SOUTH AFRICAN ROAD FEDERATION

COMPACTION OF ROAD BUILDING MATERIALS

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COURSE CONTENTS

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2. The Relationship between Strength and Density
3. Road Building Material Characteristics
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1.
THE IMPORTANCE OF COMPACTION

THE ADVANTAGE OF COMPACTION OF PATHWAYS FOR PEDESTRIANS AND PACK ANIMALS WAS REALISED BEFORE THE WHEEL WAS INVENTED MORE THAN 5 000 YEARS AGO.

INCA ROLLER -

16 000 km

ROAD NETWORK

IN 3 500 BC

THE CHINESE ALSO REALISED THE VALUE OF COMPACTION AND THEY USED AN INNOVATIVE "DYNAMIC" COMPACTION TECHNIQUE.

COSTLY ROCK LAYER

CLAY & LIME FILLING TO SAVE TIME AND COST

UNIFORMLY GRADED ON A ROCK FOUNDATION

SIMILAR BUT LARGE ROCK WAS EXPENSIVE

LAYER OF SMALL ROCKS : INTERPARTICLE FRICTION

BASE – CBR > 80
SUB-BASE – CBR > 45
SELECTED SUBGRADE – CBR > 25
SUBGRADE – CBR > 15

2.
THE RELATIONSHIP BETWEEN MATERIAL SHEAR STRENGTH AND DENSITY

IN THE 1920's THE NEED FOR GOOD ROADS FOR CARS AND TRUCKS INTENSIFIED AND THIS LED TO MORE SCIENTIFIC RESEARCH INTO THE THEORY OF COMPACTION.

BY THE LATE 1920'S ONE AMERICAN IN SIX OWNED A MOTOR CAR.

IN 1928 THE CALIFORNIA HIGHWAY DEPARTMENT UNDERTOOK A STUDY OF THEIR NETWORK TO ASSESS THE TYPES OF DISTRESS AND THE CAUSES.

FROM THESE STUDIES IT WAS DETERMINED THAT :

- VARIABLE COMPACTION WAS THE PRIMARY CAUSE OF DISTRESS.
- THE DEGREE OF COMPACTION HAD A GREATER EFFECT ON THE PERFORMANCE THAN ANY OTHER FACTOR.
- HIGH CLAY CONTENT MATERIALS SWELLED AND LOST STRENGTH SIGNIFICANTLY WHEN THEY GOT WET.
- INSUFFICIENT PAVEMENT THICKNESS TO SUPPORT THE WHEEL LOADS LED TO DEFORMATION.

SUBSEQUENT RESEARCH LED TO :

- 1930 - CALIFORNIA BEARING RATIO (CBR) TEST WHICH PROVIDED AN INDICATION OF A MATERIALS SHEAR STRENGTH.
- 1932 – PROCTOR DEVELOPED THE AASHTO STANDARD COMPACTION TEST AND DEMONSTRATED THE RELATIONSHIP BETWEEN MOISTURE CONTENT AND MAXIMUM DRY DENSITY.
- 1943 – THE TEST COMPACTION EFFORT WAS INCREASED = THE "MODIFIED" AASHTO TEST .
- Mod. AASHTO AND CBR TESTS WERE USED TO DEVELOP A SET OF PAVEMENT DESIGN CURVES WHICH LED TO A SIGNIFICANT IMPROVEMENT IN PAVEMENT DESIGN. MATERIAL STRENGTH AND COMPACTION COULD NOW BE WELL CONTROLLED.

SHEAR STRENGTH, AS MEASURED BY THE CBR TEST, INCREASES WITH INCREASING DENSITY.

NOTE THE EFFECT OF THE DENSITY ON THE STRENGTH OF THE MATERIAL !

MODERN PAVEMENT STRUCTURES NOW USE HIGHER STRENGTH MATERIALS IN THE BASE LAYER TO RESIST RUTTING AS WELL AS STABILISED SUBBASE LAYERS IN ORDER TO PROVIDE ADDITIONAL SHEAR STRENGTH AND TO IMPROVE THE LOAD DISTRIBUTION THROUGHOUT THE PAVEMENT STRUCTURE.

THESE PAVEMENTS ARE ECONOMICAL BUT THEIR PERFORMANCE IS HIGHLY DEPENDENT ON GOOD CONSTRUCTION AND WELL CONTROLLED COMPACTION.

WHEN YOU PUSH TO THE LIMITS YOU MUST MAKE SURE YOU ACHIEVE THE STANDARDS. IF NOT THEN FAILURE OCCURS QUICKLY !

WHAT HAS CHANGED SINCE 1928 ?

- VARIABLE COMPACTION IS STILL A PRIMARY CAUSE OF DISTRESS.
- THE DEGREE OF COMPACTION STILL HAS A GREATER EFFECT ON THE PERFORMANCE OF THE PAVEMENT THAN ANY OTHER FACTOR.
- MATERIALS SWELL AND LOOSE STRENGTH SIGNIFICANTLY WHEN THEY GET WET.
- INSUFFICIENT PAVEMENT THICKNESS TO SUPPORT THE WHEEL LOADS LEADS TO PERMANENT DEFORMATION.

THE TENDENCY TO SAVE MONEY BY LEAVING OUT LAYERS OR DECREASING THE LAYER THICKNESS MEANS THAT YOU NEED TO PAY MORE ATTENTION TO THE FIRST THREE FACTORS.

LOSS OF MATERIAL STRENGTH WHEN WET !

DIFFICULTIES OFTEN OCCUR DURING THE COMPACTION PROCESS DUE TO :

- **Lack of personnel training and experience.**
- **Incorrect compaction moisture content.**
- **Uneven moisture distribution.**
- **Layer thickness and depth of compaction.**
- **Density requirements that are too high.**
- **Poor control of vibration / poor roller choice.**
- **Unusual circumstances.**

3.
ROAD BUILDING MATERIAL CHARACTERISTICS

HRB SOIL CLASSIFICATION

TRH 14 MATERIAL CLASSIFICATION

G1 G2 G3	G4 G5 G6	G7 - 10
Crushed Stone	Natural Gravel	Natural Soil

TRH 14 MATERIAL CLASSIFICATION

Code	PI	LS	GM	CBR	Swell
G1	≤ 5	≤ 2			
G2	≤ 6	≤ 3			
G3	≤ 6	≤3			
G4	≤ 6	≤ 3		≥ 80 @ 98%	≤ 0.2
G5	≤ 10	≤ 5	1.5 ≤ GM ≤ 2.5	≥ 45 @ 95%	≤ 0.5
G6	≤ 12 or 2 x GM +10	≤ 5	1.2 ≤ GM ≤ 2.6	≥ 25 @ 95%	≤ 1.0
G7	≤ 12 or 3 x GM + 10		0.75 ≤ GM ≤ 2.7	≥ 15 @ 93%	≤ 1.5
G8				≥ 10 @ 93%	≤ 1.5
G9				≥ 7 @ 93%	≤ 1.5
G10				≥ 3 @ 93%	

KNOWLEDGE OF SOIL TYPES

Defined by the granular scale

AWARENESS OF MATERIAL CHARACTERISTICS :

Resistance to compaction

FRICTION WHICH IS DEPENDENT ON PARTICLE SIZE AND SHAPE

COHESION CAUSED BY VAN DER WAAL'S FORCES

APPARENT COHESION DUE TO SURFACE TENSION

COBBLE / BOULDER

Resistance to compaction :
FRICTION

- Sensitive to max particle size
  - Max particle size < 2/3 of layer thickness (recommended 1/3)
- Less sensitive to particle shape
- Not sensitive to gradation
- Not sensitive to water content

GRAVEL / SAND

Resistance to compaction :
FRICTION
APPARENT COHESION

- Sensitive to water content
  (Free draining if fines content <5-10%)
- Sensitive to gradation (C_u>10)
  (Uniformly graded - less bearing capacity but easier to compact)
- Sensitive to particle shape

Gravels and Sands

The soil is a gravel or sand if 65% by mass is ≥ 0,075 mm in particle size.

<u>Gravel is coarse grained :</u>

Particles mainly larger than 4,75 mm

<u>Sand is fine grained :</u>

Particles mainly smaller than 4,75 mm

THESE SOILS ARE GRADED BY USING SIEVES

<u>SILT</u>

Resistance to compaction :

APPARENT COHESION

FRICTION

<u>AND</u> COHESION

- **Very sensitive to water content**
  - **Check plasticity index**
- **Less sensitive to particle shape**
- **Less sensitive to gradation (C_u<10)**

SILTS AND CLAYS

When soil has more than 35% by mass of less than 0,075 mm sized particles then the soil is FINE GRAINED.

(These particles cannot be isolated by the naked eye.)

SILTS fall between 0,075 and 0,002 mm
(observed by optical microscope)

CLAYS: less than 0,002 mm

(Clay soils are graded using a Hydrometer.)

Grading analysis

> 0,075mm

Pn = % age less than "n" mm in diameter

Sieve analysis

Hydrometer analysis

< 0,075mm

$D = 0{,}1/\ t^{0{,}5}$

Where:

D = dia in mm

t = time lapse in seconds

Soil - It's Make Up Illustrated

Water in the Voids :

- **The degree of saturation : S**
  - **Shows the quantity of water filling the voids**
- **The size of the passages**
  - **Dictates the rate of water movement: in or out**

UNIFORM or OPEN GRADING

High voids content

Few contact points

= <u>low friction</u>

= less compactive effort required but also less strength.

CONTINUOUS or DENSE GRADING

Few voids

Many contact points

= <u>a lot of friction</u>

= more compactive effort required but also more shear strength.

TOO FEW FINES - VOIDS UNFILLED

LOW DENSITY

TOO MANY FINES – PARTICLES PUSHED APART

BALANCED or OPTIMUM FINES :

FINES JUST FILL ALL THE VOIDS IN THE COARSE AGGREGATE

HIGH DENSITY

THE GRADING INFLUENCES THE DENSITY YOU CAN ACHIEVE

LOW DENSITY

Poor interlock
= low strength

HIGH DENSITY

Good interlock
= high strength

As you compact material the inter- particle friction increases so more effort required.

To reduce the inter-particle friction water is added.

THE LUBRICATION REDUCES THE COMPACTIVE EFFORT REQUIRED TO ACHIEVE THE REQUIRED DENSITY.

BUT OPTIMUM MOISTURE CONTENT TO SUIT MATERIAL TYPE, GRADING AND COMPACTION EQUIPMENT BEING USED IS VERY IMPORTANT :

- Large comp. force - less moisture needed
- Small comp. force - more moisture needed

- Coarse material - less moisture needed
- Fine material - more moisture needed

Discuss why ?

COEFFICIENT OF UNIFORMITY *(Dynapac)*

$C_u = d_{60}/d_{10}$

Cu for base gravel = 15 / 0.3 = 50.
This is > 10 so material is sensitive to gradation.

Cu for sand = 1 / 0.09 = 11.
This is > 10 so material is sensitive to gradation.

Cu for silt = 0.01 / 0.003 = 3.3
This is < 10 so material less sensitive to gradation.

THE SOIL MODEL

Some factual Relationships

$$W = \text{Moisture content} = \frac{\text{Mass of water}}{\text{Mass of solids}} = \frac{Mw}{Ms}$$

$$D = \text{Density} = \frac{\text{Mass of solids}}{\text{Total volume}} = \frac{Ms}{Vt}$$

$$Dw = \text{Wet density} = \frac{\text{Mass of solids + water}}{\text{Total volume}} = \frac{Ms + Mw}{Vt}$$

$$Dd = \text{dry density} = \frac{\text{Mass of solids only}}{\text{Total volume}} = \frac{Ms}{Vt}$$

$$Dd = Dw / (1 + W)$$

S = Degree of Saturation
= the fraction of the voids filled with water

$$= \frac{\text{Volume of water}}{\text{Volume of voids}} = \frac{Vw}{Vv}$$

Wsat = Moisture content where the water is just filling the voids in a soil. (S=1)

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Soils with high clay content should not be compacted !

- swelling will destroy density
- like trying to compact water
- heaving action will occur

High clay and silt content in soils results in

- swelling
- cracks
- difficult compaction / low density

Particle Size and Forces

MAIN INFLUENCES :

Particle Mass	Surface forces
GRAVITATIONAL FORCES	VAN DER WAAL'S FORCES AND SURFACE TENSION
Gravels	Fine silts
Sands	Clays
Low water adsorption	High water adsorption

ADSORBED WATER
is not removed by sun or oven drying
(Approximately 50 litre/m³ of clayey soil)

What increases Strength of a Soil ?

- Large particles
- Proper grading
- Good interlock (rough vs smooth)
- Low voids
- Low moisture content
- Low clay content
- Stabilization

What Reduces Strength of a Soil and its Durability ?

- Water in excess
- Clay in excess
- Chemical weathering
  - Dolerite
  - Granite
  - Shale / mudstone

WEATHERED DOLERITE

- Do not try to compact clays
- Avoid soils with high clay and silt content
- Do not try to compact silt - clay soils to > 90% Mod. AASHTO
- Look out for soils where silt and clay content is excessive

NATURAL SOILS AND GRAVELS ARE A VARIABLE COMBINATION OF CLAY, SILT, SAND AND COBBLES.

There are also naturally cemented materials such as CALCRETE, SILCRETE, FERRICRETE etc.

Be aware that material characteristics vary, even in the same soil type from the same borrow pit or quarry.

MATERIAL GRADING VARIATIONS

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MATERIAL QUALITY VARIATIONS

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MATERIAL GRADING VARIATIONS

Weathering (Weinert's N-value)

If N < 5 then "Acid" and "Basic" crystalline rocks can decompose.

"Acid" rocks contain quartz as one of the principal minerals. The other non-quartz minerals such as feldspar decompose into kaolinite clay.

"Basic" rocks have no quartz. The feldspars and mafic minerals decompose into montmorillonite clay.

REMEMBER THAT ALL MATERIALS ALWAYS VARY IN GEOLOGICAL COMPOSITION, PARTICLE SIZE AND SHAPE, CLAY CONTENT, NATURAL CEMENTING AGENTS AND MOISTURE CONTENT !

and they sometimes contain deleterious chemicals or decomposed vegetation which affect the action of any stabilising agents you may be adding !

ALL THESE VARIABLES AFFECT THE COMPACTIVE EFFORT REQUIRED AS WELL AS THE DENSITY YOU CAN ACHIEVE BECAUSE THEY AFFECT TO DIFFERENT DEGREES THE :

- INTERPARTICLE FRICTION
- APPARENT COHESION
- COHESION
- VOIDS IN THE LAYER

You can and will get every combination you can think of because material composition and grading are infinitely variable !

4.
THE INFLUENCE OF MOISTURE & CLAY

Unlike a solid material the strength of a soil is variable depending on the moisture content:

- Wet strength is low – water in pores
- Dry strength is high – no water in pores

Soil also has a “Pseudo” strength due to pore pressure and soil suction

During compaction water helps to lubricate the soil by forcing the particles apart which reduces the inter-particle friction. The water is eventually squeezed out as the particle interlock increases and the volume of voids decreases during compaction.

Extra water also reduces surface tension BUT too much water (> volume of voids) increases the pore pressure which creates heaving / pumping.

Hence there is an
Optimum Moisture Content
for compaction
which we will discuss later.

A clay particle is like a book !

"Pages" made up of:

- Silica (Tetrahedra) and
- Magnesium or Aluminium (Octahedra)

Water enters between the "pages" and the clay <u>expands</u> !

Clays have a very large surface area which attracts water

Rock particle is solid.

Clay particle is like a book with separate pages.

A Kaolin particle @ 7 000 magnification

A CLAY PARTICLE CONSISTS OF A GREAT NUMBER OF VERY SMALL PLATELETS

Adsorbed water held on the surface of each platelet so water enters and is retained between each platelet.

Kaolin

Particle Size:
Dia. = 0,3 – 2 µm
Thickness = 0,1 x dia.

Opposite electrical charges on the aluminium and silica platelets creates a weak bond so harder for water to penetrate.

Kaolin has a low water adsorption and therefore it has a lower swell potential.

Montmorillonite

Particle Size:
Dia. = 0,01 – 0,1 µm
Thickness = 0,01 X dia.

Same electrical charges on the silica platelets repel each other so it is very easy for water to penetrate. Particle size also much smaller as charges keep them separate.

Montmorillonite has a large water adsorption and therefore it has a high swell potential.

Load required to press out clay's adsorbed water : 550 MPa.
Equivalent to a water head of 55 km so clay will expand no matter how much fill on top.)

CLAY ADSORBS more water when any is available.

THUS: Clays swell, dry out and swell again repeatedly every wet and dry season !

The amount of clay in a soil is measured by the ATTERBERG LIMITS.
(Liquid, plastic and shrinkage limits)

These limits can also tell us what type of clay is present.

The type of clay determines the degree of expansiveness of the soil when it gets wet.

LIQUID, PLASTIC & SHRINKAGE LIMITS

LIQUID LIMIT (LL)

The LL of a soil is the moisture content of a soil at the boundary between the liquid and plastic states.

(TMH 1 – Method A2)

PLASTIC LIMIT (PL)

The PL of a soil is the moisture content of a soil at the boundary between the plastic and semi-solid states. (TMH 1 – Method A3)

SHRINKAGE LIMIT (SL)

The SL of a soil is the moisture content where further loss of moisture will not result in any more volume reduction. (ASTM – Method D4943)

PLASTICITY INDEX, PLASTICITY RATIO AND SHRINKAGE LIMIT

PLASTICITY INDEX : PI

The PI of a soil tells us the quantity of water the clay in the soil can hold

PI = LL – PL

PLASTICITY RATIO : PR

= LL / PL

The PR tells us the TYPE of clay in the soil

SHRINKAGE LIMIT : SL

The SL tells us how much the clay will shrink and crack when dry and swell again when wet

LIQUID, PLASTIC & SHRINKAGE LIMITS

Important Clay Types

Clay type	Montmorillonite	Illite	Kaolin
	Very small particles		*Small particles*
Specific Surface m^2/g	200 – 800	80 – 100	20 – 40
Plasticity Index *	200 – 650	45 – 70	12 - 33
Shrinkage Limit	10 - 15	14 – 18	25 – 30
Plasticity Ratio	> 3.0	2 - 3	< 1,5

* (PI of the clay, not of the soil containing some clay which is the PI result you get from the laboratory test.)

When clay is useful:

In Dam Cores

Bonds gravel roads when dry

When clay is not wanted:

In road pavement layers

Weakens road foundation layers

Expands and contracts

Deforms on gravel roads when wet

Causes potholes under heavy wheel loads (pumping action)

REVISION QUIZ : CHARACTERISTICS OF MATERIALS

What were the 4 main findings of the 1928 California Highway study ?

1. _____

2. _____

3. _____

4. _____

REVISION QUIZ : CHARACTERISTICS OF MATERIALS

Why were the California Bearing Ratio (CBR) and the American Association of State Highway Officials (AASHTO) standard density tests so important ?

_____

_____

What is the relationship between the two tests ?

_____

_____

REVISION QUIZ : CHARACTERISTICS OF MATERIALS

What contributes to the strength of a soil or gravel ?

_____

What reduces the strength of a soil of gravel ?

_____

What tests are used to determine the characteristics of a soil or gravel ?

_____

_____

REVISION QUIZ : CHARACTERISTICS OF MATERIALS

Name three important types of clay :

_____

Which type is the most expansive ?

_____

PI is short for _____

What limits are used to calculate the PI value ?

_____ **PI =** _____

5.
THE PRINCIPLES OF COMPACTION

STATIC MASS

Mass / Contact Area = Pressure

Boussinesq's theory

Effect of vertical stress σ_v attenuates with depth

Material at the top denser than below.

Note : Attenuation of stress due to contact point losses

FALLING MASS

The pressure wave generated by the impact of the falling mass on the surface extends down further than the static pressure generated by the same static Mass >

pressure waves

VIBRATING MASS

Rapid succession of impacts generate successive pressure waves to increase the rate that the compaction energy is generated.

STATIC COMPACTION

- Steel tyred rollers, grid rollers and pneumatic rollers
- They are self propelled or towed
- Mass – most important

Roller or tyre diameter and width (& tyre pressure) control the contact area.

Weight divided by contact area = the pressure exerted by the roller which in turn dictates the effective depth.

Increasing the static roller mass may increase the DENSITY achieved

but

It may only slightly increase the DEPTH of compaction

Static rollers therefore have a limited depth of compaction !

IMPACT COMPACTION

Falling Mass

Energy = ½ x mass x velocity ^{2}

= mass x s x g

Effective impact compaction depth depends on
- Mass
- Diameter
- Fall height

Impact compaction is used for densifying loose sands and gravels.

It is not effective in saturated clays because:
- Clay is slow draining – you can't easily displace the water in the voids
- Water not compressible
- Pore pressure blow up!

IMPACT ROLLER

$$\text{Energy} = 0{,}5\ [\ M\ (\ v + \sqrt{2Sg}\ )^2\ ]$$

where v = roller speed (m / s)

M = roller mass

S = R-r

VIBRATORY COMPACTION

Vibration forces generated by an eccentric rotating Mass.

Force generated is related to the amplitude and the frequency of the vibrations.

AMPLITUDE controlled by the size and eccentricity of the moving mass inside the roller drum.

FREQUENCY is controlled by the rotational speed of the moving mass inside the drum.

SOME DEFINITIONS

Frequency: (Hz) = Cycles/sec

ROLLER SPEED & PASSES

The energy imparted to the layer causing its densification

- **falls off with speed**
- **falls off with number of passes**

So:

keep speed low and try to get density within 6 to 10 passes.

If density not achieved in a maximum of 12 passes then change something !

QUERY

Why does density increment drop off with the number of passes ?

- **Number of contact points increases**
  - **Friction increases as the interlock increases.**
- **More energy lost in elastic deflection**
  - **Strain hardening**
- **Less energy available for plastic deformation of the material.**

DRIVEN vs NON-DRIVEN DRUM

A driven wheel or drum forces the material backwards under the drum as the drum moves forward.

A non-driven drum pushes material forwards in a bow wave in front of the drum.

This displaces the material.

Driven

Non- Driven

NOTE: Horizontal displacement of the material causes cracks and / or lamination.

OVER VIBRATION

MORE VIBRATORY PASSES ARE NOT ALWAYS THE ANSWER TO INCREASING LOW DENSITIES.

BEWARE OF OVER VIBRATION WHICH WILL START TO BREAK UP THE LAYER WHICH YOU HAVE JUST COMPACTED.

USE THE CORRECT VIBRATION EFFORT AND SELECT THE CORRECT ROLLER :

Use thinner layers if you only have a light, low amplitude vibratory roller. Do not use a heavy, high amplitude vibratory roller on thin layers.

Vary compaction moisture to suit rollers being used !

6.
COMPACTION EQUIPMENT

Three wheeled steel static roller

Use this roller for compaction of layers which require high compaction energy, usually asphalt but also gravel and crushed stone layer works.

HIGH POINT PRESSURES

HIGH STATIC PRESSURE
Load is distributed over small contact area as steel drum is rigid so contact area = drum width x width of a narrow strip at bottom of the drum.

Pressure reduces with depth so steel wheel rollers only used to compact thin layers < 150 mm.

Three wheel Static Rollers :

For :

- Good final finishing
- Good for Asphalt
- May be ballasted to increase mass

Against :

- Seldom good for layers > 200mm
- Biscuiting – lamination on sands

Grid Roller
Static with some impact

For:

- At speed it crushes & improves shape
- Good compaction due to concentrated point loads at mesh joints
- Avoids lamination

Against:

- Limited layer thickness < 200 mm
- Not good for finishing
- Needs towing

Pneumatic tyred static roller

Use this roller for compaction of the upper portion of all layers and also for compaction in depth if roller weight is high enough.

HIGH STATIC & KNEADING PRESSURES

LOWER STATIC PRESSURE THAN A THREE WHEEL STEEL ROLLER AS THE LOAD IS DISTRIBUTED OVER THE TYRE CONTACT AREA AND OVER 7 or 9 TYRES.

Pneumatic rollers only used to compact thin layers as pressure reduces with depth but the flexible tyre contact surface also provides a kneading action.

Pneumatic tyred static roller (PTR)

For:

- **Good surface finisher of compaction**
- **Compacts uneven surfaces**
- **Good for asphalt – kneading action**
- **Avoids lamination**
- **Can be ballasted –**

Against:

- **Limited depth compaction < 200mm**
- **Does not improve an uneven top layer finish**

Impact roller

Very low frequency / very high amplitude !

FILL / THICK LAYERS ONLY.

ONLY LARGE WORK AREAS.

Impact Roller

For :

- Excellent depth compaction: 1 to 2m
- Good for large fill areas e.g. dams, airports

Against :

- Needs powerful tractor to pull at speed
- Not suitable for thin layers
- Gives very poor surface finish

Single drum vibratory roller
High amplitude (> 1 mm) / low frequency

Use this roller for compaction of thick fill layers and thinner layers of higher quality material which require more compaction energy.

HIGH POINT PRESSURES AND VIBRATION

High Amplitude Vibratory Roller (Amplitude = 1 – 1.8 mm)

For :

- Good for thick fill layers
- Good for compaction in depth up to 1.0 m
- Compaction at bottom of layer
- Good compaction with low M/C

Against :

- Top of layer not well compacted
- Speed sensitive
- Too fast – poor compaction
- Too slow – wave action

Single, high amplitude / low frequency vibratory roller (with "pad-foot" drum)

Use this roller for compaction of thick fill layers, especially clayey material as well as thinner layers of higher quality material which require a lot of compaction energy such as G1 base.

Vibratory Pad Foot Roller

For :

- Compacts from bottom up
- Lateral compaction
- Good for clays and silts / kneading action between pads.

Against :

- Poor surface finish
- Tends to "slot in". Driver must zig-zag

Single, high amplitude / low frequency vibratory roller (with "polygonal" drum)

COMBINED VIBRATION & IMPACT

FILL / THICK LAYERS ONLY

Tandem drum vibratory roller
Low amplitude (< 1.0 mm) / high frequency

Use this roller for compaction of thinner layers, usually asphalt.

Low Amplitude Vibratory Roller (Amplitude = 0.3 – 0.8mm)

For :

- Good for finishing top of layer
- Good for Asphalt

Against :

- Limited effective depth < 200mm
- Not suitable for G1, G2, G3, G4 & G5 layers as roller is light and amplitude low.

Variable Vibratory Rollers

Most modern vibratory rollers have a mechanism to change the amplitude and / or frequency.

Some can also measure the degree of compaction achieved and automatically vary the amplitude, frequency and the direction that the compactive force is applied.

COMPACTION IN DEPTH

Why does density decrease towards the surface when using a high amplitude vibratory roller ?

CONTROLLING COMPACTIVE EFFORT

low dynamic energy
due to horizontally directed vibrations

Compaction effect
Deadweight and dynamic energy, the compaction effect is automatically adapted to compactibility of material, layer thickness and subbase.

high dynamic energy
due to vertically directed vibrations

Application: all soil types, granular bases and subbases

Gravel-sand

INSIDE THE VIBRATORY DRUM

GPS for soil and asphalt compaction

with reference station

accuracy ~ 2 - 10 cm

with reference satellite

accuracy ~20 - 100 cm

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Measuring and documentation :

Get all the important information on your computer.

Compaction results being displayed and stored at site.

BCM05 Tablet-PC with touch screen

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AUTOMATED ROLLERS NOW ELIMINATE OVER COMPACTION

$$E_v = 1{,}5 \cdot r \cdot \frac{\Delta\sigma}{\Delta s}$$

$$E_{VIB} = f(F_B, \delta, b)$$

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Vibration Modulus (EVIB) Measurement

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Asphalt Manager

A new *physical* Value stops guess work at site

E_{VIB} (MN/m²)

Dynamic stiffness value

Continuous indication of Compaction Progress

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Operational Panel / Display

Fixed positions:
1 x horizontal
5 x vertical

Working ranges
0 - 0,3 mm
0 - 0,6 mm
0 - Max.

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BOMAG ASPHALTMANAGER

UEBERGANG 1 VOR.
BOMAG AM REV 6 DEU
BW 174 AM

Einstellung : Hand / 0,40 mm

Evib Max.	=	206	MN/m2
Evib Min.	=	124	MN/m2
Evib Mittelwert	=	168	MN/m2
Frequenz	=	44,3	Hz
Mittlere Fahrgeschw.	=	3,3	km/h
Bahnlänge	=	22,9	m

Raster 5m ---> Evib (MN/m2) ------
---> Temperatur (°C) .....

E_{VIB} Max.

E_{VIB} Min.

E_{VIB} Average

Frequency

Speed Average

Track length

Temperature

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7.
COMPACTION MOISTURE

COMPACTION MOISTURE CONTENT

THE CORRECT COMPACTION MOISTURE CONTENT IS DEPENDENT MAINLY ON :

- Soil type (grading and clay content)
- Type of roller or rollers being used
- Prevailing weather conditions which affect drying out during the compaction process

THE CORRECT COMPACTION MOISTURE CONTENT IS OF PARAMOUNT IMPORTANCE.

IT AFFECTS INTER-PARTICLE FRICTION AND COHESION DURING THE COMPACTION PROCESS

DENSITY MEASUREMENT
Modified AASHTO Density Test

COMPACTION MOISTURE CONTENT

THE CORRECT COMPACTION MOISTURE CONTENT IS CALLED THE OPTIMUM "FIELD" MOISTURE CONTENT.

REMEMBER THAT THE FIELD COMPACTION MOISTURE CONTENT IS USUALLY 0.5 % TO 1.0 % BELOW THE LABORATORY OPTIMUM MOISTURE CONTENT DEPENDING ON THE TYPE OF COMPACTION EQUIPMENT BEING USED.

(Field compaction equipment is not the same as the impact compaction hammer used in the laboratory.)

TRIAL SECTION

ALWAYS CARRY OUT A TRIAL SECTION TO DETERMINE :

- **The correct compaction moisture.**
- **The correct mixing procedure.**
- **The most suitable layer thickness if compaction is required in more than one lift.**
- **The required number of roller passes for each type of roller & the required vibratory settings.**
- **The final layer finishing method.**

EVERY JOB IS DIFFERENT FROM THE PREVIOUS ONE !

MOISTURE DISTRIBUTION

THE COMPACTION MOISTURE MUST BE CORRECT AND IT MUST ALSO BE EVENLY DISTRIBUTED IN THE

LONGITUDINAL,

TRANSVERSE

AND

VERTICAL DIRECTIONS

LONGITUDINAL DISTRIBUTION

THE COMPACTION WATER IS ADDED IN A LONGITUDINAL DIRECTION BY THE WATER TANKER.

- Calculate the correct quantity of water in advance.
- Apply it evenly using several passes of the tanker to even out distribution variables.
- Add more water to compensate for drying out during the mixing process if necessary.

SUBSEQUENT MIXING DOES NOT MOVE THE MATERIAL OR THE MOISTURE LONGITUDINALLY

TRANSVERSE AND VERTICAL DISTRIBUTION

TRANSVERSE & VERTICAL DISTRIBUTION OF THE WATER IS ACHIEVED BY MIXING THE MATERIAL ACROSS AND BACK OVER THE WIDTH OF THE ROAD WITH A GRADER AND /OR A PLOUGH.

NOTE :

- **A grader mixes transversely and vertically but not longitudinally.**
- **A plough or a recycling machine only mixes vertically, not longitudinally nor transversely.**
- **Only water tanker or a recycling machine controls the longitudinal distribution.**

LONGITUDINAL, TRANSVERSE & VERTICAL WATER DISTRIBUTION

VERTICAL WATER DISTRIBUTION

LONGITUDINAL AND VERTICAL WATER DISTRIBUTION

TRANSVERSE DISTRIBUTION CONTROLLED BY SPRAY NOZZLES INSIDE THE RECYCLING DRUM.

8.
COMPACTION OF CRUSHED STONE BASE

INITIAL COMPACTION

HIGH AMPLITUDE / HEAVY VIBRATORY ACTION TO COMPACT IN DEPTH. (1st Roller pass static !)

WITH DIFFICULT MATERIAL YOU CAN ALSO USE A PADFOOT ROLLER.

THE IDEAL GRADING IS ONE WITH EVENLY DISTRIBUTED PARTICLE SIZES WHICH FILL THE VOIDS WHEN THE MATERIAL IS COMPACTED.

A coarse grading = more voids so a greater compactive effort is required to close the voids and achieve the required density.

A fine grading has too many small particles so a greater compactive effort is required achieve the required density.

"DOG-LEG" GRADING EVEN HARDER TO COMPACT !

FINAL COMPACTION

COMPACT UPPER 50 mm BY FILLING SURFACE VOIDS WITH WATER TO TRANSMIT COMPACTION FORCES TO SOFTER AREAS BETWEEN THE COARSE AGGREGATE. ALSO SOME KNEADING ACTION.

WELL COMPACTED CRUSHED STONE BASE

POORLY MIXED & COMPACTED CRUSHED STONE BASE

THE "WET" METHOD WHERE THE CRUSHED STONE BASE IS COMPACTED WELL OVER OPTIMUM MOISTURE CONTENT IS PREFERRED BY SOME CONTRACTORS.

THE DISADVANTAGE OF THIS METHOD IS THAT YOU ARE BUILDING IN EXCESS MOISTURE INTO THE CRUSHED STONE BASE WHICH IS NOT A GOOD IDEA !

"PUMPING" DURING COMPACTION ALSO DISTURBS THE SMOOTH LEVEL CUT BY GRADER = POOR RIDING QUALITY, ESPECIALLY WHEN BITUMINOUS SEALS ARE USED.

COMPACTION IS BOTH A SCIENCE AND THE ART OF KNOWING AND MANAGING THE MATERIAL TYPES AND THE VARIATIONS WITHIN ANY PARTICULAR MATERIAL.

SUCCESS IS ACHIEVED BY HAVING THE CORRECT MOISTURE CONTENT (keeping in mind that finer materials are more affected by apparent cohesion and are more sensitive to moisture variations)

AND THE CORRECT TYPE OF ROLLER COMBINATIONS (vibration to reduce inter-particle friction and kneading to overcome apparent cohesion.)

9.
DENSITY TESTING

HOW DO YOU EVALUATE COMPACTION ?

MORE TIME IS USUALLY SPENT ARGUING ON SITE ABOUT THIS TOPIC THAN IS SPENT ON CARRYING OUT A PROPER TRIAL SECTION IN THE FIRST PLACE !

IT IS IMPORTANT TO UNDERSTAND WHAT DENSITY YOU ARE SPECIFYING, HOW TO MEASURE IT AND HOW TO EVALUATE THE TEST RESULTS OBTAINED IN THE FIELD.

What Makes 100%?

What does it mean to give MORE than 100%?

Ever wonder about those people who say they are giving more than 100%? We have all been to those meetings where someone wants you to give over 100%.

How about achieving 103%?

Here's a little mathematical formula that might help you answer these questions:

If :
A B C D E F G H I J K L M
N O P Q R S T U V W X Y Z

Is represented as:
1 2 3 4 5 6 7 8 9 10 11 12 13
14 15 16 17 18 19 20 22 23 24 25 26

Then :

Then
H-A-R-D-W-O-R-K =
8+1+18+4+23+15+18+11 =98%
And
K-N-O-W-L-E-D-G-E =
11+14+15+23+12+5+4+7+5 =96%

But
A-T-T-I-T-U-D-E = 1+20+20+9+20+21+4+5
=100%
and
B-U-L-L-S-H-I-T = 2+21+12+12+19+8+9+20
= 103%

DENSITY SPECIFICATIONS

FILL Sel. SUBGRADE	Gravel / Sand Gravel / Sand	90% / 100% m.AASHTO 93% / 100% m.AASHTO
Lower SUBBASE Upper SUBBASE	Gravel Gravel	95% mod. AASHTO 97% mod. AASHTO
BASE – G4 BASE – G3	Gravel Crushed stone	98% mod. AASHTO 98 or 100% m.AASHTO
BASE – G2 BASE – G1	Crushed stone Crushed stone	85% Bulk Rel.Density 88% App. Rel.Density

DENSITY DEPENDENT ON MATERIAL TYPE
AND ON THE UNDERLYING SUPPORTING LAYER

DENSITY MEASUREMENT
Modified AASHTO Density Test

Interpretation of the correct Modified AASHTO density

IF HAVING DENSITY PROBLEMS DO THREE POINTS EACH SIDE OF OMC INSTEAD OF TWO TO DETERMINE THE 100% MOD VALUE MORE ACCURATELY.

WHAT ELSE CAN YOU DO ?

EVALUATION OF DENSITY TEST RESULTS

The following variables may affect the density test results measured on site :

- **Variable in the material along the road**
- **Variation in the compaction moisture**
- **Variation in the compactive effort applied**
- **Variation in the Troxler readings**
- **Variation in the laboratory Mod. Value**
- **Numerous other variables related to sampling techniques, plant operators, roller vibration efficiency, roller tyre pressures etc.**

VARIABLE MATERIAL ALONG THE ROAD :

All natural materials, even a crushed stone base, vary in grading and plasticity.

Good material selection and stockpiling control reduces the variability but does not eliminate it.

VARIABLE MOISTURE CONTENT

Uneven distribution and mixing of the compaction moisture or differential drying out during the mixing and compaction process will result in variable compaction densities.

Proper control during the addition and mixing of the compaction water is required.

VARIATION IN THE COMPACTIVE EFFORT APPLIED :

The type of rollers and the number of passes and the roller vibration settings, pneumatic tyre pressures and speed, as established during the TRIAL SECTION, must be maintained.

Variations in compactive effort will be required to suit the variations in the material and variations in moisture content along the road.

Even with good quality control you cannot eliminate all the variations !

THE TROXLER READINGS :

The density measurements obtained from a nuclear density gauge are affected by :

- **Poor calibration and inherent variables.**
- **In situ moisture content which must be compensated for by converting the measured "wet" density to a dry density.**
- **"Peg hole" error**
- **Uneven layer surface – (level with fine sand).**

VARIATION IN THE LABORATORY MOD. VALUE:

Variations in the Mod. Value will occur due to variations in the material (or very occasionally poor test result interpretation).

Take sufficient Mod. tests to ensure that you are comparing the field density against an appropriate Mod. AASHTO value.

Use statistical running average Mod. Values on long sections from the same borrow pit.

NUMEROUS OTHER VARIABLES ARE RELATED TO :

- **sampling techniques**
- **plant operators**
- **roller vibration efficiency**
  (soft or variable layer underneath ?)
- **roller tyre pressures and roller speed**
- **other factors specific to a site**

Observe, think and use your common sense.

A RE or Site Agent who sits in his office an assumes that everything is OK is not a good one !

CHECK SITE QUALITY CONTROL AND TECHNIUQUES BEFORE ASSUMING THAT THE TEST RESULTS ARE WRONG !

EVALUATION OF DENSITY TEST RESULTS

Some variability in materials, site conditions and laboratory testing is inherent to all road construction.

After reducing the variability as much as possible with good site control techniques what else can we do to ensure that a consistent standard of Quality is achieved ?

CONTROL THE VARIABILITY BY MEASURING IT !

IF YOU KNOW THE DEGREE OF VARIABILITY YOU CAN START TO INVESTIGATE THE CAUSE OF THE VARIABILITY.

WHAT IS AN AVERAGE ?

Average of 94.5, 95.0 & 95.5 = 95

Average of 90, 95 and 100 = 95

If you specify 95% density and want a quality road layer which set of density results is better ?

Ensure confidence by using statistics !

Lies, damn lies and STATISTICS !

Not as complicated as most people think !

And now students we have finally arrived at the formula for evaluating the statistical acceptance limits for testing the compaction density.

STATISTICAL EVALUATION OF DENSITY RESULTS

La = Ls + ka * Sn and Lr = Ls + kr * Sn

Where

La = acceptance limit

Lr = rejection limit

Ls = specified density

ka = probability factor which is a function of No. of test results & percentage failure (ø) allowed which = risk that an unacceptable product will be accepted

Sn = Standard Deviation of the test results

Sample size (n)	k_a		
	ϕ = 5%	ϕ = 10%	ϕ = 15%
4	0,747	0,445	0,220
5	0,821	0,520	0,300
6	0,878	0,576	0,358
7	0,923	0,620	0,403
8	0,961	0,656	0,440
9	0,993	0,687	0,470
10	1,020	0,713	0,496
12	1,065	0,755	0,538
14	1,101	0,789	0,571
16	1,131	0,817	0,598
18	1,155	0,840	0,620
20	1,177	0,860	0,640

Variable site compaction = high standard deviation which increases the rejection and acceptance limits.

GOOD QUALITY CONTROL REDUCES VARIABILITY

If the AVERAGE of all the density results for a particular section of work exceeds La then the section can be accepted with a degree of risk that not too much of it may be under the specified density.

If the AVERAGE is less than Lr then the section must be rejected as too much of it is below the specified density and the risk is <u>not</u> acceptable. It will fail !

If the AVERAGE is between Lr and La then the section may be accepted at between 67% and 99% partial payment at the discretion of the Engineer.

<u>Risk</u> of acceptance should be carefully evaluated !

Inspect the section visually before deciding on partial payment.

CONCLUSION

- CHECK THAT TESTS ARE CARRIED OUT CORRECTLY AND AT REPRESENATIVE POSITIONS.
- EVALUATE THE RESULTS CORRECTLY.
- DEVELOP A PROPER UNDERSTANDING OF STATISTICS.
- DO NOT DISCARD TEST RESULTS AS UNRELIABLE UNTIL YOU HAVE CHECKED THEM AND THE CONSTRUCTION PROCESS PROPERLY – MORE USUALLY SOMETHING IS BEING DONE INCORRECTLY ON SITE AS OPPOSED TO IN THE LABORATORY.

CONCLUSION

IF TESTS ARE CORRECT (THEY USUALLY ARE !)

AND YOU ARE STILL HAVING A PROBLEM GETTING THE SPECIFIED DENSITY

EITHER

THE CONSTRUCTION TECHNIQUE IS WRONG FOR THE TYPEOF MATERIAL BEING COMPACTED

OR

YOU HAVE SPECIFIED A DENSITY WHICH CANNOT BE ACHIEVED FOR THAT TYPE OF MATERIAL.

EVEN IF YOU FORGET

EVERYTHING ELSE

THE MOST IMPORTANT FACTORS TO REMEMBER WHEN COMPACTING SOILS AND GRAVELS ARE :

GRADING

CLAY CONTENT

MOISTURE CONTENT

ROLLER TYPE & COMBINATION

REVISION QUIZ : COMPACTION OF MATERIALS

What are the three main types of roller ?

1. _____

2. _____

3. _____

REVISION QUIZ : COMPACTION OF MATERIALS

When do you use a heavy, high amplitude single drum vibratory roller ?

_____

_____

When do you use a light, low amplitude twin drum vibratory roller ?

_____

_____

REVISION QUIZ : COMPACTION OF MATERIALS

What is the laboratory optimum moisture content and how do you determine it ?

_____

_____

_____

_____

REVISION QUIZ : COMPACTION OF MATERIALS

Why is the field compaction optimum moisture content not the same as the laboratory compaction optimum moisture content and how do you determine the field OMC ?

_____

_____

_____

_____

REVISION QUIZ : COMPACTION OF MATERIALS

Why are statistical methods used to evaluate the compaction density results ?

_____

_____

_____

_____

THANK YOU FOR ATTENDING THIS COURSE.

ANY QUERIES CAN BE ADDRESSED TO :

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