Chapter 5

Compacting and Finishing

Part 1

5-1 PRINCIPLES OF COMPACTION

- **The Compaction Process**
- **Optimum Moisture Content**
- **Compaction Specifications**
- **Measuring Field Density**

The Compaction Process

- *Compaction:*
  - is the process of increasing the density of a soil by mechanically forcing the soil particles closer together, thereby expelling air from the void spaces in the soil.
- *Consolidation:*
  - is an increase in soil density of a cohesive soil resulting from the expulsion of water from the soil's void spaces (naturally).
- Consolidation may require months or years to complete, whereas compaction is accomplished in a matter of hours.

	Compaction force	Time	Soil type
Compaction	Mechanical	hours	Almost all types
Consolidation	Natural (expulsion of water)	Months or years	Cohesive

The Compaction Process

- Compaction has been employed for centuries to improve the engineering properties of soil.
- Improvements include:
    1. increased bearing strength,
    2. reduced compressibility,
    3. improved volume-change characteristics, and
    4. reduced permeability.

The Compaction Process

- the equipment and methods employed for compaction in building construction are usually somewhat different from those employed in heavy and highway construction because of:
  - the limited differential settlement that can be tolerated by a building foundation,
  - the necessity for working in confined areas close to structures, and
  - the smaller quantity of earthwork involved.

The Compaction Process

- The degree of compaction (effectiveness) may be achieved in a particular soil depends on:
  1. the soil's physical and chemical properties (see Chapter 2),
  2. the soil's moisture content,
  3. the compaction method employed,
  4. the amount of compactive effort (from Proctor tests standard or modified), and
  5. the thickness of the soil layer being compacted (lift thickness).

The Compaction Process

- The four basic compaction forces are:
  1. static weight,
  2. manipulation (or kneading),
  3. impact, and
  4. vibration.

The Compaction Process

- Although all compactors utilize static weight to achieve compaction, most compactors combine this with one or more of the other compaction forces.
  - For example, a plate vibrator combines static weight with vibration.
- Manipulation of soil under pressure to produce compaction is most effective in plastic soil.

The Compaction Process

- The forces involved in impact and vibration are similar except for their frequency.
  - Impact or tamping involves blows delivered at low frequencies:
    - usually about 10 cycles per second (Hz),
    - It is most effective in plastic soils.
  - Vibration involves higher frequencies:
    - may extend to 80 cycles per second (Hz) or more.
    - Vibration is particularly effective in compaction of cohesionless soils such as sand and gravel.

Optimum Moisture Content

- Soil moisture content:
  - is one of the five factors influencing compaction results
  - it is a very important one.
- A standard laboratory test
  - It is called a *Proctor test*
  - It has been developed to evaluate a soil's moisture density relationship under a specified compaction effort.
  - There are two Proctor tests which are:
    - Standard Proctor Test (ASTM D 698, AASHTO T-99) and
    - Modified Proctor Test (ASTM D 1557, AASHTO T-180).
  - Characteristics of these two tests are given in Table 5-1.

TABLE 5-1: Characteristics of Proctor compaction tests

Test Details	Standard	Modified
Diameter of mold		
in.	4	4
mm	102	102
Height of sample		
in.	5 cut to 4.59	5 cut to 4.59
mm	127 cut to 117	127 cut to 117
Number of layers	3	5
Blows per layer	25	25
Weight of hammer		
lb	5.5	10
kg	2.5	4.5
Diameter of hammer		
in.	2	2
mm	51	51
Height of hammer drop		
in.	12	18
mm	305	457
Volume of sample		
cu ft	1/30	1/30
l	0.94	0.94
Compactive effort		
ft-lb/cu ft	12,400	56,200
kJ/m^3	592	2693

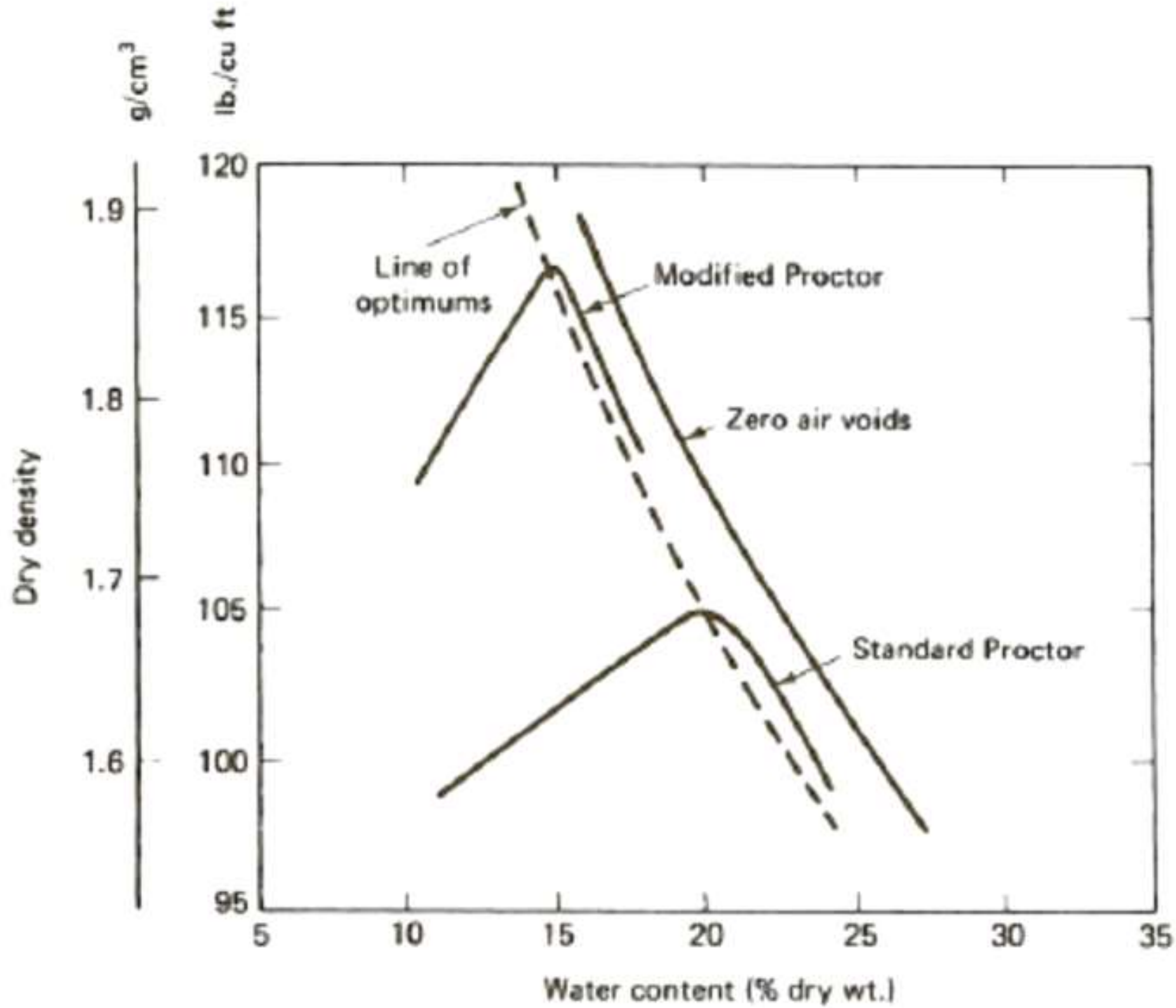
Optimum Moisture Content

- The modified test:
  - It was developed for use where high design loads are involved (such as airport runways),
  - the compactive effort for the modified test is more than four times as great as for the standard test.

Optimum Moisture Content

- To determine the maximum density of a soil using Proctor test procedures, compaction tests are performed over a range of soil moisture contents (see Figure 5-1).
- The peak of each curve represents the maximum density obtained under the compactive effort supplied by the test.

FIGURE 5-1: Typical compaction test results.



Optimum Moisture Content

- Comments on Figure 5-1 are:
  - maximum density achieved under the greater compactive effort of the modified test is **<u>higher</u>** than the density achieved in the standard test.
  - the line labeled "zero air voids“ represents the maximum possible soil density for any specified water content.

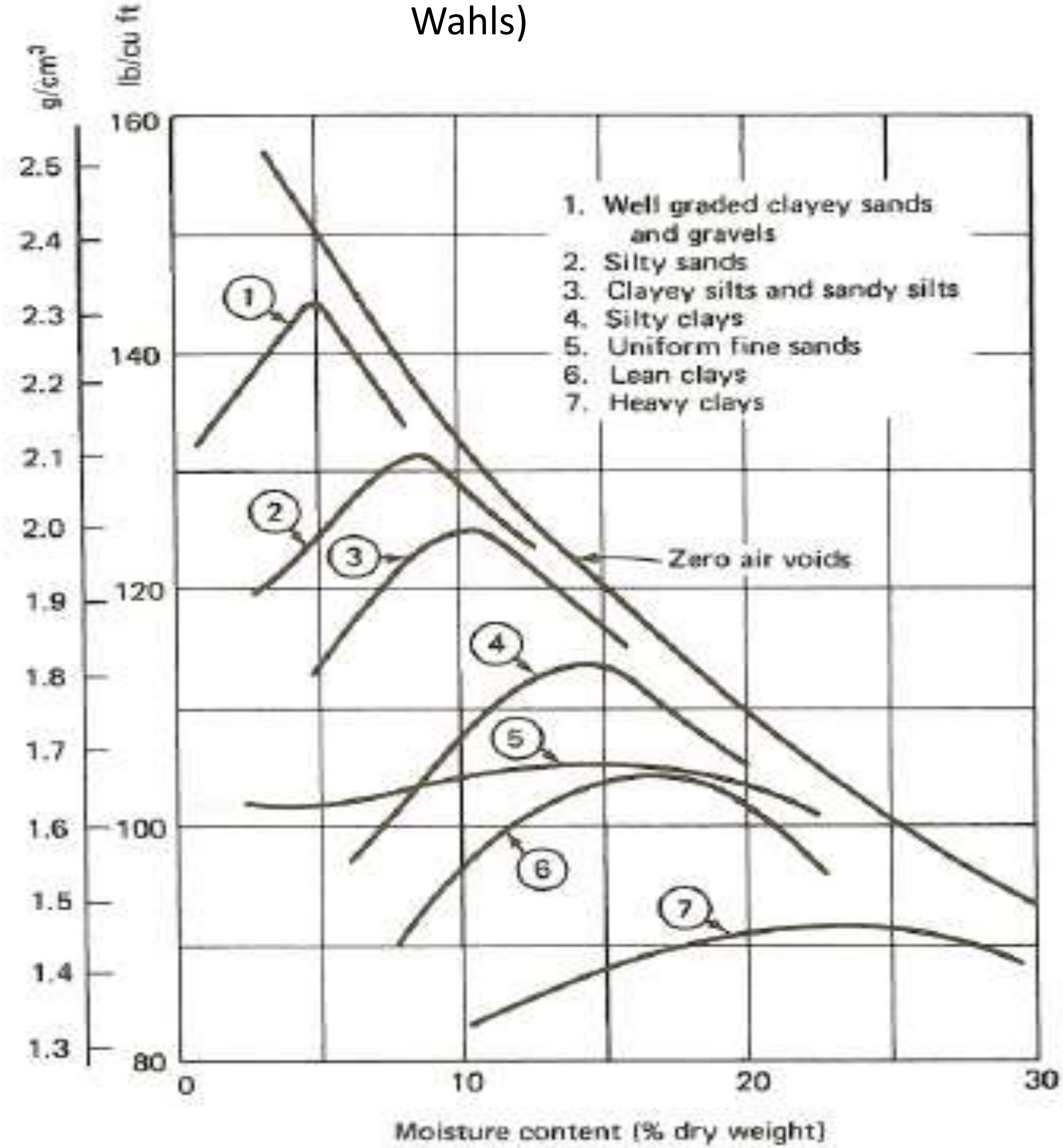
Optimum Moisture Content

- *optimum moisture content of a soil* is the moisture content at which maximum dry density is achieved under a specific compaction effort.
  - 20% for Standard Proctor Test.
  - 15% for the modified test.
- This relationship is typical for most soils where soil's optimum moisture content decreases as the compactive effort is increased.
  - The line of optimum moisture contents demonstrates that.

Optimum Moisture Content

- The importance of soil moisture content to field compaction practice can be demonstrated using Figure 5-1.
  - Suppose that specifications require a density of 100 lb/cu ft (1.6 g/cm^3) for this soil and the compactive effort being used is equal to that of the Standard Proctor Test.
    - From Figure 5-1 it can be seen that the required density may be achieved at any moisture content between 13 and 24%.
    - a density of 105 lb/cu ft (1.68 g/cm^3) can only be achieved at a moisture content of 20%.

FIGURE 5-2: Modified Proctor Test results for various soils. (Courtesy of Dr. Harvey E. Wahls)



Compaction Specifications

- Compaction specifications are intended to ensure that the compacted material provides:
- 1. the required engineering properties and
- 2. satisfactory level of uniformity.

- 1. The required engineering properties
  - A- prescribing the characteristics of the material to be used and
  - B- a minimum dry density to be achieved.
  - The Proctor test is widely used for expressing the minimum density requirement.
  - The specification will state that a certain percentage of Standard Proctor or Modified Proctor density must be obtained.

Compaction Specifications

- As in an example, the soil of Figure 5-1,
  - 100% of Standard Proctor density corresponds to a dry density of 105 lb/cu ft (1.68 glcm3).
  - Thus a specification requirement for 95% of Standard Proctor density corresponds to a minimum dry density of 99.8 lb/cu ft (1.60 g/cm3).

Compaction Specifications

- Typical density requirements range from 90% of Standard Proctor to 100% of Modified Proctor. For example,
  - 95% of Standard Proctor is often specified for embankments, dams, and backfills.
  - 90% of Modified Proctor might be used as requirement for the support of floor slabs.
  - 95 to 100% of Modified Proctor are commonly used as requirement for the support of structures and for pavement base courses where high wheel loads are expected.

Compaction Specifications

- 2. satisfactory level of uniformity :
  - A lack of uniformity in compaction may result in:
    - differential settlement of structures or
    - may produce a bump or depression in pavements.
- it is important that uniform compaction be obtained.
- Uniformity is commonly controlled by specifying a maximum variation of density between adjacent areas.

Compaction Specifications

- Compaction specifications are:
  1) performance specifications in which only a minimum dry density is prescribed.
  2) method specifications that prescribe the exact equipment and procedures to be used.

Measuring Field Density

- To verify the adequacy of compaction, the soil density actually obtained in the field must be measured and compared with the specified soil density.
- The methods available for performing in-place density tests include:
  - a number of traditional methods (liquid tests, sand tests, etc.) and
  - nuclear density devices.

Measuring Field Density

- All the traditional test methods involve:
  - removing a soil sample,
  - measuring the volume of the hole produced, and
  - determining the dry weight of the material removed.
- Density is then found as the dry weight of soil removed divided by the volume of the hole.

Measuring Field Density

- *Nuclear density devices :*
  - measure the amount of radioactivity from a calibrated source that is reflected back from the soil to determine both soil density and moisture content.
  - When properly calibrated and operated, these devices produce accurate results in a fraction of the time required to perform traditional density tests.
  - The use of nuclear density devices is becoming widespread because of increased need of rapid soil density determination.

5-2 COMPACTION EQUIPMENT AND PROCEDURES

- **Types of Compaction Equipment**
- **Compaction in Confined Areas**
- **Selection of Compaction Equipment**
- **Compaction Operations**
- **Estimating Compactor Production**
- **Job Management**

Types of Compaction Equipment

- Principal types of compaction equipment include:
  1. tamping foot rollers,
  2. grid or mesh rollers,
  3. vibratory compactors,
  4. smooth steel drum rollers,
  5. pneumatic rollers,
  6. segmented pad rollers, and
  7. tampers or rammers.

1.Tamping foot rollers:

- They utilize a compaction drum equipped with a number of protruding feet.
- They are available in a variety of foot sizes and shapes, including the sheepsfoot roller.

How it works?

- During initial compaction, roller feet penetrate the loose material and sink to the lower portion of the lifts.
- As compaction proceeds, the roller rises to the surface or "walks out" of the soil.

- All tamping foot rollers utilize static weight and manipulation to achieve compaction.
  - Therefore, they are most effective on cohesive soils.
- The sheepsfoot roller:
  - produces some impact force, and
  - tends to displace and tear the soil as the feet enter and leave the soil.

FIGURE 5-3: Major types of compaction equipment.

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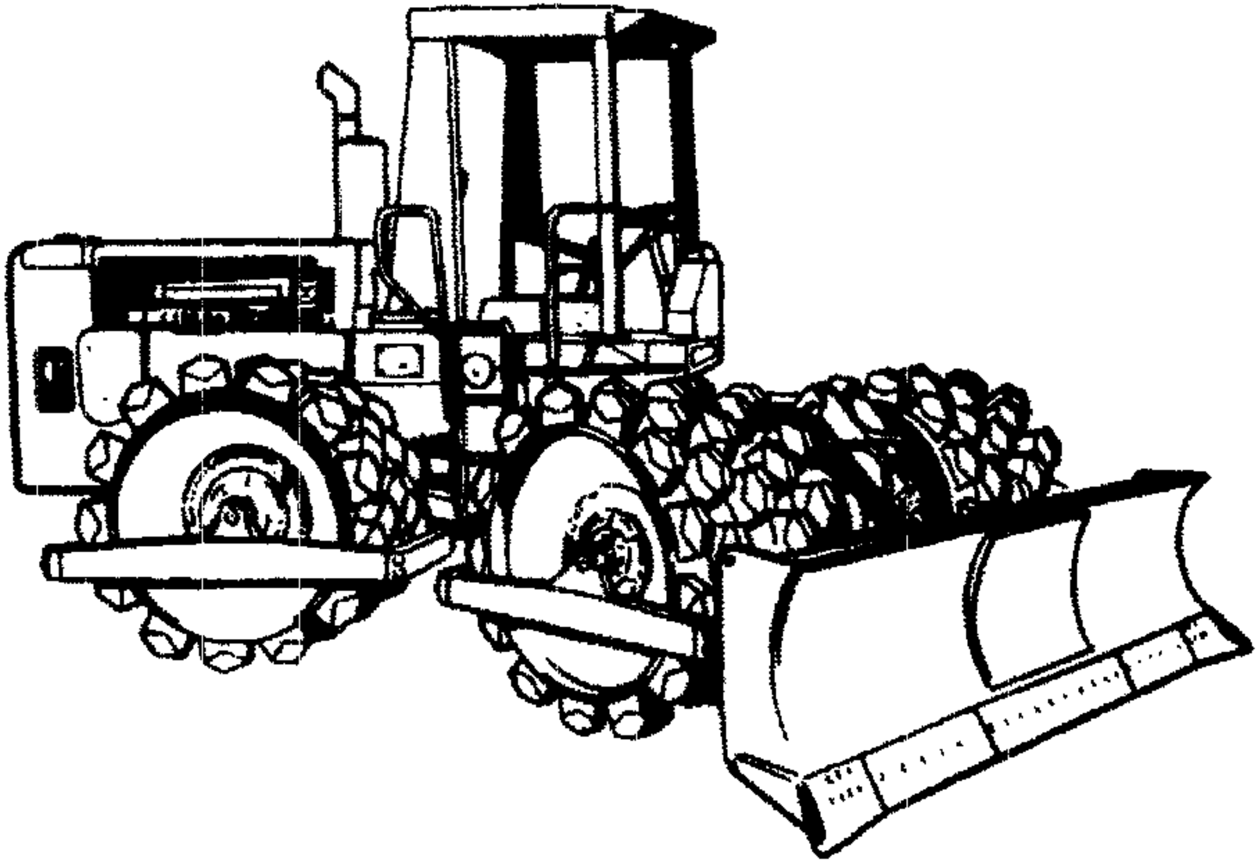

SELF-PROPELLED TAMPING
FOOT ROLLER

FIGURE 5-3: Major types of compaction equipment.

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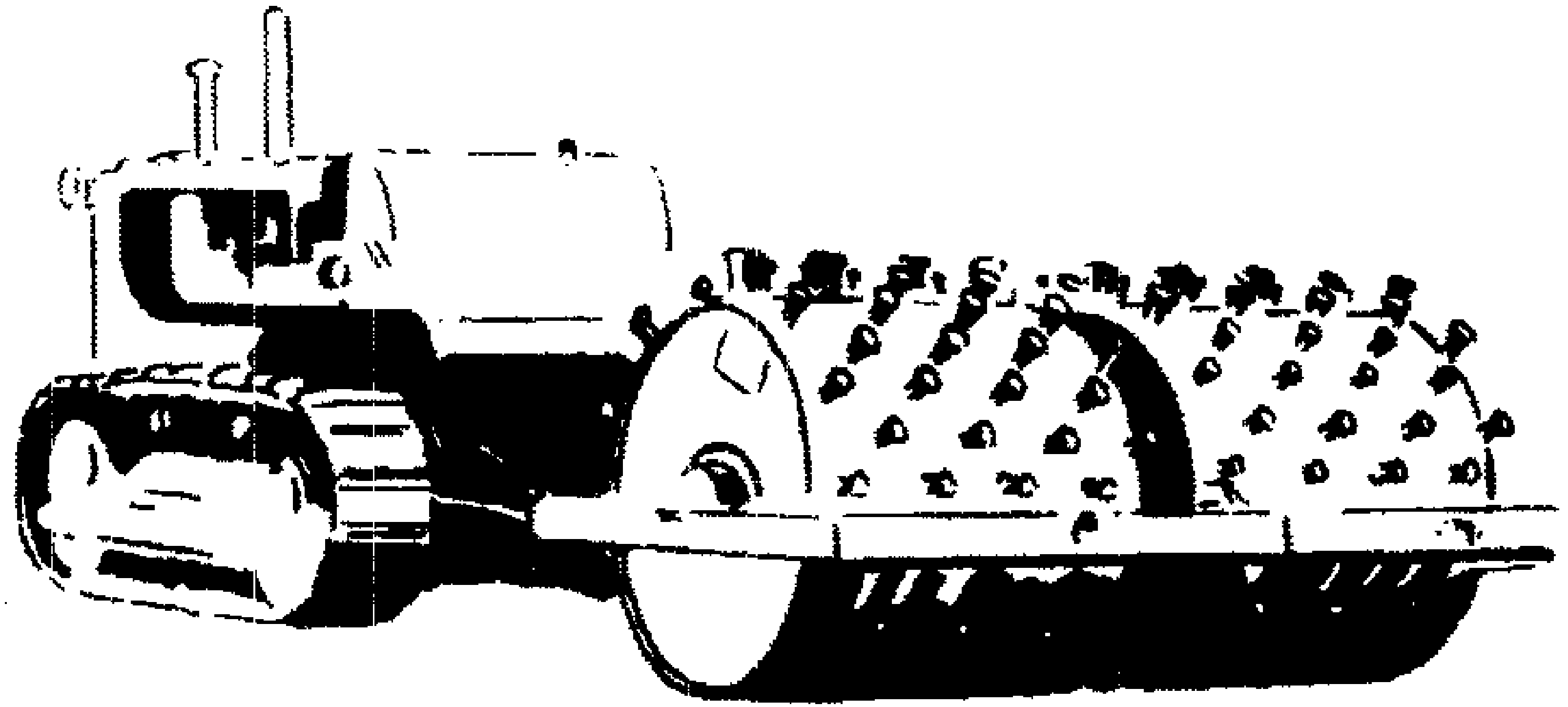

TOWED SHEEPSFOOT
ROLLER

https://youtu.be/Q7Ck7BMtSPs?t=2
https://www.youtube.com/watch?v=8zAuqGElkuw

2. Grid or mesh rollers:

- They utilize a compactor drum made up of a heavy steel mesh.
- Because of their design, they can operate at high speed without scattering the material being compacted.
- Compaction is due to static weight and impact plus limited manipulation.
- Grid rollers are used to:
  - compact clean gravels and sands (most effective).
  - break up lumps of cohesive soil.
  - crush and compact soft rock (rock losing 20% or more in the Los Angeles Abrasion Test).

2. Grid or mesh rollers

3. Vibratory compactors:

- They are available in a wide range of sizes and types.
- In size they range from:
  - small hand-operated compactors (Figure 5-4) through
  - towed rollers to large self-propelled rollers (Figure 5-5).
- By type they include:
  - plate compactors,
  - smooth drum rollers, and
  - tamping foot rollers.
- Small walk behind vibratory plate compactors and vibratory rollers are used primarily for compacting around the structures and in other confined area.

FIGURE 5-3: Major types of compaction equipment.

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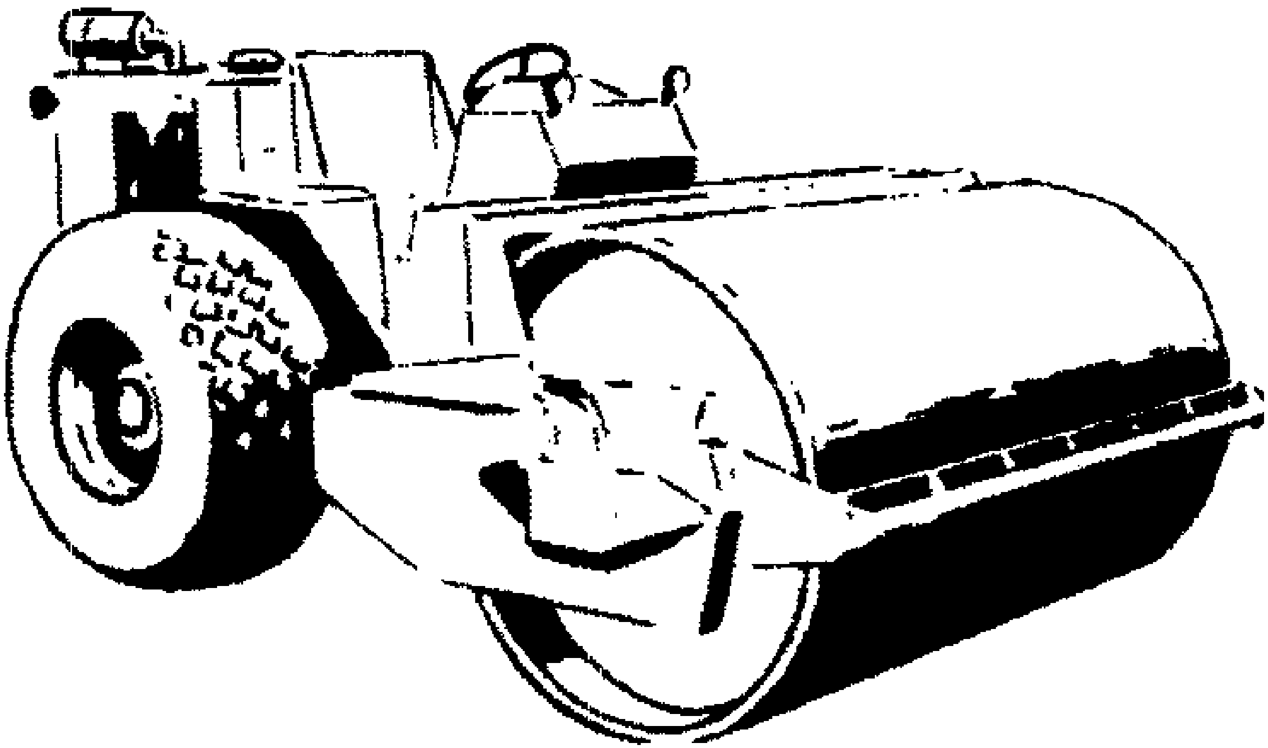

SELF-PROPELLED
VIBRATING ROLLER

FIGURE 5-4: Walk-behind vibratory plate compactor.

(Courtesy of Wacker Corp.)

FIGURE 5-5: Vibratory tamping foot compactor.
[Courtesy of BOMAG (USA)]

- Vibratory plate compactors are also available as attachments for hydraulic excavators.
- The towed and self-propelled units are utilized in general earthwork.
- Large self propelled smooth drum vibratory rollers are often used for compacting bituminous bases and pavements.

4. Steel wheel or *smooth drum rollers :*

- They are used for compacting:
  - granular bases,
  - asphaltic bases, and
  - asphalt pavements.
- The compactive force involved is primarily static weight.

FIGURE 5-3: Major types of compaction equipment.

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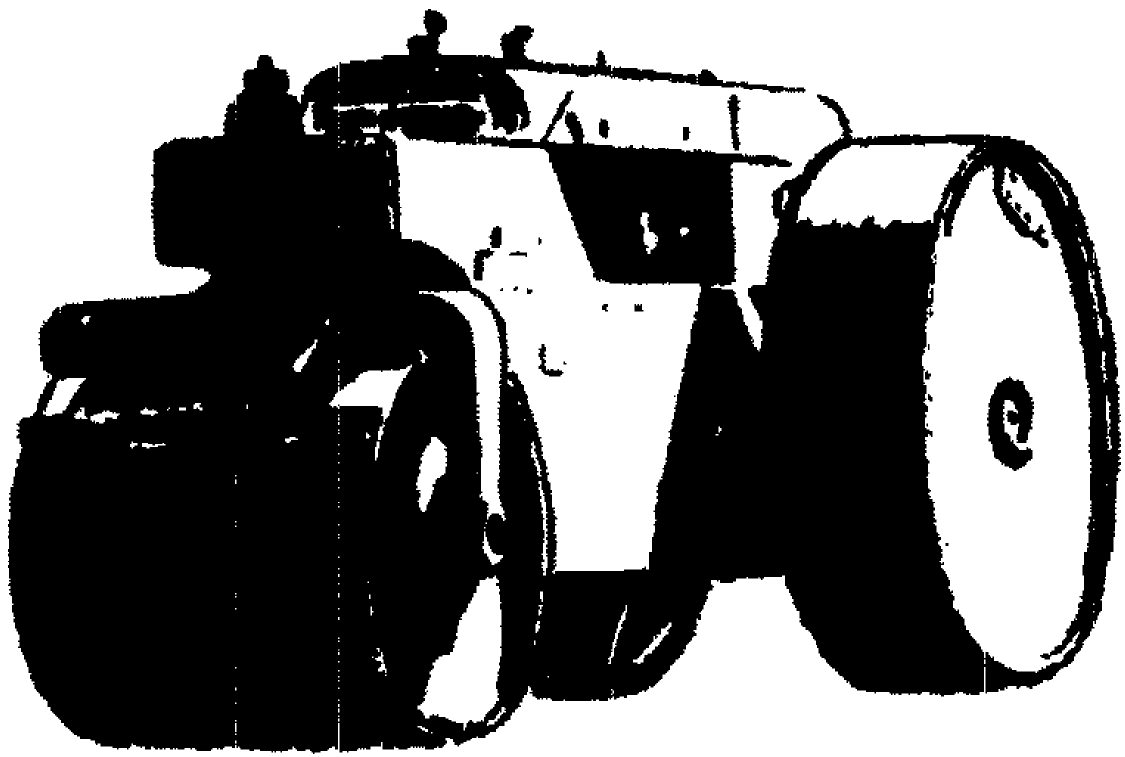

SMOOTH, STEEL WHEEL ROLLER

5. Rubber-tired or *pneumatic rollers :*

- They are available as:
  - light- to medium weight multi tired rollers and
  - heavy pneumatic rollers.
- Wobble-wheel rollers are multi tired rollers with wheels mounted at an angle so that they appear to wobble as they travel.
  - This imparts a kneading action to the soil.
- Heavy pneumatic rollers weighing up to 200 tons are used for dam construction, compaction of thick lifts, and proof rolling.
- Pneumatic rollers are
  - effective on almost all types of soils
  - least effective on-clean sands and gravels.

FIGURE 5-3: Major types of compaction equipment.

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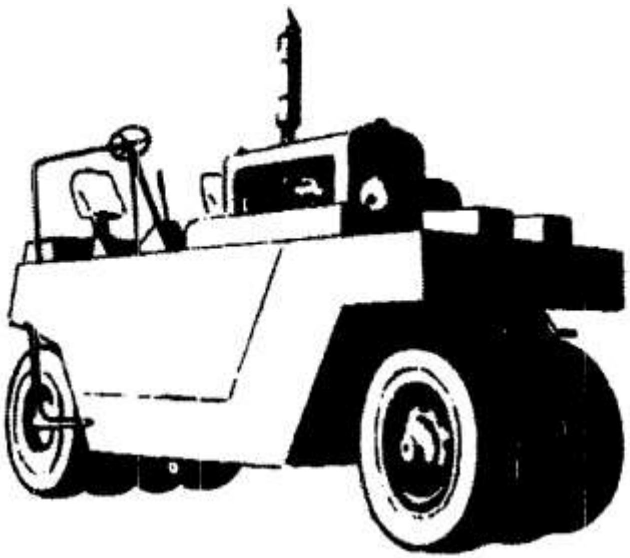
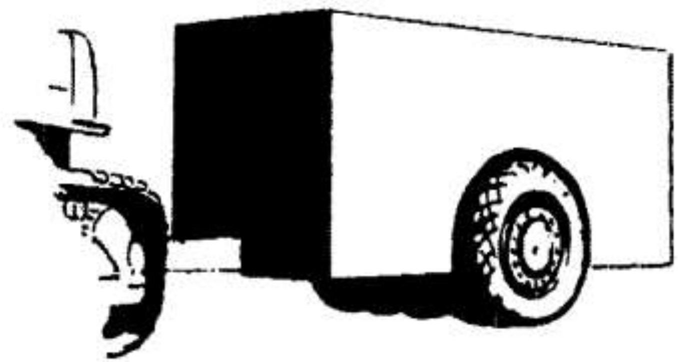


SMALL, MULTITIRED PNEUMATIC ROLLER



HEAVY PNEUMATIC ROLLER


VOLVO
VOLVO

6. Segmented pad rollers :

- They are somewhat similar to tamping foot rollers except that they utilize pads shaped as segments of a circle instead of feet on the roller drum.
- As a result, they produce less surface disturbance than do tamping foot rollers.
- Segmented pad rollers are effective on a wide range of soil types.

FIGURE 5-3: Major types of compaction equipment.

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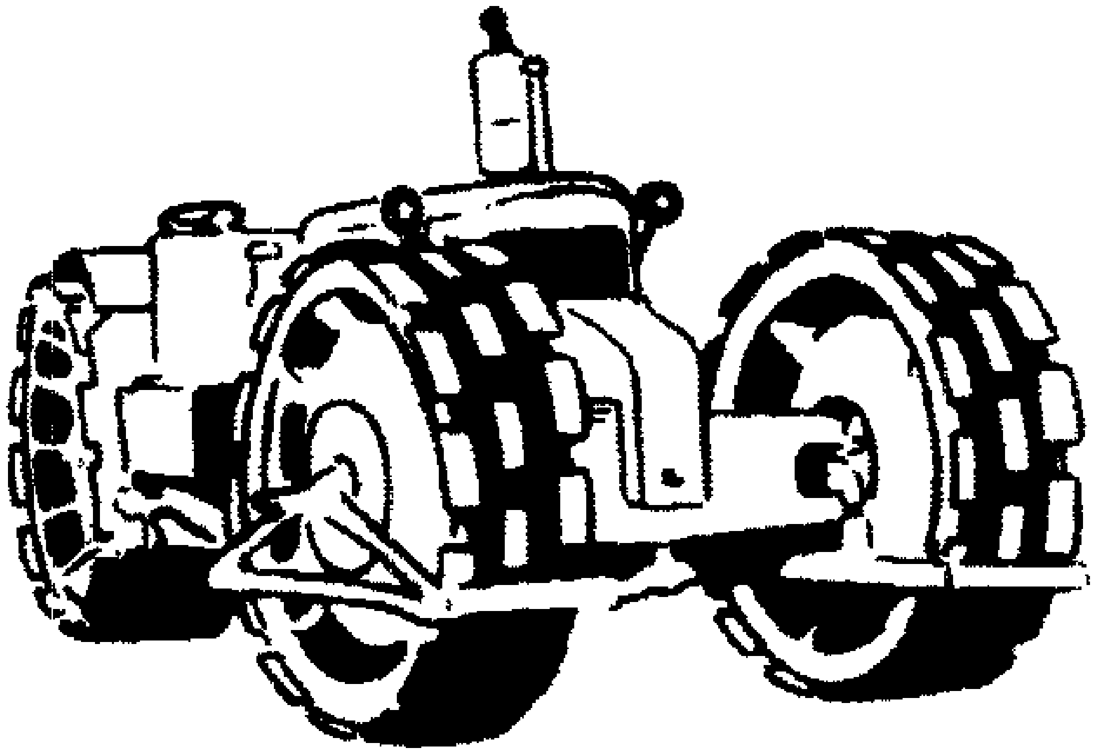


SELF-PROPELLED SEGMENTED STEEL WHEEL ROLLER

7. Rammers or *tampers :*

- They are small impact-type compactors which are primarily used for compaction in confined areas.
- Some rammers, like the one shown in Figure 5-6, are classified as vibratory rammers because of their operating frequency.

FIGURE 5-6: Small vibratory rammer.

(Courtesy of Wacker Corp.)

Compaction in Confined Areas

- The equipment available for compaction in confined areas are:
  - For trenches and around foundations includes small vibratory plate compactors (Figure 5-4),
  - tampers or rammers (Figure 5-6),
  - walk-behind static and vibratory rollers (Figure 5-7), and
  - attachments for backhoes and hydraulic excavators.
    - *Compaction Wheels* (Figure 5-8)
    - *Vibratory plate attachments* (Figure 5-9)

FIGURE 5-4: Walk-behind vibratory plate compactor.

(Courtesy of Wacker Corp.)

FIGURE 5-7: Walk-behind vibratory roller with remote control.

(Courtesy of Wacker Corporation)

FIGURE 5-8: Compaction wheel mounted on hydraulic excavator.

(Courtesy of American Compaction Equipment, Inc.)

https://www.youtube.com/watch?v=oc81V87BgpU

FIGURE 5-9: Vibratory plate compactor for excavator

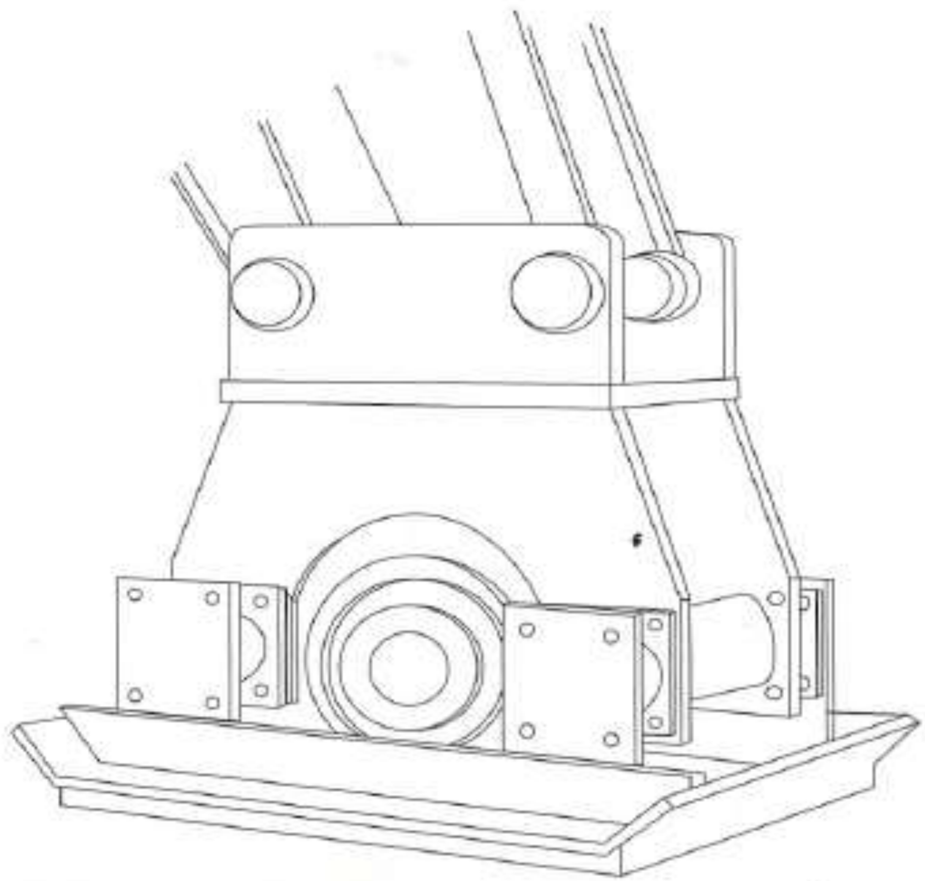
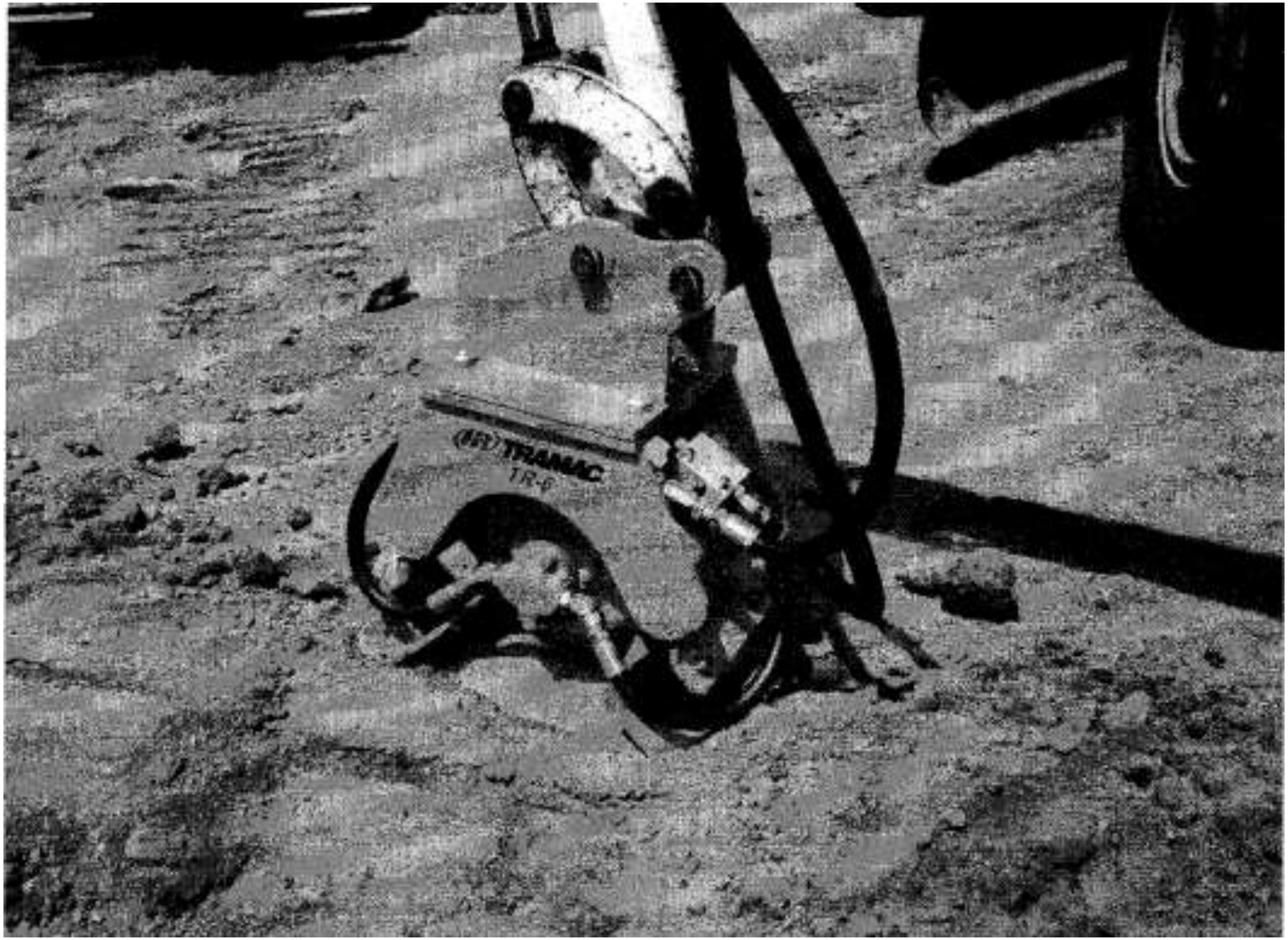


FIGURE 5-9: Vibratory plate compactor attachment for excavator

(Courtesy of Ingersoll-Rand Tramac)

https://www.youtube.com/watch?v=z7ICdFd9Y_M



Selection of Compaction Equipment

- The proper selection of compaction equipment is an important factor in obtaining the required soil density with a minimum expenditure of time and effort.
- The chart in Figure 5-10 provides a rough guide to the selection of compaction equipment based on soil type.

FIGURE 5-10: Compaction equipment selection guide.

Material	Steel wheel	Pneumatic	Vibratory	Tamping foot	Grid
Rock	●	○	●	●	●
Gravel, clean or silty	●	◐	●	●	●
Gravel, clayey	●	◐	◐	●	◐
Sand, clean or silty	○	○	●	○	◐
Sand, clayey silt	○	◐	◐	●	○
Clay, sandy or silty	○	●	◐	●	○
Clay, heavy	○	●	◐	●	○

● Recommended
◐ Acceptable
○ Marginal