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GUIDELINES ON COMPACTION EQUIPMENT FOR ROAD WORKS

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(As on 6th August, 2013)

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GUIDELINES ON COMPACTION EQUIPMENT FOR ROAD WORKS

1 INTRODUCTION

Road construction is an important part of infrastructure development. Even though compaction may account for less than 4% of the total construction cost, the benefits that accrue in terms of longevity and riding quality are immense. To achieve long life span of the road, it is essential that its structural strength is maintained. Compaction of soil helps in increasing the load bearing capacity, wear resistance, impermeability and life. Similarly, optimal compaction of bituminous binder and wearing course helps in improving the interlocking of the aggregate particles resulting in reduction in permeability and improving the durability of the road. The process of compaction of concrete involves removal of air voids to improve the strength. As such a comprehensive document "Guidelines on Compaction Equipment for Road Works" has been prepared.

Recognising the need for guidelines on compaction equipment for road works, the Mechanisation Committee (G-4) undertook the task of preparation of the guidelines for the same. The initial draft was presented by the Convenor of G-4 Committee. The Committee deliberated on the draft in a number of meetings. The Committee finally, approved the draft in its meeting held on 9th May, 2012 for placing before the GSS Committee. The General Specifications and Standards Committee (GSS) approved this document in its meeting held on 24th May, 2012. The Executive Committee in its meeting held on 30th May, 2012 at Kohima approved the document for placing it before the Council. The Council in its meeting held at Kohima on 1st June, 2012 approved the draft "Guidelines on Compaction Equipment for Road Works" subject to modification in light of comments offered in the meeting and authorized Convenor GSS Committees to finalize the document for printing. The document duly incorporating the comments of the Council members was approved by the Convenor, G-4 Committee on 5th June, 2013 for placing before the GSS Committee. The GSS Committee in its meeting held on 6th August, 2013 approved the "Guidelines on Compaction Equipment for Road Works" for publishing.

The Composition of G-4 Committee is as given below:

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1.1 Aim of the Document

With the increased emphasis on road and growth in road network, the technological development and mechanisation is taking place rapidly. Compaction is an important activity in road construction. Therefore various types of compaction equipment for soil, bituminous and concrete works have been incorporated in the document. The document will be helpful in selecting the appropriate type, better operation, and creating awareness about the maintenance aspects of the compaction equipment.

The life of the road depends on its structural strength. Optimum compaction is essential to achieve designed structural strength, long term performance, reduced maintenance costs and to enhance life of roads. Compaction of soil minimizes water seepage and helps the soil to acquire better strength. As strength increases it is possible to reduce the pavement thickness. Considerable economy in construction cost can, thus, be brought about. On account of better packing of soil grains by expelling air after compaction, the permeability of soil reduces. The densely packed soil grains do not allow water from external source to enter and hence can resist erosion. As compaction of road embankment and the subgrade is achieved under fully controlled conditions, the end result is a pavement foundation of known properties, at least within limits. This helps the pavement designer in assessing the subgrade strength to a reasonably accurate extent and thereby produces a safe and economical design.

2 PURPOSE OF COMPACTION

The purpose of compaction is to improve its engineering properties by increasing its density to make it strong enough to resist displacement or movement under loads that may be applied to it. Principal properties affected by compaction are following which are indicated in the **Fig. 1** also.

i) Structural strength.

ii) Load bearing capacity.

iii) Stability of fills.

iv) Impermeability.

v) Shear resistance.

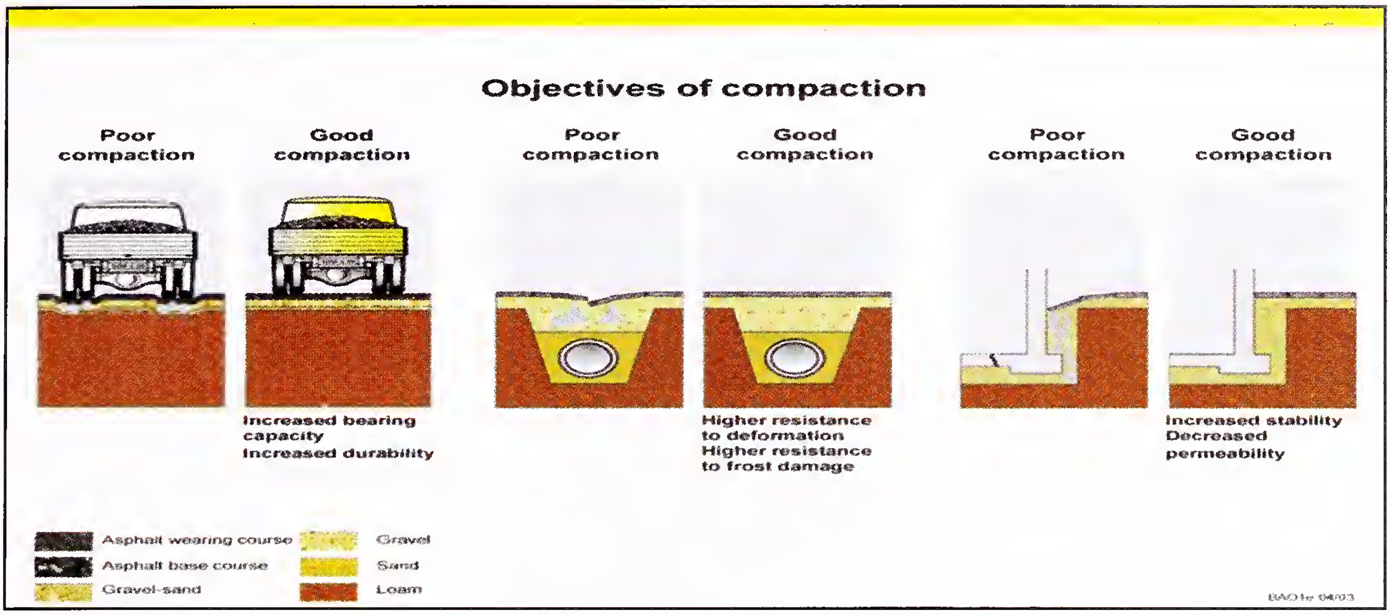


Fig. 1 Objective of Compaction

3 MECHANISM OF COMPACTION

There are four types of basic mechanisms on which different types of compaction equipment work **(Fig. 2)**. These are as under:-

a) Impact : It is a large force acting for a very short interval of time (Sharp Blow).

b) Pressure : It is the force acting on unit contact area.

c) Vibration: Shaking force.

d) Kneading : Manipulating or rearrangement.

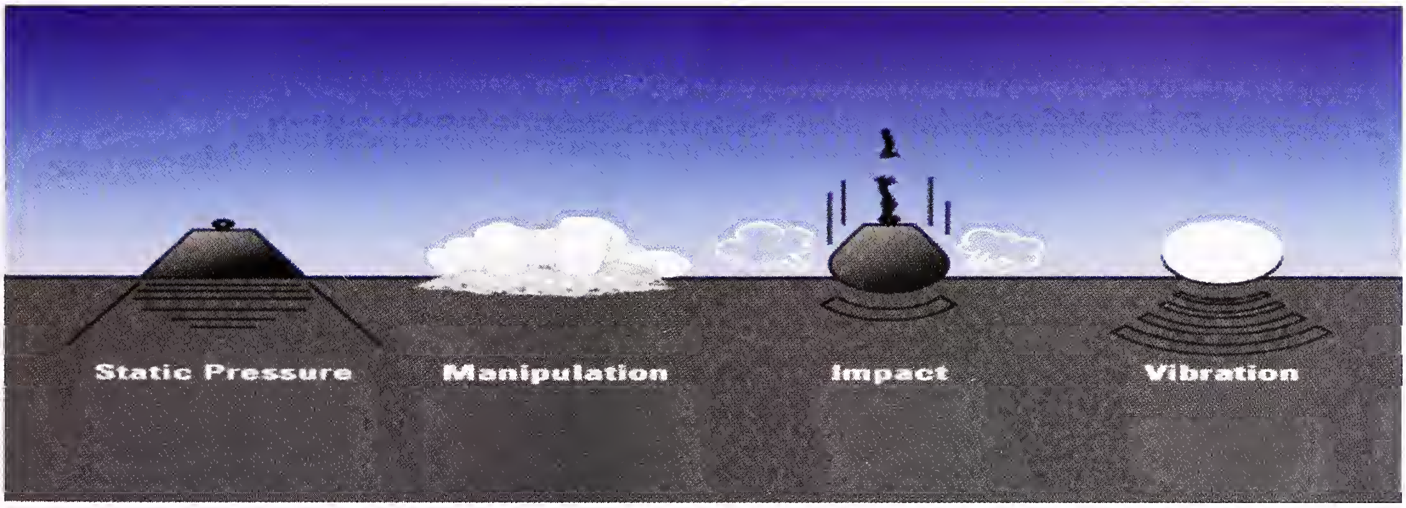


Fig. 2 Mechanism of Compaction

Compaction mechanisms available in compactors are as under **(Table 1)**.

Table 1

Compactor Type	Impact	Pressure	Vibration	Kneading
Sheepsfoot		√		√
Tamping foot	√	√		
Vibrating plate	√		√	
Rammer	√		√	
Pneumatic Roller		√		√
Static Roller		√		
Vibratory Roller	√	√	√	

4 TYPES OF COMPACTION EQUIPMENT : COMPACTION EQUIPMENT ARE OF THE FOLLOWING TYPES

i) Rammer

ii) Vibratory plate compactor

iii) Roller

4.1 Rammer

Rammer is a device used for compaction of soil through manual or mechanised means. As the machine hits the soil, the impact affects the hard surface below and then returns upward. This sets all particles in motion and compaction takes place. Rammer delivers a high impact force which is suitable for cohesive and semi-cohesive soils. Frequency range is 500 to 750 blows per minute. Rammer gets compaction force from a small gasoline or diesel engine powering a large piston set with two sets of springs. Rammer compacts the surface through impact and vibration. The diagrams of the rammer powered by an engine and manual means are shown in **Fig. 3**. The dimensions indicated in the diagram are the plate dimensions.

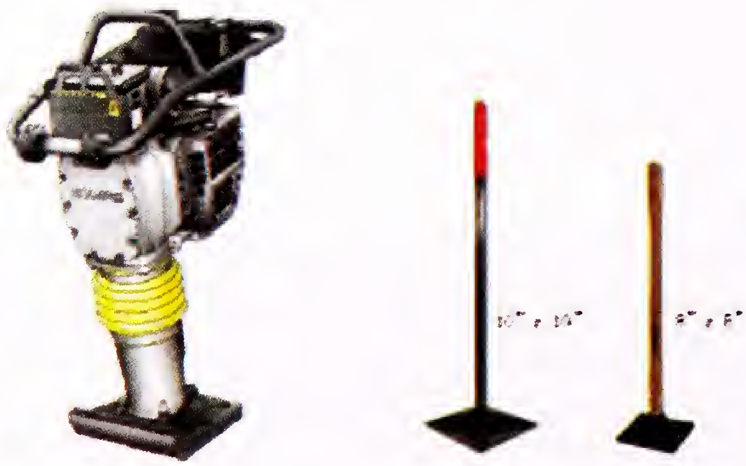


Fig. 3 Rammer

4.2 Vibratory Plate Compactor

The vibratory plate compactor has a large vibrating base plate and is suited for creating a level grade. The gasoline or diesel engine drive one eccentric weight at a high speed to generate compaction force. The engine and handle are vibration-isolated from the vibrating plate. Vibration is the one principal compaction effect. The diagram of the vibratory plate compactor is shown in **Fig. 4**.

Fig. 4 Vibratory Plate Compactor

The heavier the plate, the more compaction force it generates. Frequency range is usually 2500 vpm to 6000 vpm. Plate used for bituminous mix have a water tank and sprinkler system to prevent bitumen from sticking to the bottom of the base plate. These are used for compacting very small areas. Vibratory plate compactor operate on low amplitude and high frequency, designed to compact granular soils and bitumen.

Vibratory plate compactor is suitable for compaction of embankments, sub base and base course as well as asphalt surface, where the size of the job vary from potholes to around a thousand square metre. Light vibratory plate compactor is suitable for coarse-grained soils compacted in thin layers. Thicker layers of coarse-grained soils require larger types of plate, as do semi-cohesive soils. The compactor can be equipped with a water sprinkler system, and can be used to compact small areas of bituminous surface.

Reversible Vibratory Plate Compactor

The vibrations are generated in the plate with the help of eccentric weights rotated with a prime mover. However, in the case of reversible vibratory plate compactor (shown in **Fig. 5**), there are two eccentric weights instead of one weight as in the case of vibratory plate compactor. Due to their weight and force, reversible plate is ideal for semi-cohesive soils (mix soils). Unlike standard plate, the reversible forward travel may be stopped and the machine will maintain its force for “spot” compaction.

Fig. 5 Reversible Vibratory Plate Compactor

4.3 Roller

A roller is a compactor used to compact soil, gravel, concrete, or asphalt in the construction. Selection of roller depends on the type of application, thickness of the layer and the properties of the material to be compacted. The material properties include grain size distribution, grain shape, maximum grain size, water content etc. The machine parameters include the roller weight, the compaction type (static or vibratory) and the diameter and the surface of the drum (Sheepsfoot or smooth). The machine weight can be increased by adding water, sand/steel inside the wheels.

4.3.1 *Classification of roller*

Rollers are broadly classified into the following types depending on their utility in different situations.

a) Static Roller
   - Three wheeled roller
   - Tandem Roller (Two wheeled roller)

b) Sheepsfoot roller.

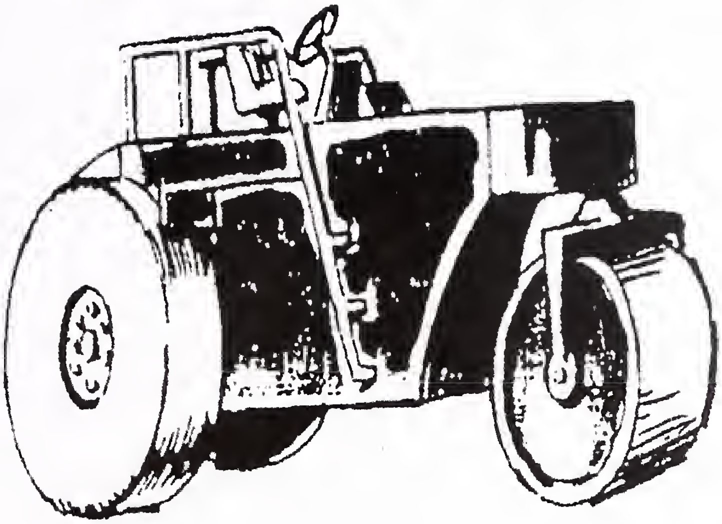
c) Tamping foot roller

d) Pneumatic tyred roller

e) Vibratory roller (Single & Double drum)

4.3.1.1 Static roller

Static roller consists of smooth wheel drum which is manufactured as three rolls, or tandem roll self propelled units. The diagram of a three wheeled roller and a tandem roller are shown in **Fig. 6(a) and 6(b)** respectively. It works on the principle of static pressure which is defined as the ratio of static weight and length of contact of the rolls with the surface. Static three wheeled roller has two driving steel rear wheels and a steering steel wheel in the front.



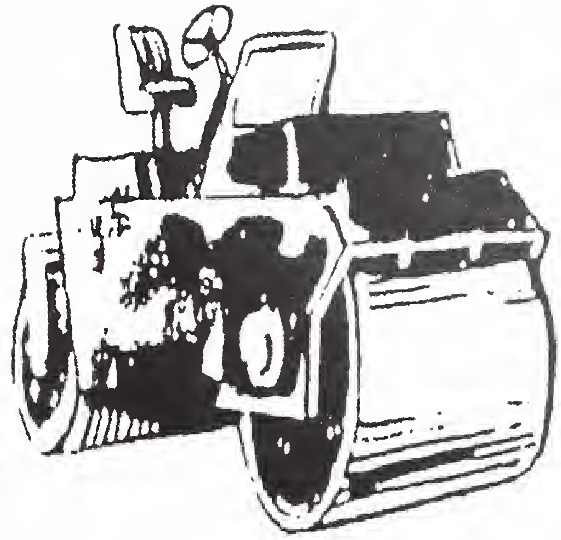


Fig. 6(a) A Conventional Three-Wheeled Roller (b) A Two-Wheeled Tandem Roller

The contact pressure exerted by the roller helps in densifying the underlying material. Axle load, roll diameter and rolling speed influence the compaction performance. Axle load measures the compaction capacity; heavier axle load have more compactive effectiveness. Roll diameter influences surface finish. Smaller diameter roller shove material ahead of the roll causing ridges and surface cracks. Rolling speed influences the periodicity of impacts and the ability of the roller to keep pace with the paver. Thicker individual layers require slower rolling speed or more passes. Thinner layers can be rolled faster or they will need fewer pass. Smooth wheeled steel roller is generally equipped with scraper bars and sprinkling device. It prevent material from sticking to the wheels and causing irregularities in the compacted surface.

The capacity of the static or smooth wheeled roller ranges from 2 to 20 Tonne which can be increased by adding sand or water as ballast to the roll.

Three wheeled roller has two large diameter wheels at the rear and one smaller diameter roll at the front. The width of the front roll is greater than that of the rear roll. The diameter of the drive wheel (Rear Roll) mounted at the rear may vary from 1.40 to 1.75 m. There is an overlap between the front and the rear roll. The weight distribution between the rear and the front roll is in the range of 55:45 to 60:40. Contact pressure is lower at deeper penetration and increases with decrease in penetration.

In the case of tandem roller, the static load per unit length (32-45 kg/cm) is less than that of three wheeled roller (50-80 kg/cm).

4.3.1.2 Sheepsfoot roller

Sheepsfoot roller has metal projections of various shapes on its rolls for penetrating and compacting the lower portions of a formation or sub-grade. One or more hollow steel cylindrical drums with rows of steel studs like sheeps foot are mounted on it. Sheepsfoot roller are slow, have high rolling resistance and the cost of compaction per unit volume is very high.

These are best suited for clayee/cohesive soils due to the small contact area of the foot and the high loading.

A Sheepsfoot pad is cylindrical and the pad face is circular. The pads on Sheepsfoot drums penetrate through the top lift and actually compact the lift below. When a pad comes out of the soil, fluffs the material. The result is a loose layer of material on top. When more fill is spread, the top lift will be fluffed and the previous layer will be compacted. A sheepsfoot roller compacts from the bottom up. The cylindrical drum can also be filled with water or sand to add extra weight while compacting. Efficient compaction is considered to take place when there is a gradual "walkout" of the roller lugs with successive coverages. The important factors are the pressure on the foot and coverage of ground obtained per pass. The parameters that really matter are gross weight of the roller, the area of each foot, the number of lugs in contact with the ground at any time.

The thickness of soil compacted is generally of the order of 30 cm with a foot/lug of 20 to 25 cm. The rolling should continue till the foot does not penetrate the surface fully. This limit is called "walkout" on the surface.

The loose top lift material can act as a sponge when it rains and can slow the compaction process. Sheepsfoot roller work normally at speeds from 6-10 km/h. Pressure and kneading are the only compactive efforts exerted on the soil.

4.3.1.3 Padfoot roller/tamping roller

A tamping roller consists of one or more hollow steel cylindrical drums with rows of steel studs mounted on it. Tamping foot compactors are high speed, self-propelled, non-vibratory roller. The pads are tapered with an oval or rectangular face. This Roller is shown in **Fig. 7**.

Fig. 7 Padfoot Roller/Tamping Roller

This roller is similar to sheepsfoot roller with lugs of larger area than Sheepsfoot roller. The static padfoot roller, also called tamping roller, have static weights in the range of 15 to 40

Tonne and their static linear loads are between 30 and 80 kg/cm. It has a higher production capacity in comparison to sheepsfoot roller.. The degree of compaction achieved is more and there is more uniformity of density. It operates at high speed and is capable of even breaking large lumps.

It compacts from the bottom of the lift to the top. But because the pads are tapered, the pads can walk out of the lift without fluffing the soil.

Tamping foot roller have working speeds in the range of 24-32 km/h, the forces of compaction are due to pressure and impact which results in increase in the compaction capacity as well as production. They are best suited for large projects.

There are also self-propelled padfoot roller weighing equal to or more than 11 tonne having a linear load of 30 kg/cm. They can compact clay materials from 30 cm to 40 cm thickness.

4.3.1.4 Pneumatic tyred roller

Pneumatic tyred roller consists of multi axles on which a number of rubber tyre wheels are fitted as shown in **Fig. 8**. Pneumatic tyred roller are available in light, medium and heavy weights. They compact soil/bituminous mix by pressure and kneading action. The mode of load application through the lift tends to compact the mix from bottom to top Hence a combination of Pneumatic tyre Roller (PTR) and Tandem Vibratory Roller can achieve best compaction results. The total weight of the PTR can be increased from 11 tonne to 25 tonne or more by ballasting with steel sections or by ballasting using water, sand or pig iron. Each manufacturer recommends his own limit for ballasting. In order to create kneading action, the "wobble-wheel roller" where the tyres are mounted at a slight angle with respect to axle is used. The pressure of the tyre should not increase beyond the bearing capacity of the soil.

Fig. 8 Pneumatic Tyred Roller

The combination of tyres on the rear and front axles may be even or odd. Some vertical movement is allowed for between individual and pair of tyres to enable the roller to move on an uneven ground while maintaining constant contact pressure.

A pneumatic tyred roller is rated in terms of ground contact pressure. The compactive effort can be varied by adjusting the inflation pressure of the tyres. Care needs to be taken to ensure that the load application is uniform over the surface area of contact which otherwise may lead to creation of irregular density zones in the pavements. Contact area, Gross weight, Tyre pressure and Speed are the factors that influence the performance of the roller. Ground contact pressure is the essential factor in determining the compacting effectiveness of the roller. This helps in determining the depth to which compaction is possible. Rolling speed also affects the compaction time and ability to keep up with the Paver.

Pneumatic tyred roller is used on small to medium size compaction jobs, primarily on granular materials. Pneumatic tyred roller is very effective in bituminous compaction where the design mix has high content of fines. With large tyres and heavy wheel loads, they are capable of considerable penetration of compactive effort. However, this often causes excessive displacement of surface material and rupture cracking. The large tyres also have a tendency to cause bouncing. The weight and high rolling resistance demand powerful prime movers, resulting in high cost. The kneading action of pneumatic tyred roller makes the bituminous surface smoother. Load requirement for compaction at different depth are shown in **Table 2**.

Table 2 : Load Requirements for Compaction at Different Depths

Passes	Job Characteristics	Maximum Depth of Layer (in mm)	Wheel Load Desired (in tons)
4 to 8	Compaction of loamy sand	300 mm 500 mm 700 mm	1.5 to 1.7 2.0 to 2.5 3.0 to 4.5
4 to 6	Compaction of bituminous material	80 mm 130 mm 200 mm	1.5 2.5 4.0
4-6	Compaction of cement concrete	100 mm 150 mm	4.0 6.0

During compaction, the contact area of tyre changes with each pass based on the mix material being compacted. If the tyre sinks in to the mix material, the tyre pressure should be reduced to have low pressure against the ground. Alternatively, if tyre remains firm on mix material, tyre pressure may be increased to have higher pressure against the ground. This can be judged by the operator of pneumatic tyred roller. Central air pressure control system provided in the machine allows the operator to maintain a selected constant pressure on all tyres during rolling.

Tyre inflation pressure should be regulated with compressor system fitted with the machine between 2 kg/cm^2 to 9 kg/cm^2 during travel. Pressure safety valve is installed at appropriate location. Pressure drop below 2 kg/cm^2 will damage the tyre as well as the laid mat surface; therefore same has to be maintained. Some manufacturers have made provision in the machine to vary the tyre pressure as per requirement from operator's cabin during operation of the machine.

Pneumatic tyred roller has been designed with specific feature to lock the surface particles together and create a surface seal for smooth riding quality. The technical aspects of pneumatic tyred roller are as under:

a) **Number of Tyres:** Self propelled pneumatic tyred roller has odd or even number of tyres mounted on tandem and rear axle.

b) **Type of Tyres:** The compaction technology depends on tyre geometry i.e. tyre diameter and ply rating, and compaction characteristics. Three types of tyres are used for this work.

   i) Flat tyres/Wide Base Tyres: These are used at a fixed pressure of 0.4 MPa and cause less lateral movement of particles than diagonal tyres. These are used for surface sealing on bituminous work.

   ii) Diagonal Tyres: Industrial tyre manufacturers make diagonal and radial tyres as standard tyres. These are more durable and can be used at different pressures ranging between 0.3 to 0.9 MPa depending on ply rating.

   iii) Radial tyres are preferred over diagonal tyres for pneumatic tyred roller used on bituminous work. Front and rear wheels are connected through different system, which prevents shoving of the mix material during turning. Radial tyre is categorized under flat tyre and differs owing to the construction of shoulder pattern. The radial pattern enables lesser rolling resistance, lesser heat generation, tread stiffness ensuring uniform distribution of load during compaction.

c) **Tyre Overlap:** There is some gap between the tyres provided in front and rear tyres. This gap is filled with the movement of tyres. To achieve uniform compaction effect and avoid tyre marks, front and rear tyres over lap in the gap between 30 to 50 mm. This is shown in **Fig. 9**.

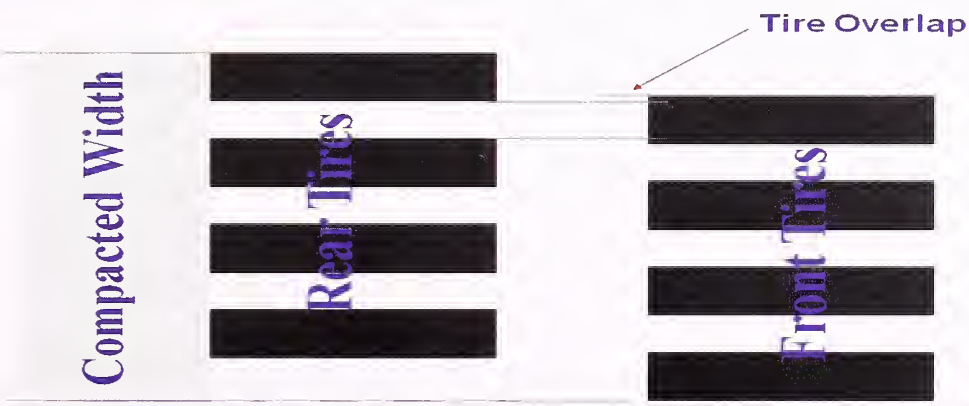


Fig. 9 Overlap of Tyres

d) **Oscillating or Pivoting Arrangement:** Pneumatic tyred roller is provided with oscillating/pivoting arrangement on at least one axle either on front or rear axle. Individual tyres fitted with this arrangement move up and down independently of one another, provide weaving action and improve kneading action. The combination of horizontal and vertical forces produces a kneading effect that achieves an excellent sealing effect. Kneading action improves bitumen pavement surface by reducing pavement permeability. This is shown in **Fig. 10**.

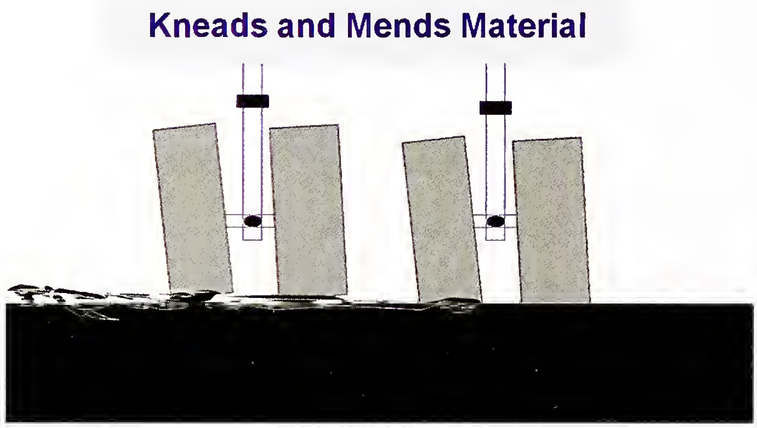


Fig. 10 Oscillating and Pivoting Arrangement of Axles

e) **Bitumen Pickup:** During initial rolling with pneumatic tyred roller, there is much variation in temperature of tyres and mat being compacted. Therefore, it is the tendency of tyres to pick up the mix particles at initial stage. To avoid this, pneumatic tyred roller should be moved on the bitumen surface, which has already been compacted and is still hot. Water from sprinkler system also prevents the pickup of mix material. Skirts around the pneumatic tyres, restrict the contact of cold winds with tyres and keep them hot.

f) **Compactive Performance:** The level of compactive harmony between a roller and the material it is expected to compact is termed as compactive performance. The user selects the parameters to match the productive requirements. It is the most important feature of pneumatic tyred roller by which its compaction performance can be measured. It is expressed in the following ways:

Operating Weight of Pneumatic Tyred Roller

Operating weight of pneumatic tyred roller can be increased by adding ballast on it. Scrap iron bars, sand or water are used as ballast. Loading and unloading of scrap iron bars is time consuming and transportation is also a costly affair. Sand has the tendency of drying up, hence there is a change in operating weight depending on the atmosphere, which has to be checked regularly.

$$\text{Load on each wheel} = \frac{\text{Weight of pneumatic roller + Ballast}}{\text{Number of wheels}}$$

Total operating weight of pneumatic tyred roller is distributed on each wheel depending on number of wheels provided on roller. The load on a single tyre ranges from 450 Kg to 3750 Kg. The tyre inflation pressure and wheel load both influence the ground contact pressure, which is depicted in the following table. For a given value of wheel load, increasing the inflation pressure results in increase in the ground contact pressure. This is shown in the **Table 3**.

Table 3 : Ground Contact Pressure for Various Wheel Loads and Inflation Pressure

Wheel Load (kg)	**Inflation Pressure (KPa)**						
	240	**350**	**480**	**620**	**720**	**830**	
1125	2.0	2.4	2.7	3.0	3.3	3.4	GCP
1375	2.2	2.6	3.0	3.3	3.5	3.8	GCP
1825	2.4	2.8	3.4	3.8	4.0	4.3	GCP
2250	2.5	3.1	3.6	4.1	4.4	4.8	GCP
2750	2.6	3.2	3.9	4.4	4.8	5.2	GCP
3000	2.7	3.3	4.1	4.6	4.9	5.4	GCP
GCP: Ground Contact Pressure (kg/cm^2)							

4.3.1.5 Vibratory roller

A vibratory roller is an improved version of an ordinary smooth- steel roller by attaching two rotating weights to the axle as shown in **Fig. 11**. Vibratory road roller may be towed, self propelled or manually controlled. Self propelled roller may have single or tandem vibrating drums. Smooth drum vibratory compactors generate three compactive efforts: pressure, impact and vibration.

Fig. 11 Smooth Drum Vibratory Roller

Vibratory Rollers are of the Following Types

a) **Towed Vibratory Roller :** The weight of the roller ranges from 4.0-6.0 Tonne but there are heavy duty roller weighing even 15 Tonne which can be towed with the help of a tractor or shovel as shown in **Fig. 12**. With the heavy roller, the layer depth to be compacted and daily output can be increased.

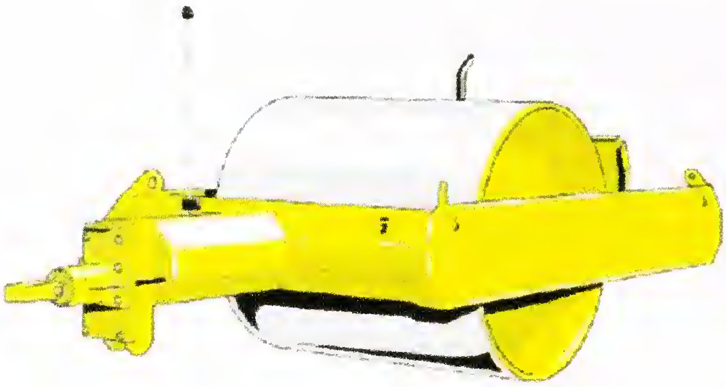


Fig. 12 Towed Vibratory Roller

b) **Self Propelled Roller :** A self propelled roller has a steel drum and two pneumatic wheels at the rear as shown in **Fig. 13**. Its dead weight vary from 8-12 Tonne. This roller can be ballasted with water, wet sand or steel. The drum drive is provided with the hydraulic motor which provides tractive effort.

Fig. 13 Self Propelled Roller

c) **Tandem Vibratory Roller :** The roller has vibration and drive on both the drums as shown in **Fig. 14**.

Fig. 14 Tandem Vibratory Roller

d) **Combination Roller :** This roller has a vibrating drum on one axle and on the other there are pneumatic tyres as shown in **Fig. 15**. It is used mostly for bituminous work where the beneficial effect of both the vibratory roller and pneumatic wheels are employed.

Fig. 15 Combination Roller

e) **Double Drum Walk Behind Roller (Duplex Roller) :** This type of roller (shown in **Fig. 16**) is used for compacting soil in restricted areas, trenches etc.

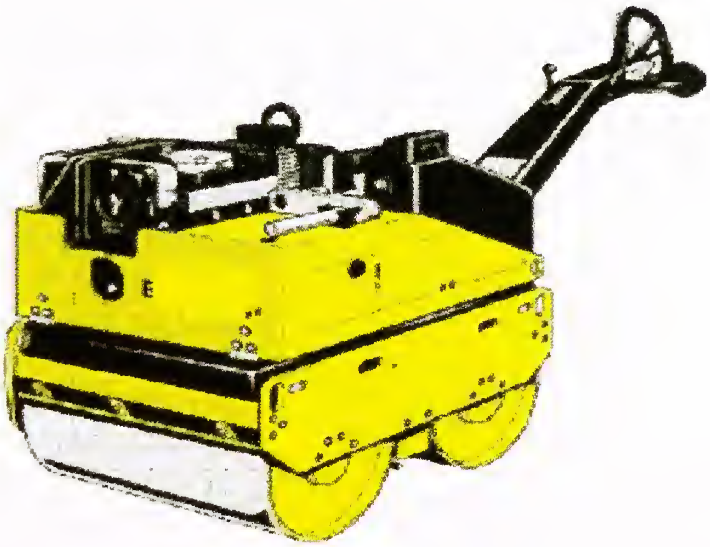


Fig. 16 Double Drum Walk Behind Roller

f) **Light Tandem Roller :** This is a versatile machine (shown in **Fig. 17**) which can be used for a wide range of Compaction jobs eg. Compaction of shoulder, approach roads and pathways. The static weight is in the range of 900-1500 Kg.

Fig. 17 Light Tandem Roller

g) **Multipurpose Roller :** This Roller is shown in **Fig. 18**. This roller is mainly used on earth work such as Trench and sever line construction, backfills and foundation work - wherever high demands are placed on mobility, maneuverability and simple operation under severe soil conditions.

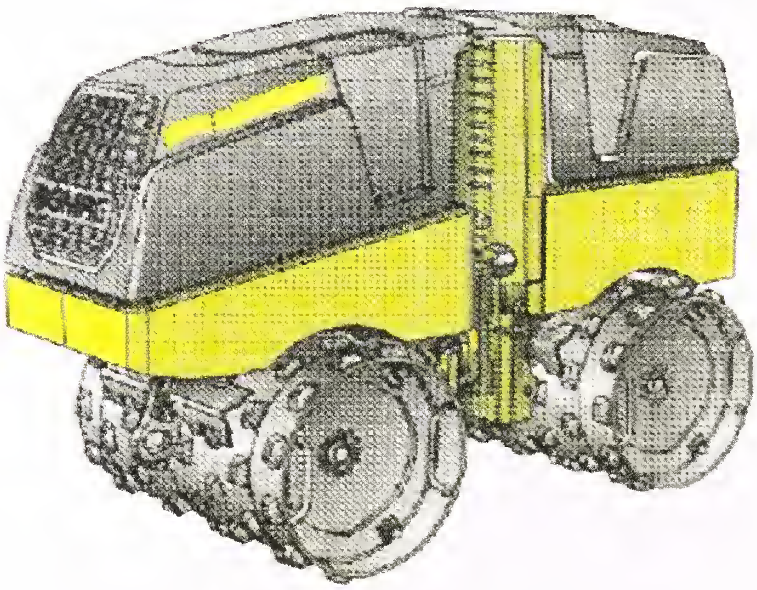


Fig. 18 Multipurpose Roller

The vibration is generated by one or more eccentric weights rotating on one shaft, centered in the drum. By changing the size of the eccentric weight, it is possible to generate different amplitude. With this type of system the drum will vibrate in a revolving motion generating "Circular amplitude". Compaction is achieved mainly by the series of compression waves penetrating the soil or bituminous mix in combination with the effective static weight of the drum. The resulting compaction force is almost vertical.

Density results from forces generated by a vibrating drum hitting the ground. Compaction results are a function of the frequency of these blows as well as the force of the blows. Working speed is important because it dictates how long a particular part of the fill will be compacted.

For vibratory compactors, working speed from 2.0 to 6.0 km/h will provide the best results. The machine should be able to move forward and reverse with vibration to achieve higher productivity.

Smooth drum vibratory compactors are used mostly in granular materials, with particle size ranging from fine sand to large rocks. They are also used on semi-cohesive soils with cohesive soil content up to 10%.

Effect of Characteristics of Vibratory Roller

High amplitude and low frequency are used to compact soft soils and to reach deeper zones while low amplitude and high frequency are used for stiff soils and shallow depth. Further High amplitude and low frequency setting is used for compaction of a thick layer whereas low amplitude and high frequency setting is used for the compaction of thin layer.

For example on a first pass the roller might use a high amplitude and low frequency but at the fourth pass, it sets itself with a low amplitude and high frequency.

The effectiveness of compaction depends upon several factors involving interaction between the equipment and the soil being compacted. Key parameters of vibratory rollers are shown in **Fig. 22**. These factors include.

a) **Operating Frequency :** Frequency control the number of impacts per metre between the drum and mat. Each material has natural frequency under which it vibrates or show maximum displacement of particles. Maximum compaction occurs when it vibrates near resonant frequency. The variation of frequency is shown in **Fig. 19**. Typical values of natural frequency for different soil type is given in **Table 4**.

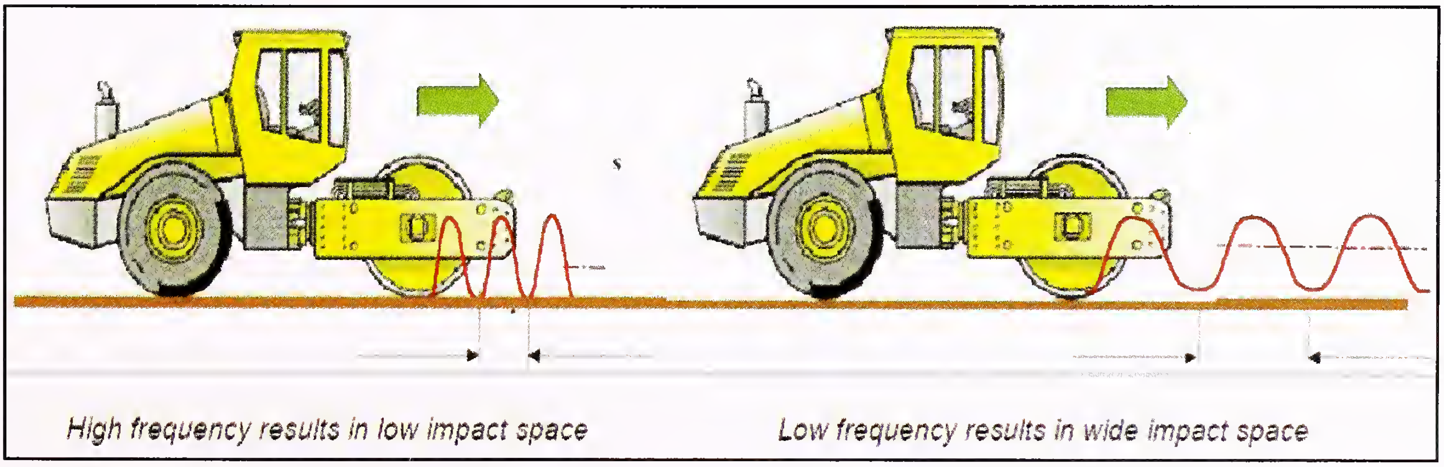


Fig. 19 Effect of Frequency

Table 4 : Natural Frequency for Different Soil Types

Soil Type	Natural Frequency Hz
Fine Sand	~24
Sand, non uniform	~27
Medium sand, uniform	~24
Sand , Wet	~33
Sand Dry	~22
Sand gravel	~24-29
Loam, solid	~25-29
Loam, Loose	~21-23
Clay, moist	~22
Clay, dry	~28
Shell limestone	~30

b) **Amplitude of vibration :** It is the vertical displacement of the roller drum. Amplitude of vibration is directly linked to the impact force. (**Fig. 20**). Higher amplitude results in achieving higher thickness of compacted material at minimum number of passes, thereby improving productivity.

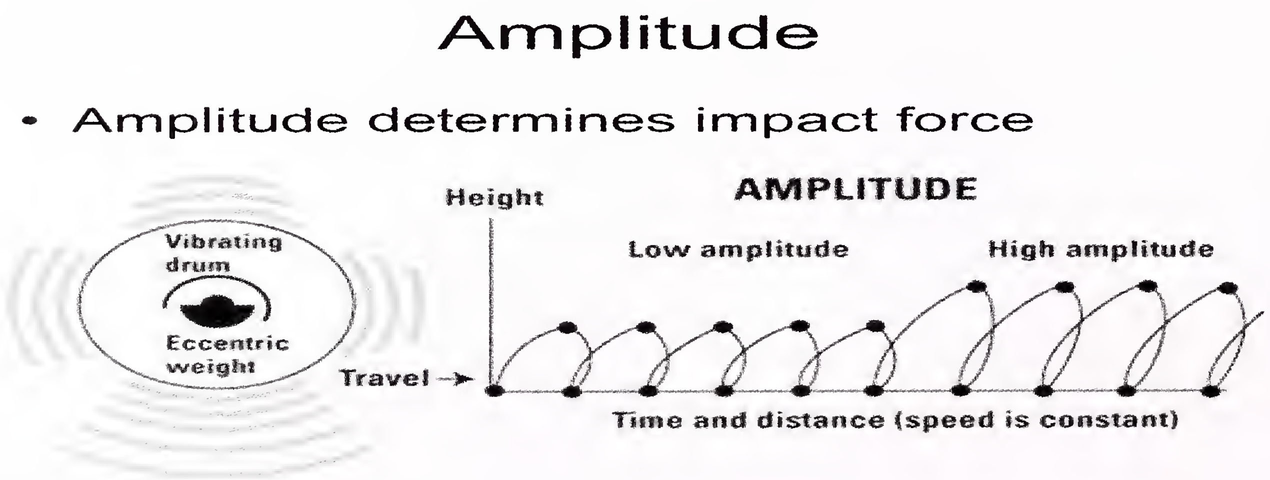
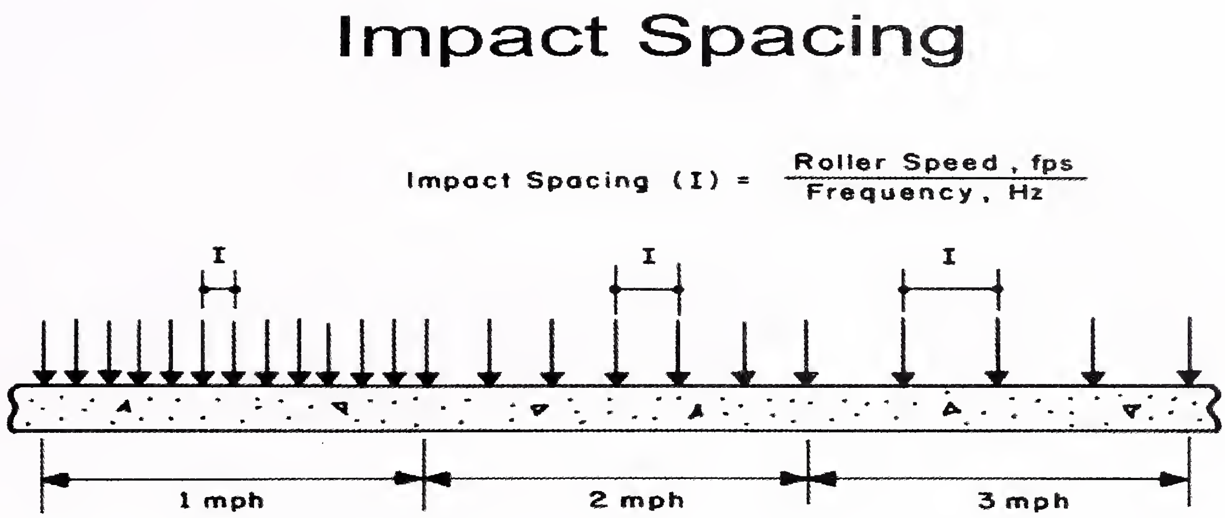


Fig. 20 Effect of Amplitude

c) **Speed of Travel :** Slow speed results in closeness of impacts, whereas high speed results in increase in the spacing between the blows. This is shown in **Fig. 21**. An even lower speed may be required for the initial passes.



Note : 1mph = 1.61 km/h

Fig. 21 Effect of Travel Speed

4.3.2 *Difference between conventional and new generation roller*

S.No.	Conventional Roller	New Generation Roller
1. a)	Conventional roller is a Static three wheeled Roller.	Vibratory road roller and its improved versions are known as new generation rollers.
b)	In case of conventional, the compactive effort is applied through static pressure only	Vibratory roller exerts compactive effort through dynamic force caused by vibration, in addition to static pressure. The dynamic force may be varied by changing the frequency and amplitude of vibration as per materials to be compacted, to achieve the best results.
c)	Compression starts from top of the surface	Vibratory road rollers, their improved version and intelligent compactors are beneficial from several considerations, like: a) Optimum compaction can be achieved with a minimum number of passes. b) Compaction can be done up to greater depths and in a uniform manner. c) Output is more than conventional roller d) Compaction starts from bottom of surface.

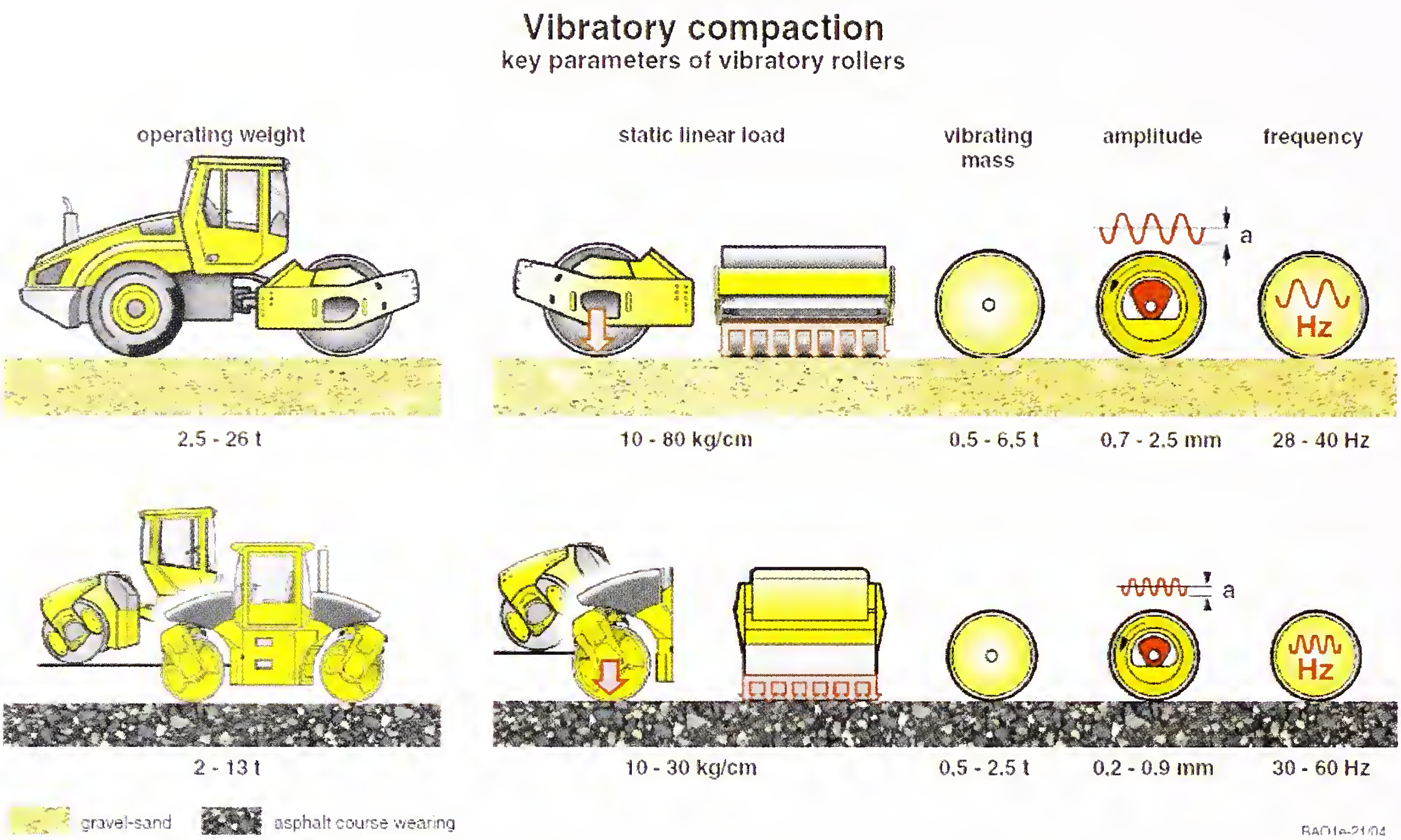


Fig. 22 Vibratory Compaction

4.3.3 *Intelligent compaction system*

This state of the art technology is the combination of the measurement technology with the regulation system, that uses the measured information to adapt the equipment performance continuously to the required conditions. This system controls and automatically changes the different compaction parameters of the roller viz., amplitude and frequency. The modulus measurements are made by the roller itself. The system is programmed with the range of acceptable modulus values (target value) and automatically adjusts the roller settings to achieve target modulus if the readings are not within tolerance. The vibration amplitude can be changed automatically with the help of accelerometer sensor to the machine. The Electronic Control Unit (ECU) gives a signal regarding the amplitude as per the stiffness of the ground. The data acquisition software with an interface will measure and record vibration which can be used for analysis as the large data stored in the roller computer. The roller's speed is controlled by the operator.

Data management is very critical while implementing Intelligent Compaction (IC). The IC technologies such as Tracking roller passes and overlap coverage are very useful during poor visibility especially when working during night times and also helps in imparting uniform compaction for full width of the road.

The Intelligent Compaction rollers are also equipped with Global Positioning System (GPS) measurements and a documentation system that allows for continuous recording of the roller location, number of passes and the corresponding stiffness-related output.

Furthermore such adjustments guarantee that the material will not be "over-compacted", the amplitude and frequency are driven down automatically when the targeted percentage of absolute compaction is achieved and the roller passes such a spot without vibration. This system goes on to check possibility of under compaction, over compaction or other problems and as a consequence goes on to offset extra expense.

Compactometer is fitted on the roller to measure the degree of compaction. The degree of compaction of the rolled surface is displayed on a panel in operator's cabin. The various types of Compactometers have been designed by different manufacturers. A brief description is as under.

Compactometer

The Compactometer consist of the following components:

i) A transducer bolted to the vibrating roller drum shaft to measure the change in rebound acceleration during compaction.

ii) An on-board computer located in driver's cabin for processing and storing information received from the transducer.

iii) A printer, display unit and control panel, providing hard copy of the output for documentation and information for the operator on compaction in progress.

Advantages of Intelligent Compaction

Intelligent compaction has the following advantages:

1) Minimize Number of Passes, Higher efficiency and maximized productivity by automatic control of amplitude, frequency, and speed.
2) More uniform and optimal compaction result, better quality.
3) Identify weak spots, Roller mapping, achieve consistent rolling patterns, Mat temperature, and level of compaction for 100% coverage.
4) Dynamic measurement of soil stiffness.
5) No danger of over compaction.
6) Recording the output.
7) Compaction control

4.3.3.1 Absolute compaction

The fundamental principle of absolute compaction is that it can adjust the amplitude and frequency of vibrations of the drum. The sensor mounted on the drum continuously monitors the machine's compaction performance by sensing the stiffness of the surface being compacted. The signal from the sensor is sent to the compaction meter processor, which in turn continuously adjusts the amplitude (up and down) depending on the stiffness of the ground. The amplitude adjusts in such a way that areas with low bearing capacity are compacted with high amplitude and areas with high bearing capacity are compacted with low amplitude. The drum has an eccentric unit with a fixed weight and a adjustable weight, which is adjustable by the system itself. In the diagram below the weights, which are red in color are adjustable. These weights rotate relative to the shaft. The other two weights are fixed. When both the weights are vertically opposite the amplitude of vibration is zero (**Fig. 23**). But when the two weights are in line the amplitude is maximum **(Fig. 24).**

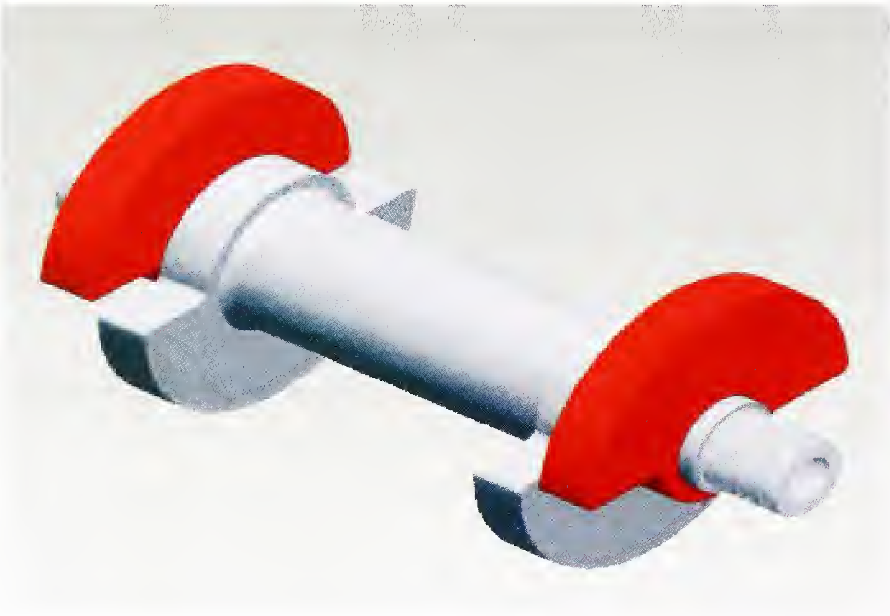


Fig. 23 Position of Eccentric Weights (Fixed and Rotating) for Zero Amplitude

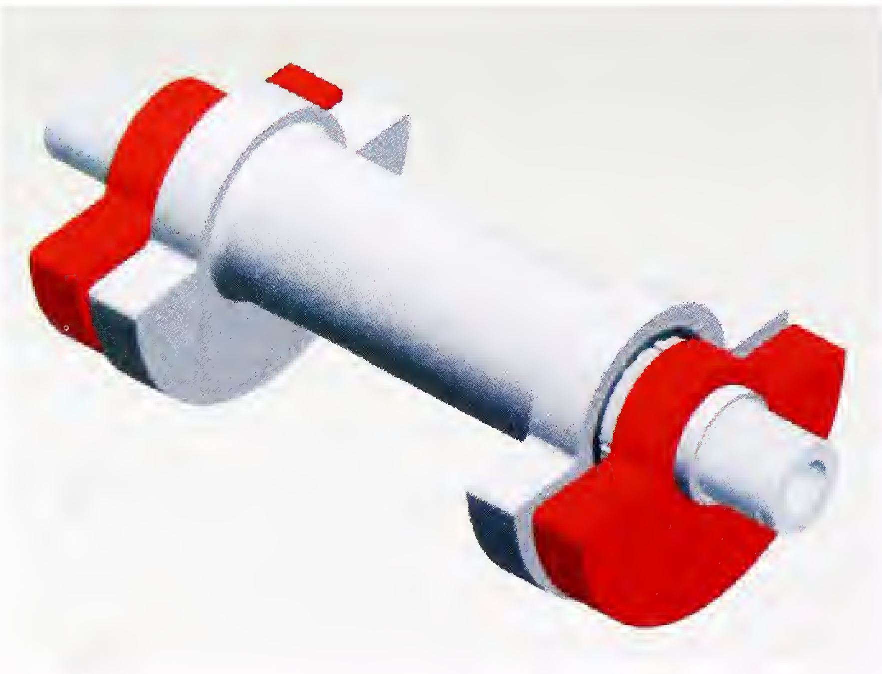


Fig. 24 Position of Eccentric Weights (Fixed and Rotating) for Maximum Amplitude

4.3.3.2 Relative compaction

In the case of a relative compaction the system measures and provides relative values i.e. the system compares the index values for two successive passes with the compaction equipment and shows the difference between values for these two passes. It does not give the absolute percent compaction, stiffness or density achieved. The system available as an attachment to the roller and consist of the following main parts:

1) Sensor (accelerometer)
2) Processor unit
3) Display instrument

The vibration created by an eccentric weight which is located at the centre of the axis. The sensor registers the vibratory movement of the roll and the information is then transferred to the processor, where it is analyzed. The analyzer can be fitted onto a static or vibratory roller of a given make only. The analysed information is presented on the display instrument as a digital value. The compaction meter provides a relative measurement of rigidity of the surface. This increases with increase in the compaction and is reflected in rising Compaction Meter Value (CMV). An accelerometer continuously measures the compaction forces that occur as the vibratory drum works on the surface. The signals from the accelerometer change as the surface becomes harder and more stable. The signals are then converted to values that can be read on the roller's instrument panel.

Each new compaction job is therefore initiated by compacting test areas to different levels and in this way correlating CMV to the degree of compaction.

Compaction Analyzer registers all the CMV data and allows the operator to see the compaction results on the computer screen. On the basis of experience or an existing calibration, the CMV limiting value can be used for each separate compaction job. The Compaction Analyzer then indicates which areas require additional compaction. In some cases, the compactor is accompanied with a GPS in which all the runs, position, utilisation of the roller can be documented . The process followed in the case of Relative compaction of soil and bitumen are as under.

Soil Compaction

The various features of relative compaction are as follows.

a) The compactor can be used to compact embankment, subgrade, Granular Sub base (GSB) as per the capacity of the machine.

b) The number of passes may differ depending upon the type of soil and moisture content.

c) Compactometer measures the compaction meter value (CMV). It does not measure the density but it estimates the stiffness of the ground in relative terms.

d) The accelerometer is fitted in the drum. It is a sensor which calculates the amount of drum movement from the ground which is sent to a processor and converted into CMV value. If the below ground is hard then the CMV value will be large.

e) In case of soil compaction if 98% density is obtained at a CMV value of 40 for a particular soil and given lift thickness then this CMV value is bench marked against the achieved density. Thereafter the operator is instructed to operate the roller until CMV value 40-45 is obtained.

Process :

In this process a sample stretch of pavement is selected. Thereafter it is compacted with the help of a soil compactor . The density is measured independently with the help of Nuclear density guage. Simultaneously the CMV (Compaction meter value) as indicated in the analyzer is checked. The CMV value corresponding to the desired density is noted and set as the target value. For the remaining pavement, compaction is undertaken with the objective to attain the desired CMV.

f) In a soil compactor - accelerometer, processor, CMV indicator, Compaction Analyser computer, GPS receiver and antennae, axle pulse sensor etc are used to regulate data.

Bituminous Compaction

A pavement with premature failure of the asphalt base course can be seen with a weak spot identified during mapping of the sub base course layer which could have occurred due to incorrect frequency setting and or amplitude setting.

In-Situ point tests are needed in order to meet the desired specifications. The density measurements are done using nuclear density gauge or Non-nuclear density gauge and this data is used to correlate the IC measurements Compaction value to establish rolling patterns. One should be careful in correlating data that depends upon the material, site, skill of the operator at the job site and many other constructional and operational factors. Density of the core sample (multiple samples) are correlated with compaction value to have a conclusion of the data available from IC.

a) The compactor can be used for compaction of all kinds of bituminous works like Dense Bituminous Macadam (DBM), Bituminous Macadam (BM), Bituminous Concrete (BC) etc.

b) In the case of tandem roller the number of passes through the width of the lane at a given temperature is calculated. Here a test patch of required thickness is prepared to calculate the number of passes required for achieving the density for a given lift thickness.

c) Two temperature sensors, machine Electronic Control Unit, (ECU) interface and vibration sensors etc. are required.

d) The two infra red sensors measure the temperature of the bituminous surface. The number of passes are plotted. The operator can verify from the display unit whether the number of passes have been completed or not. The colour of screen changes with the number of passes. This is required to achieve the desired density. At the end of the work a summary of the Temperature range and the passes is obtained in the form of the report. This helps in analyzing the compaction of the pavement.

4.3.4 Roller capacity

The amount of mix that can be produced and delivered to the job sets paver speed. The number and type of roller on the job must be selected to match the rate of mat placement. Net roller speed, the length of pavement that can be compacted in a unit of time, is influenced by

1) Roller speed
2) Number of passes
3) Number of laps
4) Overlap between adjacent laps required to cover the mat width
5) Extension overedge
6. Extra passes for joints

The formula given below is used to assess the capacity of road roller

A = (CxWxVx1000)/n m^2/hr

$$\text{Quantity of Compaction for Soil} = \frac{\text{CxWxVxHx1000 m}^3\text{/hr}}{\text{n}}$$

$$\text{Quantity of Compaction for Bituminous works} = \frac{\text{CxWxVxHx}\rho\text{x1000 t/hr}}{\text{n}}$$

Where,

A - Surface Area covered in m^2/hr.

C - Constant varying 0.5-0.6 for bitumen work and 0.75 for soil

W - Width of roller in Meter

V - Speed of Roller in km/h

H - Layer thickness in m after compaction

P - Bitumen mix density in t/m^3, the average value of which is 2.3

N - Number of passes

5 BITUMINOUS COMPACTION

5.1 Method of Bituminous Compaction

Compaction of bituminous mix is usually undertaken in the following steps:

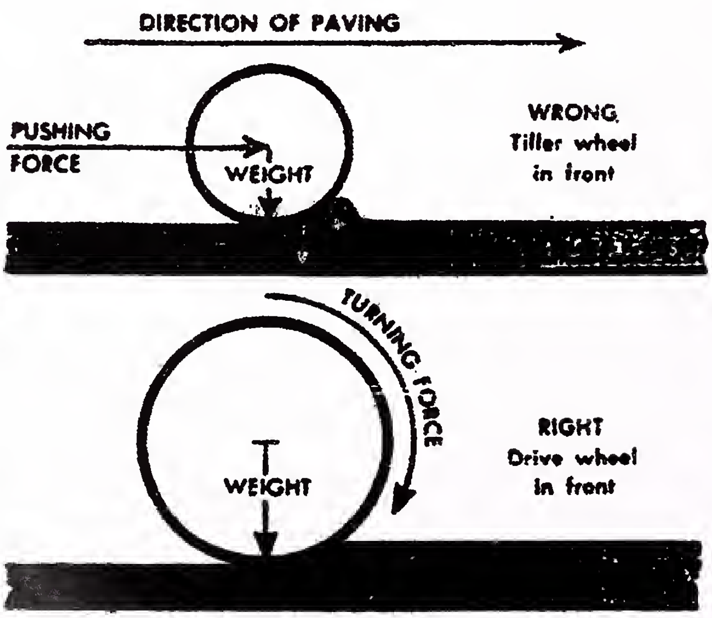
i) Paver screed
ii) Breakdown rolling
iii) Intermediate rolling
iv) Finish rolling
v) Traffic

i) Paver Screed

The screed is the first device used to compact the mat and may be operated in the vibratory mode. There are two devices attached to the paver screed. (a) Vibration mechanism for screed and (b) Tempering and pressure bar. All these are hydraulically operated and adjustable as per requirements and easily achieve compaction up to 85%.

ii) Breakdown Rolling

The rolling undertaken behind the Paver screed is Breakdown rolling. The density gain is achieved the most during breakdown rolling. This is done with a three wheeled static roller. The breakdown step seeks to achieve the required density within a time frame defined by temperature constraints and consistent with paver speed. With three wheeled roller the operation should always progress with the drive wheel (Rear Roll) forward in the direction of paving. This is shown in **Fig. 25.** This is especially important in break down rolling since the greatest percentage of compaction occurs during passes.



Forces Acting When Tiller Wheel or Drive Wheel is Forward

Fig. 25 Direction of Roller Wheel

There are exceptions to rolling with the drive wheel forward, however they usually occur when superelevations are being constructed or if the grade on which the asphalt mix is being placed is excessive. The exceptions occur when, due to these high grades, the drive wheel of the roller begins to chatter on the mat, causing displacement of the mix and a very rough surface. In these cases the roller must be turned around to allow the Front Roll to partially compact the material so that the drive wheel can then proceed over it.

iii) Intermediate Rolling

Intermediate rolling is required to supplement the breakdown step in achieving the required density. Second or intermediate rolling should closely follow breakdown rolling while the asphalt mix is still plastic. This can help further compact the mat or at the very least, rearrange the aggregate within the mat to make it receptive to further compaction

Pneumatic-tyred or Tandem vibratory roller may be used for intermediate rolling. When using pneumatic roller, keeping the tyres hot is the most effective means of preventing pickup.

Pneumatic-tired rollers have several advantages.

1) They provide uniform degree of compaction.
2) They improve the seal near the surface, thus decreasing the permeability of the layer.
3) They orient the aggregate particles for greatest stability, as high pressure truck tires do after using the asphalt surface for some time.

Ground contact pressures of the pneumatic tyre should be as high as possible without causing displacement of mix that can not be remedied in the final rolling. Pneumatic-tyred roller should be used after breakdown rolling. Turning of pneumatic-tired roller on the paving mix should not be permitted unless it does not cause undue displacement.

Tandem Vibratory rollers- of proper static weight, vibration frequency and amplitude - are used to provide densities with fewer passes than static roller.

Regardless of the type of roller used, the rolling pattern should be developed in the same manner as for the initial, or breakdown rolling. This pattern should be continued until the desired compaction is obtained.

iv) Finish Rolling

The finish rolling is done to provide a smooth mat surface. It should be accomplished with 6-8 ton tandem or tandem vibratory (without using vibration) while the material is still warm enough for removal of roller marks.

v) Traffic

After the roller has compacted the mat to the desired density and produced the desired smoothness, the new pavement is opened to traffic. Traffic loading will provide further compaction in the wheel paths of a finished mat.

5.2 Factors Affecting Bituminous Compaction

The following factors influence Bituminous Compaction.

i) Compactive Effort

The following two means of densifying bituminous mix are often referred to collectively as "compactive effort".

By applying its weight to the bituminous mix surface and compressing the material underneath the ground contact area. Since this compression will be greater for longer periods of contact, lower equipment speeds will produce more compaction. Higher equipment weight will also increase compaction.

By creating a shear stress between the compressed material underneath the ground contact area and the adjacent uncompacted material; when combined with equipment speed, this produces a shear rate. Lowering equipment speed can decrease the shear rate, which increases the shearing stress. Higher shearing stresses are more capable of rearranging aggregate into more dense configurations.

ii) Temperature

Temperature of bituminous mix has an indirect effect on the viscosity of the bitumen cement binder and thus compaction. As bituminous mix temperature decreases, its binder becomes more viscous and resistant to deformation, which results in a smaller reduction in air voids for a given compactive effort. As the mix cools, the bitumen binder eventually becomes stiff enough to effectively prevent any further reduction in air voids regardless of the applied compactive effort. The temperature is commonly referred to as cessation temperature, is a function of the mix property. The typical mix material manufacturing temperature, rolling and laying temperatures for different bitumen penetration grades is as under (**Table 5**).

Table 5 : Temperature at different Stages of Compaction

Bitumen Penetration Grade	Bitumen Mixing (°C)	Aggregate Mixing (°C)	Mixed Material (°C)	Rolling (°C)	Laying (°C)
VG-40	160-170	160-175	160-170 Maximum	100 Minimum	150 Minimum
VG-30	150-165	150-170	150-165 Maximum	90 Minimum	140 Minimum
VG-20	145-165	145-170	145-165 Maximum	85 Minimum	135 Minimum
VG-10	140-160	140-165	140-160 Maximum	80 Minimum	130 Minimum

Source : IRC:27-2009

Mat temperature, is crucial to the actual amount of air void reduction for a given compactive effort, and the overall time available for compaction. Based on data, rolling is done to:

a) Take maximum advantage of available roller compactive effort. Rollers can be used where the mat is most receptive to compaction and avoided where the mat is susceptible to excessive shoving.

b) Ensure the mat is compacted to the desired air void content before cessation temperature is reached. This can be done by calculating the time it takes the mat to cool from initial temperature to cessation temperature. All compaction must be accomplished within this “time available for compaction”.

Factors affecting time available for compaction are:

a) Initial Mat temperature: Higher initial mat temperature require more time to cool down to cessation temperature, thus increasing the time available for compaction. However, overheating the hot mix will damage the bitumen binder and cause emissions.

b) Mat or lift thickness: Thicker lifts have a smaller surface-to-volume ratio and thus lose heat more slowly, which increases the time available for compaction.

c) Temperature of the surface on which the mat is placed: Hotter surfaces will dissipate heat from the mat at a slower rate, increasing the time available for compaction.

d) Ambient temperature: Hot air temperature will dissipate heat from the mat at a slower rate, increasing the time available for compaction.

e) Wind speed: Wind speed affects the convective heat loss. Lower wind speed decrease heat loss from the mat.

Additional factors affecting mat cool-down rate are mat density, pavement layer thermal conductivity, specific heat, convection coefficient, incident solar radiation and coefficients of emission and absorption of solar radiation for the pavement surface.

iii) Roller Speed

In order to provide complete and uniform mat compaction, rollers should be operated at a slow, constant speed. Operating at high speeds will reduce compactive effort while varying roller speed can cause non-uniform compaction. **Table 6** below shows typical roller speed.

Table-6 : Typical Roller Speed Ranges

Type of Roller	Breakdown Rolling	Intermediate Rolling	Finish Rolling
Static	3.2 – 5.6 km/h	4.0 – 6.5 km/h	4.8 – 8.0 km/h
Pneumatic		4.0 – 6.5 km/h	
Vibratory		2.0 – 6.5km/h	

As mentioned previously, roller compactive effort comes in two forms: (1) material compression under the ground contact area and (2) shear stress between the compressed area and adjacent uncompressed areas. Operating at lower speeds allows the roller to remain in contact with a particular mat location longer than it would at higher speeds. This results in more compaction per roller pass and therefore increases compactive effort. Speed also affects the magnitude of shear stress developed.

Speed affects compactive effort. Varying roller speed will vary compactive effort results in uneven compaction. This typically occurs when operators are not closely monitoring their speed or when they speed up to roll an area more quickly so that they can catch up to the paver. If rollers cannot keep up with the pace of the paving operation, they should not be operated at higher speeds because this reduces compactive effort. Rather, the paving operation should be slowed down or more number of rollers should be used.

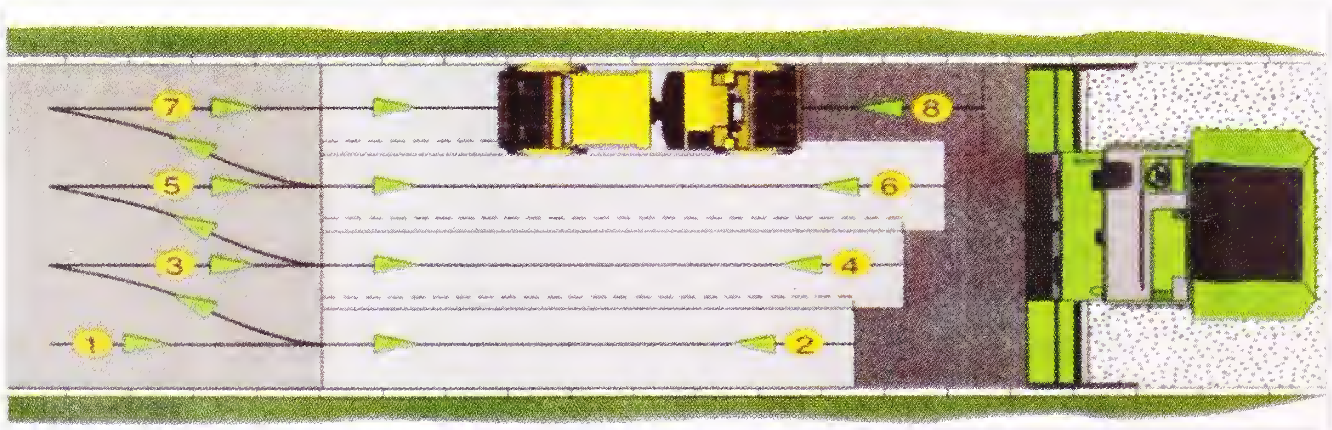
iv) Number of Roller Passes

Generally, it takes more than one roller pass over a particular area to achieve satisfactory compaction. A roller pass over a specific mat area is defined as one complete trip over the area in question by the entire roller.

v) Rolling Pattern

Rolling pattern may provide uniform coverage of lane being paved. Rollers vary in width, and a single recommended pattern is quite impractical. Therefore the best rolling pattern for each roller should be worked out and followed to obtain uniform compaction across the lane. This is shown in **Fig. 26, 27 and 28.** The rolling pattern not only includes the number of passes, but also the location of the first pass, the sequence of succeeding passes, and the overlapping between passes. The rolling operation should start from the edge of the spread on the low side with the roller moving forward as close behind the paver as possible. The second movement of the roller should be to reverse in the same path until the roller has reached previously compacted material. At this point it should swing over and move forward along path number 3, again going as close as possible behind the paver. The fourth movement is reversal in the third path and a repetition of the previous operation. After the entire width of the mix being placed has been covered in this fashion, the roller should swing across the spread to the low side and repeat the process. With this pattern, the overlap of the roller with succeeding passes need not be more than 75 to 100 mm (3 to 4 in.)

If the road has a curb, which prevents the hot asphalt mix from moving away during compaction, rolling should start at the outer lane



Rolling techniques behind the paver on roads with a curb

Fig. 26 Rolling Pattern Behind the Paver on Roads with a Kerb

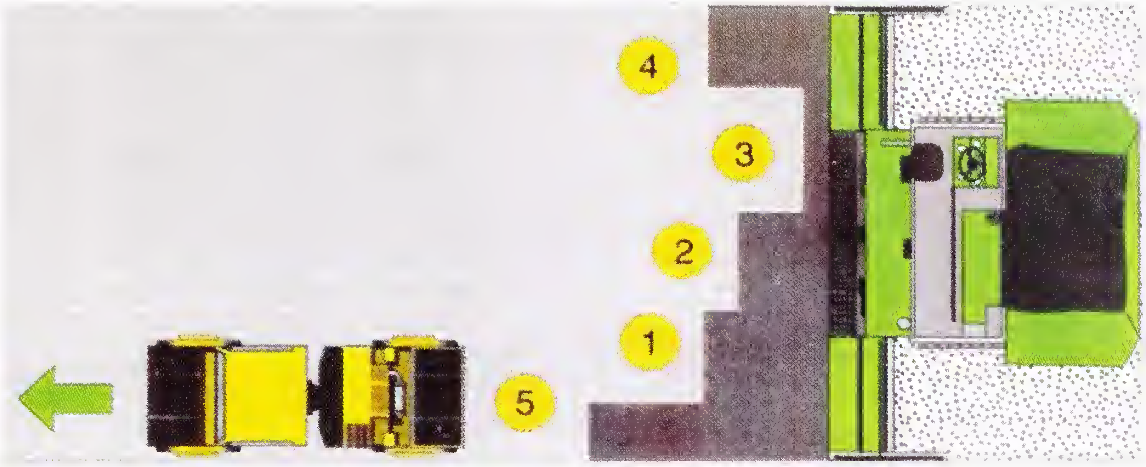


Fig. 27 Rolling Pattern Behind the Paver on Roads Without a Kerb

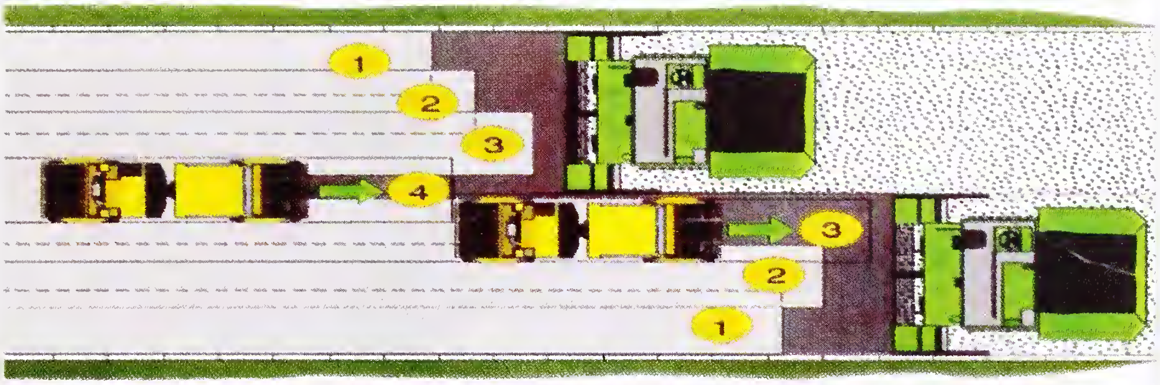


Fig. 28 Compaction of the Mat – when Paving with Two Pavers

When paving behind two pavers, rollers should start from the outer edges toward the middle. A strip of 30-40 cm should remain uncompacted in the middle. This joint is compacted last in order to produce a tight bond between the two pavings.

If the new road has no curb, there is a risk that the roller will push the asphalt outwards during compaction. To avoid this, a strip of 30-50 cm should be left non-compacted on the unsupported sides to allow the material to cool down a little bit in order to increase its stability for the rolling passes later.

For thick-lift construction, the rolling process should start 300 to 375 mm (12 to15 in.) from the lower unsupported edge until the centre portion of the spread is compacted to some degree of stability. Succeeding passes of the roller should then gradually progress toward the edges of the spread. The uncompacted edge provides initial confinement during the first pass, thus minimizing lateral movement of the mix.

After the central portion of the spread has been compacted, the mix will support the roller and allow the edge to be compacted without lateral movement.

vi) Bitumen Content

There are also many types and grades of bitumen. The effective bitumen binder content of the bitumen mix affects workability and compactability. As the bitumen content increases, the film thickness on the aggregate particles increases. This increased film thickness enhances the lubricating effect upto a point makes mix compaction easier.

vii) Base Conditions

The effect of the base type and condition is also a factor which affects the level of stiffness or compaction achieved in the new bitumen layer. The amount of compactive effort needed depends, on whether the new bitumen layer is placed on top of the Subgrade soil, an aggregate base course, cold, cracked pavement layer etc.

viii) Lift Thickness and Particle Size

In general, thick lifts of bitumen mix can be compacted more easily than thin lifts. The thicker the lift, the longer the heat is retained, and thus there is more time for the rolling to take place.

6 CONCRETE COMPACTION

The technique for compaction of Dry Lean Concrete (DLC) and Pavement Quality Concrete (PQC) are as under.

6.1 Compaction of Dry Lean Concrete

The compaction shall be carried out immediately after the material is laid and leveled. In order to ensure thorough compaction which is essential, rolling shall be continued on the full width till there is no further visible movement under the roller and the surface is closed.

Double Drum smooth-wheeled vibratory roller of minimum 8 to 10 Tonne static weight is considered to be suitable for rolling dry lean concrete. The number of passes required to obtain maximum compaction depends on the thickness of the dry lean concrete, the compatibility of the mix, and the weight and type of the roller etc, and the same as well as the total requirement of rollers for the job shall be determined during trial run by measuring the in-situ density.

In addition to the number of passes required for compaction there shall be a preliminary pass without vibration to bed the lean concrete down and again a final pass without vibration to remove roller marks and to smoothen the surface.

Special care shall be exercised during compaction near joints, kerbs, channels, side forms and around gullies and manholes. In case adequate compaction is not achieved by the roller at these points, use of plate vibrator shall be made.

Segregation of concrete in the dumper shall be controlled by moving the dumper back and forth while discharging the mix on it and other means. Even paving operation shall be such that the mix does not segregate.

6.2 Compaction of Pavement Quality Concrete (PQC)

Slipform paver is used for constructing concrete road. It has become indispensable in concrete paving because of their efficiency in the production of concrete road pavement. The fast and economically efficient process requires one single machine pass only and needs a small operating crew compared to other construction methods.

Compaction of concrete in slipform paver is done by the high frequency electrical poker vibrators placed at prefix angle. The vibrators run by 110 V, 200 Hz Generator and operate at speeds ranging from 8000 to 12000 vpm (vibrations per minute). The diameter of the poker vibrators is in the range of 20-80 mm. The diameter of influence is 900 mm and the pokers are placed at a spacing of 36 – 50 cm to ensure proper compaction of the concrete in the compaction chamber. The amplitude of vibration is in the range of 0.4-0.8 mm. For proper uniform compaction across the slab, it is essential to have same frequency of all the vibrators. The idea of compaction is to remove the air voids. This is shown in the **Fig. 29**.

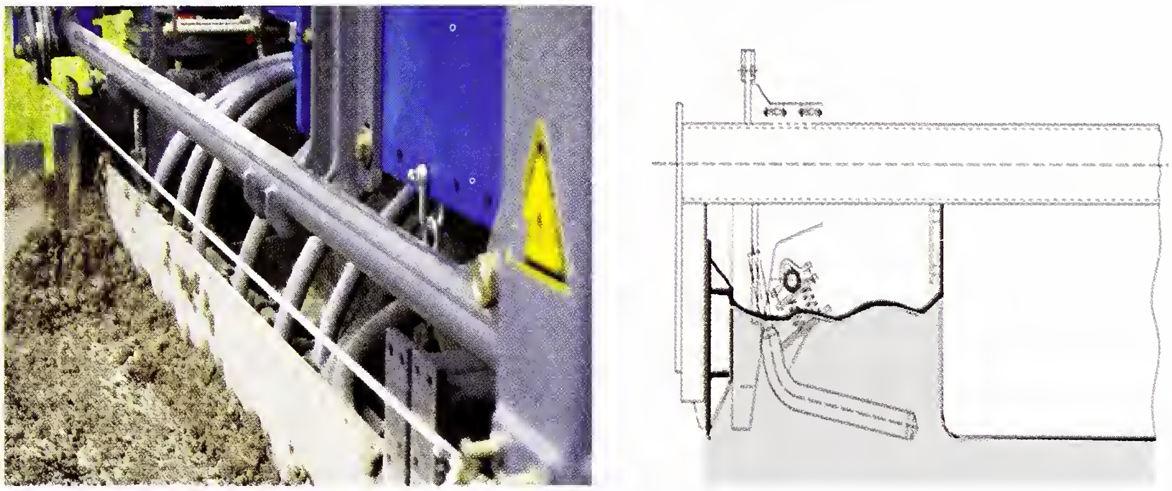


Fig. 29 Compaction of Concrete

7 SOIL COMPACTION

7.1 Properties Affected by Soil Compaction

Principal properties affected by the soil compaction include-

a) Settlement: The reason for compacting soil is to reduce settlement over the life of road. If water passes through the surface, it increases the moisture content of Subgrade. This weakens the Sub grade, causing the pavement to settle and the surface to crack. Densification by compaction prevents the settlement.

b) Strength: Compaction increases the strength to support heavy load.

c) Permeability: Compaction decreases voids and permeability. Increasing the compactive effort reduces the permeability.

d) Change in Volume: Compaction controls undesirable volume changes caused by shrinkage, swelling etc.

Based on field experience, the following guiding factors (**Table 7 and 8**) for various soil types have been evolved to select the appropriate roller:

Table 7 : Selection of Roller for Different Type of Soils

Material	Impact	Pressure	Vibration	Kneading
Gravel	Poor	No	Good	
Sand	Poor	No	Excellent	Good
Silt	Good	Good	Poor	Excellent
Clay	Excellent with confinement	Good	No	Good

Table 8 : Types of Equipment Required Based on the Material Type

Material	Lift Thickness (mm)	Number of Passes	Compactor type
Gravel	200-300	3-5	Vib padfoot Vib smooth
Sand	200-250	3-5	Vib padfoot Vib smooth Pneumatic
Silt	150-200	4-8	Vib padfoot Tamping foot Pneumatic Sheepsfoot
Clay	100-150	4-6	Vib padfoot Tamping foot Sheepsfoot

The ultimate goal is to construct a quality embankment/ roads in the shortest possible time at the least cost, and it means that the compaction equipment must be matched with the material. The proper compaction equipment cannot be selected until the soils are identified. The appropriate equipment based on the material type is mentioned below. The compacted soil is shown in **Fig. 30**.

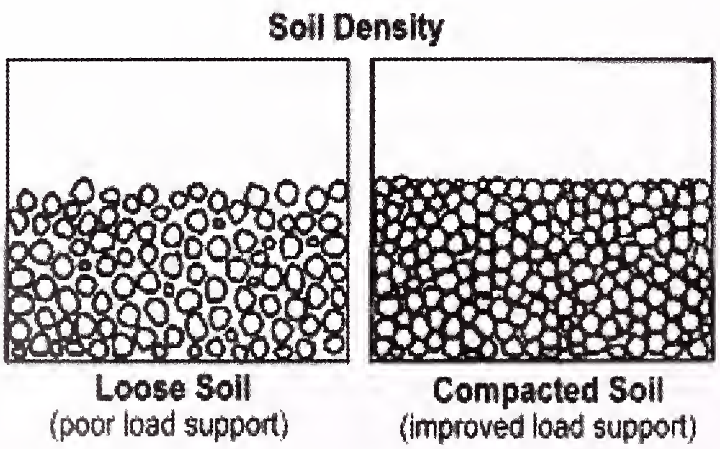


Fig. 30 Soil Density

7.2 Factors Affecting Soil Compaction

Compaction of a soil is affected by following factors :

i) Compactive Effort

Compactive effort is the external force to reorient the constituent particles into a more closely spaced arrangement to produce a corresponding increase in density. Selection of compaction equipment depends on type of soil to be compacted. The method of compaction is primarily of five types such as kneading, static, dynamic, impact and vibratory compaction. Different type of compaction is effective in different type of soils such as for cohesive soil; Sheepsfoot roller or pneumatic roller provides kneading action. Silty soils can be effectively compacted by Sheepsfoot roller/pneumatic roller or smooth wheeled roller. For compacting sandy and gravel soil, vibratory roller is most effective. The influence of vibration and amplitude on compaction of soil is profound. All soils have their natural frequency and it has been suggested that the frequency of vibration of the roller should normally between 0.5 and 1.5 times the natural frequency of soil for obtaining the best compaction. If granular soils have some fines, both vibratory and pneumatic rollers can be used.

ii) Moisture Content

Proper control of moisture content in soil is necessary for achieving desired density. Maximum density with minimum compacting effort can be achieved by compaction of soil near its Optimum Moisture Content (OMC). If natural moisture content of the soil is less than OMC, calculated amount of water should be added to soil with sprinkler attached to water tanker and mixed with soil by motor grader for uniform moisture content. When soil is too wet, it is required to be dried by aeration to reach up to OMC.

iii) Soil Type

Type of soil has a great influence on its compaction characteristics. Normally, heavy clays, clays and silt offer higher resistance to compaction whereas sandy soils and coarse grained or gravel soil is amenable for easy compaction. The coarse-grained soils yield higher densities in comparison to clays. A well-graded soil can be compacted to higher density.

iv) Contact Pressure

In general contact pressure depends on the weight of the roller wheel and the contact area. However in the case of pneumatic roller, the tyre inflation pressure also determines the contact pressure in addition to wheel load.

v) Effect of Number of Passes

Density of the soil increases with the number of passes but after optimum number of passes, further increase in density is insignificant for additional number of passes.

vi) Effect of Rolling Speed

Speed of rolling has a very important role on the roller output. Speed is a significant factor for vibratory rollers because slower the speed of travel, more are the vibrations at a given point and less number of passes required to attain a given density.

vii) Effect of Layer Thickness

The more the thickness of layer of soil subjected to field compaction, the less the energy input per unit weight of soil and hence, less is the compaction under each pass of the roller. Suitable thickness of soil of each layer is necessary to achieve uniform compaction. Layer thickness depends upon type of soil involved and type of roller and contact pressure of its drums. Normally, 200-300 mm layer thickness is optimum in the field for achieving homogeneous compaction.

8 COMPACTION OF JOINT

Compaction of Bituminous Mix is done as soon as it is placed. Compaction is typically accomplished by a sequence of operations of compaction equipment. This allows each piece of equipment to be used only in its most advantageous situation resulting in a higher quality mat (both in density and in smoothness) that could be produced with just a single method of compaction.

8.1 Transverse Joints

When a transverse joint is placed next to an adjoining lane, the first pass is made with a steel-wheel roller moving along the longitudinal joint for a short distance. The joint is then rolled transversely with all except 150 mm of the wheel width on the previously laid material. This operation should be repeated with successive passes covering 150-200 mm of fresh material until the entire width of a roll is on the new mix. During transverse rolling, boards of proper thickness should be placed at the edge of the pavement to provide the roller a surface to drive on once it passes the edge of the hot bituminous mat. If boards are not used, the transverse rolling must stop 150-200 mm short of the outside edge in order to prevent damage to the edge. The outside edge then must be rolled out during longitudinal rolling. The preparation of transverse joint is shown in **Fig. 31**.

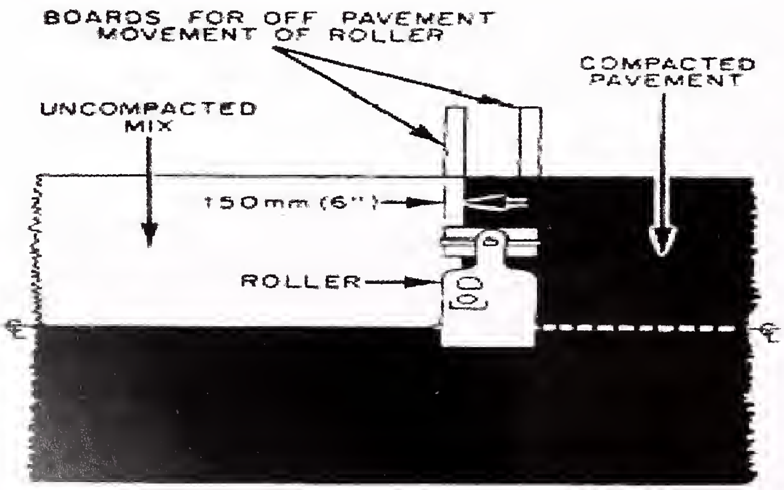


Fig. 31 Preparation of a Transverse Joint

8.2 Longitudinal Joint

A longitudinal joint occurs in a bitumen pavement when a fresh batch of bituminous mix is laid adjacent to an existing lane. It is the interface between the two bituminous mix mats. Most often, differences in the temperature and mat plasticity causes an improper bonding of the fresh bituminous mix with the older bitumen lane and this subsequently causes the longitudinal joint to possess a significantly lower density than the rest of the pavement. Over time, a longitudinal crack usually occurs between the bitumen mats, permitting the intrusion of water, increasing roughness, and potentially limiting the life of the pavement.

Based on the conditions under which the mats are laid, the resulting longitudinal joint can be of the following types:

1) **Hot Joints:** Hot joints are produced when the adjacent lanes are paved in echelon i.e. when two pavers are spaced so that the first lane does not cool significantly before the second lane is laid. If constructed properly, a hot joint appears almost seamless and produces the highest density when compared to the semi-hot and cold joints. The difficulty in obtaining hot joints is that it requires the simultaneous paving of multiple lanes, which is not possible because of constricted work zones especially in case of highways.
2) **Cold Joints:** A cold joint is produced when the first paved lane has cooled overnight before the adjacent lane is placed to match it. A cold joint will also be produced if paving of the first lane is carried too far ahead such that the bituminous mix has cooled. This would cause a significant density gradient between the two mats on either side of the joint and result in very low strength in the joint. After a short period of time under traffic, these joints tend to ravel. In some cases, the raveling is severe enough to completely erode the mix at the joint. Also, the low density at this joint enables the seepage of water into the joint which could oxidize the bituminous material. Hence, careful attention needs to be paid to the construction of these joints.

Conventional Longitudinal Joint Compaction Techniques

a) **Rolling from the Hot Side**

Running the roller on the hot mat while overlapping the joint by a distance of approximately 150 mm (6 in) over the cold mat is considered the most efficient way of compacting the longitudinal joint. Sometimes the first pass of the roller is completed with the edge of the machine about 150 mm (6 in) inside the longitudinal joint. The principle behind this method of compaction is that better compaction is obtained when the mix is shoved towards the joint by the roller. No lateral movement will occur under the roller if the mix is stable.

b) **Rolling from the Cold Side**

In this practice, initial rolling of the longitudinal joint starts from the cold side of the joint so that the cold mat supports most of the weight of the roller. In contrast to rolling from the hot side, the majority of the compactive effort is wasted. The mix on the hot side of the joint tends to cool down while the roller is operating on the cold side of the longitudinal joint.

As a result, more compactive effort is needed to achieve the required density. This method allows the roller to “pinch” the joint and obtain a higher degree of density. However, the lane placed first will have an unsupported edge that is always difficult to compact.

9 COMPACTION IN SPECIAL APPLICATIONS

9.1 Compaction of Shoulder

The sequence of operations shall be such that the construction of paved shoulder is done in layers each matching the thickness of adjoining pavement layer. Only after a layer of pavement and corresponding layers in paved and earthen shoulder portion have been laid and compacted, the construction of next layer of pavement and shoulder shall be taken up.

Where the materials in adjacent layers are different, these shall be laid together and the pavement layer shall be compacted first. The corresponding layer in paved shoulder portion shall be compacted thereafter, which shall be followed by compaction of earth shoulder layer. The adjacent layers having same material shall be laid and compacted together.

In all cases where paved shoulders have to be provided along side of existing carriageway, the existing shoulders shall be excavated in full width and to the required depth.

9.2 Compaction of Embankment

The embankment and subgrade material is spread in layers of uniform thickness over the entire width with the help of a motor grader. Moisture level of the layer is checked before compaction in accordance with IS:2720. Compaction of the embankment is undertaken in layers. Each compacted layer should not be more than 250 mm when compacted with the help of vibratory soil compactor and not more than 200 mm when compacted with 8-10 tonne Static roller. Static three wheeled roller, self propelled single drum vibratory roller, tandem vibratory roller, pneumatic tyre roller, self propelled single drum vibratory roller, tandem vibratory roller, pneumatic tyre, roller, pad food roller etc. of suitable size and capacity is used for compaction. The density of the embankment as per IS:2720 should not be less than 95 percent. Successive layer are placed after the layer under construction has been compacted up to a level of 95 percent. Each compacted layer is finished parallel to the final cross-section of the embankment.

9.3 Use of Compactors in Pothole Repair

All materials used for the pot-hole and patch repair of bituminous surface and underlying layers shall be in accordance with Specification and shall be of the same type as specified for the original construction.

A mix superior to the one on the existing surface may also be used for repair work. The sequence of activities for pothole repair and compaction are as under.

a) Preparation of the area for pot-hole and patch repair

   Each pot-hole and patch repair area shall be inspected and all loose material removed. The area shall be cut/trimmed either with jack hammers or with hand tools suitable for the purpose, such that the defective materials responsible for the failure is all removed and such that the excavation is of a regular shape.

b) The edges of the excavation be cut vertically. The area shall be thoroughly cleaned with compressed air or any appropriate method to remove all dust and loose particles.

c) Layers below the level of the bituminous construction shall be replaced using material of the original construction, which shall particularly include the specified standards of compaction. The area for bituminous construction shall be tacked or primed with cutback or emulsion depending upon whether the lower area is bituminous or granular in nature. The sides, however, are to be painted with hot tack coat material.

d) The mixture to be used in bituminous patching shall be either a hot mix or a cold mix in accordance with the Ministry's Specifications. Mixing shall be done in a plant of suitable capacity.

   The bituminous mixture shall be placed in layers of thickness not more than 100 mm (loose) and shall be compacted in layers with roller/plate compactor/hand roller/rammer to the compaction standards defined in the specifications.

e) In case of potholes repaired with the help of Pothole machine based on Infra Red technology , where the patch is heated over a size of 2 m x 1 m, scraped and the heated aggregates are spread over the area, emulsion is poured over it and mixed manually with the help of a hand shovel .

The area is then compacted with the help of a plate compactor/walk behind roller.

9.4 Compaction of Curved Surfaces

Articulated roller should be used when compacting along the edge of the carriage way. This enables the roller driver to direct his attention to one drum when compacting the Edge. (This is shown in **Fig. 32**).

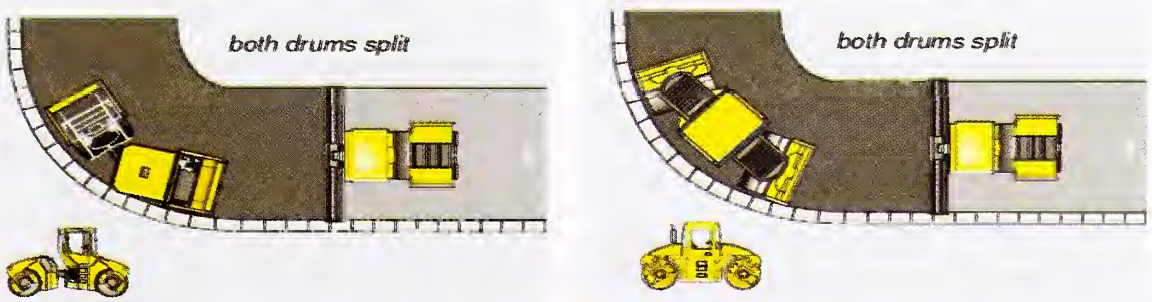


Fig. 32 Compaction Along the Curves

10 QUALITY CONTROL

Compaction is required to be undertaken at the right temperature with the right kind of roller for adequate number of passes to ensure that required density is obtained. The roller should be operated in a manner as explained in preceding sections. However, as a check or to exercise control over the process on each layer at least one measurement of density for each 1000 square meters of compacted area, for evaluating a day's work is required. The process to determine the density shall be in accordance with IS: 2720 (Part-28). Test locations shall be chosen randomly. Thereafter a mean value may be obtained from the series of observations which may be indicative of the actual result.

11 SELECTION OF ROAD ROLLER

11.1 Selection Based on Type of Work is shown in Table 9 below.

Table 9 :

S. No.	Layer	Layer Thickness (mm)	Type of Roller
1)	WMM	≤100 mm	Static Roller (8-10 Tonne)
		100 mm - 200 mm	Vibratory Road Roller with a minimum static weight of (8-10 Tonne) Speed not to exceed 5 km/h
2)	Bituminous Compaction		
		Initial or Breakdown Rolling	Roller with a dead weight of 8-10 Tonne
		Intermediate Rolling	Roller with a dead weight of 8-10 Tonne or Vibratory Roller or Pneumatic tyre Road Roller of 12-15 Tonne weight Or combination roller of 8-10 Tonne weight
		Finish Rolling	6-8 Tonne Smooth wheeled Tandem Roller
3)	Embankment		Static Roller of 8-10 Tonne or Padfoot Roller or Heavy Pneumatic Tyred Roller
4)	Special Applications on soils	250 mm	Vibratory Roller of 8-10 Tonne static weight
		500 mm	Vibratory Roller of 15-20 Tonne static weight

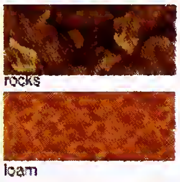
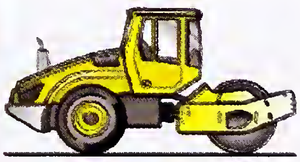
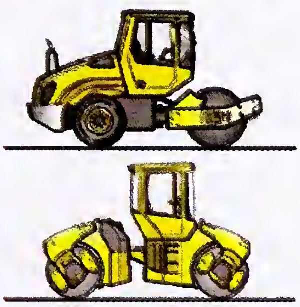
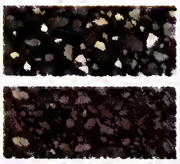
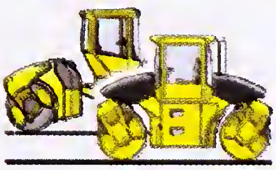
11.2 The selection of Road Roller based on the specification of the job being undertaken is as under. This is shown in **Table 10**.

Table 10

S. No.	Layer	Layer Thickness (mm)	Roller in Order of Preference
1)	BM	50 mm - 75 mm	Static Roller (8-10 Tonne) Vibratory Roller (8-10 Tonne) Pneumatic Tyred Roller, Or combination roller of 8-10 Tonne weight Tandem Static Road Roller (6-8 Tonne)
		80 mm - 100 mm	Static Roller (8-10 Tonne) Vibratory Roller (8-10 Tonne) Pneumatic Tyred Roller, Or combination roller of 8-10 Tonne weight Tandem Static Road Roller (6-8 Tonne)
2)	SDBC	25 mm - 50 mm	Static Roller (8-10 Tonne) Vibratory Roller (8-10 Tonne) Pneumatic Tyred Roller, Or combination roller of 8-10 Tonne weight Tandem Static Road Roller (6-8 Tonne)
3)	DBM	50 mm - 125 mm	Static Roller (8-10 Tonne) Vibratory Roller (8-10 Tonne) Pneumatic Tyred Roller, Or combination roller of 8-10 Tonne weight Tandem Static Road Roller (6-8 Tonne)
4)	BC	25 mm - 50 mm	Static Roller (8-10 Tonne) Vibratory Roller (8-10 Tonne) Pneumatic Tyred Roller, Or combination roller of 8-10 Tonne weight Tandem Static Road Roller (6-8 Tonne)
5)	WMM	75 mm - 100 mm	Static Roller (8-10 Tonne)
6)	WMM	100 mm - 200 mm	Vibratory Roller (8-10 Tonne)

11.3 The suitable frequencies and amplitudes for different applications are as under **Table 11**.

Table 11 : Application Guidelines-Vibratory Rollers

application		roller	static linear pressure kg/cm	amplitude mm	frequency Hz	rolling speed km/h
earthworks dams			≥ 30	$\geq 1,5$	28 - 35	1 - 2,5
granular bases subbases			≥ 10	$\geq 0,4$	28 - 60	2 - 4
asphalt base course			10 - 30	0,35 - 0,9	30 - 60	2 - 4
asphalt wearing course				$\leq 0,5$	40 - 60	2 - 6

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11.4 The choice of a roller for the compaction of embankment and sub grade is as mentioned in **Table 12** below.

Table-12

S. No.	Type of Soil	Choice of Roller	Remarks
1)	Granular	i) Static three wheeled roller (8-10 Tonne) ii) Vibratory Roller (8-10 Tonne) iii) Pneumatic Tyred Roller (12-15 Tonne)	
2)	Uniformly graded soil	i) Static three wheeled roller (8-10 Tonne) ii) Pneumatic Tyred Roller (12-15 Tonne) iii) Vibratory Roller (8-10 Tonne)	
3)	Clay and silty soil	Sheepsfoot Roller	

11.5 Light plate compactors (<400 Kg) work on high frequencies and comparatively low amplitude are suitable for compacting thin layers of sand and gravel. When used with a sprinkling system, it can be used for bituminous surface. Heavy vibratory plate compactors (> 400 Kg) are applicable for semi- cohesive soils and on large amplitudes. Plate compactor can either be attached to a roller or can be mounted on a second machine (say a skid steer loader or a tractor).

11.6 The choice of a roller for maintenance works is as mentioned below **Table 13**.

Table 13 :

S. No.	Type of Maintenance Work	Choice of Roller	Remarks
1)	Compaction of Shoulder	i) Static Road Roller (3 Tonne) ii) Light Tandem Roller (2-3 Tonne)	
2)	Compaction of Potholes	i) Static Road Roller (3 Tonne) ii) Plate compactor iii) Hand Roller iv) Rammer v) Light Tandem Roller (2-3 Tonne)	

12 OPERATION OF ROLLER

Following methodology should be observed in the operation of road roller.

12.1 Static Road Roller

a) Rolling shall commence at the lower edge and proceed towards the upper edge longitudinally for portions having unidirectional cross fall and super elevation shall commence at the edge and progress towards the centre having cross fall on both the sides.

b) Each pass of the roller shall uniformly overlap 1/3rd of the track made in the preceding pass.

c) During rolling, rolls should be kept moist in case of bituminous compaction and not wet to avoid packing up of mix material by moving rolls.

d) The motion of the roller should not be jerky during bituminous compaction.

12.2 Pneumatic Tyred Road Roller

a) Pneumatic tyred roller should be equipped with smooth tyres of equal size, ply in good running condition and inflated to nearly equal pressure on pneumatic tyres such as to get uniform pressure during rolling.

b) Desired ground pressure may be achieved by inflation/adjusting the ballast on the roller.

c) All wheels should roll true without wobble.

d) Rolling operation should commence at the outside edge of the surface and progress towards the center or crown of the road.

e) Each pass of the pneumatic tyred roller should overlap the preceding pass by at least ½ of the roller width. Rolling should be discontinued as soon as uniform coverage is accomplished and there does not appear any unevenness.

f) It should be ensured that all subsequent passes to achieve required density are completed before mix temperature drops to the minimum recommended temperature.

g) Pneumatic tyred roller should be operated with uniform speed not exceeding 6.5 km/hr to prevent the tyres from displacing or picking up the mix material.

h) Line of action should neither be changed suddenly nor the direction be reversed at random, which will cause displacement of the mix. Any pronounced change in direction should be made on stable material.

i) If the rolling causes any displacement of pavement, the effected area to be loosened up immediately with strike rakes and fresh mix material of original grade placed before being rolled again.

j) Pneumatic tyred roller should not be allowed to stand on a finished paver surface before it has thoroughly cooled.

k) During rolling, pneumatic tyres should be kept moist and not wet to avoid picking up of mix material by moving tyres.

l) Intermediate rolling should be continued until all the mix material has been compacted thoroughly. The rolling pattern should be followed in the same sequence as for break down rolling.

12.3 Vibratory Road Roller

a) Rolling shall commence at the lower edge and proceed towards the upper edge longitudinally for portions having unidirectional cross fall and super elevation shall commence at the edge and progress towards the centre having cross fall on both the sides.

b) Each pass of the roller shall uniformly overlap 1/3rd of the track made in the preceding pass.

c) During rolling, rolls should be kept moist and not wet to avoid packing up of mix material by moving rolls.

d) High amplitude and low frequency are used to compact soft soils and to reach deeper zones while low amplitudes and high frequencies are used for stiff soils and shallow depth.

e) The motion of the roller should not be jerky.

f) The speed of the roller should be dependent on the surface of the mat being compacted. Initial compacting should be at low speeds. Subsequently, the speed of the compactor may increase.

13 MAINTENANCE OF COMPACTION EQUIPMENT

The most efficient equipment are those which have lower repair costs and less downtime. Proper maintenance system is to be followed for keeping the equipment in efficient condition. The different types of maintenance schedule are as under.

13.1 Running Maintenance

- Regular monitoring of the operation of equipment
- Spot the problems – Listen for any unusual sounds, smell something out of the ordinary, touch Vibration, Monitor Temperature of Bearings, oil temperature, oil pressure etc
- Housekeeping - Access to maintenance points, Clean equipment makes repairs easier and quicker
- Check any leakage of oil, water, air & exhaust smoke.

13.2 Routine Maintenance

Daily, monthly, semi annual maintenance are as follows:

i) Daily Maintenance

- Inspect oil level
- Check level of water
- Inspect V-Belt

- Requirement of lubricants
- General condition of the equipment.
- No leakage of oil, water, air and smoke.
- Check hardware for proper tightness
- Check battery connection and electrolyte level

ii) Monthly Maintenance

- Check oil level in Gear Box.
- Inspect and tighten Conveyor Belts for wear/tear
- Check Hydraulic Filters and replace as per manufacturer's instructions or if the condition of the filter warrants a change.
- Change oil in air compressor.

iii) Semi-Annual Maintenance

- Inspect oil filter
- Change oil in Gear Box.
- Tighten/Replace V-Belts.
- Inspect Bearings.
- Visually inspect the motors
- Inspect and/or replace bin aeration pads.

13.3 Preventive Maintenance (PM)

Preventive Maintenance is the routine, of scheduling and performing repair tasks on equipment before it becomes necessary. Preventive Maintenance is required to prevent frequent breakdown of the compactor. To attain this objective, the periodicity of the change of spares as recommended by the supplier has to be observed. Equipment where a formalized inspection and maintenance schedule is in place tend to have fewer breakdowns.

Preventive Maintenance should be undertaken regularly to identify the condition of bearings, belts, and filters and the defective item may be repaired/ replaced before breakdowns interrupt operations. Proper inventory of fast moving spares for preventive and periodic maintenance should be maintained at site.

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