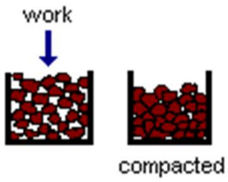
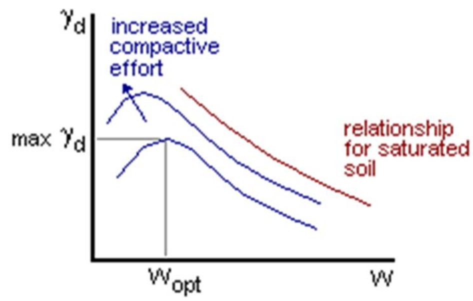
Compaction

- Compaction purposes and processes
- Laboratory compaction tests
- Specification and quality control
- Moisture condition value





Compaction is a process that brings about an **increase in soil density or unit weight**, accompanied by a **decrease in air volume.** There is usually **no change in water content.** The degree of compaction is measured by dry unit weight and depends on the water content and compactive effort (weight of hammer, number of impacts, weight of roller, number of passes). For a given compactive effort, the maximum dry unit weight occurs at an **optimum water content**.

Compaction

Compaction purposes and processes

- Compaction as a construction process
- Objectives of compaction
- Factors affecting compaction
- Types of compaction plant

Compaction is a process of increasing soil density and removing air, usually by mechanical means. The size of the individual soil particles does not change, neither is water removed.

Purposeful compaction is intended to improve the strength and stiffness of soil. Consequential (or accidental) compaction, and thus settlement, can occur due to vibration (piling, traffic, etc.) or self-weight of loose fill.

Compaction purposes and processes

Compaction as a construction process

Compaction is employed in the construction of road bases, runways, earth dams, embankments and reinforced earth walls. In some cases, compaction may be used to prepare a level surface for building construction.

Soil is placed in layers, typically 75 mm to 450 mm thick. Each layer is compacted to a specified standard using rollers, vibrators or rammers.

Refer also to Types of compaction plant and Specification and quality control

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Compaction purposes and processes

Objectives of compaction

Compaction can be applied to improve the properties of an existing soil or in the process of placing fill. The main objectives are to:

- increase shear strength and therefore bearing capacity
- increase stiffness and therefore reduce future settlement
- decrease voids ratio and so permeability, thus reducing potential frost heave

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Compaction purposes and processes

Factors affecting compaction

A number of factors will affect the degree of compaction that can be achieved:

- Nature and type of soil, i.e. sand or clay, grading, plasticity
- Water content at the time of compaction
- Site conditions, e.g. weather, type of site, layer thickness
- Compactive effort: type of plant (weight, vibration, number of passes)

Compaction purposes and processes

Types of compaction plant

- Smooth-wheeled roller
- Grid roller
- Sheepsfoot roller
- Pneumatic-tyred roller

- Vibrating plate
- Power rammer

Construction traffic, especially caterpillar-tracked vehicles, is also used.

In the UK. further information can be obtained from the Department of Transport and handbooks on civil engineering construction methods.

Types of compaction plant

Smooth-wheeled roller

- Self-propelled or towed steel rollers ranging from 2 - 20 tonnes
- Suitable for: well-graded sands and gravels silts and clays of low plasticity
- Unsuitable for: uniform sands; silty sands; soft clays

Types of compaction plant

Grid roller

- Towed units with rolls of 30-50 mm bars, with spaces between of 90-100 mm
- Masses range from 5-12 tonnes
- Suitable for: well-graded sands; soft rocks; stony soils with fine fractions
- Unsuitable for: uniform sands; silty sands; very soft clays

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Types of compaction plant

Sheepsfoot roller

- Also known as a 'tamping roller'
- Self propelled or towed units, with hollow drum fitted with projecting club-shaped 'feet'
- Mass range from 5-8 tonnes
- Suitable for: fine grained soils; sands and gravels, with >20% fines
- Unsuitable for: very coarse soils; uniform gravels

Types of compaction plant

Pneumatic-tyred roller

- Usually a container on two axles, with rubber-tyred wheels.
- Wheels aligned to give a full-width rolled track.
- Dead loads are added to give masses of 12-40 tonnes.
- Suitable for: most coarse and fine soils.
- Unsuitable for: very soft clay; highly variable soils.

Types of compaction plant

Vibrating plate

- Range from hand-guided machines to larger roller combinations
- Suitable for: most soils with low to moderate fines content
- Unsuitable for: large volume work; wet clayey soils

Types of compaction plant

Power rammer

- Also called a 'trench tamper'
- Hand-guided pneumatic tamper
- Suitable for: trench back-fill; work in confined areas
- Unsuitable for: large volume work

Compaction

Laboratory compaction tests

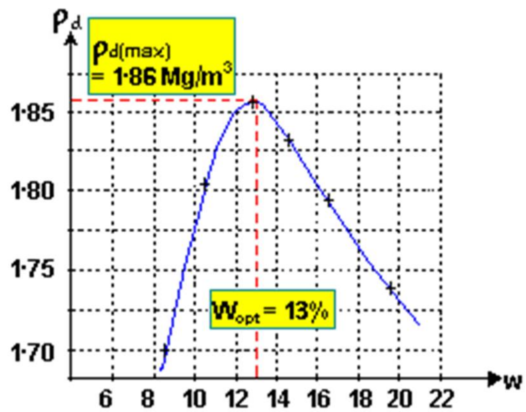
- Dry-density/water-content relationship
- Dry density and air-voids content
- Effect of increased compactive effort
- Effect of soil type
- Interpretation of laboratory data

The variation in compaction with water content and compactive effort is first established in the laboratory. Target values are then specified for the dry density and/or air-voids content to be achieved on site.

Laboratory compaction tests

Dry-density/water-content relationship

- Explanation of the shape of the curve
- Expressions for calculating density



The aim of the test is to establish the maximum dry density that may be attained for a given soil with a standard amount of compactive effort. When a series of samples of a soil are compacted at different water content the plot usually shows a distinct peak.

- The **maximum dry density** occurs at an **optimum water content**
- The curve is drawn with axes of dry density and water content and the controlling values are values read off:
  ρ_d(max) = maximum dry density
  w_{opt} = optimum water content
- Different curves are obtained for different compactive efforts

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Dry-density/water-content relationship

Explanation of the shape of the curve

For clays
Recently excavated and generally saturated lumps of clayey soil have a relatively high undrained shear strength at low water contents and are difficult to compact. As water content increases, the lumps weaken and soften and maybe compacted more easily.

For coarse soils
The material is unsaturated and derives strength from suction in pore water which collects at grain contacts. As the water content increases, suctions, and hence effective stresses decrease. The soil weaken, and is therefore more easily compacted.

For both
At relatively high water contents, the compacted soil is nearly saturated (nearly all of the air has

been removed) and so the compactive effort is in effect applying undrained loading and so the void volume does not decrease; as the water content increases the compacted density achieved will decrease, with the air content remaining almost constant.

Dry-density/water-content relationship

Expressions for calculating density

A compacted sample is weighed to determine its mass: **M** (grams)
The volume of the mould is: **V** (ml)
Sub-samples are taken to determine the water content: **w**
The calculations are:

$$\text{Bulk density, } \rho = \frac{M}{V} \quad [g/ml = Mg/m^3]$$

$$\text{Dry density, } \rho_d = \frac{\rho}{1+w} \quad [g/ml = Mg/m^3]$$

Worked example

A compacted soil sample has been weighed with the following results:
Mass = 1821 g Volume = 950 ml Water content = 9.2%
Determine the bulk and dry densities.

Bulk density ρ = 1821 / 950 = 1.917 g/ml or Mg/m^3

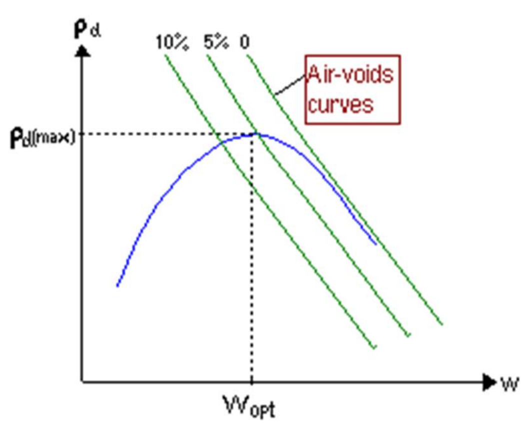
Dry density ρ_d = 1.917 / (1+0.092) = 1.754 Mg/m^3

Laboratory compaction tests

Dry density and air-voids content

A fully saturated soil has zero air content. In practice, even quite wet soil will have a small air content

$$\text{Air - voids content, } A_v = \frac{\text{Volume of air}}{\text{Total volume}}$$



The maximum dry density is controlled by both the water content and the air-voids content. Curves for different air-voids contents can be added to the ρ_d / w plot using this expression:

$$\rho_d = \frac{G_s \rho_w}{1 + wG_s}(1 - A_v)$$

The air-voids content corresponding to the maximum dry density and optimum water content can be read off the ρ_d/w plot or calculated from the expression (see the worked example).

Worked example

Determine the dry densities of a compacted soil sample at a water content of 12%, with air-voids contents of zero, 5% and 10%. (G_s = 2.68).

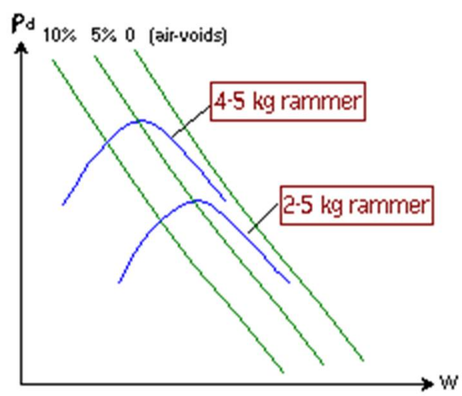
$$\text{For } A_v = 0: \quad \rho_d = \frac{2.68 \times 1.0}{1 + 2.68 \times 0.12} = 2.03 \text{ Mg/m}^3$$

$$\text{For } A_v = 5\%: \quad \rho_d = \frac{2.68 \times 1.0}{1 + 2.68 \times 0.12}\left(1 - \frac{5}{100}\right) = 1.93 \text{ Mg/m}^3$$

$$\text{For } A_v = 10\%: \quad \rho_d = \frac{2.68 \times 1.0}{1 + 2.68 \times 0.12}\left(1 - \frac{10}{100}\right) = 1.83 \text{ Mg/m}^3$$

Laboratory compaction tests

Effect of increased compactive effort

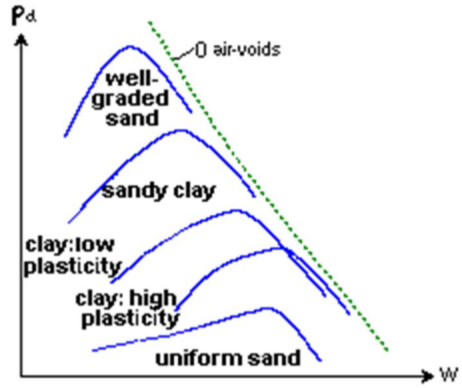


The compactive effort will be greater when using a heavier roller on site or a heavier rammer in the laboratory. With greater compactive effort:

- maximum dry density increases
- optimum water content decreases
- air-voids content remains almost the same.

Laboratory compaction tests

Effect of soil type



- Well-graded granular soils can be compacted to higher densities than uniform or silty soils.
- Clays of high plasticity may have water contents over 30% and achieve similar densities (and therefore strengths) to those of lower plasticity with water contents below 20%.
- As the % of fines and the plasticity of a soil increses, the compaction curve becomes flatter and therefore less sensitive to moisture content. Equally, the maximum dry density will be relatively low.

Laboratory compaction tests

Interpretation of laboratory data

- Example data collected during test
- Calculated densities and plot ρ_d / w curve
- Air-voids curves

During the test, data is collected:

1. Volume of mould (V)
2. Mass of mould (M_o)
3. Specific gravity of the soil grain (G_s)
4. Mass of mould + compacted soil - for each sample (M)
5. Water content of each sample (w)

Firstly, the densities are calculated (ρ_d) for samples with different values of water content, then ρ_d / w curve is plotted together with the air-voids curves.

The maximum dry density and optimum water content are read off the plot.

The air content at the optimum water content is either read off or calculated.

Interpretation of laboratory data

Example data collected during test

In a typical compaction test the following data might have been collected:
Mass of mould, M_o = 1082 g
Volume of mould, V = 950 ml
Specific gravity of soil grains, G_s = 2.70

Mass of mould + soil (g)	2833	2979	3080	3092	3064	3027
Water content (%)	8.41	10.62	12.88	14.41	16.59	18.62

For method of determining water contents see Soil Description and Classification

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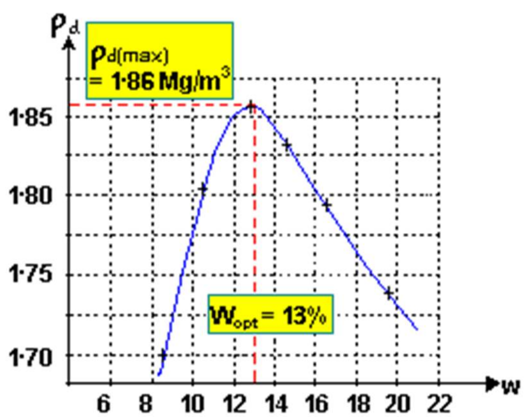
Interpretation of laboratory data

Calculated densities and density curve

The expressions used are:

$$\rho = \frac{M - M_o}{V} \quad \text{and} \quad \rho_d = \frac{\rho}{1 + w}$$

Bulk density, ρ (Mg/m^3)	1.84	2.00	2.10	2.12	2.09	2.05
Water content, w	0.084	0.106	0.129	0.144	0.166	0.186
Dry density, ρ_d (Mg/m^3)	1.70	1.81	1.86	1.851	1.79	1.73



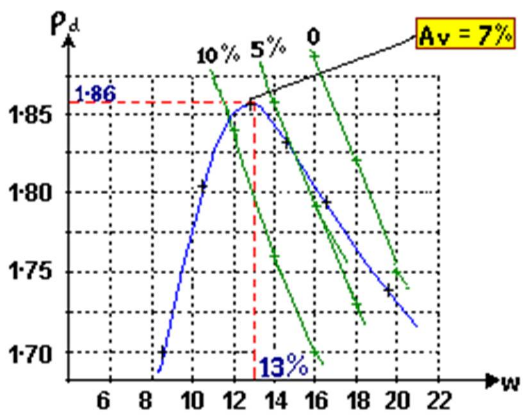
Interpretation of laboratory data

Air-voids curves

The expression used is:

$$\rho_d = \frac{G_s \rho_w}{1 + wG_s}(1 - A_v)$$

Water content (%)	10	12	14	16	18	20
ρ_d when A_v = 0%	2.13	2.04	1.96	1.89	1.82	1.75
ρ_d when A_v = 5%	2.02	1.94	1.86	1.79	1.73	1.67
ρ_d when A_v = 10%	1.91	1.84	1.76	1.70	1.64	1.58



The **optimum air-voids content** is the value corresponding to the maximum dry density (1.86 Mg/m³) and optimum water content (12.9%).

$$A_{v(opt)} = 1 - \frac{1.86}{2.70 \times 1.0}(1 + 0.129 \times 2.70) = 0.071 \quad (7.1\%)$$

[Compaction]

Specification and quality control

- [End-result specifications]
- [Method specifications]

The degree of compaction achievable on site depends mainly on:

- Compactive effort: type of plant + No of passes
- Water content: can be increased if dry, but vice-versa
- Type of soil: higher densities with well-graded soils; fine soils have higher water contents

End-result specifications require predictable conditions
Method specifications are preferred in UK.

End-result specifications

Target parameters are specified based on laboratory test results:

$$\text{Relative compaction} = \frac{\text{Achieved dry density}}{\text{Laboratory max dry density}}$$

Optimum water content working range, i.e. ± 2%
Optimum air-voids content tolerance, i.e. ± 1.5%

For soils wetter than w_{opt}, the target A_v can be used, e.g.
10% for bulk earthworks
5% for important work

The end-result method is unsuitable for very wet or variable conditions.

Specification and quality control

Method specifications

A site procedure is specified giving:

- type of plant and its mass
- maximum layer thickness and number of passes.
  This type of specification is more suitable for soils wetter than w_{opt} or where site conditions are variable - this is often the case in the UK. The Department of Transport publishes a widely used method specification for use in the UK.

Compaction

Moisture condition value

This is a procedure developed by the Road Research Laboratory using only one sample, thus making laboratory compaction testing quicker and simpler. The minimum compactive effort to produce near-full compaction is determined. Soil placed in a mould is compacted by blows from a rammer dropping 250 mm; the penetration after each blow is measured.

Moisture condition value

Apparatus and sizes

Cylindrical mould, with permeable base plate:
internal diameter = 100 mm, internal height at least 200 mm
Rammer, with a flat face:
face diam = 97 mm, mass = 7.5 kg, free-fall height = 250 mm
Soil:
1.5 kg passing a 20 mm mesh sieve

Moisture condition value

Test procedure and plot

- Firstly, the rammer is lowered on to the soil surface and allowed to penetrate under its own weight
- The rammer is then set to a height of 250 mm and dropped on to the soil
- The penetration is measured to 0.1 mm
- The rammer height is reset to 250 mm and the drop repeated until no further penetration occurs, or until 256 drops have occurred
- The change in penetration (**$\Delta\pi$**) is recorded between that for a given number of blows (**n**) and that for **4n** blows
- A graph is plotted of **$\Delta\pi$ / n** and a line drawn through the steepest part
- The **moisture condition value (MCV)** is give by the intercept of this line and a special scale

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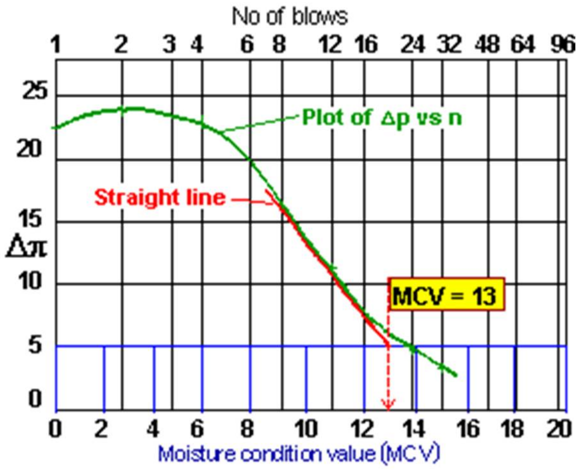
Moisture condition value

Example plot and determination of MCV



After plotting $\Delta\pi$ against the number of blows n, a line is drawn through the steepest part.

The intercept of this line and the 5 mm penetration line give the MCV

The defining equation is:**MCV = 10 log B**
(where B = number of blows corresponding to 5 mm penetration)

On the example plot here an MCV of 13 is indicated.

Moisture condition value

Significance of MCV in earthworks

The MCV test is rapid and gives reproducible results which correlate well with engineering properties. The relationship between MCV and water content for a soil is near to a straight line, except for heavily overconsolidated clays.A desired value of undrained strength or compressibility can be related to limiting water content, and so the MCV can be used as a control value after calibrating MCV vs w for the soil. An approximate correlation between MCV and undrained shear strength has been suggested by Parsons (1981).

Log s_u = 0.75 + 0.11(MCV)