

THE DETERMINATION OF THE MAXIMUM DRY DENSITY AND OPTIMUM MOISTURE CONTENT OF MATERIALS USING THE VIBRATORY HAMMER COMPACTION

1. SCOPE

The maximum dry density and optimum moisture content, as defined below, is determined by establishing the moisture-density relationship of the material when prepared and compacted with a vibratory hammer at different moisture contents.

1.1 Definitions

Maximum density: The maximum density of a material for a specific compactive effort is the highest density obtainable when the compaction is carried out on the material at varied moisture contents.

Optimum moisture content: The optimum moisture content for a specific compactive effort is the moisture content at which the maximum density is obtained.

2. APPARATUS

2.1. A vibratory hammer with the following specifications;

Power rating 1500 W
Frequency 900 to 1890 beats/min (15 – 31.5Hz)
Point Energy 25 J

The vibratory Hammer should be mounted on two guide rods; one on either side of the hammer. A mounting head should be fitted to the vibratory hammer to allow a surcharge of 10kg to be mounted to the vibratory hammer. The total mass of vibratory hammer, surcharge and mounting head should be $30\text{kg} \pm 1.5\text{kg}$. There should be a pulley system connecting the frame and mounting head. This allows for easy lifting and lowering of the vibratory hammer.

2.2 A 10kg surcharge weight, to mount onto vibratory hammer.

2.3 A steel split mould, $152,4 \pm 0,5\text{mm}$ in diameter, $152,4 \pm 1$ mm high, with detachable collar, base plate and a $25,4 \pm 1$ mm thick spacer plate with the proviso that with the spacer plate inside the mould the effective depth of the mould shall be 127 ± 1 mm.

2.4 A 150mm diameter tamping foot.

2.5 A steel rule or vernier caliper, minimum length 300mm.

2.6 A balance to weight up to 15kg, accurate to 1g.

2.7 A balance to weigh up to 2kg, accurate to 0.1g.

2.8 Suitable air-tight containers, approximately capacity 15 to 20 litres.

2.9 A mixing basin, approximately 500mm in diameter.

2.10 A mixing trowel.

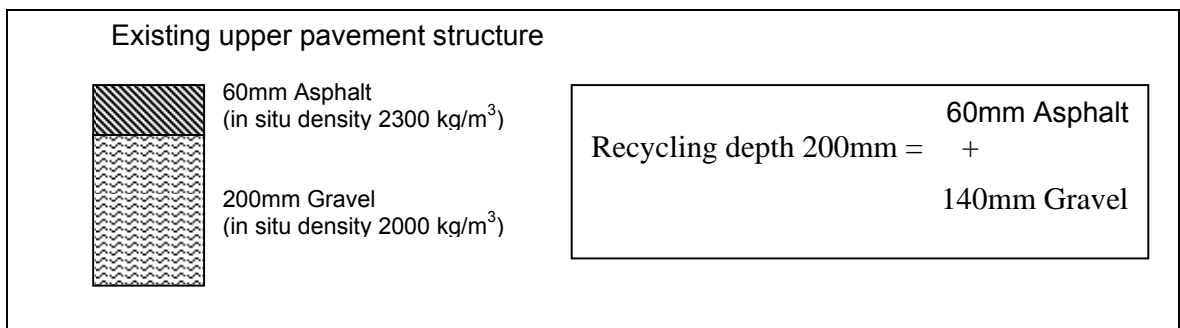
2.11 A chisel or spatula, approximate length 200mm.

- 2.12 Suitable containers to hold 1kg of material for moisture content determination.
- 2.13 A force draft drying oven, thermostatically controlled and capable of maintaining a temperature of 105 to 110 °C.
- 2.14 A 1000 ml measuring cylinder.
- 2.15 Filter paper, 150mm in diameter.
- 2.16 Lubricating grease or non-stick spray.
- 2.17 A sample extruder to remove sample from the mould, if split mould is not used.
- 2.18 Material Scoop (90mm Φ x 85mm h)
- 2.19 Suitable marker e.g. permanent marker
- 2.20 Adjustable spanner to fasten and loosen surcharge load to the vibratory hammer.

3. METHOD

3.1 Sample blending

Where necessary, blend the materials sampled from the different layers or from different sources to obtain a combined sample representing the material that will be stabilised. The in-situ density of field samples from different layers should be considered when blending materials, as illustrated in the boxed example below. Determine the grading and plasticity index of the blended sample.



To obtain a representative mix, the two materials from the above example are blended in proportion to layer thickness and in-situ density as follows:

Material	Per square metre (kg)	Proportion	Per 50kg sample (g)
Asphalt (60mm at 2300 kg/m ³)	0.06 x 2300 = 138	138/418 = 0.33	0.33 x 50000 = 16500
Gravel (140mm at 2000 kg/m ³)	0.14 x 2000 = 280	280/418 = 0.67	0.67 x 50000 = 33500
Total	418	1.00	50000

3.2 Sample preparation

Approximately 50kg of the blended sample (where necessary) is separated into the following four fractions:

- Retained on the 19.0mm sieve;
- Passing the 19.0mm sieve, retained on the 13.2mm sieve;
- Passing the 13.2mm sieve, retained on the 4.75mm sieve; and
- Passing the 4.75mm sieve.

Reconstitute representative samples in accordance with the grading (determined in 3.1 above) up to the portion passing the 19.0 mm sieve. Substitute the portion retained on 19.0mm sieve with material that passes the 19.0 mm sieve, but is retained on the 13.2mm sieve. If there is insufficient material for substituting that retained on the 19.0mm sieve (i.e. material passing the 19.0mm sieve but retained on the 13.2mm sieve), then lightly crush the material retained on the 19.0mm sieve to provide more of this fraction.

The example in the table below explains this procedure:

Sieve analysis		Quantity of material to be added for 7 000g sample		
Sieve size (mm)	Percentage Passing from sieve analysis	Passing 4.75mm	Passing 13.2mm Retained 4.75mm	Passing 19.0mm Retained 13.2mm
19.0	90.5	(53.6/100*7000) = 3752g	((72.3-53.6)/100*7000) = 1309g	((100-72.3)/100*7000) = 1939g
13.2	72.3			
4.75	53.6			

For each moisture-density relationship, reconstitute 5 samples of 7kg ± 1g and place in air-tight containers. Determine the hygroscopic moisture of the air-dried blended material.

3.3 Mixing

3.3.1 Untreated Material

Moisture is added to the untreated material, using a range of moisture contents, normally between 2% moisture and 12% moisture; increasing in nominal increments of 2%. Place the mixed material in an air-tight container. The mixed sample should be set aside for 15 to 30 minutes prior to compaction.

3.3.2 BSM-Emulsion Stabilised Material

For BSM-emulsion, the Optimum Fluid Content for bitumen emulsion treated material is determined and is the percentage, by mass, of bitumen emulsion plus additional moisture required to achieve the maximum dry density of the treated material. The OFC is determined by adding a constant percentage of bitumen emulsion (normally between 2 and 3% residual bitumen) whilst varying the amount of water added, normally increasing in increments of 1 to 2%.

The cement or lime, if required, is added to the air-dried material and mixed thoroughly. Add the water to the material and mix thoroughly and allow to stand in an air-tight container for 15 to 30 minutes. Add the emulsion and again mix thoroughly. Allow this emulsion treated material to stand for 40 to 60 minutes to allow breaking of the bitumen emulsion prior to compaction. Care should be taken to prevent loss of moisture when the materials are left to stand – **use a moist Hessian bag over the material.**

Repeat the procedure at different moisture contents to achieve a moisture – density curve.

3.3.3 BSM – Foamed Bitumen Stabilised Material

For BSM-foam, the OMC of the untreated material has to be determined. The OMC of the foamed bitumen treated material is determined by first adding 60% of the OMC of the untreated material and then injecting a constant percentage of foamed bitumen (normally between 2 and 3% residual bitumen) and increasing the amount of water in nominal 1% increments.

The following percentages of residual bitumen are recommended;

Material Type	100% Reclaimed asphalt pavement (RAP)	Granular materials or blends Grading modulus > 2	Granular materials or blends Grading modulus < 2
Recommended percentage of residual bitumen	2.0%	2.5%	3.0%

The air-dried material is placed into the mixer of the foamed bitumen laboratory unit. The cement or lime, if required, is added to the air-dried material and mixed thoroughly. Water is added to the material to bring the material to 60% of the OMC for the untreated material (added water + hygroscopic water) and mixed thoroughly. The mixed material should be completely moist with no dry material evident. (See note 6.5).

Place the calibrated foamed bitumen laboratory unit in position to spray the foamed bitumen into the moist material in the mixer. Set the laboratory unit to spray the required amounts of foamed bitumen and foamant water, start the mixer and inject the foamed bitumen into the mixer. Mix the foamed bitumen treated material for 30 seconds or until thoroughly mixed.

Add increments of 1% additional water to the foamed bitumen treated material and compact to achieve a moisture – density curve.

3.4 Preparation of the vibratory hammer and mould

3.4.1 Preparing the vibratory hammer

Fix the mounting head and tamping foot to the vibratory hammer and fit hammer onto guide rods. Place 10kg surcharge weight onto mounting head and fasten tightly. (See Figures 1 to 3). Using the pulley system raise the vibratory to the maximum height it can be raised or to an adequate height that will allow operator to work safely beneath the vibratory hammer.

3.4.2 Preparing the mould

Clean the mould, collar and base plate. Lubricate the inside mould wall with a very light application of lubricating grease or non-stick spray. This allows for easy removal of the compacted sample and easy cleaning of the mould thereafter. Determine the mass of the mould (without collar).

Fix the mould to the base of the compaction frame directly below the foot piece of the vibratory hammer. Place two sheets of circular filter paper at the bottom of the mould. Lower the vibratory hammer into the mould, checking that the vibratory hammer is perpendicular to the base of the mould i.e. the tamping foot is flat on the base with no point of the foot raised. Allow the vibratory hammer to rest in the mould with no material present. Where the lower end of sleeve of the mounting head rests on the guide rod, mark that position clearly on the vertical guide using the suitable marker (non-erasable).

3.5 Compaction

The prepared material should be mixed immediately prior to compaction and be compacted at a temperature between 22 and 25 °C.

Compaction is done in two layers. Material is placed in the mould using a material scoop. Add sufficient material (normally three scoops) to provide a starting uncompacted layer thickness of 90 to 95mm. Use the chisel to work the material around in order to evenly distribute the material in the mould without segregating the sample. Ensure that the material is as level as possible before lowering the vibratory hammer until the foot piece comes to rest on the material. The operator should ensure that the tamping foot is kept clean and no material build-up is formed on the tamping face.

The compaction time for each layer is as follows;

Phase	Level 1	Level 2		Level 3
Test	ITS	ITS	UCS	Triaxial
Sample diameter (mm)	101	152	152	152
Sample height (mm)	65	95	125	300
Approximate volume of compacted specimen – Vcs in Eq 4 (cm ³)	520	1725	2270	5445
Surcharge on Hammer	5kg	10kg	10kg	10kg
Number of layers	1	2	2	5
Compaction time per layer (secs)	(per side)	15	15	15
BSM-emulsion	10	25	25	25
BSM-foam	10			
Tamping foot diameter (mm)	100	150	150	150

After compaction of the layer, raise the vibratory hammer and secure. Measure the compacted thickness of the layer and adjust for the amount of material to be added for the second layer such that a final compacted thickness of approximately 125mm is achieved. Using the chisel, scarify the entire surface area of the top of the compacted layer to a depth of ± 10mm (see Note 6.2). Add the required amount of material (this will require that the collar is in place), ensure material is level as possible, place a sheet of circular filter paper on top of the material, lower vibratory hammer and compact as for first layer.

After final compaction, prior to raising the vibratory, measure the distance from the initial position of rest of the lower end of the sleeve of the mounting head (without material in mould) to the final position of the lower end of the sleeve of the mounting head (after final compaction). This distance represents the final height of the compacted specimen.

3.6 Determination of moisture content

After the material for the second layer has been placed in the mould, a representative sample (± 1000g) is taken and placed in a suitable container for determination of moisture content.

The moist sample is weighed immediately to the nearest 0.1g and placed in an oven a 105 to 110 °C. The moisture content is determined to the nearest 0.1 percent.

3.7 Determination of the mass of compacted material

Raise the vibratory hammer and remove the collar. Remove the mould with the compacted material from the base plate and weigh to the nearest 1g. The compacted material can now be removed from the mould.

3.8 Development of the moisture-density curve

The above represents the determination of one point in the moisture- density curve. At least 5 samples needs to be compacted at various moisture contents. Samples shall be compacted at moisture contents either side of the optimum moisture content to obtain a curve. The final sample should be compacted as close to the optimum moisture content as possible. A temporary curve can be plotted using the amount of water added against the bulk density of the sample at compaction to assist with obtaining points either side of the optimum moisture content.

4. CALCULATIONS

4.1 Determine the moisture content of the sample using equation 1

$$MC = \frac{a - b}{b - c} \times 100 \quad \text{[Equation 1]}$$

where MC = moisture content expressed as a percentage of the dry sample [%]
a = mass container and wet material [g]
b = mass of container and dry material [g]
c = mass of container only [g]

4.2 Determine the volume of the compacted sample using equation 2

$$Vol = \frac{Dm^2}{4 \times 1000} \times \pi \times Hc \quad \text{[Equation 2]}$$

where Vol = volume of compacted sample [cm³]
Dm = diameter of mould [mm]
Hc = height of compacted sample [mm]

4.3 Determine the dry density of the compacted sample using equation 3

$$Dd = \frac{Mw}{100 + MCt} \times \frac{100}{Vol} \times 1000 \quad \text{[Equation 3]}$$

where Dd = Dry density of compacted sample [kg/m³]
Mw = mass of wet compacted sample [g]
MCt = moisture content of compacted sample [%]

4.4 Determine the quantity of foamed bitumen and/or active filler using equation 4

$$Q = \frac{Ma}{100 + MCh} \times P \quad \text{[Equation 4]}$$

where Q = Quantity of foamed bitumen or active filler [g]
Ma = mass of air-dried sample [g]
MCh = hygroscopic moisture of sample [%]
P = percentage of foamed bitumen or active filler required [%]

4.5 Determine the quantity of emulsion using equation 5

$$Q_e = \frac{Ma}{100 + MCh} \times \frac{P \times 100}{E_b} \quad \text{[Equation 5]}$$

where Q_e = Quantity of emulsion [g]
Ma = mass of air-dried sample [g]
MCh = hygroscopic moisture of sample [%]
P = percentage of residual bitumen required [%]
E_b = percentage of residual bitumen in emulsion (eg 60%) [%]

5. REPORTING

The moisture-density relationship curve is developed by plotting the final Dry Density of each sample against their respective final moisture contents. The peak of the curve indicates the Optimum Moisture Content and the Maximum Dry Density of the material under vibratory hammer compaction.

The maximum dry density is reported to the nearest 1 kg/m³ and the optimum moisture content to the nearest 0.1 percent.

6. NOTES

- 6.1 For a final specimen of 125mm high a sample mass of around 7kg is recommended when preparing the BSM. This mass is influenced by the achieved Dry Densities and as a result will vary with the type of material being compacted.
- 6.2 Layers should not be scarified deeper than 10mm. Scarifying deeper than 10mm results in inadequate bonding on the layers during compaction. There is therefore an increase in voids at this interface.
- 6.3 Should the vibratory hammer not meet the specifications provided and where no suitable alternative compaction hammers can be sourced, then a vibratory hammer with a point energy of 25 Joule ± 2 Joule should be used. If the weight of the hammer deviates from the specifications by more than 5%, then calibration tests need to be made.
- 6.4 After a specimen has been compacted and removed from the mould, the mould should be cleaned by wiping off excess material from the mould walls. This should be done prior to the compaction of the next specimen.

- 6.5 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 “fluffy” state. If any dust is observed at the end of the mixing process, add small amounts of water and remix until a “fluffy” state is achieved with no dust.
- 6.6 The material is at r near its optimum moisture content when it can be readily pressed by hand to form a lump that will not crumble. A spongy feeling is an indication that the moisture content exceeds optimum.

7. DRAWINGS AND PHOTOGRAPHS

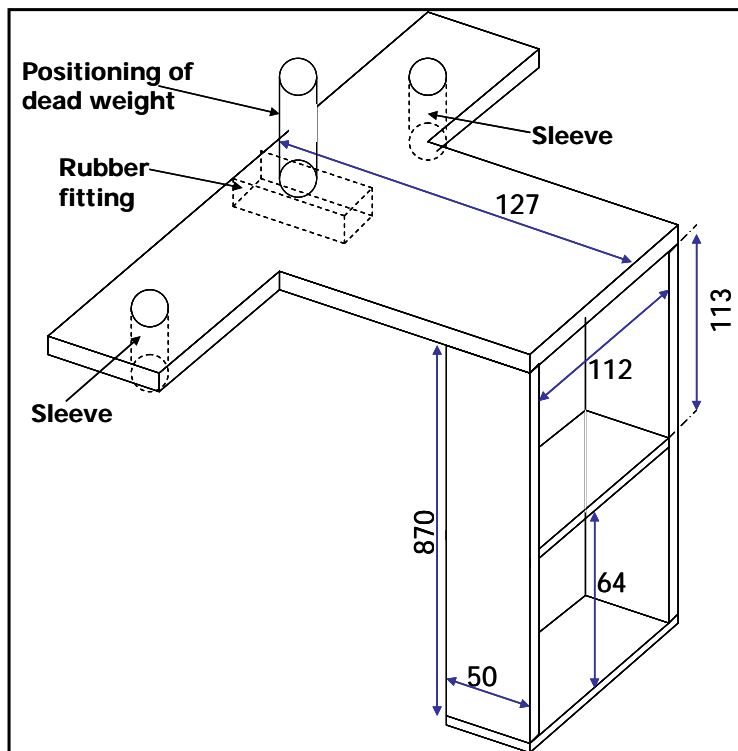


Figure 1: Schematic drawing of the Mounting head for the Bosch GSH 11E®

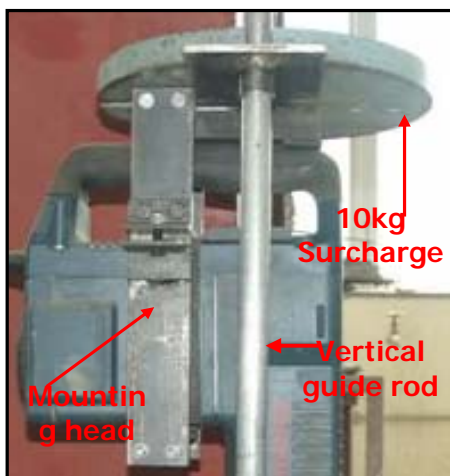


Figure 2: Left view of Mounting head

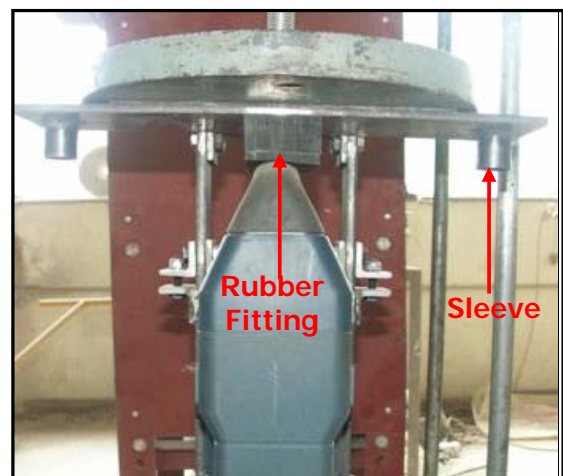


Figure 3: Front view of Mounting head

1. Summary of vibratory hammer compaction procedure

Outlined in this summary is the sequential procedure of the vibratory hammer.

Step 1. When material is obtained that is to be compacted in the laboratory, the first step is to perform a grading on the material. Following the grading, samples for individual specimens are reconstituted from the grading results.

Step 2. The first set of samples reconstituted is samples with a mass of 7kg that are used to perform a moisture sensitivity analysis using Mod AASHTO compaction (TMH 1: Method A7). Two moisture sensitivity analyses are performed. The first is an analysis on the untreated material, i.e. material only having moisture added to it and not having undergone bitumen stabilization. The OMC of the untreated material (OMC-U) is obtained from this the first analysis (Figure L.113).

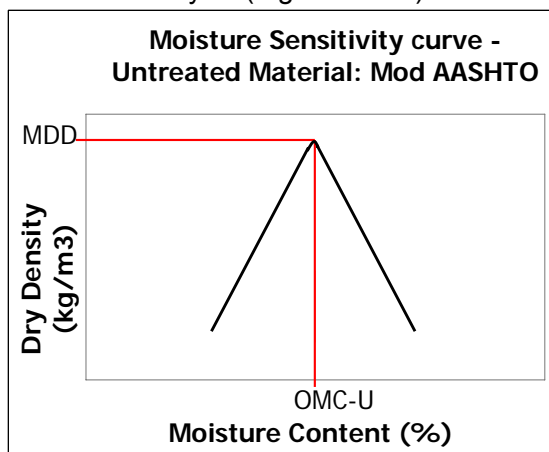


Figure L.113: Moisture Cure: Mod AASHTO- Untreated Material

The second analysis is a moisture sensitivity analysis on the BSM i.e. the material after it has undergone bitumen stabilization. This analysis is performed using the OMC-U to determine the moisture content of each sample. A fraction of the OMC-U is added to the material prior to bitumen stabilization that will provide the target moisture content once the material has undergone bitumen stabilization. The fractions of OMC-U start at 60% increasing in increments of 10 until 110%. From this analysis the OMC of the BSM material is obtained (Figure L.114).

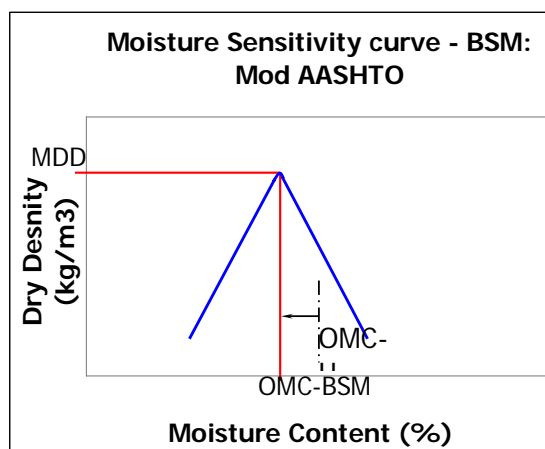


Figure L.114: Moisture Cure: Mod AASHTO- BSM

- Step 3.** The second set of samples reconstituted is samples with a mass of 14kg. These are used for to perform the moisture sensitivity analysis for the vibratory hammer. At least 5 samples should be reconstituted. Cement or lime is first added to the material; should the mix being prepared require these stabilizers. Moisture is then added to the material in varying amounts across the samples. The moisture added starts at 2% moisture for sample 1 increasing in increments of 2% until a content of 10 or 12% for the final sample. The material is then allowed to stand for ± 60 minutes. The bitumen stabilizer (Emulsion or Foamed) is then added after the 60 minute time period. The material is once again allowed to stand for ± 60 minutes to allow for the breaking of the bitumen.
- Step 4.** The mould and vibratory hammer are prepared as outlined in 2.2.1 of the procedure.
- Step 5** Each sample is compacted individually to produce a specimen for a specific sample. Specimens are compacted in five layers. Material from the specific sample is placed into the mould using a material scoop. Three scoops of material per layer are placed into the mould and each layer is compacted for a set period of time (Table L.29).
- Step 6.** Prior to removing each specimen from the mould the final height of the specimen is measured. The specimen is then removed and the final mass is measured. The remaining material from the sample is used to perform a moisture content test for that specimen. The Dry Density of each sample is then calculated.
- Step 7.** The moisture curve for the vibratory hammer is plotted. This is done by plotting the Dry Density of each specimen against its own moisture content. All specimens are plotted on the same set of axis. The Maximum Dry Density and OMC of the vibratory hammer are then read off the curve (Figure L.115).

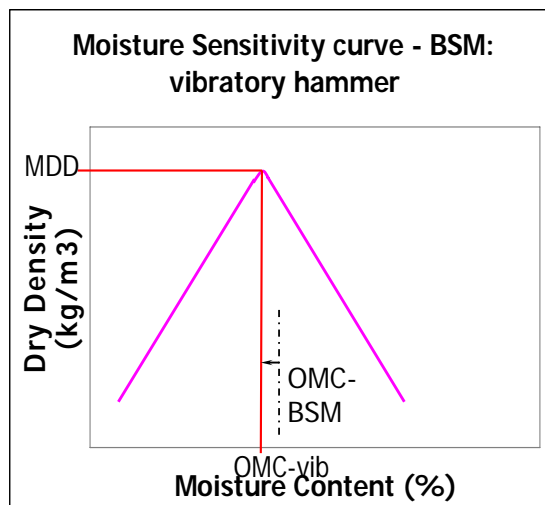


Figure L.115: Moisture Cure: vibratory hammer- BSM

- Step 8.** The Maximum Dry Density for the vibratory hammer is then used to specify the target level of compaction for site (Subsection 2.3 of this procedure).
- Step 9.** The OMC of the vibratory hammer (OMC-vib) is then compared to the OMC of the Mod AASHTO compaction for the specific mix. The lower OMC of the two is then selected for site compaction. See the figures below. Figures L.113 to L.115 show that the OMC of the vibratory hammer is typically lower than the Mod AASHTO OMC. The BSM-emulsion however may provide a curve which has an OMC-vib higher than the Mod AASHTO OMC. Therefore it becomes necessary to compare the moisture curves of the vibratory hammer and Mod AASHTO compaction methods as the lower OMC is used for site specification.

Step 10 Should specimens be prepared in the laboratory for testing purposes then specimens are compacted at 100% of OMC-vib.