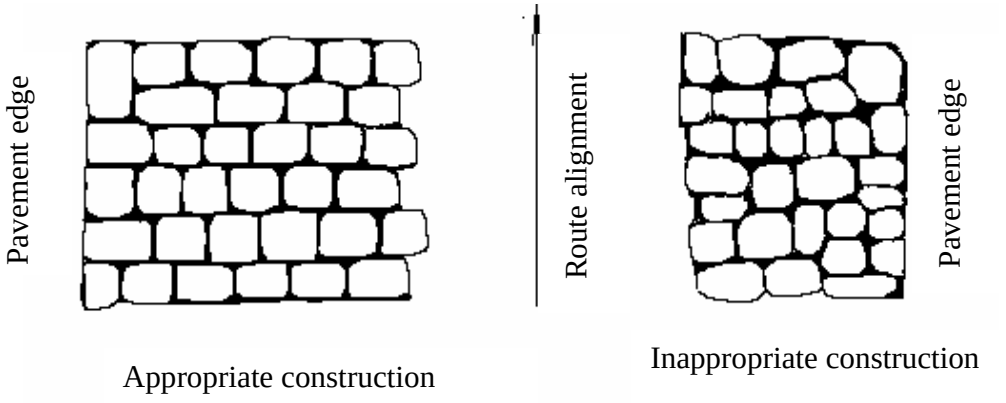
Preparation - bedding layer - cobble stone laying - joint filling - curing

Construction procedure:

1. Preparation: Based on the design document, do setting out pegs and string lines on the prepared sub-base layer to define the required surfacing level, dimensions, camber and pavement edges.

2. Bedding layer construction: After removing any deleterious material, bedding layer can be built. Then cobble stone layer will be built on the bedding layer and compacted as required within the same day.

3. Cobble stone laying: Pavement edges should be built first to define the route alignment and provide edge restraint (stone or concrete strip). Then cobble stone pavement can be built with the larger cobble surface uppermost as pavement surface. Each cobble stone will be tapped into the position with at least 1/4 to 1/3 of the stone cobble bedded firmly into the bedding layer (in terms of height). The residual thickness of the bedding layer underneath the cobble stone layer is not less than 3cm.



Cobble stone laying patterns

4. Shoulder construction (cobble stone is not used for shoulders): shoulders will be built with gravel or crushed stone with high drainage capacity. A 3 - 4cm gravel or crushed stone layer will be provided for shoulders. Required drainage capacity, shoulder width and cross fall should be achieved according to the design. Each shoulder should not be less than 30cm wide.

5. Joint filling and compaction: After laying cobble stones, the pavement should be checked to ensure the required pavement quality, then joints can be in-filled with gravel or coarse sand.

Water can be added to facilitate the compaction activities that follow. A 6-8 ton roller will be used to initially compact the pavement with 4-5 passes per point, then a 10-12 ton roller will be used instead of the previous one to finally compact the pavement with 3-4 passes per point. Compaction will be started from the edges and working in towards the centre line of the pavement. At the curving sections, compaction will be done from the lower side. For pavement located on longitudinal gradient sections, compaction will be done from the bottom up to the higher levels. After compaction, if there appears to be any loose joint, filling material should be added. At least 1cm

filling material should be spread on the pavement surface before opening the road for traffic.

6. Curing: For the beginning period when the cobble stones have not become totally stable and joint filling material can be loosened, additional filling material should be provided and traffic should be under controlled speed.

7. Drainage: Camber, cross fall and gradient should be built pursuant to the design and side drainage should be sufficient as well. For the road sections with higher ground moisture content, deeper drainage system should be provided. At the same time, cross fall should be provided to ensure that cobble stone carriageway is not damaged due to the inappropriate shape or poor drainage of the shoulder.

7.0 Cobble stone pavement quality assessment

During construction phase, it is necessary to have intermediate checks on the quality of the sub-grade, sub-base and surfacing layer. After joint filling and compaction, overall checks should be done again for the whole pavement.

Intermediate checks will be conducted for:

1. Sub-grade 2. Sub-base layer 3. Bedding layer 4. Surfacing layer

Final check will be conducted for:

1. Pavement width: At every km, select 10 points to check the pavement width. The final pavement width is not less than the design one.

2. Longitudinal and transverse sections: Use spirit level to check the pavement gradient and cross fall. Use 3m straight edge to measure the evenness along the route link.

3. Natural gravel or crushed stone sub-base assessment

Visual assessment should be conducted. The appearance should look firm without loose material and with regular edges.

4. Cobble stone pavement assessment

Visual assessment should be conducted. The surface should look even, firm without loose material and with regular edges.

8.0 Repair and maintenance

Cobble stone pavement can be easily damaged in the forms of abrasion, pothole, local depression, edge break etc. due to the direct impacts and

abuse by traffic and other natural factors such as climate, hydrography etc. If no appropriate action is taken, the surfacing evenness will decrease substantially. The pavement can also be deformed under the impacts by traffic movements and crashes. Thus, to keep the pavement in good condition in order to prolong the pavement life cycle, programmes for routine and regular maintenance, rehabilitation, technical improvement and repairs to secure traffic flow safety should be well arranged.

Pavement repairs and maintenance

1. Remove any dust, loose stone, soil and waste on the pavement. Keep the pavement clear of standing water and clean.

2. Conduct regular checks and repair any crack on the cobble stone pavement.

3. Find out any loose stone cobbles and repair the joints immediately as required.

4. Find out any pothole, local settlement etc. Replace the defected areas by new and appropriate material.

5. Find out and repair any edge break. Shoulder and drainage system also need attention and care.

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