8 RECYCLED AND STABILISED ROAD MATERIALS

8.1 GENERAL

8.1.1 Scope

1 This Part includes materials, equipment, mix design guidelines and other requirements for the construction of insitu and exsitu recycled pavement layers.

2 Incorporation of stabilized or cement bound materials in pavement layers shall be based on pavement structural design criteria such as layer(s) strength characteristics, load distribution, layer(s) thickness equivalency, layers strength balance and the target level of pavement performance.

3 Use of recycled and stabilized materials and their associated construction and quality assurance and quality control processes shall be approved by the Engineer.

4 Related Parts are:

Section 6
Part 1............... General
Part 3............... Earthworks
Part 5............... Asphalt Works

Section 5
Part 4.............. Water

8.1.2 References

AASHTO T180 ....Standard Method of Test for Moisture-Density Relations of Soils

ASTM C150................Standard Specification for Portland Cement

ASTM C977................Standard Specification for Quicklime and Hydrated Lime for Soil Stabilization

ASTM C1097 ....Standard Specification for Hydrated Lime for Use in Asphalt Cement or Bituminous Pavements

ASTM D422 ....Standard Test Method for Particle-Size Analysis of Soils

ASTM D946 ....Standard Specification for Penetration-Graded Asphalt Cement for Use in Pavement Construction

ASTM D1556 ....Standard Test Method for Density and Unit Weight of Soil in Place by Sand-Cone Method

ASTM D1632 ....Standard Practice for Making and Curing Soil-Cement Compression and Flexure Test Specimens in the Laboratory

ASTM D1633 ....Standard Test Methods for Compressive Strength of Molded Soil-Cement Cylinders

ASTM D2216 ....Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass

ASTM D2922 ....Standard Test Methods for Density of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth)

ASTM D4215 ....Standard Specification for Cold-Mixed, Cold-Laid Bituminous Paving Mixtures

ASTM D4318 ....Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils

ASTM D4944..............Standard Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

ASTM D4944..............Standard Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester

ASTM D6926 ....Standard Practice for Preparation of Bituminous Specimens Using Marshall Apparatus

ASTM D6931 ....Standard Test Method for Indirect Tensile (IDT) Strength of Bituminous Mixtures

ASTM D6938 ....Standard Test Method for In-Place Density and Water Content of Soil and Soil-Aggregate by Nuclear Methods (Shallow Depth)

ASTM D7382 ....Standard Test Methods for Determination of Maximum Dry Unit Weight and Water Content Range for Effective Compaction of Granular Soils Using a Vibrating Hammer

ASTM E2583 ....Standard Test Method for Measuring Deflections with a Light Weight Deflectometer (LWD)

MCHW Specification for Highways Works Series 900, UK

TG2 Technical Guideline: Bitumen Stabilised Materials: Asphalt Academy, South Africa

TRL 611: A Guide to the Use and Specification of Cold Recycled Materials

8.1.3 Definitions

1 Stabilisation is the permanent modification of soils and aggregates, including recycling existing pavements, to enhance the engineering properties thereby improving the load bearing capacity and performance of a new pavement structure.

2 Aggregate: Granular material used in construction. Aggregate may be natural, manufactured or recycled.

3 Primary Aggregate: aggregate extracted directly from the ground in quarries or pits, or dredged from rivers or the sea. They can be either hard rock such as gabbro and limestone, or sand and gravel.

4 Secondary Aggregate: materials produced as a by-product of other mining or quarrying activities or as a by-product of other industrial processes, incinerator ash, or the ash from power stations.

5 Recycled Aggregate: materials produced by the recycling of construction and demolition waste. These can be crushed concrete, bricks or glass, asphalt planings (i.e. the asphalt layers of roads removed during roadworks, also known as RAP – Recycled Asphalt Pavement).

6 Cold Stabilised Material (CSM): materials produced for pavement construction structural layers using recycled or secondary aggregates.

7 Bitumen Stabilised Material (BSM): granular aggregate materials bound with foamed bitumen or bitumen emulsions.

8 Cement Treated Base (CTB): granular aggregate materials bound with cement or hydrated lime hydraulic binder.

9 Exsitu Stabilisation: mixing processes that are carried out away from the construction location in a remote mixing plant.

10 Insitu Stabilisation: mixing processes that are carried out at the construction location by specialised stabilisation equipment.

11 Optimum Moisture Content: the moisture content of soil at which a specific degree of compaction will produce the maximum dry density when determined in accordance with the AASHTO T180.

12 Maximum Dry Density: the dry density of soil obtained using a specific degree of compaction at the optimum moisture content when determined in accordance with AASHTO T180.

8.1.4 Submittals

1 The Contractor shall submit recent test results for the proposed sources of materials for all quality requirements of the Contract. The contractor shall submit a test certificate that proves that the raw materials that are purchased/used comply with specifications. The testing may be performed by an approved private laboratory or by the laboratory associated with the plant itself.

2 The contractor shall submit to the Engineer for approval method statements, which includes but not limited to the following:

(a) Quality assurance and quality control plans of all construction activities

(b) Material, handling, storage, identification and marking, traceability to source of production and testing.

(c) Equipment suitability to fulfil all construction activities to the required quality

(d) Personnel capability

(e) Safety and environment preservation plans

3 The Contractor will be required to produce detailed method statements for the chosen method of recycling rehabilitation and shall include all stages of the process for approval by the Engineer. This shall include the credentials and details of experience of the stabilising contractor, the site investigation report, the stabilised material mix design and the equipment to be used for the entire process. A separate method statement shall be submitted for each of the production and construction activities of each layer.

8.1.5 Quality Assurance

1 If requested the Contractor shall arrange for the Engineer to visit the source of the materials and jointly take samples for testing. The Contractor shall carry out testing as directed by the Engineer.

8.2 COLD STABILISED MATERIAL - GENERAL

1 Cold Stabilised Material (CSM) comprises base and binder courses produced by the process of in-place recycling (insitu) or in a fixed or mobile mixing plant (exsitu) where the aggregate source shall be obtained by cold pulverisation of all, or part, of the existing road structure, blended if necessary with other aggregate and bound with cementitious / hydraulic (CTB) or bituminous binders (BSM), separately or in combination, or by the use of primary aggregates.

2 Cold Stabilised Material (CSM) shall be designed and produced to form the foundation or main structural layer of the road pavement.

3 For Bitumen Stabilised Material (BSM) the primary active binder (stabilising agent) shall be foamed bitumen, with cement as an adhesion agent as required by the design. For Cement Treated Base (CTB) the primary active binder shall be cement, hydrated lime or a blend of both in accordance with the mix design. The aggregate grading may be adjusted by the addition of inactive mineral filler.

4 Insitu and exsitu methods of stabilisation rehabilitation are permissible with the approval of the Engineer on a site by site basis.

5 Stabilisation design and installation processes shall be in accordance with internationally recognised standards and specifications, and shall meet the necessary pavement structural design according to the appropriate traffic classification.

6 The Cold Stabilised Material shall be designed to achieve the specified level of the appropriate end performance property to the requirements of the total pavement design. The minimum layer thickness shall be as required by the design method used, as approved by the Engineer.

7 The asphalt type and thickness above the CSM shall be as required by the pavement design method and shall also be sufficient to prevent reflective cracking and early life trafficking, to the satisfaction of the Engineer.

8.3 MATERIALS

1 The method statement submitted by Contractor shall contain details of all aggregates to be used in the CSM.

2 Aggregates may include:

(a) Material planed or excavated from a road or other paved area.

(b) Primary, secondary or recycled aggregate from other sources.

(c) Mineral filler from primary or secondary sources.

3 The aggregate including added inactive filler shall not contain deleterious material that adversely affects the performance of the mixture. This includes clay materials, friable materials, organic and metallic materials, or other extraneous or detrimental material.

4 The aggregate gradation for CSM shall follow the requirements stated in the mix design method, as approved by the Engineer, and shall generally follow the recommended gradations in Table 8.1 Recommended Gradations for Cold Stabilised Materials.

5 For BSM, material passing the 0.425mm sieve shall have a maximum liquid limit of 25% and the plasticity index shall not exceed 6.

6 Bitumen specified for use in BSM shall be 60/70 penetration grade in accordance with ASTM D946 and shall only be obtained from approved sources. The temperature of the bitumen prior to foaming shall be greater than 175°C but less than 195°C. Bitumen shall not contain any additives which may suppress foaming.

Table 8.1 Recommended Gradations for Cold Stabilised Materials

Sieve Size (mm)	Cement Treat Base (CTB)		Bitumen Stabilised Material (BSM)		Job Mix Control Sieve Tolerances
50	100	100	100	100	- 2
37.5	85	100	87	100	± 5
25	72	100	77	100	-
19	60	100	67	99	± 8
12.5	50	100	67	90	-
9.5	42	90	48	80	± 8
6.3	35	80	40	62	-
4.75	30	72	35	56	± 10
2.36	21	56	25	42	-
1.18	14	44	18	33	-
0.6	9	35	14	28	± 5

Sieve Size (mm)	Cement Treat Base (CTB)		Bitumen Stabilised Material (BSM)		Job Mix Control Sieve Tolerances
0.425	7	31	12	26	-
0.3	5	27	10	24	-
0.15	2	21	7	17	-
0.075	2.0	18.0	4.0	10.0	± 3

7 Cement specified for use in BSM and CTB shall be Portland cement in accordance with ASTM C150 and shall only be obtained from approved sources. Sulfate resisting cement shall be used if instructed by the Engineer.

8 Hydrated lime for use in BSM shall be in accordance with ASTM C1097 and for CTB shall be in accordance with ASTM C977, and shall only be obtained from approved sources.

9 Water for use in CSM shall in accordance with Section 5 Part 4.

8.4 CEMENT TREATED BASE (CTB)

8.4.1 Preparation And Mix Design For Cement Treated Base

1 The Contractor shall produce a detailed existing pavement investigation report and the proposed stabilised material mix design which shall be submitted for approval by the Engineer, at least 30 days prior to the commencement of the stabilisation works. The pavement investigation report shall consist of cores and trial pits excavated to the existing subgrade and include tests for, but not limited to, California Bearing Ratio, Dynamic Cone Penetrometer, gradation, plasticity index and liquid limit, and other tests required by the selected design method.

2 All equipment and method statements shall be submitted for approval by the Engineer at least 30 days prior to commencement of works.

3 The mix design method for the CTB mix shall be as approved by the Engineer. Methods may include that stated in this part, MCHW Specification for Highways Works Series 900: UK, or other similar and equivalent recognised international design methods for cement or hydraulic bound materials.

4 The CTB mix shall have a minimum individual 7 day compressive strength > 2.1 MPa with a maximum average 7 day compressive strength of 4.2 MPa when tested in accordance with ASTM D1633.

5 The mix design shall derive the gradation tolerance parameters of the pulverised material, moisture content at the point of compaction and target flow rates for the active filler, binder and added water at the point of mixing, appropriate to the production or stabilisation method used for the approval of the Engineer.

8.4.2 Site Trials For Cement Treated Base And Bitumen Stabilised Material

1 The CTB mix design shall be subjected to full preliminary trials and testing at least 10 days prior to commencement of the full works and shall determine:

(a) The effectiveness of the production and laying plant for exsitu processes;

(b) The number of passes of the stabilisation machine necessary to achieve uniform pulverisation and mixing for insitu processes;

(c) The field moisture content control required to achieve specified compaction requirements;

(d) The compaction routine and rolling patterns necessary to meet the specified compaction requirements;

(e) The reference density;

(f) The effectiveness of the contractor's inspection and test plan.

2 The length of the trial section shall be at least 150 metres and the full width of the carriageway proposed for stabilisation to ensure joints and full width compaction can be achieved without excessive segregation or other significant defects.

3 The trial area shall be sprayed with bituminous prime coat at a rate of 0.45 to 0.75 kg/m2 and allowed to cure for a minimum of 24 hours without trafficking unless otherwise authorised by the Engineer.

4 Tests from the trial areas shall be submitted to the Engineer for approval at least 3 days prior to commencement of the works. No works may proceed until all tests and final method statements have been submitted and approved by the Engineer.

5 Where materials and processes are demonstrably similar, mix designs and trials tests from previous projects may be approved at the discretion of the Engineer.

8.4.3 Insitu Stabilisation And Compaction Of Cement Treated Base

1 The insitu CTB stabilisation/recycling shall be produced by specialist equipment specifically designed for the purpose of insitu recycling processes.

2 The material shall be pulverised and stabilised in a single layer if its compacted thickness is 300 mm or less. If the compacted thickness is greater than 300 mm, the material shall be pulverised and stabilised in the minimum number of layers between100 mm and 300 mm thick. Where more than one layer is required, the Contractor shall satisfy the Engineer that the lower layer has achieved adequate stability before proceeding with the overlying layer.

3 Where required by the Engineer the stability of a layer in any area shall be assessed after a curing period of at least 24 hours by channelled trafficking using a rigid three-axle tipper truck loaded to a gross mass of 24 tonnes (assumed equivalent to three standard axles). The vertical deformation shall be measured in all wheel-tracks at monitoring points on each of 5 transverse sections set 1 metre apart after 5, 15, 30 and 40 passes of the truck. The mean vertical deformations at the above trafficking increments shall be plotted against the respective number of truck passes and the mean vertical deformation corresponding to 100 standard axles shall be interpolated. The layer shall be deemed acceptable if the mean vertical deformation corresponding to 100 standard axles is less than 10 mm.

4 The active filler (cement/hydrated lime) shall be supplied to the recycler by a specifically designed and calibrated mobile slurry mixer to ensure the dustless addition of the cement/hydraulic binder. The addition shall be continuously monitored with records taken to confirm the target addition rate, ± 10%, according to the mix design.

5 Mixing uniformity shall be continuously inspected visually by the contractor and work shall stop when the cement or hydrated lime is seen to agglomerate or not fully mix in during the production process.

6 Should either the slurry mixer supply to the mixer fail to operate or deliver the correct proportions to the recycler, all work shall cease until this has been corrected. Prior to resuming work, the process shall be checked fully by trialling in a short sacrificial trial strip exceeding 50 metres to ensure the process is fully operational and under control.

7 The recycler shall proceed in a continuous operation to the full depth of the layer being recycled as required by the pavement design.

8 The CTB moisture content prior to compaction shall be within ± 2 % of the target determined during the mix design procedure to achieve maximum density.

9 Initial rolling shall be carried out using a single-drum vibrating roller with a static mass that is appropriate with the thickness of the layer being compacted. The vibration mode must be set on high amplitude to achieve maximum penetration of compactive effort.

10 The rolling pattern should first concentrate on the middle section between the rear wheel paths of the recycler, then across the full cut width to achieve uniform density. The travel speed of the roller shall not exceed 3 km/h.

11 When initial compaction is complete, the surface shall be struck off to level by a grader and the surface again checked for level and any defects or damage caused during the operation which shall be corrected prior to final compaction.

12 Where the recycler has a screed finisher which achieves the required level, initial compaction shall follow the recommendations of the recycler supplier.

13 Where a second adjacent strip is to be laid immediately an additional insitu stabilisation, the recycler shall overlap the previously stabilised strip by 300mm, ensuring the strip is not excessively over or under bindered, or watered.

14 Upon completion of compaction the surface shall be sprayed with bituminous prime coat at a rate of 0.45 to 0.75 kg/m^2 and allowed to cure for a minimum of 24 hours without trafficking unless otherwise authorised by the Engineer. Where the surface is to be opened to traffic prior to surfacing with asphalt, the prime coat shall be blinded with fine aggregate or sand applied at a rate of 5.5 to 7.0 kg/m^2.

15 Traffic, including delivery vehicles shall not be permitted on the uncompacted or semi-compacted recycled material. The exposed longitudinal joint shall be protected from damage by construction plant and vehicles.

8.4.4 Exsitu Production Of Cement Treated Base

1 The exsitu production of CTB shall be produced by specialist recycling and stabilisation production equipment specifically designed for the purpose of exsitu processes.

2 The active filler (cement/hydrated lime) shall be supplied to the mixer by specifically designed and calibrated weighing apparatus to ensure the correct addition of the cement/hydraulic binder. The addition shall be continuously monitored with records taken to confirm the target addition rate, ± 10%, according to the mix design.

3 Mixing uniformity shall be continuously inspected visually by the contractor and work shall stop when the cement or hydrated lime is seen to agglomerate or not fully mix in during the production process.

4 CTB shall not segregate significantly during production and all measures shall be taken to avoid this occurrence.

5 CTB shall be conveyed from the mixer to its place in the Works as rapidly as possible in covered vehicles which will prevent segregation or drying out and ensure that the material is of the required workability and moisture content at the point of delivery to the paving equipment.

6 Where CTB is produced on an exsitu production plant, the material shall be laid and fully compacted within 2 hours of production, ensuring that the moisture content is within the required limits at the time of laying. CTB that exceeds 2 hours shall be rejected.

8.4.5 Laying And Compaction Of Cement Treated Base

1 Exsitu produced CTB materials shall be laid with paving machines and compaction plant as detailed in Section 6 Part 5, but may include additional specialist equipment deemed appropriate indicated in the detailed method statement.

2 The CTB moisture content prior to compaction shall be within ± 2 % of the target determined during the mix design procedure to achieve maximum density.

3 Material shall be laid to a thickness that would result in layers not more than 150 mm thick after compaction. Where the finished compacted thickness exceeds 150 mm placing shall be executed in composite layers each layer not exceeding 150 mm in compacted thickness as directed by the Engineer.

4 Final compaction for CTB shall follow the general requirements Section 6 Part 6 using a combination of tandem steel wheeled rollers and pneumatic tyred rollers in accordance with the approved method statement.

5 Where the surface of the recycled layer has been graded to level, it may be dampened with a water spray prior to compaction. Care shall be taken not to use excessive watering.

6 To prevent adhesion of the mix to steel-wheeled rollers, the wheels shall be kept properly moistened but excess water shall not be permitted.

7 Where a second adjacent strip is to be laid immediately by echelon paving of exsitu material, the requirements of Section 6 Part 5 shall be followed.

8 After final rolling, the smoothness, levels, crossfalls, density and thickness shall be checked and any irregularity of the surface exceeding the specified limits and any areas defective in texture, density or composition shall be corrected as directed by the Engineer, including removal and replacement as directed by the Engineer.

9 Upon completion of compaction the surface shall be sprayed with bituminous prime coat at a rate of 0.45 to 0.75 kg/m^2 and allowed to cure for a minimum of 24 hours without trafficking unless otherwise authorised by the Engineer. Where the surface is to be opened to traffic prior to surfacing with asphalt, the prime coat shall be blinded with fine aggregate or sand applied at a rate of 5.5 to 7.0 kg/m^2.

8.4.6 Joints In Cement Treated Base

1 Transverse joints shall be made by cutting back at least 2 metres to the position of conforming level and compaction, and cleaned to remove any loose material. The joint shall be fully compacted and left level and smooth.

2 Longitudinal joints shall be formed as follows:

3 For paver laid materials, fresh joints may be formed by compacting 500mm at the edge of the initial stabilised strip with a single roller pass and abutting the adjacent new strip prior to cross compaction. Joints are deemed to be fresh when the pavement materials on both sides of the joint have been stabilised and are able to be compacted within 1 hour. The 500mm partially compacted strip together with the exposed edge shall be lightly moistened prior to placement of the second strip.

4 For paver laid materials and where the stabilised layer has been laid previously or is deemed unworkable, the existing strip shall be cut back by 150mm to its full depth and cleaned to remove any loose material prior to paving the new adjacent strip.

5 Longitudinal construction joints in CTB shall always be formed at the lane line marking positions where practically possible.

8.4.7 Sampling And Testing - Cement Treated Base

1 The Contractor shall produce an inspection and test plan for the complete process which shall include daily production control and the finished stabilised pavement for approval by the Engineer.

2 Bulk samples shall be taken from the stabilised material to the full depth of the layer.

3 Sample increments will be wrapped tightly in plastic bags to prevent moisture loss and protected from the heat and sun in an ambient temperature of no greater than 20°C.

4 Samples shall be provided from the laid CTB before compaction, as approved by the Engineer. One group of five samples shall be provided from five locations equally spaced along a diagonal that bisects each 800m2 or part thereof laid each day. The number of groups may be increased if required by the Engineer. Each group shall be combined to provide samples for reference density, compressive strength and laboratory determined moisture content.

5 For each group, 3 specimens for reference density and compressive strength testing shall be compacted in accordance with AASHTO T180within 2 hours of the addition of the cement and cured in accordance with ASTM D1632, and tested in accordance with ASTM D1633.

6 To determine the reference density of test specimens the mould shall be weighed prior to making the specimen and the mass recorded. Immediately after completion of compaction, the specimen and mould shall be weighed and the mass recorded. These masses together with the nominal volume of the mould shall be used to derive the reference density of the specimen.

7 The in-situ density of a layer of cement bound material shall be taken as the average of the densities at five locations equally spaced along a diagonal that bisects each 800 m2 or part thereof laid each day. The in-situ density at each location shall be the average of two readings obtained using a nuclear density gauge in compliance with ASTM D6938. Readings shall be taken within two hours of completing final compaction.

8 Testing for CTB shall be required as Table 8. 2 Sampling and Testing Requirements for Cement Treated Base

Table 8. 2 Sampling and Testing Requirements for Cement Treated Base

TEST	METHOD	SAMPLE POINT	SPECIFICATION	FREQUENCY
Sieve Analysis	ASTM D422	Pre-Stabilised Pulverised Materials	Design mix gradation	1/1000m^3
Liquid Limit	ASTM D4318	Pre-Stabilised Pulverised Materials	Less than design mix determination	1/1000m^3
Plasticity Index	ASTM D4318	Pre-Stabilised Pulverised Materials	Less than design mix determination	1/1000m^3
Field Density	ASTM D1556/D6938	Compacted Stabilised Material	100% reference density	5/800m^2
Field Moisture Content	ASTM D4944	Pre-compacted Stabilised Material	± 2% OMC	1/800m^2
Surface Modulus	ASTM E2583	Compacted Stabilised Material	Report Values[1]	5/800m^2
Compressive Strength	ASTM D1633	Pre-compacted Stabilised Material	Individual >2.1 MPa Average of 3 <4.2 MPa	1/800m^2
Reference density	AASHTO T-180	Pre-compacted Stabilised Material	-	1/800m^2

TEST	METHOD	SAMPLE POINT	SPECIFICATION	FREQUENCY
Moisture Content	ASTM D2216	Laid Stabilised Material	± 2% OMC	1/800m^2

Note 1 – The surface modulus determined in accordance with ASTM E2583 shall be reported as directed by the Engineer for data collection. It shall not form part of the acceptance or rejection criteria.

8.4.8 Evenness And Level

1 The transverse regularity of the surface of the CTB shall be tested by means of a 4 metre long straight edge. No irregularity in excess of 10 mm shall be permitted.

2 The longitudinal regularity of the surface of the CTB shall be tested by means of a rolling straight edge. No irregularity in excess of 10 mm shall be permitted.

3 The finished surface shall also be checked by dips or spot levels and shall be constructed to the designated grade levels to within ± 10 mm.

4 Where these requirements are not met, the Contractor shall determine the full extent of the area which is out of tolerance and shall make good the surface of the course by scarifying to a minimum depth of 75 mm or 4 times the maximum particle size, whichever is greater, reshaping by adding or removing material as necessary, adding water if necessary and recompacting the layer. The minimum length of rectification shall be 50 metres.

5 Acceptance of the stabilised pavement is subject to completion of all testing and inspection requirements to the satisfaction of the Engineer.

8.5 BITUMEN STABILISED MATERIAL (BSM)

8.5.1 Preparation And Mix Design For Bitumen Stabilised Material

1 The Contractor shall produce a detailed existing pavement investigation report and the proposed stabilised material mix design which shall be submitted for approval by the Engineer, at least 30 days prior to the commencement of the stabilisation works. The pavement investigation report shall consist of cores and trial pits excavated to the existing subgrade and include tests for, but not limited to, California Bearing Ratio, Dynamic Cone Penetrometer, gradation, plasticity index and liquid limit, and other tests required by the selected design method.

2 All equipment and method statements shall be submitted for approval by the Engineer at least 30 days prior to commencement of works.

3 The mix design method for the BSM mix shall be as approved by the Engineer. Methods may include that stated in this part, or MCHW Specification for Highways Works Series 900: (UK), or other similar and equivalent recognised international design methods for Bitumen Stabilised Material.

4 The aggregate gradation for BSM shall follow the approved guidelineby the Engineer unless otherwise stated in the approved alternative design method.

5 The Design Mixture for BSM shall have minimum bitumen content of 2.5% with an active filler content no greater than 1%, by mass of total mix.

6 The Binder Expansion Ratio (ER) shall be greater than 10 times and the Binder Half Life (T½) greater than 12 seconds.

7 The Indirect Tensile Strength dry (ITSdry - 100mmØ specimens) shall be greater than 225 kPa and the Indirect Tensile Strength wet (ITSwet - 100mmØ specimens) shall be greater than 100 kPa when tested in accordance with ASTM D6931. The Tensile Strength Ratio (TSR) shall be greater than 80%

8 The Unconfined Compressive Strength of the mixture shall be between 1200 and 3500 kPa when tested in accordance with ASTM D1633.

8.5.2 Site Trials For Bitumen Stabilised Material

1 The BSM mix design shall be subjected to full preliminary trials and testing at least 10 days prior to commencement of the full works and shall determine:

(a) the effectiveness of the production and laying plant for exsitu processes;

(b) the number of passes of the stabilisation machine necessary to achieve uniform pulverisation and mixing for insitu processes;

(c) the field moisture content control required to achieve specified compaction requirements;

(d) the compaction routine and rolling patterns necessary to meet the specified compaction requirements;

(e) the reference density;

(f) the effectiveness of the contractor's inspection and test plan.

2 The length of the trial section shall be at least 150 metres and the full width of the carriageway proposed for stabilisation to ensure joints and full width compaction can be achieved without excessive segregation or other significant defects.

3 The trial area shall be sprayed with bituminous prime coat at a rate of 0.45 to 0.75 kg/m^2 and allowed to cure for a minimum of 24 hours without trafficking unless otherwise authorised by the Engineer.

4 Tests from the trial areas shall be submitted to the Engineer for approval at least 3 days prior to commencement of the works. No works may proceed until all tests and final method statements have been submitted and approved by the Engineer.

5 Where materials and processes are demonstrably similar, mix designs and trials tests from previous projects may be approved at the discretion of the Engineer.

8.5.3 Insitu Stabilisation And Compaction Of Bitumen Stabilised Material

1 The insitu BSM stabilisation/recycling shall be produced by specialist equipment specifically designed for the purpose of insitu recycling processes.

2 The material shall be pulverised and stabilised in a single layer if its compacted thickness is 300 mm or less. If the compacted thickness is greater than 300 mm, the material shall be pulverised and stabilised in the minimum number of layers between100 mm and 300 mm thick. Where more than one layer is required, the Contractor shall satisfy the Engineer that the lower layer has achieved adequate stability before proceeding with the overlying layer.

3 Where required by the Engineer the stability of a layer in any area shall be assessed after a curing period of at least 24 hours by channelled trafficking using a rigid three-axle tipper truck loaded to a gross mass of 24 tonnes (assumed equivalent to three standard axles). The vertical deformation shall be measured in all wheel-tracks at monitoring points on each of 5 transverse sections set 1 metre apart after 5, 15, 30 and 40 passes of the truck. The mean vertical deformations at the above trafficking increments shall be plotted against the respective number of truck passes and the mean vertical deformation corresponding to 100 standard axles shall be interpolated. The layer shall be deemed acceptable if the mean vertical deformation corresponding to 100 standard axles is less than 10 mm.

4 The bitumen tanker shall a consistent flow of binder to the recycler. The addition shall be continuously monitored with records taken to confirm the target addition rate, ± 10%, according to the mix design.

5 The active filler (cement) shall be supplied to the recycler by a specifically designed and calibrated mobile slurry mixer to ensure the dustless addition of the cement/hydraulic binder. The addition shall be monitored with records taken to confirm the correct addition rate according to the mix design.

6 Mixing uniformity shall be continuously inspected visually by the contractor and work shall stop when bitumen streaks or blotches are observed, or where cement is seen to agglomerate or not fully mix in during the production process.

7 Should either the slurry mixer or the binder supply to the mixer fail to operate or deliver the correct proportions to the recycler, all work shall cease until this has been corrected. Prior to resuming work, the process shall be checked fully by trialling in a short sacrificial trial strip exceeding 50 metres to ensure the process is fully operational and under control.

8 The recycler shall proceed in a continuous operation to the full depth of the layer being recycled as required by the pavement design.

9 The BSM moisture content prior to compaction shall be within ± 2 % of the target determined during the mix design procedure to achieve maximum density.

10 Initial rolling shall be carried out using a single-drum vibrating roller with a static mass that is appropriate with the thickness of the layer being compacted. The vibration mode must be set on high amplitude to achieve maximum penetration of compactive effort.

11 The rolling pattern should first concentrate on the middle section between the rear wheel paths of the recycler, then across the full cut width to achieve uniform density. The travel speed of the roller shall not exceed 3 km/h.

12 When initial compaction is complete, the surface shall be struck off to level by a grader and the surface again checked for level and any defects or damage caused during the operation which shall be corrected prior to final compaction.

13 Where the recycler has a screed finisher which achieves the required level, initial compaction shall follow the recommendations of the recycler supplier.

14 Where a second adjacent strip is to be laid immediately an additional insitu stabilisation, the recycler shall overlap the previously stabilised strip by 300mm, ensuring the strip is not excessively over or under bindered, or watered.

15 Upon completion of compaction the surface shall be sprayed with bituminous prime coat at a rate of 0.45 to 0.75 kg/m2 and allowed to cure for a minimum of 24 hours without trafficking unless otherwise authorised by the Engineer. Where the surface is to be opened to traffic prior to surfacing with asphalt, the prime coat shall be blinded with fine aggregate or sand applied at a rate of 5.5 to 7.0 kg/m2.

16 Traffic, including delivery vehicles shall not be permitted on the uncompacted or semi-compacted recycled material. The exposed longitudinal joint shall be protected from damage by construction plant and vehicles.

8.5.4 Exsitu Production Of Bitumen Stabilised Material

1 The exsitu production of BSM shall be produced by specialist recycling and stabilisation production equipment specifically designed for the purpose of exsitu processes.

2 The bitumen shall be supplied to the mixer by specifically designed and calibrated metering apparatus to ensure the correct addition of the binder. The addition shall be continuously monitored with records taken to confirm the target addition rate, ± 10%, according to the mix design.

3 The active filler (cement) shall be supplied to the mixer by specifically designed and calibrated weighing apparatus to ensure the correct addition of the cement/hydraulic binder. The addition shall be continuously monitored with records taken to confirm the target addition rate, ± 10%, according to the mix design.

4 Mixing uniformity shall be continuously inspected visually by the contractor and work shall stop when bitumen streaks or blotches are observed or where cement is seen to agglomerate or not fully mix in during the production process.

5 BSM shall not segregate significantly during production and all measures shall be taken to avoid this occurrence.

6 BSM shall be conveyed from the mixer to its place in the Works as rapidly as possible in covered vehicles which will prevent segregation or drying out and ensure that the material is of the required workability and moisture content at the point of delivery to the paving equipment.

7 Where BSM is produced on an exsitu production plant, the material shall be laid and fully compacted within 2 hours of production, ensuring that the moisture content is within the required limits at the time of laying. BSM that exceeds 2 hours shall be rejected.

8.5.5 Laying And Compaction Of Bitumen Stabilised Material

1 Exsitu produced BSM materials shall be laid with paving machines and compaction plant as detailed in Section 6 Part 5, but may include additional specialist equipment deemed appropriate indicated in the detailed method statement.

2 The BSM moisture content prior to compaction shall be within ± 2 % of the target determined during the mix design procedure to achieve maximum density.

3 Material shall be laid to a thickness that would result in layers not more than 150 mm thick after compaction. Where the finished compacted thickness exceeds 150 mm placing shall be executed in composite layers each layer not exceeding 150 mm in compacted thickness as directed by the Engineer.

4 Final compaction for BSM shall follow the general requirements Section 6 Part 5 using a combination of tandem steel wheeled rollers and pneumatic tyred rollers in accordance with the approved method statement.

5 Where the surface of the recycled layer has been graded to level, it may be dampened with a water spray prior to compaction. Care shall be taken not to use excessive watering.

6 To prevent adhesion of the mix to steel-wheeled rollers, the wheels shall be kept properly moistened but excess water shall not be permitted.

7 Where a second adjacent strip is to be laid immediately by echelon paving of exsitu material, the requirements of Section 6 Part 5 shall be followed.

8 After final rolling, the smoothness, levels, crossfalls, density and thickness shall be checked and any irregularity of the surface exceeding the specified limits and any areas defective in texture, density or composition shall be corrected as directed by the Engineer, including removal and replacement as directed by the Engineer.

9 Upon completion of compaction the surface shall be sprayed with bituminous prime coat at a rate of 0.45 to 0.75 kg/m^2 and allowed to cure for a minimum of 24 hours without trafficking unless otherwise authorised by the Engineer. Where the surface is to be opened to traffic prior to surfacing with asphalt, the prime coat shall be blinded with fine aggregate or sand applied at a rate of 5.5 to 7.0 kg/m^2.

8.5.6 Joints In Bitumen Stabilised Material

1 Transverse joints shall be made by cutting back at least 2 metres to the position of conforming level and compaction, and cleaned to remove any loose material. The joint shall be fully compacted and left level and smooth.

2 Longitudinal joints shall be formed as follows:

(a) For paver laid materials, fresh joints may be formed by compacting 500mm at the edge of the initial stabilised strip with a single roller pass and abutting the adjacent new strip prior to cross compaction. Joints are deemed to be fresh when the pavement materials on both sides of the joint have been stabilised and are able to be compacted within 1 hour. The 500mm partially compacted strip together with the exposed edge shall be lightly moistened prior to placement of the second strip.

(b) For paver laid materials and where the stabilised layer has been laid previously or is deemed unworkable, the existing strip shall be cut back by 150mm to its full depth and cleaned to remove any loose material prior to paving the new adjacent strip.

3 Longitudinal construction joints in BSM shall always be formed at the lane line marking positions where practically possible.

8.5.7 Sampling And Testing - Bitumen Stabilised Material

1 The Contractor shall produce an inspection and test plan for the complete process which shall include daily production control and the finished stabilised pavement for approval by the Engineer.

2 Bulk samples shall be taken from the stabilised material to the full depth of the layer.

3 Sample increments will be wrapped tightly in plastic bags to prevent moisture loss and protected from the heat and sun in an ambient temperature of no greater than 20°C.

4 Samples shall be provided from the laid BSM before compaction, as approved by the Engineer. One group of five samples shall be provided from five locations equally spaced along a diagonal that bisects each 800m^2 or part thereof laid each day. The number of groups may be increased if required by the Engineer.

5 For each group, 3 specimens for strength based testing shall be compacted within 2 hours of the addition of the bitumen binder. Reference density and UCS shall be compacted and cured in accordance with AASHTO T-180, and tested in accordance with ASTM D1633. ITS testing shall be compacted in accordance with ASTM D6926 and tested in accordance with ASTM D6931.

6 The foamed bitumen expansion ratio and half life shall be determined at the commencement of works each day if required by the Engineer.

7 To determine the reference density of test specimens the mould shall be weighed prior to making the specimen and the mass recorded. Immediately after completion of compaction, the specimen and mould shall be weighed and the mass recorded. These masses together with the nominal volume of the mould shall be used to derive the reference density of the specimen.

8 The in-situ density of a layer of cement bound material shall be taken as the average of the densities at five locations equally spaced along a diagonal that bisects each 800 m^2 or part thereof laid each day. The in-situ density at each location shall be the average of two readings obtained using a nuclear density gauge in compliance with ASTM D6938. Readings shall be taken within two hours of completing final compaction.

9 Testing for BSM shall be required as Table 8.3 Sampling and Testing Requirements for BSM.

Table 8.3 Sampling and Testing Requirements for BSM

TEST	METHOD	SAMPLE POINT	SPECIFICATION LIMIT	FREQUENCY
Sieve Analysis	ASTM D422	Pre-Stabilised Pulverised Materials	Design mix gradation	1/1000m^3
Liquid Limit	ASTM D4318	Pre-Stabilised Pulverised Materials	Maximum 25	1/1000m^3
Plasticity Index	ASTM D4318	Pre-Stabilised Pulverised Materials	Maximum 6	1/1000m^3
Field Density	ASTM D1556/D6938	Compacted Stabilised Material	100% reference density	5/800m^2
Field Moisture Content	ASTM D4944	Pre-compacted Stabilised Material	± 2% OMC	1/800m^2
Surface Modulus	ASTM E2583	Compacted Stabilised Material	Report Test Values[1]	5/800m^2
Binder Expansion Ratio	This Part:8.6	Pre-mixing/ stabilisation	>10 times	1/first 500 m^2/day

TEST	METHOD	SAMPLE POINT	SPECIFICATION LIMIT	FREQUENCY
Binder Half Life (τ½)	This Part:8.6	Pre-mixing/ stabilisation	> 12 seconds	1/first 500 m^2/day
Unconfined Compressive Strength	ASTM D1633 (150mmØ)	Pre-compacted Stabilised Material	1200 to 3500 kPa	1/800m^2
Moisture Content	ASTM D2216	Laid Stabilised Material	± 2% OMC	1/800m^2
Indirect Tensile Strength	ASTM D6931 (100mmØ)	Pre-compacted Stabilised Material	ITS_{dry} >225 kPa ITS_{wet} >100 kPa	1/day if >800m^2
Tensile Strength Retained (TSR)	ITS_{wet} / ITS_{dry}	Pre-compacted Stabilised Material	> 80%	1/day if >800m^2

Note 1 – The surface modulus determined in accordance with ASTM E2583 shall be reported as directed by the Engineer for data collection. It shall not form part of the acceptance or rejection criteria.

8.5.8 Evenness And Level

1 The transverse regularity of the surface of the BSM shall be tested by means of a 4 metre long straight edge. No irregularity in excess of 10 mm shall be permitted.

2 The longitudinal regularity of the surface of the BSM shall be tested by means of a rolling straight edge. No irregularity in excess of 10 mm shall be permitted.

3 The finished surface shall also be checked by dips or spot levels and shall be constructed to the designated grade levels to within ± 10 mm.

4 Where these requirements are not met, the Contractor shall determine the full extent of the area which is out of tolerance and shall make good the surface of the course by scarifying to a minimum depth of 75 mm or 4 times the maximum particle size, whichever is greater, reshaping by adding or removing material as necessary, adding water if necessary and recompacting the layer. The minimum length of rectification shall be 50 metres.

5 Acceptance of the stabilised pavement is subject to completion of all testing and inspection requirements to the satisfaction of the Engineer.

8.6 DETERMINATION OF THE FOAMING CHARACTERISTICS OF BITUMEN (EXPANSION RATIO AND HALF LIFE)

8.6.1 Scope

1 The foaming characteristics of bitumen are defined by the Expansion Ratio and Half Life of the bitumen in its expanded state. The expanded state of the bitumen is achieved when a small percentage of water is introduced into hot bitumen. The objective is to determine the percentage of water required that will produce the best foam characteristics for a particular source of bitumen. The aim is to produce foamed bitumen with the largest expansion ratio with the longest half-life possible.

8.6.2 Definitions

1 The expansion ratio is a measure of the viscosity of the foam and provides an indication of how well the binder will disperse in the mix. It is calculated as the ratio of the maximum volume of foam relative to the original volume of bitumen. The half-life is a measure of the stability of the foam and provides an indication of the rate of collapse of the foam during mixing. It is calculated as the time taken in seconds for the foam to collapse to half of its maximum volume.

8.6.3 Apparatus

1 The following equipment shall be required:

(a) For mix design only: Foamed Bitumen Laboratory Unit, capable of producing foamed bitumen at a rate of between 50g and 200g per second. The method of production shall closely simulate that of full scale production of foamed bitumen on the recycling machine. The apparatus shall have a thermostatically controlled kettle capable of holding a mass of 10kg of bitumen at a constant temperature between the range of 160ºC and 200ºC, ± 5ºC. The unit shall have an expansion chamber similar to that on the recycling machine in which cold water is injected into hot bitumen. Water injection shall be variable from 0 to 5% (by mass of the bitumen) with an accuracy of 0.25%. The plant shall capable of accurately discharging a predetermined mass of foamed bitumen directly into the mixing bowl of an electrically driven laboratory mixer with a minimum capacity of 10kg.

(b) Cylindrical metal container, 250mm diameter and at least 20 litre capacity.

(c) Calibrated Dip Stick, calibrated for the cylindrical metal container with 500g of bitumen as 1 unit measure. Prongs are attached to the dip stick at every 5 or 6 times the unit volume.

(d) A stop-watch with 60 second dial.

(e) Heat resistant gloves.

(f) An electronic balance to weigh up to 10kg, accurate to 1g.

8.6.4 Method

1 Preparation

(a) The foamed bitumen laboratory unit discharge rates are checked in accordance with the manufactures specifications. If the unit is being used for the first time then the pump rate and water flow rates need to be calibrated as per the manufactures specifications. Check that 500g of bitumen is being discharged at the predetermined settings.

(b) Ensure that the cylindrical metal container and dip stick are reasonably clean. Discharge foamed bitumen, at least twice, into cylindrical metal container prior to testing in order to pre-heat the container. Decant excess bitumen from the container into a suitable waste receptacle.

2 Testing

(a) Heat the bitumen in the kettle of the foamed bitumen laboratory unit with the pump circulating the bitumen through the system until the required temperature is achieved (normally starting with 160 °C). Maintain the required temperature for at least 5 minutes prior to commencing with testing.

(b) Set the water flow-meter to achieve the required water injection rate (normally starting with 2 % by mass of the bitumen).

(c) Discharge foamed bitumen into the preheated steel drum for the calculated spray time for 500 g of bitumen. Immediately after the foamed bitumen discharge stops, start a stopwatch.

(d) Using the calibrated dipstick measure the maximum height the foamed bitumen achieves in the drum. This maximum volume is recorded as the expansion. Continue to measure the time in seconds that the foam takes to dissipate to half of its maximum volume. This is recorded as the foamed bitumen's half-life.

(e) Repeat the above procedures three times or until similar readings are achieved.

(f) The expansion and half-life are determined at different percentages of water. Typically, values of 2 %, 3 % and 4 % by mass of bitumen are used.

(g) Plot a graph of the expansion ratio versus half-life at the different water injection rates on the same set of axes. The optimum water addition is chosen as an average of the two water contents required to meet the minimum criteria. (Figure 7.1 Determination of Optimum Foaming Water)

(h) If the required properties are not met at 160°C, further testing should be carried out with the bitumen at higher temperatures (typically 170°C and 180°C).

8.6.5 Reporting

1 The foamed bitumen characteristics and optimum water content are reported as;

Optimum water content (%): Percentage by mass of bitumen;
Expansion (times): Ratio of maximum expansion to original volume of bitumen;
Half-life (sec): Time taken from maximum expansion to half this volume.

8.6.6 Site Quality Control

The above method may be used to determine the expansion ratio and half-life of foamed bitumen dispensed by the production plant or recycler.

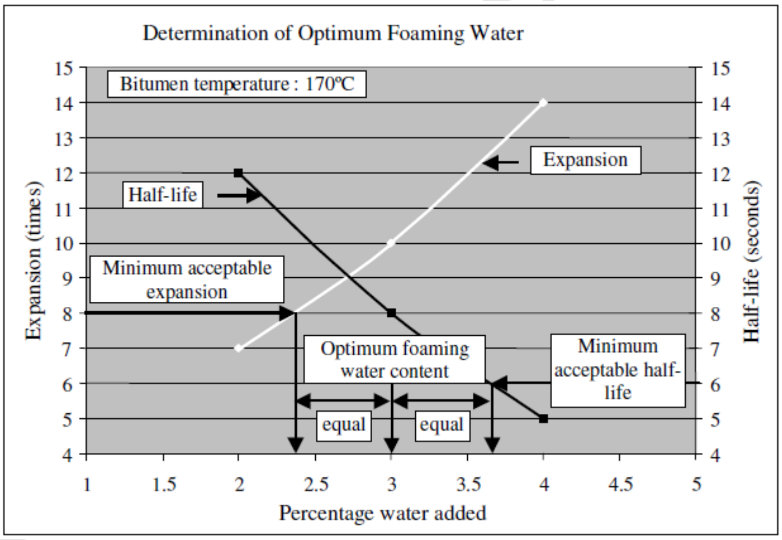


Figure 7.1 Determination of Optimum Foaming Water

APPENDIX

GUIDANCE FOR THE DESIGN OF RECYCLED AND STABILISED MATERIALS (MIX DESIGNS)

8.7 GENERAL

The detailed procedures for carrying out stabilisation mix designs in a laboratory are described below. Procedures for both cement (or lime) and bitumen stabilisation are included as well as guidelines for interpreting the test results for bitumen stabilised materials (BSMs). Comprehensive lists of laboratory equipment are provided. In addition, a chart has been included showing how laboratory test results can be utilised to indicate the relevant structural coefficient for a BSM (for use in the AASHTO 1993 pavement design method).

8.7.1 Preparation Of Samples For Mix Design Procedures

1 Field Sampling: Bulk samples are obtained from test pits excavated as part of the field investigations. Each layer in the upper pavement (± 300mm) must be sampled separately and at least 150kg of material recovered from each layer that is likely to be included in any mix design procedure. Representative samples shall be obtained and prepared either from the excavation process at source or by laboratory crushing and screening.

2 Standard soil tests: Carry out the following standard tests on the material sampled from each individual layer:

(a) Sieve analysis to determine the grading (ASTM D 422);

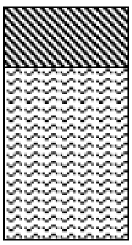
(b) Atterberg limits to determine the liquid limit and plasticity index (ASTM D 4318); and

(c) Moisture / density relationship (AASHTO T-180).

3 Sample blending: Where necessary, blend the materials sampled from the different layers to obtain a combined sample representing the material from the full recycling depth. The in-situ density of the various components must be considered when blending materials, as illustrated in

4 Figure 7.1 Determination of Optimum Foaming Water Repeat the standard soil tests described above to determine the grading and plasticity index of the blended sample.

Existing upper
pavement structure



60mm Asphalt
(in situ density 2300 kg/m³)

200mm Subbase
(in situ density 2000 kg/m³)

Recycling depth 200mm = 60mm Asphalt + 140mm Gravel

The materials are blended in proportion to layer thickness and insitu density as follows:

Material	Per square metre (kg)	Proportion by mass (%)	Per 10kg sample (g)
Asphalt (60mm at 2300 kg/m3)	0.06 x 2300 = 138	138/418 = 0.33	0.33 x 10000 = 3300
Gravel (140mm at 2000 kg/m3)	0.14 x 2000 = 280	280/418 = 0.67	0.67 x 10000 = 6700
Total	418	1.00	10000

Figure 7.2 Example of Density Proportioning

5 Representative proportioning: Separate the material in the representative sample into the following four fractions:

– Retained on the 19.0mm sieve;

- Passing the 19.0mm sieve, but retained the 12.5 mm sieve;
- Passing the 12.5 mm sieve, but retained on the 4.75mm sieve; and
- Passing the 4.75mm sieve.

Reconstitute representative samples in accordance with the grading up to the portion passing the 19.0mm sieve. Substitute the portion retained on 19.0mm sieve with material that passes the 19.0mm sieve, but is retained on the 12.5 mm sieve. The example in Table 8.4 Material Combination explains this procedure:

Table 8.4 Material Combination

Sieve analysis		Quantity of material to be included in a 10kg sample		
Sieve size (mm)	Percentage passing (from sieve analysis)	Passing 4.75mm	Passing 12.5mm Retained 4.75mm	Passing 19mm Retained 12.5mm
19	90.5	(53.6/100 x 10000) = 5360g	((72.3-53.6)/100 x 10000) = 1870g	((100-72.3)/100 x 10000) = 2770g
12.5	72.3			
4.75	53.6			

If there is insufficient material (i.e. passing the 19mm sieve but retained on the 12.5mm sieve) for substituting that retained on the 19mm sieve, then lightly crush the material retained on the 19.0mm sieve to provide more of this fraction.

6 Sample quantities: The guidelines shown Table 8.5 Test Quantities should be used for the quantity of material required for the respective tests:

Table 8.5 Test Quantities

Test	**Sample quantity required**
Moisture / density relationship (AASHTO T180)	5 x 7kg
Unconfined Compressive Strength (150mm Ø specimens)	20kg per stabiliser content
Bitumen stabilisation mix design (100mm Ø specimens)	Minimum 10kg per stabiliser content
Bitumen stabilisation mix design (150mm Ø specimens)	Minimum 20kg per stabiliser content
Determination of moisture content	Approximately 1kg

7 Hygroscopic moisture content: Two representative air-dried samples, each approximately 1kg, are used to determine the hygroscopic (air dried) moisture content of the material. (Note: Larger sample size should be used for more coarsely-graded materials.) Weigh the air-dried samples, accurate to the nearest 0.1g, and then place them in an oven at a temperature of between 105ºC and 110ºC until they achieve constant mass. The hygroscopic moisture content ($W_{air\text{-}dry}$) is the loss of mass expressed as a percentage of the dry mass of the sample. Determine the hygroscopic moisture using equation 1:

$$\boxed{W_{air\text{-}dry} = (M_{moist} - M_{dry}) / M_{dry} \times 100} \qquad \text{[Equation 1]}$$

where: $W_{air\text{-}dry}$ = hygroscopic moisture content [% by mass]

M_{moist} = mass of moist material [g]

M_{dry} = mass of dry material [g]

8.7.2 Mix Design Procedure For Cement Stabilised Materials

1 Determination of the Moisture / Density Relationship: This test is carried out using standard compaction effort to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the cement stabilised material.

Step 1: Weigh out the required mass of stabilising agent for each of five 7kg samples prepared as described in 8.7.1. The amount of stabilising agent required (expressed as a percentage by mass of the dry sample) should be close to the anticipated optimum for the material being treated. In the absence of previous tests, the following can be used as a guideline:

Subbase layers:	2% for coarse material (> 50% retained on 4.75mm sieve)
	3% for fine material (< 50% retained on 4.75mm sieve)
Base layers:	4% for coarse material (> 50% retained on 4.75mm sieve)
	6% for fine material (< 50% retained on 4.75mm sieve)

Step 2: Add the stabilising agent to the raw material and mix immediately prior to the addition of water. In order to simulate conditions on the road, compaction of the stabilised material is delayed for one hour after mixing the untreated material with stabilising agent and water. The mixed material is placed in an air-tight container to prevent loss of moisture and is thoroughly mixed every fifteen minutes.

Step 3: Determine the OMC and MDD for the stabilised material in accordance with the modified moisture-density relationship test procedure (AASHTO T-180).

2 Manufacture of Specimens for Strength Testing: The procedure described below is for the manufacture specimens that are of 150mm in diameter and 127mm in height. These specimens will be used to determine the Unconfined Compressive Strength (UCS) and Indirect Tensile Strength (ITS) of the material.

Step 1: Place the 20kg sample, prepared as described in 8.7.1, into a suitable mixing container.

Step 2: Determine the dry mass of the sample using equation 2:

$$\boxed{M_{sample} = (M_{air\text{-}dry} / (1 + (W_{air\text{-}dry} \times 100))} \qquad \text{[Equation 2]}$$

where:	M_{sample}	= dry mass of sample	[g]
	$M_{air\text{-}dry}$	= air-dried mass of the sample	[g]
	$W_{air\text{-}dry}$	= moisture content of air-dried sample	[% by mass]

Step 3: Determine the required amount of stabilising agent using equation 3:

$$\boxed{M_{cement} = (C_{add} / 100) \times M_{sample}} \qquad \text{[Equation 3]}$$

where:	M_{cement}	= mass of lime or cement to be added	[g]
	C_{add}	= percentage of lime or cement required	[% by mass]
	M_{sample}	= dry mass of the sample	[g]

Step 4: Determine the percentage water to be added for optimum mixing purposes using equation 4 and then the mass of water to be added to the sample using equation 5:

$$\boxed{W_{add} = W_{OMC} - W_{air\text{-}dry}} \qquad \text{[Equation 4]}$$

$$\boxed{M_{water} = (W_{add} / 100) \times (M_{sample} + M_{cement})} \qquad \text{[Equation 5]}$$

where:			
	W_{add}	= water to be added to sample	[% by mass]
	W_{OMC}	= optimum moisture content	[% by mass]
	$W_{air\text{-}dry}$	= moisture content of air-dried sample	[% by mass]
	M_{water}	= mass of water to be added	[g]
	M_{sample}	= dry mass of the sample	[g]
	M_{cement}	= mass of lime or cement to be added	[g]

Step 5: Mix the material, cement and water until uniform. Allow the mixed material to stand for one hour with occasional mixing, as described above, before compacting three 150mm diameter specimens using modified AASHTO (T-180) compaction effort. (Note: Two 150mm diameter specimens are normally manufactured for each test.)

Step 6: Samples are taken during the compaction process and dried to a constant mass (at 105 to 110°C) to determine the moulding moisture content (W_{mould}). Determine the moulding moisture using equation 6:

$$\boxed{W_{mould} = (M_{moist} - M_{dry}) / M_{dry} \times 100)} \qquad \text{[Equation 6]}$$

where:			
	W_{mould}	= moulding moisture content	[% by mass]
	M_{moist}	= mass of moist material	[g]
	M_{dry}	= mass of dry material	[g]

Steps 7 to 9: Repeat the above steps for at least three different stabiliser contents.

Step 10: Remove the specimens from the moulds either by dismantling the split moulds or, if ordinary moulds are used, extruding the specimens carefully with an extrusion jack, avoiding distortion to the compacted specimens.

Step 11: Record the mass and volume of each specimen and determine the dry density using equation 7:

$$\boxed{DD = (M_{briq} / Vol) \times (100 / W_{mould} + 100) \times 1000} \qquad \text{[Equation 7]}$$

where:			
	DD	= dry density	[kg/m^3]
	M_{briq}	= mass of specimen	[g]
	Vol	= volume of specimen	[cm^3]
	W_{mould}	= moulding moisture content	[%]

Note: With certain materials lacking cohesion, it may be necessary to leave the specimens in the moulds for 24 hours to develop strength before extracting. When this is necessary, the specimens in the moulds should be kept in a curing room or covered with damp cloth (hessian).

3 Curing the Specimens: Cure the specimens for seven days at 95% to 100% relative humidity and at a temperature of 20ºC to 25ºC in a suitable curing room.

An alternative curing method is to place the specimen in sealed plastic bags and cure in an oven at:

70ºC to 75ºC for 24 hours for cement; or

60ºC to 62 ºC for 45 hours for lime.

After the curing period, remove the specimens from the curing room (or plastic bags) and allow to cool to ambient temperature, if necessary. Specimens for unconfined compressive strength (UCS) tests should be submerged in water at 22°C to 25°C for four hours prior to testing.

4 Strength Tests: The Unconfined Compressive Strength (UCS) test and the Indirect Tensile Strength (ITS) test procedures are described under 8.7.11.

5 Determination of the Optimum Stabiliser Content: The ITS and UCS strengths achieved are plotted against the percentage stabilising agent added using the average UCS or ITS of the three specimens for each stabiliser content, ignoring any obvious incorrect result that may have been caused by damage to the specimen before testing. The required application rate of stabilising agent is that percentage at which the minimum required criteria are met.

8.7.3 Mix Design Procedure For Bitumen Stabilised Materials (Bsms)

1 Active Filler Requirements: Bitumen stabilisation is normally carried out in combination with a small amount (1% by mass) of active filler (cement or hydrated lime) to enhance the dispersion of the bitumen and/or the breaking time (where bitumen emulsion is used as the stabilisation agent). The PI of the material is used as an initial guideline for the use of hydrated lime or cement in the mix:

Table 8.6 Guide to Addition of Active Filler

Plasticity Index: < 10	Plasticity Index: > 10
Carry out Preliminary Level 1 tests (explained below) to determine the need to add cement or hydrated lime.	Pre-treat with hydrated lime (ICL value) (The initial consumption of lime (ICL value) must first be determined using the appropriate pH test.)

Pre-treatment of material with a PI > 10 requires that the lime and water be added at least 2 hours prior to the addition of the bitumen emulsion or foamed bitumen. (The treated material must be placed in an air-tight container to retain moisture and the moisture content checked and, if necessary, adjusted prior to adding the bitumen stabilising agent.) Such materials are not subjected to “Preliminary Level 1” tests.

2 Preliminary Level 1 Tests: Where the PI < 10, the need for an active filler and the type of active filler (cement or hydrated lime) that is appropriate for the material must first be determined by carrying out “Level 1” tests on three different mixes. The same amount of bitumen (residual bitumen for bitumen emulsion treatment) is added to all three mixes, determined from the fractions passing the 4.75mm and 0.075mm sieves, as shown in Table 8.7 Suggested bitumen addition relative to key aggregate fractions.

Table 8.7 Suggested bitumen addition relative to key aggregate fractions

Percentage passing sieve size (%)		Bitumen addition (% of dry aggregate)
4.75mm	**0.075mm**	
< 50	< 5.0	2.0
	5.0 – 7.5	2.25
	7.5 – 10.0	2.5
	> 10.0	2.75
> 50	< 5.0	2.25
	5.0 – 7.5	2.5
	7.5 – 10.0	3.0
	> 10.0	3.5

The first mix contains no active filler, 1% cement is added to the second mix and 1% hydrated lime is added to the third mix. 100mm diameter specimens are manufactured, cured and tested to determine the relevant ITSDRY, ITSWET and TSR values as described in 8.7.12.

Where the TSR value for the mix with no active filler added is in excess of 60%, the mix design should be undertaken with no active filler. (This situation is usually confined to materials consisting of good quality crushed stone, often including a high proportion of reclaimed asphalt pavement (RAP) material.)

Where the TSR value of the mix with no active filler added is less than 60%, the mix with the type of active filler that produces a significantly higher TSR value (> 5%) indicates whether cement or hydrated lime should be used. If the TSR values for both active fillers are of the same order (difference < 5%) then either type of active filler is suitable.

Note. Should cement and/or hydrated lime be not readily available and tests indicate the need for an active, the use of 15% (by volume) quarry fine aggregate (5mm to 0mm) or similar material with > 10% passing the 0.075mm sieve may be used as a substitute in the mix designs.

8.7.4 Determination Of The Fluid / Density Relationship

The Optimum Fluid Content (OFC) and the Maximum Dry Density (MDD) of the stabilised material is determined using standard compaction effort.

Note: For foamed bitumen stabilisation, the OFC and MDD can be assumed to be the same as the OMC and MDD, as determined for representative samples of the untreated material. The OFC for bitumen emulsion treated material is the percentage by mass of bitumen emulsion plus additional moisture required to achieve the maximum dry density in the treated material. As described below, the OFC is determined by adding a constant percentage of bitumen emulsion whilst varying the amount of water added.

Step 1: Measure out the bitumen emulsion as a percentage by mass of the air-dried material for each of five prepared samples following the procedure described in 8.7.1. The percentage of bitumen emulsion added is normally between 2 and 3% residual bitumen (e.g. for 3% residual bitumen, add 5% of a 60% bitumen emulsion).

Step 2: The bitumen emulsion and water is added to the material and mixed until uniform immediately prior to compaction.

Step 3: Determine the OFC and MDD for the stabilised material in accordance with the modified moisture-density relationship test procedure (AASHTO T-180).

8.7.5 Preparation For Stabilising With Bitumen Emulsion (Bsm-Emulsion)

Step 1: Place the required quantity of sample into a suitable mixing container (10kg for the manufacture of 100mm diameter specimens, or 20kg for the manufacture of 150mm diameter specimens).

Step 2: Determine the dry mass of the sample using equation 1.

Step 3: Determine the required percentage of active filler (lime or cement) using equation 3.

Step 4: Determine the required percentage (by mass) of bitumen emulsion using equation 8:

$$\boxed{M_{emul} = (RB_{reqd} / PBE) \times M_{sample}} \qquad \text{[Equation 8]}$$

where:

M_{emu}	= mass of bitumen emulsion to be added	[g]
RB_{reqd}	= percentage of residual bitumen required	[% by mass]
PBE	= percentage of bitumen in emulsion	[% by mass]
M_{sample}	= dry mass of the sample	[g]

Step 5: Determine the amount of water to be added for optimum compaction purposes using equation 9:

$$\boxed{M_{water} = \{((W_{OFC} - W_{air\text{-}dry}) / 100) \times M_{sample}\} - M_{emul}} \qquad \text{[Equation 9]}$$

where:

M_{water}	= mass of water to be added	[g]
W_{OFC}	= optimum fluid content	[% by mass]
$W_{air\text{-}dry}$	= moisture content of air-dried sample	[% by mass]
M_{emul}	= mass of bitumen emulsion to be added	[g]
M_{sample}	= dry mass of the sample	[g]

Step 6: Mix the material, active filler, bitumen emulsion and water together until uniform. Immediately manufacture specimens following the relevant procedure for either 100mm or 150mm diameter specimens, as described in 8.7.7 and 8.7.9 respectively.

Repeat above steps for at least four mixes with different bitumen emulsion contents.

Recommended bitumen addition interval for different specimen sizes	
Specimen diameter (mm)	Difference in amount of bitumen added (%) to each mix
100 (Level 1)	0.25
150 (Level 2)	0.1

For 100mm diameter specimens, use the approved reference by the Engineer as a guideline for the amount of bitumen addition that the material will require for effective stabilisation.

For 150mm diameter specimens, use the results of Level 1 tests from 8.7.8 as the maximum addition of bitumen (i.e. the three other mixes will be in intervals of 0.1% less than this value).

8.7.6 Preparation For Stabilising With Foamed Bitumen (Bsm-Foam)

1 Determination of the foaming properties of the bitumen: The foaming properties of each bitumen type is characterised by:

Expansion Ratio. A measure of the viscosity of the foamed bitumen, calculated as the ratio of the maximum volume of the foam relative to the original volume of bitumen; and

Half Life. A measure of the stability of the foamed bitumen, calculated as the time taken in seconds for the foam to collapse to half of its maximum volume.

The objective is to determine the temperature and percentage of water addition that is required to produce the best foam properties (maximum expansion ratio and half-life) for a particular source of bitumen. This is achieved at three different bitumen temperatures (not exceeding 195°C) with the following procedure:

Step 1: Heat the bitumen in the kettle of the Wirtgen WLB10 S laboratory unit with the pump circulating the bitumen through the system until the required temperature is achieved (normally starting with160°C). Maintain the required temperature for at least 5 minutes prior to commencing with testing.

Step 2: Calibrate the discharge rate of the bitumen and set the timer on the Wirtgen WLB10 S to discharge 500g of bitumen ($Q_{bitumen}$).

Step 3: Set the water flow-meter to achieve the required water injection rate (normally starting with 2% by mass of the bitumen).

Step 4: Discharge foamed bitumen into a preheated (± 75°C) steel drum for a calculated spray time for 500g of bitumen. Immediately after the foam discharge stops, start a stopwatch.

Step 5: Using the dipstick supplied with the Wirtgen WLB10 S (which is calibrated for a steel drum of 275mm in diameter and 500g of bitumen) measure the maximum height the foamed bitumen achieves in the drum. This is recorded as the maximum volume.

Step 6: Use the stopwatch to measure the time in seconds that the foam takes to dissipate to half of its maximum volume. This is recorded as the foamed bitumen's half-life.

Step 7: Repeat the above procedure three times or until similar readings are achieved.

Step 8: Repeat steps 3 to 7 for a range of at least three water injection rates. Typically, values of 2%, 3% and 4% by mass of bitumen are used.

Step 9: Plot a graph of the expansion ratio versus half-life at the different water injection rates on the same set of axes (see the example in graph below). The optimum water addition is chosen as an average of the two water contents required to meet these minimum criteria.

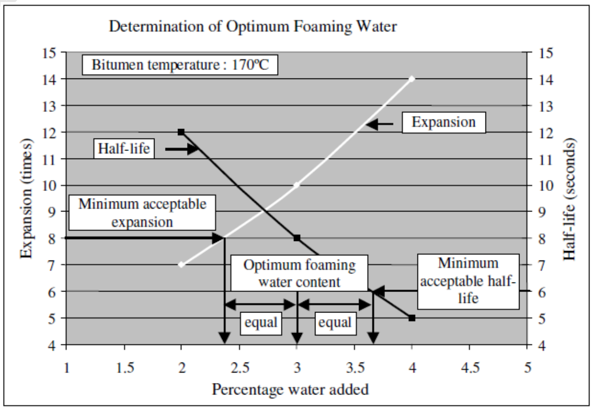
Repeat Step 1 to 9 for two other bitumen temperatures (normally 170°C and 180°C).

The temperature and optimum water addition that produces the best foam is then used in the mix design procedure described below.

Note: The absolute minimum foaming properties that are acceptable for effective stabilisation (material temperature of 25°C) are:

- Expansion ratio: 10 times
- Half-life: 12 seconds

2 If the minimum requirements cannot be met, the bitumen should be rejected as unsuitable for use.



3 Prepare the material for foamed bitumen treatment as follows:

Step 1: Place 20 to 25kg of sample prepared as described in 8.7.1 into the Wirtgen WLM30 pugmill mixer.

Step 2: Determine the dry mass of the sample using equation 2.

Step 3: Determine the required percentage of active filler (lime or cement) using equation 3.

Step 4: Determine the percentage water to be added for optimum mixing moisture content as calculated using equation 10. The amount of water to be added to the sample is determined using equation 11.

$$\boxed{W_{add} = 0.75W_{OMC} - W_{air\text{-}dry}} \qquad \text{[Equation 10]}$$

$$\boxed{M_{water} = (W_{add} / 100) \times (M_{sample} + M_{cement})} \qquad \text{[Equation 11]}$$

where:

W_{add}	= water to be added to sample	[% by mass]
W_{OMC}	= optimum moisture content	[% by mass]
$W_{air\text{-}dry}$	= moisture content of air-dried sample	[% by mass]
M_{water}	= mass of water to be added	[g]
M_{sample}	= dry mass of the sample	[g]
M_{cement}	= mass of lime or cement to be added	[g]

Step 5: Mix the material, active filler and water in the mixer until uniform.

Note: Inspect the sample after mixing to ensure that the mixed material is not packed against the sides of the mixer. If this situation occurs, mix a new sample at a lower moisture content. Check to see that the material mixes easily and remains in a “fluffed” state. If any dust is observed at the end of the mixing process, add small amounts of water and remix until a "fluffed" state is achieved with no dust.

Step 6: Determine the amount of foamed bitumen to be added using equation 12:

$$\boxed{M_{bitumen} = (B_{add} / 100) \times (M_{sample} + M_{cement})} \qquad \text{[Equation 12]}$$

where:

$M_{bitumen}$	= mass of foamed bitumen to be added	[g]
B_{add}	= foamed bitumen content	[% by mass]
M_{sample}	= dry mass of the sample	[g]
M_{cement}	= mass of lime or cement to be added	[g]

Step 7: Determine the timer setting on the Wirtgen WLB10 S using equation 13:

$$\boxed{T = M_{bitumen} / Q_{bitumen}} \qquad \text{[Equation 13]}$$

where:

T	= time to be set on WLB10 S timer	[s]
$M_{bitumen}$	= mass of foamed bitumen to be added	[g]
$Q_{bitumen}$	= bitumen flow rate for the WLB10 S	[g/s]

Step 8: Position the mixer adjacent to the foaming unit so that the foamed bitumen can be discharged directly into the mixing chamber.

Step 9: Start the mixer and allow it to mix for at least 10 seconds before discharging the required mass of foamed bitumen into the mixing chamber. After the foamed bitumen has discharged into the mixer, continue mixing for a further 30 seconds or until uniformly mixed.

Step 10: Determine the amount of water required to bring the sample to the OMC using equation 14.

M_{plus}	$= (W_{OMC} - W_{sample}) / 100 \times (M_{sample} + M_{cement})$	[Equation 14]

where:

M_{plus}	= mass of water to be added	[g]
W_{OMC}	= optimum moisture content	[% by mass]
W_{sample}	= moisture content of prepared sample	[% by mass]
M_{sample}	= dry mass of the sample	[g]
M_{cement}	= mass of lime or cement added	[g]

Note: This moisture adjustment is to be carried out when 150mm diameter specimens are to be manufactured. Where 100mm diameter specimens are to be manufactured, the moisture content of the material is to be adjusted to 90% of OMC.

Step 11: Add the additional water and mix until uniform.

Step 12: Transfer the foamed bitumen treated material into a container and immediately seal the container to retain moisture. To minimise moisture loss from the prepared sample, manufacture the specimens as soon as possible following the relevant procedure for either 100mm or 150mm diameter specimens, as described in 8.7.7 and 8.7.9 respectively.

Repeat the above steps for at least four mixes with different foamed bitumen contents.

Recommended bitumen addition interval for different specimen sizes	
Specimen diameter (mm)	Difference in amount of bitumen added (%) to each mix
100 (Level 1)	0.25
150 (Level 2)	0.1

For 100mm diameter specimens, use the approved reference by the Engineer as a guideline for the amount of bitumen addition that the material will require for effective stabilisation.

For 150mm diameter specimens, use the results of Level 1 tests in 8.7.8 as the maximum addition of bitumen (i.e. the three other mixes will be in intervals of 0.1% less than this value).

8.7.7 Manufacture Of 100mm Diameter Specimens

1 For Level 1 mix designs ITS tests are carried out on 100mm diameter specimens. Six specimens are manufactured for each sample at the different bitumen contents. The two primary objectives of undertaking the Level 1 mix design are to determine:

- the optimum bitumen content for the BSM, and
- the need for an active filler.

2 Specimens may be made using either Marshall or vibratory compaction methods.

3 Marshall Compaction shall be carried out as follows:

Step 1: Prepare the Marshall mould and hammer by cleaning the mould, collar, base-plate and face of the compaction hammer.

Note: the compaction equipment must not be heated but kept at ambient temperature.

Step 2: Weigh sufficient material to achieve a compacted height of 63.5mm ± 1.5mm (usually 1150g is adequate). Spade the mixture with a spatula 15 times around the perimeter and 10 times on the surface, leaving the surface slightly rounded.

Step 3: Compact the mixture by applying 75 blows with the compaction hammer. Care must be taken to ensure the continuous free fall of the hammer. Remove the mould and collar from the pedestal, invert the specimen (turn over). Replace it and press down firmly to ensure that it is secure on the base plate. Compact the other face of the specimen with a further 75 blows.

Step 4: Take approximately 1kg representative samples after compaction of the second and fifth specimen and dry a constant mass (at 105 to 110°C). Determine the moulding moisture using equation 15:

$$W_{mould} = (M_{moist} – M_{dry}) / M_{dry} \times 100 \qquad \text{[Equation 15]}$$

where: W_{mould} = moulding moisture content [% by mass]

M_{moist} = mass of moist material [g]

M_{dry} = mass of dry material [g]

Step 5: After compaction, remove the mould from the base-plate and extrude the specimen by means of an extrusion jack. Measure the height of the specimen and adjust the amount material if the height is not within the required limits.

Note: With certain materials lacking cohesion, it may be necessary to leave the specimen in the mould for 24 hours, allowing sufficient strength to develop before extracting.

4 Vibratory Compaction shall be carried out as follows:

Step 1: Fix the mounting head and appropriate tamping foot to the vibratory hammer and fit hammer onto guide rods. Place 5kg surcharge weight onto mounting head (total mass of assembly [Hammer + foot + surcharge] = 25kg) and fasten tightly. Using the pulley system raise the vibratory hammer to an adequate height that will allow operator to work safely beneath the vibratory hammer and lock in position.

Step 2: Clean the mould, collar and base plate. Fix the mould to the base of the compaction frame.

Note: the compaction equipment must not be heated but kept at ambient temperature.

Step 3: Weigh sufficient material to achieve a compacted height of 63.5mm ± 1.5mm (usually 1150g is adequate). Spade the mixture with a spatula 15 times around the perimeter and 10 times on the surface, leaving the surface slightly rounded.

Step 4: Lower the vibratory hammer into the mould, checking that the vibratory hammer is perpendicular to the base of the mould. Apply 15 seconds of vibratory compaction to the sample in the mould.

Step 5: Raise hammer to the safe position, remove mould, invert mould and secure to base.

Step 6: Lower vibratory hammer to surface of material in mould and ensure vibratory hammer rests freely on sample and is perpendicular to the base of the mould. Apply further 15 seconds of vibratory compaction to sample in the mould.

Step 7: Take approximately1kg representative samples after compaction of the second and fifth specimen and dry to constant mass (at 105 to 110 oC). Determine the moulding moisture using equation 15.

Step 8: After compaction, remove the mould from the base-plate and extrude the specimen carefully by means of an extrusion jack.

Note: With certain materials lacking cohesion, it may be necessary to leave the specimen in the mould for 24 hours, allowing sufficient strength to develop before extracting.

5 Curing procedure: Compacted specimens shall be cured by placing the specimens on a steel mesh and curing in a forced-draft oven until a constant mass is obtained (normally 72 hours at 40°C). Remove from oven after curing and allow to cool to ambient temperature.

6 When specimens have cooled to ambient temperature determine the bulk density for each specimen:

Step 1. Determine the mass (M_{briq}).

Step 2. Measure the height at four evenly-spaced places around the circumference and calculate the average height (h).

Step 3. Measure the diameter (d).

Step 4. Calculate the bulk density using equation 16:

	$BD = (4 \times M_{briq}) / (\square\square \times d^2 \times h) \times 1000$	[Equation 16]
where:	BD = moulding moisture content	[kg/m³]
	M_{briq} = mass of specimen	[g]
	h = average height of specimen	[cm]
	d = diameter of specimen	[cm]

Note: Exclude from further testing any specimen whose bulk density differs from the mean bulk density of the batch by more than 50 kg/m³.

7 The bulk density may alternatively be determined by using the "weigh-in air / weigh-in water" method for those specimens designated for soaked testing.

8.7.8 Determination Of The Strength Of 100mm Diameter Specimens

1 The 100mm diameter specimens are tested for indirect tensile strength under dry and soaked conditions to determine the ITS_{DRY} and the ITS_{WET} values. To prevent moisture loss, specimens should be tested as soon as they are prepared. The results are used to indicate the optimum bitumen content and the need for active filler. In addition, these test results are used as a guide for the classification of the BSM.

8.7.9 Manufacture Of 150mm Diameter Specimens

1 Level 2 mix designs ITS tests are carried out on specimens that are 150mm diameter and 95mm in height. These specimens are cured to simulate the equilibrium moisture content achieved in the field. This method of curing provides more realistic values for classification of the bitumen stabilised materials.

2 The procedures described allow for the manufacture of four 150mm diameter specimens to a compacted height of 95mm. If additional specimens are required, the sample quantity shall be increased.

3 Specimens may be made using either Modified AASHTO (T-180) or vibratory compaction methods.

4 MODIFIED AASHTO (T-180) compaction shall be carried out as follows:

Step 1: Prepare and treat at least 24kg of sample for each selected bitumen content.

Step 2: Where required, add sufficient moisture to bring sample to optimum compaction moisture content and mix until uniform. Immediately after mixing, place material in an air-tight container.

Step 3: Take approximately 1kg representative samples after compaction of the first and third specimen and dry to a constant mass (at 105 to 110°C). Determine the moulding moisture using equation 15.

Step 4: Compact at least 4 specimens using a 150mm diameter split-mould, applying modified AASHTO (T-180) compaction effort (4 layers approximately 25mm thick, 56 blows per layer using a 4.536kg hammer with a 457mm drop).

Step 5: Carefully trim excess material from specimens, as specified in the AASHTO T180 test method.

Step 6: Carefully remove the specimen from the spilt-mould and place on a steel mesh.

Note: With certain materials lacking cohesion, it may be necessary to leave the specimen in the mould for 24 hours, allowing sufficient strength to develop before extracting.

5 Vibratory compaction shall be carried out as follows:

Step 1: Fix the mounting head and appropriate tamping foot (150mm diameter) to the vibratory hammer and fit hammer onto guide rods. Place 10kg surcharge weight onto mounting head (total mass of assembly [hammer + foot + surcharge] = 30kg) and fasten tightly. Using the pulley system raise the vibratory to an adequate height that will allow operator to work safely beneath the vibratory hammer and lock in position.

Step 2: Clean the 150mm diameter spilt mould, collar and base plate. Fix the mould to the base of the compaction frame.

Step 3: Weigh sufficient material to achieve a compacted height of 47.5mm ± 1.5mm. An approximation of the quantity required can be calculated using equation 17. Spade the mixture with a spatula 15 times around the perimeter and 10 times on the surface, leaving the surface slightly rounded.

$$\boxed{M_{mix} = (\pi \times d^2 \times h / 4) \times (MDD) / 1000} \quad \text{[Equation 17]}$$

where:	M_{mix}	= Mass of mixed material	[g]
	d	= diameter of specimen	[cm]
	h	= required height of layer (4.75cm for ITS)	[cm]
	MDD	= maximum dry density	[kg/m³]

Step 4: Lower the vibratory hammer into the mould, checking that the vibratory hammer is perpendicular to the base of the mould.

Apply 25 seconds of vibration for bitumen emulsion stabilised materials
35 seconds of vibration for foamed bitumen stabilised materials.

Step 5: Raise hammer to safe position.

Step 6: For the second layer, if necessary, adjust for the amount of material to be added such that the final compacted thickness is 95mm. Using a chisel, scarify the entire surface area of the top of the compacted layer to a maximum depth of 10mm. Add the required amount of material and ensure the material is as level as possible.

Step 7: Lower the vibratory hammer into the mould, checking that the vibratory hammer is perpendicular to the base of the mould.

Apply 25 seconds of vibration for bitumen emulsion stabilised materials
35 seconds of vibration for foamed bitumen stabilised materials.

Step 8: Raise hammer to safe position. Remove mould from base plate and open the split mould to remove the specimen.

Step 9: Take approximately 1kg representative samples after compaction of the first and third specimens and dry to a constant mass. Determine the moulding moisture using equation 15.

Note: With certain materials lacking cohesion, it may be necessary to leave the specimen in the mould for 24 hours, allowing sufficient strength to develop before extracting.

6 Curing procedure: Place the specimens in an oven at 40°C for 24 hours (or until the moisture content has reduced to at least 50% of OMC). Thereafter place each specimen in a sealed plastic bag (at least twice the volume of the specimen) and place in an oven at 40°C for a further 48 hours.

7 Remove specimens from the oven after 48 hours and remove the respective plastic bags, ensuring that any moisture in the bags does not come into contact with the specimen. Allow to cool to ambient temperature.

8 When specimens have cooled to ambient temperature determine the bulk density for each specimen:

Step 1: Determine the mass (M_{briq}).

Step 2: Measure the height at four evenly-spaced places around the circumference and calculate the average height (h).

Step 3: Measure the diameter (d).

Step 4: Calculate the bulk density using equation 16:

Note: Exclude from further testing any specimen whose bulk density differs from the mean bulk density of the batch by more than 50 kg/m³.

9 The bulk density may alternatively be determined by using the "weigh-in air / weigh-in water" method for those specimens designated for soaked testing.

8.7.10 Determination Of The Strength Of 150mm Diameter Specimens

1 The 150mm diameter specimens are tested for indirect tensile strength under equilibrium moisture content and soaked conditions to determine the ITS_{EQUIL} and the ITS_{SOAK} values. To prevent moisture loss, specimens should be tested as soon as they are prepared. The results are used to refine the optimum bitumen content and amount of active filler that was initially determined from the 100mm diameter specimens. In addition, these test results are used to classify the BSM with additional confidence.

2 Additional ITS tests should be carried out using 150mm diameter specimens to determine the sensitivity of the mix to minor variations in both the amount of added bitumen and active filler.

If, for example, Level 2 test results indicated an optimum bitumen addition (OBA) of 2.2% with an active filler addition of 1%, then the following further tests should be undertaken:

Step 1: To check the sensitivity of the bitumen addition, follow the Level 2 procedure in 8.7.9 to manufacture, cure and test the following mixes:

Added bitumen (%)	Active filler (%)
2.2 (Level 2 OBA)	1
2.1	1
2.0	1
1.9	1

ITS test results will allow the optimal bitumen addition (OBA) to be refined.

Step 2: To check the sensitivity of the amount of active filler added, follow the Level 2 procedure in 8.7.9 to manufacture, cure and test the following mixes:

Added bitumen (%)	Active filler (%)
OBA	0.9
OBA	0.7
OBA	0.5

ITS test results will indicate the minimum amount of active filler required in the mix.

8.7.11 Strength Test Procedures

1 The Unconfined Compressive Strength (UCS) of a cement stabilised material is determined by measuring the ultimate load to failure of a 127mm high and 150mm diameter specimen that is subjected to a constant loading rate of 140kPa/s (153kN/min), as follows:

Step 1: Place the specimen on its flat side between the plates of the compression testing machine. Position the specimen such that it is centred on the loading plates.

Step 2: Apply the load to the specimen, without shock, at a rate of advance of 140kPa/s until the maximum load is reached. Record the maximum load P in kN, accurate to 0.1kN.

Step 3: Immediately after testing a specimen, break the specimen up and take a sample of approximately 1000g to determine the moisture content (W_{break}). This moisture content is used to determine the dry density of the material using equation 21.

Step 4: Calculate the UCS for each specimen to the nearest 1 kPa according to equation 18.

$$UCS = (4 \times P) / (\pi \times d^2) \times 10000 \qquad \text{[Equation 18]}$$

where:	UCS	= unconfined compressive strength	[kPa]
	P	= maximum load to failure	[kN]
	d	= diameter of specimen	[cm]

2 Indirect Tensile Strength (ITS) of a stabilised material is determined by measuring the ultimate load to failure of a specimen (both 100mm and 150mm diameter specimens) that is subjected to a constant deformation rate of 50.8 mm/minute on its diametrical axis, as follows:

Step 1: Place the specimen onto the respective ITS jig for the 100mm and 150mm diameter specimens. Position the sample such that the loading strips are parallel and centred on the vertical diametrical plane.

Step 2: Place the load transfer plate on the top bearing strip and position the jig assembly centrally under the loading ram of the compression testing device.

Step 3: Apply the load to the specimen, without shock, at a rate of advance of 50.8 mm per minute until the maximum load is reached. Record the maximum load P in kN, accurate to 0.1kN.

Step 4: Immediately after testing a specimen, break it up and take a sample of approximately 1000g to determine the moisture content (W_{break}). This moisture content is used in equation 21 to determine the dry density of the material in the specimen.

Step 5: Immediately after testing a specimen, measure the temperature of the broken face using a digital thermometer. Record the temperature, accurate to 0.1°C.

Step 6: Calculate the ITS for each specimen to the nearest 1 kPa using equation 19:

$$ITS = (2 \times P) / (\pi \times h \times d) \times 10000 \qquad \text{[Equation 19]}$$

where:	ITS	= indirect tensile strength	[kPa]
	P	= maximum applied load	[kN]
	h	= average height of the specimen	[cm]
	d	= diameter of specimen	[cm]

Step 7: To determine the soaked ITS, place the specimens under water at 25°C ± 1°C for 24 hours. Remove specimen from water, surface dry and repeat steps 1 to 5.

Record the results and determine the following as required:

100mm Ø specimens:	ITS_{DRY}	= average of 3 specimens cured to constant mass
	ITS_{WET}	= average of 3 ITS_{DRY} specimens soaked for 24 hours.
150mm Ø specimens:	ITS_{EQUIL}	= average of 2 specimens cured at equilibrium moisture
	ITS_{SOAK}	= average of 2 ITS_{EQUIL} specimens soaked for 24 hours

Step 8: Determine the Tensile Strength Retained (TSR). The TSR is the relationship between the average soaked and unsoaked ITS values for a specific batch of specimens, expressed as a percentage using equation 20:

$$TSR = \text{Average soaked ITS} / \text{Average unsoaked ITS} \times 100 \qquad \text{[Equation 20]}$$

Step 9: Using the moisture content determined in each test described above, calculate the dry density using equation 21:

$$DD = (M_{briq} / Vol) \times (100 / (W_{break} + 100) \times 1000 \qquad \text{[Equation 21]}$$

where:	DD	= dry density	[kg/m³]
	M_{briq}	= mass of cured specimen	[g]
	Vol	= volume of specimen	[cm³]
	W_{break}	= moisture content of the specimen	[%]

Report the results using the template sheet shown in 8.7.16 as a guide.

8.7.12 Selection Of The Amount Of Bitumen To Be Added For Bsm

1 Plot the results of the respective soaked and unsoaked ITS test results against the relevant bitumen content that was added. The added bitumen content that best meets the desired BSM classification is selected as the optimum amount of bitumen to be added, as shown in the example below (Figure 7.3 Determination of BSM class and added bitumenFigure 7.3 **Determination of BSM class and added**)

Interpretation of ITS Tests					
Test	Specimen Ø	BSM1	BSM2	BSM3	Purpose
ITS_{DRY}	100 mm	> 225	175 to 225	125 to 175	Indicates the optimum bitumen content
ITS_{WET}	100 mm	> 100	75 to 100	50 to 75	Indicates need for active filler.
TSR	100 mm	N/A	N/A	N/A	Indicates problem material where TSR < 50 and ITS_{DRY} > 400 kPa
ITS_{EQUIL}	150 mm	> 175	135 to 175	95 to 135	Used for classifying the BSM and for optimising the bitumen and active filler content.
ITS_{SOAK}	150 mm	> 150	100 to 150	60 to 100	Check value on ITS_{WET}

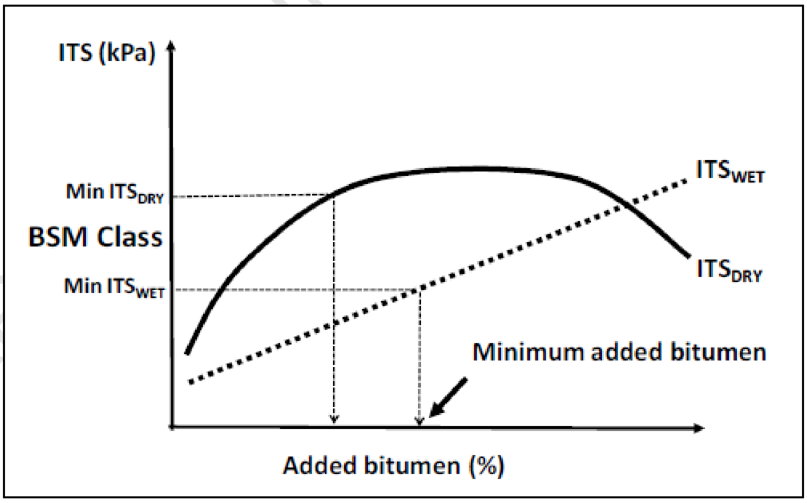


Figure 7.3 Determination of BSM class and added bitumen

2 The TSR value is useful for identifying problem materials. If the TSR is less than 50%, it is recommended that active filler is used. If such treatment does not increase the ITS_{WET} value with a maximum application of 1% lime or cement, then the nature of the material being stabilised should be investigated:

3 Where the material is granular, a TSR value below 50% combined with an ITS_{DRY} value in excess of 400 kPa suggests contamination (normally attributed to clay or deleterious materials). In this situation, it is suggested that material is pre-treated with hydrated lime and the Level 1 tests repeated.

4 Where the material is 100% RAP, a TSR value below 50% combined with an ITS_{DRY} value in excess of 500 kPa indicates that the treated material is partly stabilised and partly continuously bound (cold mix). In this situation, the material probably requires blending with crusher dust to ensure that the stabilisation process dominates the mix.

5 Level 2 testing using 150mm diameter specimens should be undertaken to verify the relevant ITS values for BSM classification.

8.7.13 Determination Of The Shear Properties Of Bsm

1 Triaxial testing is carried out to determine the cohesion and angle of internal friction of BSM specimens. Testing is normally carried out at the bitumen content selected from the results of ITS tests carried out on 150mm diameter specimens (see above). Additional tests at different bitumen contents can always be carried out to investigate the sensitivity of the shear properties.

2 Specimens for triaxial testing shall be produced as follows:

Step 1: Prepare and treat 50kg of sample (adequate for manufacture of 4 specimens) with either bitumen emulsion or foamed bitumen at the optimum bitumen content. Include any active filler requirements.

Step 2: Where required, add moisture to bring sample to optimum compaction moisture content and mix until uniform. Place the mixed material in an air-tight container.

Step 3: Take approximately1 kg representative samples of each specimen to determine the moulding moisture using equation 15.

Step 4: Compact at least four (4) specimens using a 150mm diameter split mould with an effective internal height of 300mm, using equation 17 to calculate the approximate quantity for each layer.

3 Specimens may be made using either Modified AASHTO (T-180) or vibratory compaction methods.

4 Compaction using modified AASHTO (T180) shall be in 12 layers, each approximately 25mm thick, compacted with 56 blows using a 4.536kg hammer with a 457mm drop. Carefully trim any excess material from the specimen.

5 Compaction using vibratory compaction shall be in 5 layers, each approximately 60mm thick, using a hammer assembly of 30kg total mass. Each layer is compacted for:

- 25 seconds for BSM-emulsion, or
- 35 seconds for BSM-foam

The height of each compacted layer is measured and, if necessary, an adjustment made for the quantity of material used for the next layer to achieve the required height for the respective layers.

6 The specimens shall be cured using the same procedure for 150mm diameter specimens.

8.7.14 Determination Of Triaxial Shear Parameters Using Simple Triaxial Test

1 This method describes the determination of triaxial shear parameters (cohesion and internal angle of friction) of Bitumen Stabilised Materials by measuring the resistance to failure (monotonic) of a cylindrical 150 mm diameter and 300 ± 2 mm height specimen prepared according to Vibratory Hammer Compaction Procedure.

2 Apparatus:

(a) Triaxial Cell comprising a galvanised steel casing 5 mm thick comprising a ring handle and simple mechanical clamps top and bottom, a base with bottom platen for sitting specimen, top disk and a latex tube at least 320 mm in height.

(b) Testing System comprising a Material Testing System (MTS) or its equivalent system must at least comprise of an actuator, reaction frame, a control panel and data acquisition system. The system must be capable of providing ramp loads with minimum loading capacity of 100 kN and a minimum stroke of 40 mm. The actuator should be operated by a servo-controlled hydraulic pressure system with a closed loop feedback system that is capable of both displacement and load controlled testing if required.

(c) Measuring devices should include but not limited to a load cell (100 kN Capacity) for measuring load, an actuator displacement transducer (> 40 mm stroke) for measuring displacement (deformation) and pressure regulator, gauges, and valves for lateral pressure.

(d) Additionally air compressor, loading ram and silicon oil or grease.

3 The specimen must be prepared and cured according to Vibratory Hammer Compaction Procedure as stated previously.

4 The triaxial testing of the specimens must be planned to take place within 48 – 72 hours after completion of the curing procedure. This delay must be kept as constant as possible. The following steps describe the procedure taken to assemble specimen in the simple triaxial cell and the cell in the loading frame:

(a) Place the specimens, casing with tube, top disk and base plate in a climate chamber and condition them overnight at 25ºC.

(b) Lightly grease the sides of the top disk and base plate to reduce friction as much as possible.

(c) Place the specimen in the middle of the base plate.

(d) Carefully introduce the casing, comprising the tube, around the specimen. Take care not to damage the edges of the specimen during this procedure.

(e) Clamp the casing in position on to the base plate using simple mechanical clamps on the casing.

(f) Put the top disk on top of the specimen.

(g) Place the cell in the hydraulic loading frame; adjust actuator position until visual contact is made with the loading ram.

(h) Connect the air supply to the cell; open the regulator and valve on the cell pressure port until the cell pressure is stable at the desired level.

(i) Set monotonic test parameters on the MTS controller including displacement rate of strain (2.1%), full-scale for the loading (10.0V = 98.1 kN) and half-scale for the displacement (10.0V = 40mm), and run the test

5 Monotonic Triaxial Test: Select four specimens of comparable density, moisture content and conditioned at 25°C. Assemble the specimen in the triaxial cell according to 4 ensuring the tube is air tight.

(a) Operate the testing system in displacement control mode. Ensure that there is sufficient space between the actuator and the reaction frame to accommodate the triaxial cell. Place the triaxial cell in the hydraulic loading frame.

(b) Adjust the actuator position until visual contact is made with the loading ram. Monitor the load cell reading to prevent loading of the specimen during this process. Connect the air supply to the cell pressure port. Open the valve on the cell pressure port and open the regulator until the cell pressure is stable at the desired level. The cell pressures for a series of monotonic tests are 0 kPa, 50kPa, 100 kPa and 200 kPa.

(c) Test the first specimen without confinement pressure (0 kPa). Begin the test by compressing the specimen at a constant rate of displacement of 2.1%. Record the load versus displacement during the test with a minimum sampling rate of 10 Hz, as well as the cell pressure, temperature and specimen identifier.

(d) Stop the test and the recording when the total displacement exceeds 18 mm (6% strain) or when the specimen bulges excessively before the end displacement is reached.

(e) Repeat this procedure for other three specimens until all specimens have been tested at the four levels of confinement pressures.

6 Remove the specimens after completion of test after completion of a test. Hold the actuator to its current position, close the valve on the cell pressure port and release the cell pressure by disconnecting the pressure supply tube to the cell (if possible speed up the pressure release by applying suction). Return the actuator to a position whereby the cell can easily be removed from the loading frame. Remove the top disk. Clean the top disk and wipe off any grease. Unclamp the casing and lift the casing with tube from the cell base. Clean the tube from possible remains of the deformed specimen (it is not necessary to remove the tube from the casing). Remove the tested specimen from the base plate. Place it in the plastic bag and seal. Clean the base plate and wipe off any grease.

7 When all the specimens have been tested, remove the tested specimens one by one from the plastic bags. Break the tested specimens up and sample between 500 and 1000 gr. of material from the middle of the specimen. Use this sample to determine the moisture content of each specimen.

8 Calculations:

(a) Determine the applied failure load $P_{a,f}$ for each specimen tested. The applied failure load is defined as the maximum applied load during the test. Calculate the applied failure stress $\sigma_{a,f}$:

$$\sigma_{a,f} = \frac{P_{a,f}}{A} \cdot 10^{-3}$$

where:

$\sigma_{a,f}$	= applied failure stress	[kPa]
$P_{a,f}$	= applied failure load	[N]
A	= end area of a cylindrical specimen at beginning of test	[m²] or **mm² ??**

(b) Calculate the major principle stress at failure $\sigma_{1,f}$ for each tested specimen:

$$\sigma_{1,f} = \sigma_{a,f} + \sigma_{dw}$$

where:

$\sigma_{1,f}$	= major principle stress at failure	[kPa]
$\sigma_{a,f}$	= applied failure stress	[kPa]
σ_{dw}	= pressure resulting from dead weight of top disk and loading ram	[kPa]

(c) The relationship between $\sigma_{1,f}$ and confinement stress (σ_3)is determined by:

$$\boxed{\sigma_{1,f} = A.\sigma_3+B}$$

where:

$$A = \frac{1+\sin\varphi}{1-\sin\varphi}$$

$$B = \frac{2\cdot C\cdot\cos\varphi}{1-\sin\varphi}$$

Values of A and B can be determined by performing a linear regression analysis on the four combinations of $\sigma_{1,f}$ and σ_3 per mix.

(d) Values of φ [°] and C [kPa] can be calculated as follows:

where:

$$\varphi = \sin^{-1}\left(\frac{A-1}{A+1}\right)$$

$$C = \frac{B(1-\sin\varphi)}{2\cdot\cos\varphi}$$

9 Report the following in the table format as illustrated in

10 Table 8. 8 Format Report for Simple Triaxial Test below:

(a) Specimen number or identifier;

(b) Confinement pressure (σ_3);

(c) Applied stress at failure ($\sigma_{a,f}$);

(d) Major principal stress at failure ($\sigma_{1,f}$);

(e) Cohesion, C [kPa];

(f) Angle of internal friction, φ [°]; and

(g) Coefficient of variance, R^2

11 Plot the Mohr Circles and the Mohr-Coulomb failure envelope as shown in Figure 7.4 Example of Mohr Circle Plot, noting:

(a) The centre of Mohr circle must be on the abscissa and is given by (σ1,f + σ3)/2;

(b) The radius of such circle is ($\sigma_{1,f}$ - σ_3)/2;

(c) Angle of internal friction is the angle of the Mohr-Coulomb failure envelope (failure line);

(d) The failure line intersects with ordinate at the cohesion value.

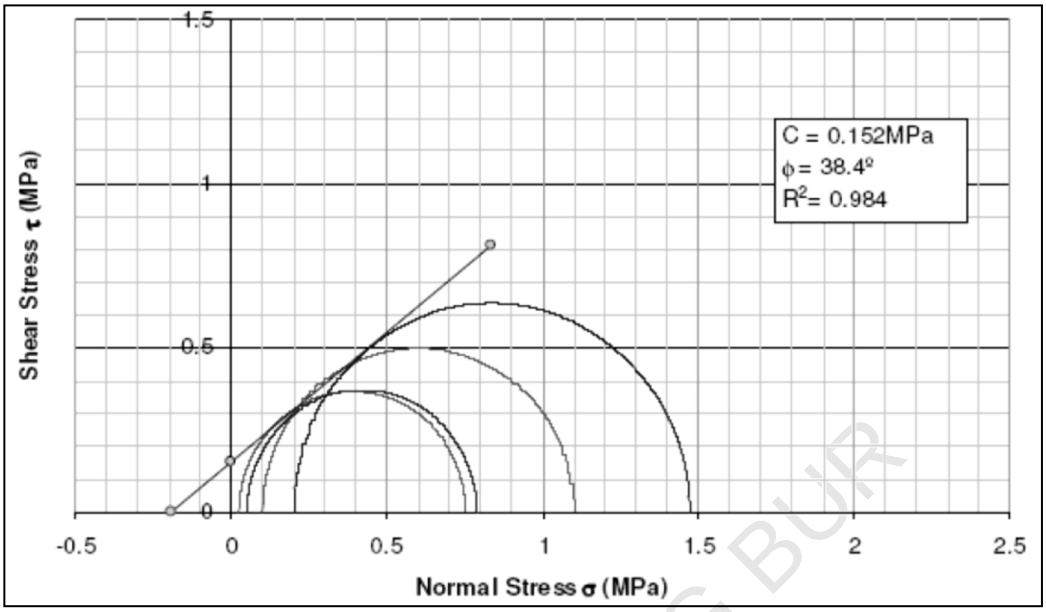
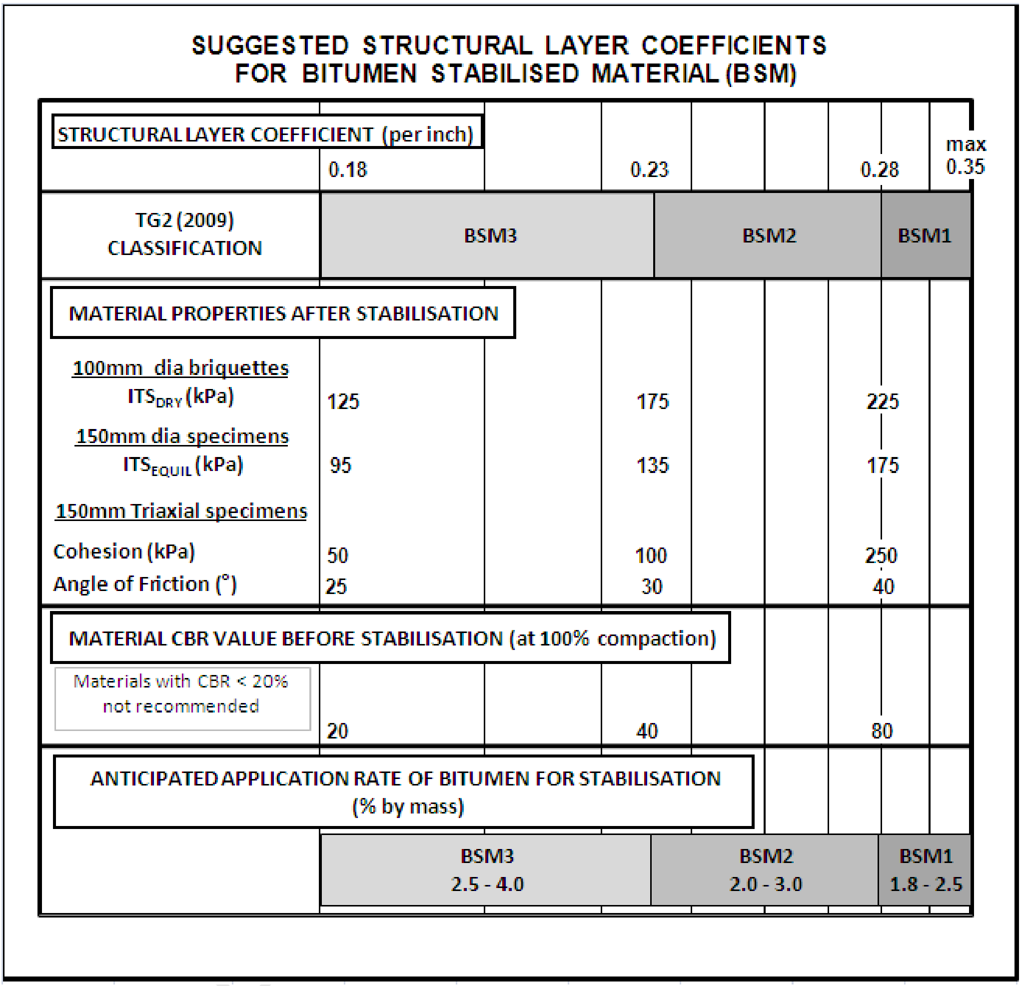


Figure 7.4 Example of Mohr Circle Plot

Table 8. 8 Format Report for Simple Triaxial Test

Specimen No.	Confining Pressure, σ_3 [kPa]	Applied Stress at Failure $\sigma_{a,f}$ [kPa]	Principle stress at Failure $\sigma_{1,f}$ [kPa]	Cohesion [kPa]	Internal Friction Angle [°]	Correlation Coefficient [R^2]

8.7.15 Using Laboratory Test Results For Estimating Structural Layer Coefficients



Notes:
The minimum Retained Tensile Strength (%) requirement should be 75%.
The following minimum compaction requirements are recommended:

Material Type	BSM3	BSM2	BSM1
Percentage of Modified AASHTO compaction T180	> 97%	> 100%	> 102%

- The material passing the 0.075mm sieve to be >2% for BSM-emulsion and >4% for BSM-foam.
- The maximum recommended addition of cement (active filler) is 1% by mass.
- Materials with a Plasticity Index > 10 to be pre-treated with hydrated lime to reduce the PI to <6.

8.7.16 Proforma Report Sheet For Its Testing

The report sheet shown below may be used for all ITS tests, regardless of whether the tests were carried out for mix design purposes or for testing field samples.

INDIRECT TENSILE STRENGTH - REPORT SHEET

Project descrition			
Location of Sample		Date	
Sample Description:		Sample No.	
Maximum dry density (MDD)	kg/m3	Optimum moisture content (OMC)	%

Moisture content of sample			From field		At moulding
Pan Number					
Mass wet sample + pan	m1	g		g	
Mass dry sample + pan	m2	g		g	
Mass pan	mp	g		g	
Mass moisture	m1 - m2 = Mm	g		g	
Mass dry sample	m2 - Mp = Md	g		g	
Moisture content	Mm/Md x 100 = Mc	%		%	
Percent water to be added to field sample:	Pa = 0.75(OMC - Mc)	%			
Water added to 10 000g field sample:	(10 000/(100+Mc) x Pa) =	g			

BRIQUETTE MANUFACTURE, CURING AND TESTING									
Briquette number									
Date manufactured									
Date placed in oven									
Date tested									
Average height	h	cm							
Diameter	d	cm							
Mass after curing	M	g							
Bulk density	BD	kg/m³							
Average Bulk Density		kg/m³							
Strength of Briquettes			Dry			Soaked			
Temperature at centre of broken briquette		°C							
Maximum load applied		kN							
Indirect Tensile Strength (ITS) = 2 x Load / (3.1416 x d x h)		kPa							
Average ITS		kPa							
Tensile strength ratio (TSR)		%							

DRY DENSITY OF BRIQUETTES WHEN TESTED									
Briquette number									
Pan number									
Mass wet sample + pan	m1	g							
Mass dry sample + pan	m2	g							
Mass pan	mp	g							
Mass moisture	m1 - m2 = Mm	g							
Mass dry sample	m2 - Mp = Md	g							
Moisture content	Mm/Md x 100 = Mc	%							
Dry Density	DD = BD x 100/(Mc+100)	kg/m³							

8.7.17 Laboratory Equipment Requirements

1 Laboratory Equipment For Soils Testing

Description		Quantity
Sample Preparation		
Riffler (25mm openings)		1
Riffler pans		3
Sieves 450mm diameter		
19.0 mm		1
13.2 mm		1
4.75 mm		1
Air-tight containers (Plastic buckets with lids)	20 litre	20
Mechanical Balance (or use balance in Modified Proctor section)	50kg	1
Sieve Analysis		
Sieves 200mm diameter		
50.0 mm		1
37.5 mm		1
25.0 mm		1
19.0 mm		1
12.5 mm		1
9.5 mm		1
4.75 mm		1
2.36 mm		1
1.18 mm		1
0.60 mm		1
0.30 mm		1
0.15 mm		1
0.075 mm		3
Pan		1
Lid		1
Balance (Electronic)	15kg ± 0.1g	1
Force-draft Drying Ovens	240 litre	1
Pans	300mm	10
Sieve brushes		1
Optional Equipment		
Mechanical Sieve Shaker		1
Atterberg Limits		
Casagrande Liquid Limit Device		1
Grooving tool		1
Mixing bowl	± 100mm Φ	2
Spatula		1
Wash bottle	250ml	1
Timer		1
Glass pane	300x300mm	1
Glass jars	100ml	50
Drying oven (or use oven in Sieve Analysis section)	40 litre	1

Description		Quantity
Modified Proctor (AASHTO T-180)		
Mould (including base plate, spacer and collar)	150mm Φ	1
Compaction rammer 457mm drop and 50mm diameter)		1
Balance (Electronic)	12kg ±1g	1
Mixing basin (approximately 500mm x 500mm x 300mm)		1
Mixing trowel		1
Measuring cylinder (plastic)	1 litre	1
Steel straight edge (for trimming)		1
Containers for moisture content (half liter capacity)		50
Drying oven (for small projects use oven in sieve analysis section)	400 litre	1
Optional Equipment		
Mechanical compactor with rotating base plate		1
California Bearing Ratio		
Moulds (including perforated base plate and surcharge weights)	150mm Φ	30
Compaction rammer (2.495kg mass with 305mm drop and 50mm diameter)		1
Swell gauge		1
Soaking baths	2x1x0.4m	1
Compression testing machine (preferably with adjustable rates to include ITS and UCS testing)		1

2 Additional Laboratory Equipment for Cement or Lime Stabilisation

Description		Quantity	Description		Quantity
Compaction			**Ancillary Equipment**		
Steel split moulds and collar (150mm Ø)		3	Teltru Thermometer (For bath and ovens)	$\pm 250^{o}C$	3
Curing of Specimens			Shovel	300mm	1
Perforated flat trays/mesh	250x350mm	12			
			Gloves (heat resistant)		1
Curing oven	400 litre	1			
			Paint brushes	50mm	2
Plastic bags	± 10 litre	500			
			Broom with handle (soft)		1
Balance (Electronic) section)	10kg ± 0.1g	1			
			Hammer	2kg	1
			Silicon grease	100g	1
waterbath (or use CBR		1			
			Hand cleaner	500g	1
Indirect Tensile Strength Testing			Rags for cleaning	box	1
ITS test jig for	150mm Φ	1	String	ball	1
machine (rate of advance		1	briquettes)		1
			Grain scoop or similar		2
Unconfined Compressive Strength Testing					
Load transfer plate	150mm Φ	1	Electronic Thermometer		1
machine (rate of loading		1			

3 Additional Laboratory Equipment for Bitumen Stabilisation

Description		Quantity
<u>BSM-foam</u> Wirtgen WLB 10 S foamed bitumen laboratory unit complete with compressor		1
Wirtgen WLM 30 pugmill mixer		1
Marshall Briquette Manufacture		
Compactor (Manual/Automatic with wooden pedestal and hammer)		1
Moulds (with collar and base plate)	100mm Φ	6
Vernier calipers	250mm	1
Extrusion jack		1
Vibratory Compaction		
A vibratory hammer with the following specifications; Power rating 1500 W Frequency 900 to 1890 beats/min (15 – 31.5Hz) Point Energy 25 J		1
Surcharge weight for hammer	10kg	1
	5kg	1
Steel split moulds (150mm Ø)	125mm high	3
	300mm high	2
Moulds (with collar and base plate)	100mm Φ	6
Tamping foot	100mm Φ	1
	150mm Φ	1
Chisel or spatula 200mm long		1
Adjustable spanner		1
Curing of Specimens		
Perforated flat trays/mesh	250x350mm	12
Drying oven	400 litre	1
Plastic bags	± 10 litre	500
Balance (Electronic) (or use from sieve analysis section)	10kg ± 0.1g	1
Temperature controlled waterbath (or use CBR soaking bath when ambient temp. ± 25deg. C)		1

Description		Quantity
Indirect Tensile Strength Testing		
ITS test jig for	100mm Φ	1
ITS test jig for	150mm Φ	1
Compression testing machine (rate of advance 50.8mm/min, use press in CBR section if rate of press is adjustable)		1
Unconfined Compressive Strength Testing		
Load transfer plate	150mm Φ	1
Compression testing machine (rate of loading 153kN/min, use press in CBR section if rate of press is adjustable)		1
Ancillary Equipment		
Teltru Thermometer (For bath and ovens)	± 250°C	3
Shovel	300mm	1
Gloves (heat resistant)		1
Paint brushes	50mm	2
Broom with handle (soft)		1
Hammer	2kg	1
Silicon grease	100g	1
Hand cleaner	500g	1
Rags for cleaning	box	1
String	ball	1
Marker pen/paint (to label briquettes)		1
Grain scoop or similar		2
Electronic Thermometer		1

END OF PART