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Heavy Earth Moving Equipment

1.1. INTRODUCTION TO CONSTRUCTION EQUIPMENT

As we know, construction activity is an integral part of a country's infrastructure and industrial development. It includes buildings such as hospitals, educational institutions, townships, offices, commercial complexes, etc.; urban infrastructure such as water supply, sewerage, drainage etc.; highways, flyovers, tunnels, ports, railways, airports; power systems; irrigation and agriculture systems; telecommunications, industrial plants.

Construction has become the basic input for socio-economic development. Besides, the construction industry generates substantial employment and provides a growth impetus to other sectors through backward and forward linkages.

The upswing in the Indian Economy has enhanced the demand for the construction and material handling equipments. The demand for construction and material handling equipments is correlated with the growth of other segments. Prior to 1960's, domestic requirements of construction equipment were entirely met by the imports.

Domestic production in India began in 1964 with the start of manufacturing of bulldozers, scrapers, dumpers, graders etc. by Bharat Earth Movers Ltd. (BEML), a Public Sector Underdating. In private sector, the Hindustan Motors established its Earthmoving Equipment Division in 1969. Thereafter L & T in 1974 began to manufacture hydraulic excavators under license from Poclain. In 1980's and 1990's several other private sector undertakings entered in the field, while many companies started as Joint Ventures with global players.

During last 3 to 4 decades, construction industry has made enormous progress and has grown both in terms of size and diversity. The construction and mining industry are the primary users of the heavy earthmoving equipments in India. The organised construction sector accounts for about 55% of the total construction equipment industry.

Construction equipment plays a significant role in the execution of modern high cost time-bound construction projects. These produce output at accelerated speed, and enables completion of tasks in a limited time. The equipment saves manpower which is becoming scarce, costly and more demanding day-by-day. In addition, equipment improves productivity, quality and safety. Thus the construction equipment have become indispensble item of resources and their role continues to grow steadily.

This book concenetrates on the engineering fundamentals for planning, selection, and utilization of construction equipment. The book also describes the basic operational characteristics of different types of construction equipments. It also explains the fundamental concepts of machine utilization, which economically match machine capability to specific project construction requirements.

In most cases, a piece of equipment does not work as a stand-alone unit. Pieces of different types of equipment work in groups, therefore the optimization in the management of an equipment spread is critical for a contractor, both in achieving a competitive pricing position and for arranging the capital required to finance the project.

The project planner/engineer on the job is required to match the right machine or combination of machines to the job at hand.For this purpose, he is required to identify the construction equipment for executing the project tasks, assessing equipment performance capability, forecasting date wise requirement of numbers and types of equipment, and then selecting the equipment to be acquired.

The production tasks which can be performed with equipment include excavating, hauling transporting, compacting, grading, hoisting, concreting, precasting, trenching, pipe-laying etc. In addition, the support equipment are also required, at the project site, which include generators, compressors, pumping sets and other utility services equipment.

The proper emphasis is required to be given by the equipment engineer on reduction of down-time, achieving optimum utilization, increase in production at minimum cost through right selection and management of these equipment. He is expected to coordinate with various wings of the project in discharging his job of equipment planning, balancing, selection of equipment, its deployment, personnel selection and training, preventive maintenance etc.

1.2. CLASSIFICATION OF CONSTRUCTION EQUIPMENT

Construction equipments can be broadly classified on the basis of their functions as under:

1. Earthwork Equipments

(*i*) *Earth cuting and moving equipment* : Bulldozers, Scrapers, Front-end loaders, Motor graders.

(*ii*) *Excavation and lifting equipment* : Backhoes, Power Shovels, Draglines, Clamshells.

(*iii*) *Loading equipment* : Loaders, Shovels, Excavators.

(*iv*) *Transportation equipmnt* : Tippers, Dump Trucks, Scrapers, Conveyors.

(*v*) *Compacting equipment* : Tamping Foot Rollers, Smooth Wheel Rollers, Pneumatic Rollers, Vibratory Rollers, Plate Compactors.

2. Concreting Plant and Equipments

(*i*) *Production equipment* : Batching Plants, Concrete Mixers.

(*ii*) *Transportation equipment* : Truck mixers, Concrete dumpers.

(*iii*) *Placing equipment* : Concrete pumps, Conveyors, Hoists, Grouting equipment.

(*iv*) *Concrete Vibrating equipment* : Needle vibrators, Plate compactors.

3. Material Hoisting Equipments

(*i*) *Hoists* : Fixed, Mobile, Fork-lifts.

(*ii*) *Mobile Cranes* : Crawler-mounted, self-propelled rubber-tyred, truck-mounted.

(*iii*) *Tower Cranes* : *Stationary, Travelling type.*

4. Special Purpose Heavy Construction Plant and Equipments

(*i*) *Aggregate production equipment* : Crushing plants, Rock blasting equipment, Screening plants.

(*ii*) *Concrete paving equipment* : Concrete paver finishers.

(*iii*) *Pile driving equipment* : Pile driving hammers.

(*iv*) *Asphalt mix production and Placement equipment* : Asphalt plants, asphalt pavers.

(*v*) *Tunneling equipment* : Drill jumbos, Muck-hauling equipment, Rock bolters, Tunnel boring machines.

5. Support and Utility Services Equipment

(*i*) Pumping and Dewatering equipment.

(*ii*) Pipe laying equipment.

(*iii*) Generators. (*iv*) Welding equipment.

1.3. INTRODUCTION TO HEAVY EARTH MOVING EQUIPMENTS

Modern mechanised earthmoving really started when the crawler tractor was adopted from its agricultural antecedent. To meet the growing demand of minerals particularly coal, the earthmoving equipment was first introduced in 1940's in open-cast coalmines in our country. Shovels of about 2.2 cum capacity with dumpers of 12 to 15 tonnes capacity were introduced in these mines. Bhakra Nangal Dam started in 1950's used higher capacity and sophisticated earthmoving equipment like dozers, scrapers, shovels, draglines and dumpers. Almost same time in 1950's shovels of 1.5 to 2.5 m^3, front-end loaders, dozers with rippers, and 15 to 25 tonnes dumpers were introduced in iron ore mines, replacing manual minining and locomotive traction. With the introduction of heavy earthmoving equipment, bigger size operations were taken up in construction of Hydel dams, irrigation schemes, coal and metal mining. Kudremukh Iron Ore Project in late 1970's used 15 cu m shovels, 120 tonnes diesel engine dumpers, 15 cu m front-end loaders and dozers of over 600 H.P.

The equipment of various sizes used for various projects were imported from various countries. The indigenous manufacturers in the country are now planning to manufacture 10-12.5 m^3 shovels, 85-120 tonnes dumpers, about 450 H.P. class dozers, 30 m^3 scrapers, 30 m^3/90 m draglines etc. With indigenous manufacature, it will save high cost of importation and also help in standardisation which will solve the problems of spare parts stocking, maintenance and downtime.

With the application of heavy earthmoving euipment (H.E.M.), production of coal has increased from 25 million tonnes to 570 million tonnes, of iron ore from 3 million tonnes to 150 million tonnes, similarly Hydel power has also increased manifolds in last 30 years. All these activities involve movement of rock, earth, and minerals in such a huge quantities that these works of irrigation, hydel, and mining (coal and mineral) projects can not be undertaken manually within the time schedule set for the projects.

Types of Earth Moving Equipments

Earth Moving Equipments can be classified into following two types :

(*i*) **Production Equipment.** Equipment used for digging, moving the material to the site of construction (may be dam, irrigation project, road project, mining project or building construction project) or to the crushing plant.

(*ii*) **Service Equipment.** These are for the help of main production equipment to achieve optimum capacity. For small works dozers can be used as productive equipment. Motor Grader is used as production equipment in road construction projects, while it is used as service equipment for keeping proper gradient of service road for dams, mines, and quarries.

1.4. TRACTORS

Tractors are the machines which change energy of the engine into tractive energy. The tractors are primarily used to pull or push loads,but they are also used for mounting many types of accessories like, bulldozer blades, rippers, front end shovels, hoes, draglines, clamshells, trenchers, winches, side booms, frontend bucket loaders, pipe layers etc.

As mentioned above, the tractor is a basic equipment and available in two types ; namely (*i*) crawler or track type, and (*ii*) Rubber-tired or wheel-type. The tractor is a multi-purpose machine, light models of which are used for agricultural or short haulage works, whereas heavy models are employed for earth moving works, cranes, shovels or special rigs. Wheeled units are employed for light but speedy jobs, whereas cralwer units are rugged machines and are used for heavy duty works, where more tractive power is required.

Tractor Construction

Main constituents of a tractor are : Engine, clutch, transmission system, ground drive and controls.

A diesel engine is generally used as prime mover and mounted on the tractor frame and delivers the power through a clutch to the main power shaft. The power is transmitted from the engine to the final drive through engine clutch, torque convertor, change speed gear box transmission to rear differential and then finally to the rear drive axle. The drive is also transmitted through front differential to the front axle.

Engine clutch is provided to disconnect the engine from the rest of the transmission system so that gears can be changed to change the speed of the tractor. Care should be taken while changing the gears that the engagement of the clutch should be gradual to avoid undue strain on the surfaces of the clutch plates. The clutch control in small and medium sized tractors is through pedal like that of a truck, but in large tractors it is through lever operated by hand.

Transmission system provides speed reduction and multiplication of torque of the engine shaft, since final drive needs a high torque at low speed. The reduction in speed is done by means of a change speed gear box. Now-a-days torque conerters are also used for the purpose. The power is then given to the drive axle through the differential, which changes the direction of the drive to 90° by using bevel gears and also reduces the speed upto some extent. Differential also facilitate in steering. As tractor changes its direction, one of the rear wheels must travel faster than the other, and this is achieved by the diferential. In the wheeled tractor the steering is done through the front wheel. The outer ends of the two half shafts carry pinions which mesh with larger gears of the final drive, resulting variation in speed when the tractor is taking a turn. The change in the speeds of the track is made directly by stopping power supply to one, while the other continues to rotate.

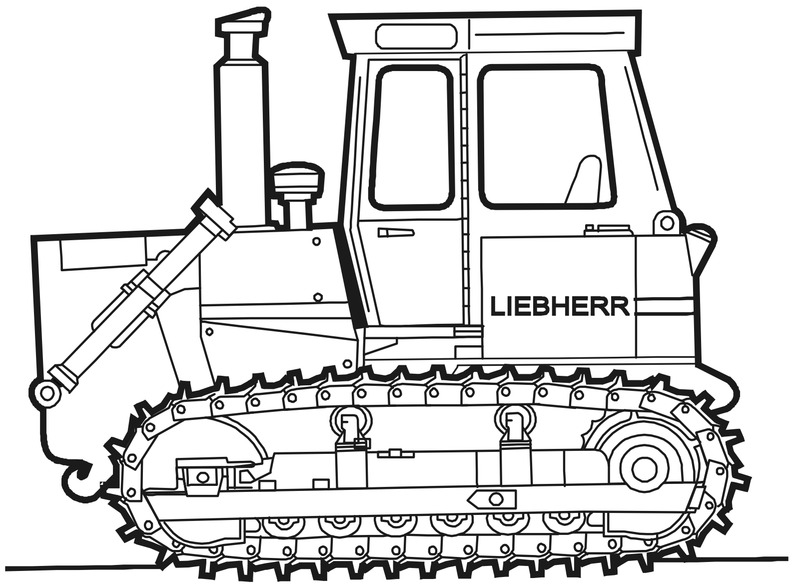


Fig. 1.1. Crawler tractor (courtesy : Liebherr)

The power from drive axle is transmitted through wheels or crawler chains in wheeled tractors and crawler tractors respectvely. Wheeled tractors generally have two large wheels in the rear and two smaller wheels in the front. For better traction under adverse load and ground conditions two wheels are fitted on each of the rear hubs. To make rear heavy for better stability of the tractor rear tyres are filled with water. The tread of the tyre should be selected carefully as it greatly affects its tractive efforts on a particular type of soil where it operates.

In Crawler tractors, live axles rotate large toothed wheels, known as drive sprockets, located at the rear of the track frame. In the front of each track frame, an idler is provided. An endless track chain is mounted on the sprockets and idlers. The chain is made of flat shoes pinned together end-to-end.

1.4.1. Crawler v/s Tyred Tractors

Each type of tractor has certain advantages in certain condtions. A comparative study of both the types of tractors is given hereunder to help in deciding that which of the two will suit more in a particular set of conditions.

(*a*) **Advantages by using Crawler mounted tractors :**

(*i*) More tractive efforts, hence can also operate on loose or muddy soil.

(*ii*) In absence of tyres, can easily operate in rocky conditions, as there is no danger for the damage of the tyres.

(*iii*) Where maintenance of haul roads is difficult, it can easily travel, specially in rough terrains.

(*iv*) Crawler tractors are more compact and powerful and hence can handle difficult jobs as well.

(*v*) Greater floatation because of the lower pressure under the tracks.

(*b*) **Advantages by using wheel-mounted tractors :**

(*i*) Can travel at higher speeds during the operation and also from one job to another.

(*ii*) Ease in operation. Operator feels less fatigue.

(*iii*) Can travel on paved roads without damaging them.

(*iv*) Can travel long distances at its own power, whereas Crawler mounted needs trailers.

(*v*) When work is spread over long area, these are found to be producing more output.

(*vi*) Operation, maintenance and repair costs less in wheeled tractors as compared to Crawler tractors. As large number of track parts are subjected to more wear.

(*vii*) Initial cost of the Crawler tractor is higher than the wheeled tractors, due to expensive track system.

(*viii*) Easy to manoeuvre.

Dozer Specifications

At the time of purchasing of dozens following points should be clearly specified after examining the exact job requirements and the manufacturer's limitations.

Engine horsepower at the flywheel, total operating weight, speed range in various gear positions ; blade type and size and also maximum tilt position or angle position; number, type and size of rippers; turning radius, fuel tank capacities. In case of wheel dozer also mention, number and sizes of the tyres, wheel base, ground clearance etc.

Following main factors should be considered while selecting a tractor dozer :

(*i*) Size of the dozer for a given job.

(*ii*) The type of work expected from the tractor dozer *e.g.* bull-dozing, ripping, land clearing, pulling a scraper etc.

(*iii*) The Type and condition of haul road.

(*iv*) Gradient of the haul road. (*v*) Distance to be moved.

(*vi*) Type of work expected to be taken from the equipment after the present job is completed.

1.5. BULL-DOZERS

Dozers are machines designed primarily for cutting and pushing the material over relatively short distances. They consist of a tractor with a front mounted blade, controlled by hydraulic cylinders to vary the depth of cut and rate of levelling depending on the material and application. Rear mounted hydraulic sacrifiers and rippers can be fitted to loosen hard material prior to dozing. A dozer is a frame mounted unit whith a blade, curved in its section, extending in front of the tractor.

Bulldozer is a most versatile and most important equipment on construction projects. Basically it is a pushing unit, but is widely used as a multipurpose equipment and can perform large number of operations with minor changes under different names like ; angle dozer, tilt dozer, tree dozer, and push dozer. Bulldozer scraps soft and granular material, pushes it in front or stock-piles. These are used for short hauls upto 100 metres only.

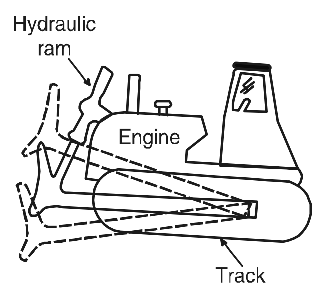


Fig. 1.2. Bulldozer with blade.

Angle dozer is used to push its load at an angle of nearly 25° to the direction of travel of the dozer. This is helpful where the material is pushed down the slope on hill work or where the material to be collected in a long windraw on one side of the line of travel of the dozer. The tilt dozer is used where blade is required to be tilted by raising one end upto 25 cm above the other, so as to start excavating a ditch or a trench or for excavation in hard ground. The push dozer is used to push the scraper unit during digging or loading operation by means of a rectangular plate, called the pusher plate. The tree dozer is used to remove the trees.

1.5.1. Dozer Blades

A heavy blade of slightly concave profile is attached in the front of the tractor. It is connected through two arms and a yoks to the tractor. The blade has a replaceable cutting edge, which wears out with the use of the blade. The blade is controlled by means of hydraulic cylinders. The Dozer blades are also known as moldboard and are available in sizes from 2 m to 7.5 metres wide and 0.8 m to 1.5 m in height.

Dozer blades vary in sizes and design based on spcific work applications. The hardened cutting edges and side bits are bolted, as it enables easy replacement when worn out.

Dozer blades can have three types of movements, namely; tilt, pitch, and angling. All these three features are not available to all blades, but any two of these may be incorporated in a single mount.

(1) *Tilt.* In this case Dozer can raise or lower the either end of the blade in the vertical plane. Tilting permits concentration of dozer driving power on a limited portion of the blade's length.

(2) *Pitch.* In this case the top of the blade can be pitched forward or backward varying the angle of attack of the cutting edge. This is a pivotal movement about the point of connection between the dozer and blade. When the top of the blade is pitched forward, the bottom edge moves back which increases the angle of cutting edge attack.

(3) *Angling.* In this case blades mounted on a C-frame can be turned from the direction of travel. In angling the blade is turned so that it is not perpendicular to the direction of travel of the dozer. This results in pushing the material to roll off the trailing end of the blade.

Types of Blades

1. **Blades for Production Dozing**

(*i*) **Universal U-Blade (Fig. 1.4.a).** U-Blade should be selected for moving large amount of materials over long distances, and is appropriate for moving easily dozed material. These blades are used for stockpile work, trapping for loaders, and land reclamation. (Ref. Fig. 1.6)

(*ii*) **Straight or S-Blade (Fig. 1.4.b).** Being smaller than the U-blade, it is easier to manoeuvre. This blade penetrates material easily. Addition of a tilt cylinder increases the versatility of this blade. It can move heavy materials more efficiently. These have no curvature in their length, and are mounted in a fixed position, perpendicular to the line of travel. (Ref. Fig. 1.5)

2. **Blades for Special Applications**

Some of the more familiar special applications of dozing blades are described below :

(*i*) **Angle Blade (Fig. 1.4.c).** The angle blade can be mounted straight or angled 25° to either side. It is designed to move material towards the sides of a cut, as required in road construction, backfilling or cutting ditches, and substantially reduces the amount of manoeuvring.

(*ii*) **Special application U-blades (Fig. 1.4 d).** These blades provide the capability to move a high volume of light and non-cohesive materials, such as coal, wood chips etc.

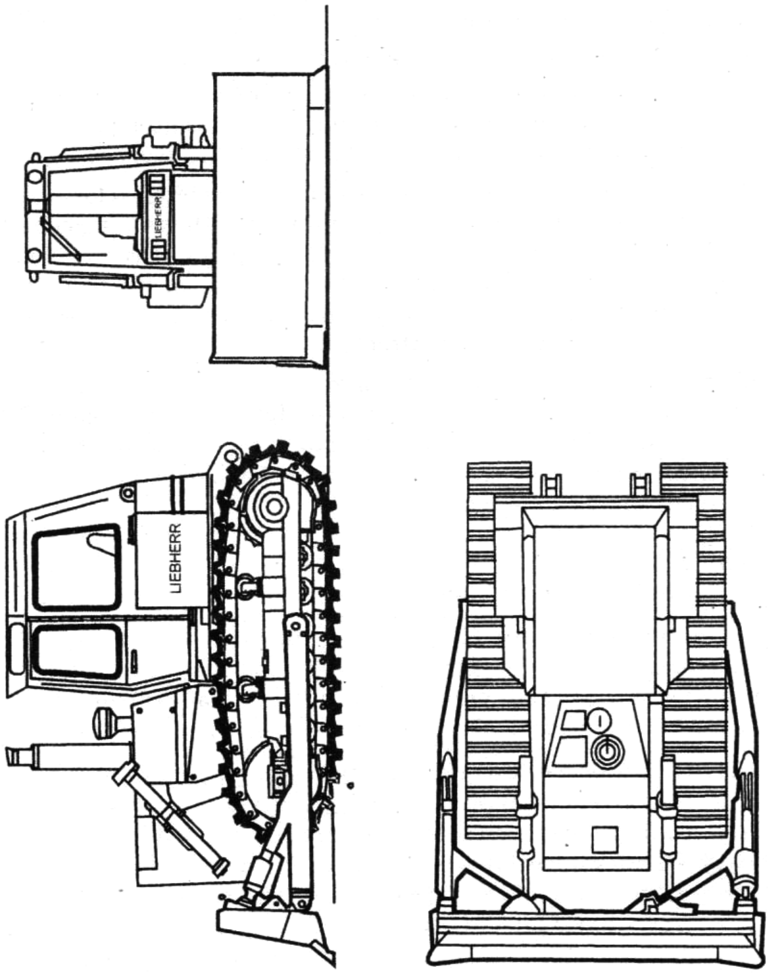


Fig. 1.3. Crawler Dozer with blade. (Courtesy : Liebherr)

(*iii*) **Landfill Blade (Fig. 1.4 e).** These blades are specially designed to handle refuse and/or fill material. A screen mounted on top of the blade offers good visibility and protects the radiator. The curved moldboad impart a rolling motion to the material being pushed and reduces horsepower demand.

(*iv*) **Clearing blade (Fig. 1.4 f).** This blade is chosen when land clearing operations are of primary importance. The blade will cut tree, pile vegetation and cut drainage ditches.

(*v*) **V-blade (Fig. 1.4 g).** This is used to shear trees, stumps and brushes at ground level. The two cutting edges form a sharp 'V' and bring the full machine power output to bear on the center of the blade. This means that vegetation can be cut and pushed to the side at a constant dozing speed.

(*vi*) **Rake (Fig. 1.4 h).** These are used in land clearing operations. They remove vegetation, including trees, and penetrate soil well. They perform efficiently when removing smaller stumps, root or rocks. They are generally replaceable.

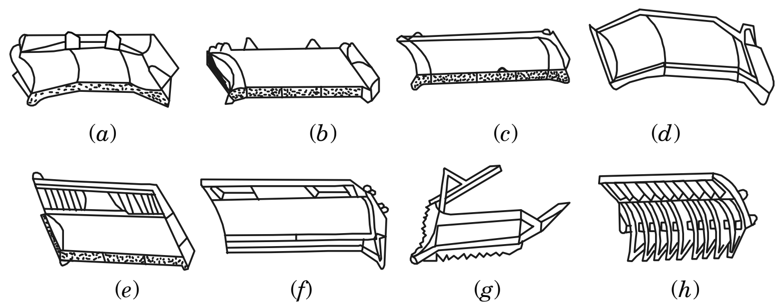


Fig. 1.4. Different types of Dozer blades.

Blade Performance

A dozer's blade performance is measured by two standard ratios :

(1) Horsepower (or kW) per unit length of cutting edge, known as cutting ratio.

A blade's ability to penetrate material and breakout a full load is measured by establishing the ratio of available machine horsepower to the length of the blade cutting edge *i.e.* HP/m (or kW/m). A higher ratio indicates a blade with a corresponding higher penetration capability.

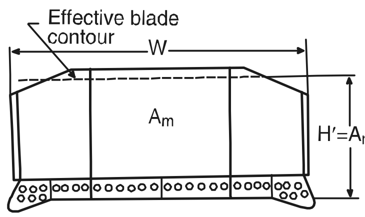
(2) Horsepower (or kW) per unit loose volume of material retained in front of the blade, known as load ratio.

One of the factors which can be used to determine the performance potential of a particular blade is the relationship between available machine horse power and the volume of displaced material, expressed in H.P./cu m loose or kW/m^3 loose. A numerical increase in this ratio indicates a greater potential for the blade to move material at greater speeds.

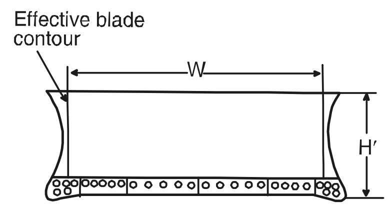
Blade Capacities

(1) **Straight blade and angle blade**

Blade capacity : $V = 0.8 \times W \times (H)^2$ (m^3)



Straight blade



Angle blade

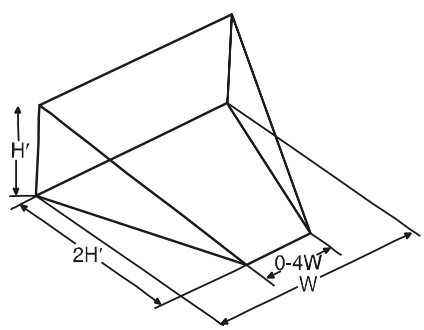
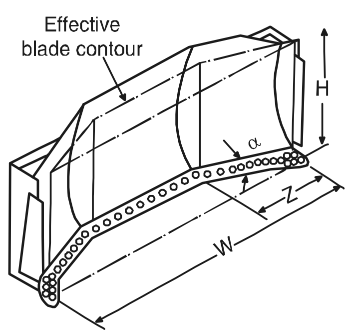
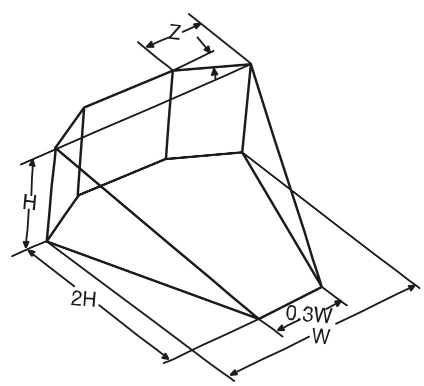


Fig. 1.5. Blade volume with straight and angle blade.

(2) **U-blade and Semi-U-blade**

Blade capacity : $V = 0.8 \times W \times (H)^2 + Z \times H \times (w - 2) \times \tan \alpha \ (m^3)$





U-Blade Semi-U-blade Blade volume U- and Semi-U-blade.

Fig. 1.6. Blade capacities for crawler dozers. (courtesy : Liebherr)

Material Evaluation

All other factors being equal, dozing performance will still vary considerably, depending on the nature of the material to be displaced. Moisture content, particle size and number of voids are the more important characteristics influencing dozing performances.

(*a*) **Moisture Content.** If moisture falls below the optimum moisture content value, particles will adhere to each other more and more and, in effect, it make it difficult to break material out of its natural state. If the moisture content increases above the optimum, material becomes heavy and will thus have a negative effect on dozing performance.

(*b*) **Particle Size.** The size of the individual particles making up a specific type of material has a direct bearing on the ability of a dozer blade to penetrate and loosen material. Large particles resist penetration more than smaller ones, requiring more dozing power. Additionally, sharp-edged particles exert more force against the curl movement of the blade. Therefore, material consisting of irregularly and sharp-edged particles is more difficult to doze than material composed of round-edged particles.

(*c*) **Voids.** Relatively dense materials with few voids contain large numbers of individual particles in close contact with each other. Because of this, more force is required to break up this tightly bonded material. Also such material is generally heavy, making additional demands on the available horse power of the dozer.

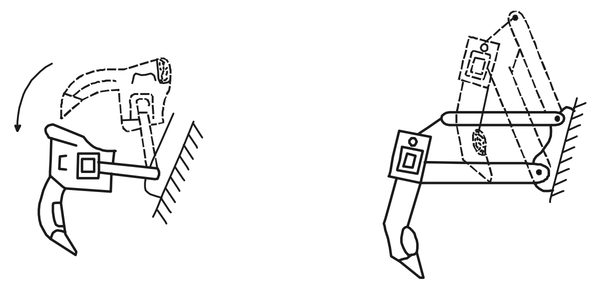
1.5.2. Rippers

Crawler-tractor, mounted with ripper is finding increasing use in construction, mining and quarrying. Cost of ripping vary from material to material to be ripped and some times very hard rock formations cannot be ripped. Cost of ripping should be compared with the cost of 'drilling—blasting' to consider economical way of excavation. While considering ripping cost, life of ripping tips as well as shortening of life of undercarriage should be considered.

Characteristics of the material to be ripped influence the selection of ripper type ; number of shanks required, ripping speed and amount of ripper penetration. For hard material single shank is preferred, but where material is easily penetrated and fractured into small pieces, a two or three shank ripper is used.

Ripper Types

Various types of rippers are used with the dozers. These may be towed units, integrated units, backrippers. Towed units are generally cable operated and are hard to manoeuvre, whereas integrated ripper units are hydrualically operated. With crawler mounted tractors these integrated units are easy to manoeuvre and provides a more compact and efficient units, while damage to tires is expected in rocky conditions. Integral rippers are of two types—hinge or parallelogram. Backrippers are mounted on dozer blades, so that as the dozer proceeds forward, the back rippers pivot in the mounting brackets and drag over the ground. Those are used in light duty works.



(*a*) Hinge type (*b*) Parallelogram type

Fig. 1.7. Rippers.

The construction of ripper is shown in Fig. 1.7 and 1.8. The tip can be replaced whenever it breaks, and protects the shank and adopter from damage. When adopter is breaking frequently, use the next shorter tip so as to reduce the load on the adopter. The protector is provided to support the tip as well as to provide wear protection for the adopter. This protector is replaced when it is worn out to 6 mm, so that any likely protector failure (which may cause adopter damage) may not occur.

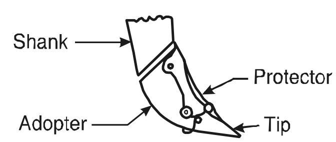


Fig. 1.8. Ripper shank with tip.

Rippers can also be classified as follows :

(*i*) Fixed Multiple-shank Ripper.

(*ii*) Variable Multiple-shank Ripper.

(*iii*) Fixed Giant Ripper. (*iv*) Variable Giant Ripper.

The fixed multiple shank ripper is used for comparatively simple ripping operations. The shank moves only up and down during digging operation. Digging depth is adjustable by changing shank pin position or shank. Fixed Giant ripper has only single powerful shank, but is not common as compared to variable giant rippers.

The variable multiple-shank ripper can change the angle of its shanks by means of ripper tilt cylinders. These are used wheere there are many boulders, or where the quality of rock is not consistent. The variable giant ripper has a single power shank. The angle of this ripper can be changed according to the ground requirements.

Ripping Efficiency

In order to achieve high ripping efficiency, following suggestions should be considered during ripping operations :

(*i*) When material is not broken, loosen the surface in one direction, then cross-ripping should be adopted.

(*ii*) If material is soft, use more than one shank ripper.

(*iii*) Ripping should be done downhill.

(*iv*) Avoid reversing when shank is in the ground.

(*v*) When both dozing and ripping operations are required to be done, it should rip going out and doze on the way in.

(*vi*) Shank tip should be sharp.

(*vii*) Use low gear range so as to get as low speed as possible.

(*viii*) When tracks start slipping, ripper and shank should be raised.

(*ix*) For hard material, use shorter tips, and for ordinary work use longest and sharpest point.

(*x*) Do not uncover the unripped portion of the rock during dozing of the material loosened by ripping. This will reduce the wear of under-carriage parts.

Rippability

With the manufacture of powerful tractors, availability of larger and improved rippers, most rocks can now be ripped. In order to know whether a particular rock can be ripped or whether it is economical to rip the rock or it should be drilled and blasted, rippability of the rock should be determined. It has been established that rippability of most rocks are related to the speed at which the sound wave travels through the rock. Sound travels faster in a dense medium *i.e.* the greater the speed the greater is the hardness of material. The speed of sound can be determined by the 'refraction seismograph'. Thus rocks which propagate sound waves at low velocities are rippable while rocks which propagate waves at high velocities are not rippable. Rocks having intermediate velocities are marginal. For such rocks, it is necessary to know whether ripping is economical or drilling and blasting will be economical. For such rocks correct size of ripper and capacity of tractor should be selected for ripping.

Cost of earth excavation, without rock is very less as compared to excavating a rock by ripping. When ripping a rock, life of undercarriage components will be shortened due to fast wear and shocks etc. hence ripping tips wear out at a faster rate. This also reduces the life of the tractor. These factors need be considered while determining the ripping cost. This cost should be compared with excavation of rock using "drilling and blasting" technique to determine an economical method.

Effectiveness of a ripper depends on :

(*a*) Down pressure at the ripper tip.

(*b*) The tractor usable to advance the tip; a function of power available, tractor weight and coefficient of traction.

(*c*) Properties of the material being ripped, faulted, weathered and crystalline structure.

The number of shanks used depends on the size of the dozer, the depth of penetration desired, the resistance of the material being ripped, and the degree of breakage of the material desired.

Physical Characteristics that favour ripping are :

(*i*) Fractures, faults and joints indicate weak rock and facilitate ripping.

(*ii*) Weathering makes the rock to be easily ripped. As greater the degree of weatheing the more easily the rock is ripped.

(*iii*) Brittleness and crystalline structure.

(*iv*) High degree of stratification offers good possibilities for ripping.

(*v*) Large grain size and coarse-grained rocks rip more easily than fine-grained rocks.

1.5.3. Power Train of a Dozer

In a tractor Dozer the driving power from the diesel engine is transmitted to the main clutch through the flywheel. Power from the main clutch shaft is transmitted through the universal joint to the main shaft of the transmission. Power obtained through a gear selected according to the load is transmited from the transmission to the bevel pinion at the rear end of the transmission case. This power is directed into the right and left directions by the bevel pinion and the bevel gear. Steering clutches which are provided at both the ends of the bevel gear shaft intercept and control the direction of power from the bevel gear shaft to the final drive.

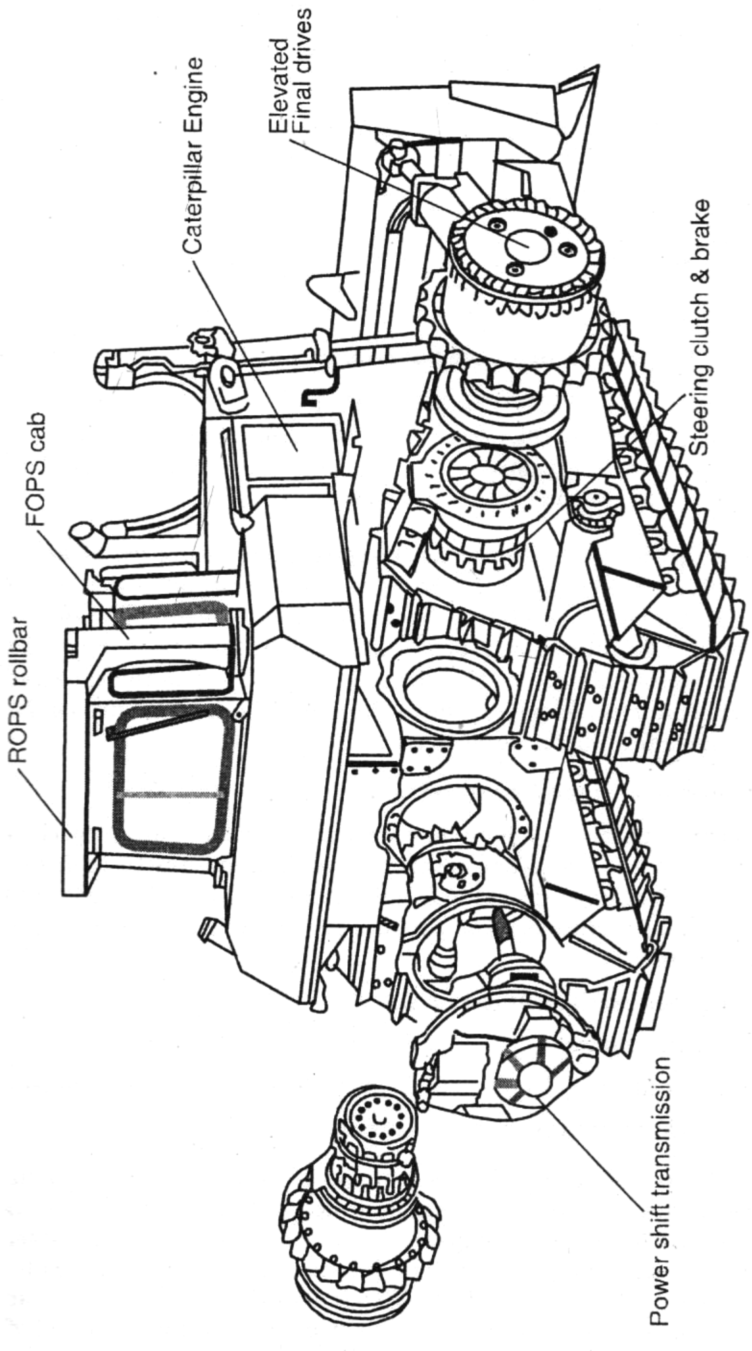


Fig. 1.9. Main components of a tractor dozer. (courtesy : Caterpillar)

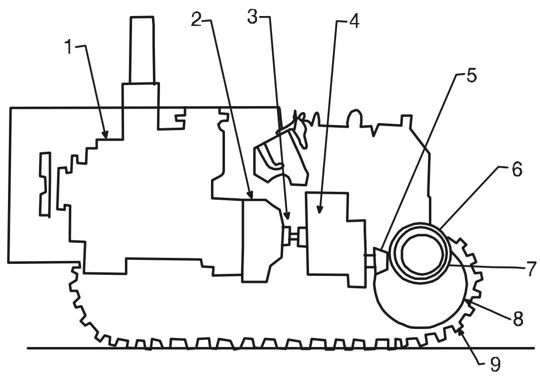


Fig. 1.10. Power-train of a tractor dozer. (1-Engine, 2-Main Clutch, 3-Universal Joint, 4-Transmission, 5-Bevel Pinion, 6-Steering clutch, 7-Steering brake, 8-Sprocket, 9-Track).

The direction of the dozer is changed by operating the steering control valve provided at the steering case top to cut off power of the steering clutch on the side interested for travelling. The turning radius is determined by the steering brake mounted on the periphery of the steering clutch brake drum. The power is transmitted to the sprocket by means of pinions and gears. The revolution of the sprocket drives the track to cause the tractor dozer to travel.

1.5.4. Under-Carriage Construction

During operation, the under-carriage components are subject to high impact load, severe wear condition due to riding over metal to metal, working in mud, hard gravel and hard stone. In order to meet this requirement, undercarriage components are manufactured with wear resistant materials.

An under-carriage unit consists of :

1. Track Frame	2. Equaliser bar	3. Sprocket
4. Front idler	5. Track rollers	6. Carrier rollers
7. Track chain assembly	8. Guards.	

(1) **Track Frame :** This is a support frame on which various components are mounted. This is a built up steel structure shaped to present a box like construction in cross-section and fabricated with steel plates by welding. This is designed to withstand the severe shock loads, bending, deformation and breakage. This is arranged in such a way that its up and down movement avoid tilting or pitching of the front end of the machine during crawling on rough ground. Track frame vibration

while travelling are absorbed by the rubber pads for improved machine's life and operator's comfort.

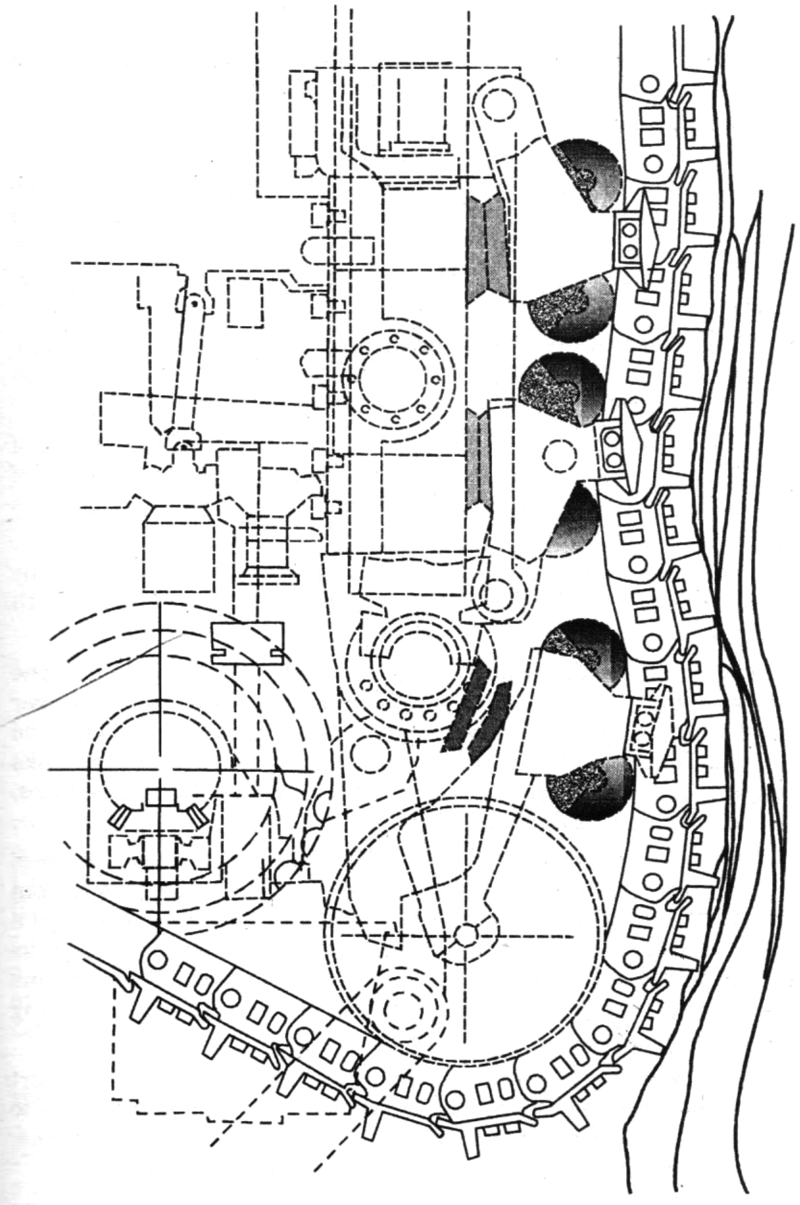


Fig. 1.11. Under-carriage of a tractor dozer.
(courtesy : Caterpillar)

(2) **Equaliser Bar :** This is a welded box like beam of steel plates which distributes the weight of front portion of the machine equally to the two track frames. Its centre point is pivoted to the cross bar of the chassis.

(3) **Sprocket.** Sprocket revolves in a loop of endless track chain to transmit driving power to the track to roll.

(4) **Front Idler.** This supports the front end part of the track chain to allow the track to roll straight over rough ground. The idler slides as well as can move upward and downward at the front end of the frame by the guide plates attached to the underside of the bearing and connected to the recoil spring assembly through yock to maintain track tension tight enough to keep suficient engagement of the sprocket wheel with track.

(5) **Track Rollers :** These are arranged under each track frame and bolted on to it. They evenly distribute the weight of the machine on the track and ride on the tread surface of track link.

(6) **Carrier Rollers :** These are installed on to the upper side of the track frame over a support. It guides and support the upper half of the track loop to proper rolling condition and avoids dangling due to its weight.

(7) **Track Chain Assembly :** Track chain assembly is formed by joining links, pins, bushings and mounting track shoes on the links with the help of bolts and nuts.

(*a*) **Track link assembly :** The links support the weight of the machine and are subjected to frequent impact load due to riding over rocks. These are made by forging of alloy steel (manganese steel) and surface hardened to provide wear and shock resistance property. Links act as rail along direction of machines travel. A pair of links fix shoes, pins and bushings, seals and spacers.

Pins and bushes both are press fitted in their respective holes provided in the links. Sections of the track are joined by passing the pin of one section through the bush of the next section. Outer surface of a bushing wears out as it comes in contact with sprocket teeth where as inner suface wears out as it is rotationally supported by the pins involved. The bushing act as the medium of transmission of driving power from sprocket wheel to the track.

(*b*) **Track shoe :** A track sho is composed of a plate which support a part of the machine weight and grousers which permits the shoe to grip the ground and penetrate soil to its full depth for a good traction and protection against side slippage under most conditions.

Track shoes are subjected to impact load, large stress and abration due to sliding contact with ground. These are cast or forged of special alloy steel and heat treated. The shoes are bolted to the links.

Narrow shoes with heavy, rugged grousers and plate sections are recommended for rock jobs. Wider track shows are suitable for soft underfooting to acquire maximum floatation and maximum drawbar pull.

(8) **Track roller guards :** These protects track rollers from being damaged by rocks and debris, these also prevents track from slipping.

How to Achieve Long Life of Under-Carriage

Following are the few tips which help in getting long life of under carriage.

(1) Avoid unnecessary high speed operation.

(2) Avoid sharp and pivot turn.

(3) Avoid reverse direction travelling.

(4) Avoid loading only on one side for long period of time.

(5) Avoid track shoe slip under undue load.

(6) Avoid riding over big boulders.

(7) Avoid leaving a machine stopped on slant.

(8) Avoid turning machine only in one direction.

(9) Follow maintenance schedule as recommended by manufacturer

Undercarriage Maintenance

Since undercarriage parts are very costly (about 40% of the cost of equipment) and these are subjected to severe applications, regular checking and maintenance is most necessary to get the best peerformance. Even in the best maintained equipment, the replacement cost of undercarriage parts is almost 100% of the capital cost of the equipment during its economical life. This is very high as compared to the 50% for all other components put together. This itself justifies the importance of regular inspection and maintenance of undercarriage parts and its proper operation. Bad operation too causes premature wear and failures, spinning causes fast wear and reduced life, more severe applications, like ripping specially on hard strata considering its capacity, also shortens the under-carriage life.

During spinning, tracks drag over the abrasive material and shoe steel is ground away unnecessarily. Inspite of lot of improvement in track construction, dirt is still the main enemy of the tracks and rollers. The wear is proportional to the degree of abrasiveness of the material to be moved and load of the components.

For better tracklife, always provide right quality bolts and nuts purchased from the right source. Loose, broken or low quality bolts and nuts cause abnormal wear on track shoes and assemblies and affects the life of undercarriage.

Proper track tension plays an important role in the service life of the undercarriage. Too tight track increases the load and cause faster track component wear, while too loose track causes links to beat against the top carrier rollers, damaging it. As a thumb rule 25 mm of slack (not sag) gives correct tension on undercarriage of most equipment. The expception is equipment fitted with only one carrier roller per side, where 20 mm slack produces best results. This slack should be checked under the actual working conditions.

Experiments have shown that, in order to extend track joint life, pins and bushes should be turned before the link wear reaches the halfway point to total destruction due to wear. This is done to bring unused wear surfaces into play, and by turning there is less chance of metal fatigue, cracking, bending or breaking.

Fig. 1.12. Bulldozer indicating major components.

1.6. APPLICATIONS OF DOZER

Following are the main dozer applications :

(*i*) **Land Clearing.** On every project, a bulldozer is the first equipment and its first task is to clear the ground for camp-site, and site for installing various plants.

Clearing of the land involves several operations depending upon the condition of soil and topography, the amount of clearing required, type of vegetation and the purpose for which clearing is done. The operations may include, removal of soil to remove unevennesss of the ground, removal of trees and stumps including roots, removal of vegetation etc.For this purpose various types of equipment can be used. These may be tractor mounted bulldozers, tractor mounted special blades in which the stringer penetrates the ground to cut the main horizontal roots of the tree or a blade which slides along the surface of the ground for cutting vegetation, tractor mounted rakes to be used to grab and pile trees, boulders etc. without transporting excess amount of soil, tractor mounted clamp rakes to pick up felled trees and transport them to a place of dumping.

(*ii*) **Stripping.** It is the removal of top soil that is not usable. Stripping is planned in such a way so that haulage is for minimum distance. Upto the distance of 100 meters dozer itself is used, but for more distances scrapers should be employed.

(*iii*) **Sidehill cuts.** Sidehill cuts should always be started from the top and then worked downward.

(*iv*) **Backfilling.** In backfilling material is pushed ahead of the dozer over embankments into ditches or against a structure. Angle dozers are found more suitable for this job as they can drift material into the trench while maintaining forward motion.

(*v*) **Ditching.** The rough ditches can be prepared by the dozers. These are constructed with a straight blade by working at right angles to the length of the ditch.

(*vi*) **Spreading.** These are also used for spreading the material hauled by trucks, scrapers etc. Depth of spread is adjusted considering the thickness required.

(*vii*) **Dozing rocks and frozen ground.** Rocks are generally removed by using one corner of the blade, as the full power is thus applied on this section of the blade. Large sections of rocks are removed by using the blade to lift the rock, simultaneously applying power to the tracks.

(*viii*) Maintaining haul roads.

(*ix*) Clearing the floors of borrow and quarry pits.

(*x*) **Digging.** A dozer while moving forward with the blade inserted in the soil digs it. If the blade is lowered further, more work can be done, thereby resistance will increase, as a thick slice requires more digging power than a thin one. The blade, during operation, should be lowered or raised gradually to avoid bumps in the path.

(*xi*) **Breaking Pile.** A pile may be knocked down by walking into it with the blade at the desired grade, after which it may be spread or piled elsewhere. If the heap is too large, it may be cut away in parts, either directly, or if it is not possible, the side cut should be repeated from different angles.

1.7. OUTPUT OF BULL DOZERS

The production of bull dozers mainly depend upon the following factors :

(*i*) Size and condition of the bulldozer
(*ii*) Distance travelled by the bulldozer
(*iii*) Speed of operaton
(*iv*) Characteristics of soil being handled
(*v*) Surface on which bulldozer is operating
(*vi*) Efficiency.

When dozing the materials that tend to stick together and remain in front of the blade during dozing, the efficiency is higher as compared to that when dozing loose granular earth or shattered rock. Whereas hard and cemented material needs extra efforts in preblasting or ripping.

Output of a dozer in bank-volume/hr.

$$= \text{Loose volume handled/trip} \times S \times \frac{60}{t} \times \text{efficiency}$$

where, S = Swell factor,

and t = Cycle time (time required/trip) in minutes.

Swell Factor. As we know that, loosening of earth causes an increase in volume, which if expressed as a % of original undisturbed volume gives the percentage of swell earth. The ratio of volume of original earth to the loose earth is known as swell factor.

Loose volume handled/trip = Production per cycle

$$= \text{Blade width} \times (\text{Blade height})^2 \times \text{Blade factor.}$$

Blade factor depends upon the type of soil and generally taken between 0.4 to 1.1. depending upon difficulty to easy dozing work.

$$\text{Cycle time (in minutes)} = \frac{D}{F} + \frac{D}{R} + G$$

where, D = Haul distance (metres)

F = Forward speed (m/min)

R = Reverse speed (m/min)

G = Gear shifting and manoeuvre time (minutes)

Volume Conversion

The volume measure varies with the state of the soil. States of soil encountered in earthmoving operations are : (*a*) in-place natural soil (known as bank soil); (*b*) loose excavated bulk soil, and (*c*) compacted soil. The bank volume swells when heaped in a loose state after excavation, and shrinks when compacted.

Volume conversion of common natural soils into three states is given hereunder :

Nature of soil	*Bank volume*	*Loose volume*	*Compacted volume*
Common earth	1.00	1.25	0.90
Sand	1.00	1.12	0.95
Clay	1.00	1.27	0.90
Rock (blasted)	1.00	1.50	1.30

For a given soil, the swell factor and shrinkage factor are defined as under :

(*i*) Swell factor = Loose volume/Bank volume.

(*ii*) Shrinkage factor = Compacted volume/Bank volume.

Dozer Prdocution Estimating

The major factors that control dozer production rates are :

(1) **Blade type.** As discussed earlier, straight (S) blades roll material in front of the blade, and universal (U) and semi-universal (SU) blades control side spillage by holding the material within the blade. The blade capacity is a function of blade type and physical size. Manufacturers' specification sheets provide information in this regard.

(2) **Job Conditions and condition of material.** The type and condition of material handled affects the shape of the pushed mass in front of the blade. The volumetric load a blade will carry can be estimated by following methods :

(*a*) Manufacturer's blade rating.

(*b*) Previous experience (similar material, equipment, and work conditions).

(*c*) Field measurements.

Correction Factors		
Operator	1. Highly skilled	1.00
	2. Average	0.80
	3. Unskilled	0.65
Material	1. Loose stockpile	1.20
	2. Easy to dig : loam, sand, gravel	1.00
	3. Medium dig, common earth in natural state	0.80
	4. Hard to push, dry ripped or blasted rock	0.67
Slot dozing	Ditches	1.20

Correction Factors

Visibility	1. Clear	1.00
	2. Darkness, fog, rain, snow or dust	0.80
Efficiency	1. 50 min/hr.	0.84
	2. 40 min/hr.	0.67
Blade	1. Straight blade	1.00
	2. U-blade for light material	1.20
	3. Angle blade	0.50—0.75
Grades	Favourable (– 30%) to unfavourable (+ 30%)	1.25—0.40

Traction Coefficient. The available push power and drawbar pull of a crawler tractor depends on the traction between the ground and tracks. The traction is determined by the weight of the machine and the type of ground surface. The available push power and drawbar is derived from the following formula :

Available push power/drawbar pull (in kg)

= Machine weight (in kg) × traction coefficient.

Following table shows the values of traction coefficient for different materials :

Material	*Traction Coefficient*
1. Concrete	0.45
2. Dry clay, loam	0.90
3. Wet clay, loam	0.70
4. Dry sand	0.30
5. Wet sand	0.50
6. Quarry pit	0.55
7. Gravel road (loose)	0.50
8. Packed snow	0.27
9. Firm earth	0.90
10. Loose earth	0.60
11. Coal, stockpiled	0.60

(3) **Cycle Time.** As discussed earlier, one dozer production cycle is the sum of the time required to push a load, back track and manoeuvre into the position to push again. Dozing, is generally peformed at low speed, 2.5 to 4 km/hr. The lower figure is suitable for very heavy cohesive materials. Return speed is usually the maximum that can be attained in the distance available.

1.7.1. Output of Rippers

Output of rippers depend upon the characateristics of soil, size of the tractor dozer, speed of the machine, shape and size of the ripper tooth, number of shanks used, and depth and width of ripping pass. However, following are the formulae used in general for calculating the output of ripper :

Production per hour

= (Bank-volume ripped per pass) × (Number of passes per hour)

where, Bank-volume ripped per pass

= Length of pass × Width of ripping pass × Depth of penetration × Efficiency

Number of passes per hour

$$= \frac{60}{\text{Time for making one pass (in min)}}$$

and time taken in one pass $= \dfrac{\text{Length of pass}}{\text{Travelling speed}} + \text{Turn round time}$

Fig. 1.13. Crawler dozer in operation

How to Increase Ripping Production

(1) Rip downhill.

(2) If material is not broken in one direction, cross-ripping should be adopted.

(3) Ripping can be made easier by adding water to the area.

(4) Do not reverse when shank is in the ground.

(5) Use shorter points when ripping hard material.

(6) For reducing wear of undercarriage parts, traction should be reduced by leaving a thin layer of loose material over the unripped rock.

(7) As soon as tracks starts slipping, ripper and shanks should be raised.

(8) Use low gear while ripping a rock.

The biggest bulldozer : The biggest bulldozer manufactured so far, is fitted with the turbocharged engine capable to produce 574 kw power and has a weight of nearly 93 tons. The blades are capable of handling upto 32 m^3. The single ripper having 4 operating positions, adjustable for a maximum digging depthof 1.8 m with a force of 26 tons is available.

1.8. SCRAPERS

Scrapers are the devices to scrap the ground and load it simultaneously, transport it over the required distance, dump and then spread the dumped material over the required area in required thickness level, and return to the pit for the next cycle. Thus the scrapers are designed to dig, load, haul, dump and spread and some times called as carry all.

The scrapers are of three types : (*a*) towed type, (*b*) self propelled or motorised or conventional type, (*c*) self loading or elevating scraper.

Scrapers can also be classified as (1) Crawler tractor scrapers or Wheel tired tractor scrapers, (2) Pusher loaded or self loaded scrapers.

The towed scrapers are provided with either cable or hydraulic control. Although these are becoming obsolete but even then some contractors use them because when coupled to a suitably powered crawler tractor, they can operate in extremely adverse conditions.

Self-propelled or motorised or conventional scrapers are most popular now-a-days. These are generally manufactured in ranges from 10 to 25 cubic metres. A motorised scraper needs push loading by a crawler mounted or a wheeled tractor. Wheeled scrapers have more hauling speed and hence are suitable for long distance hauling while crawler-towed scrapers travel at slower speed and can be used for short hauls only.

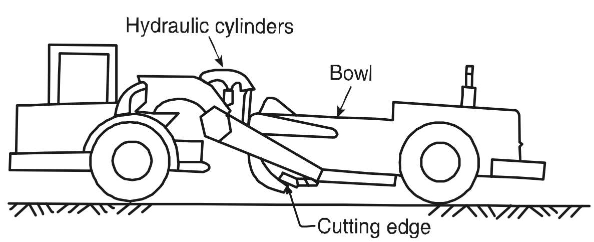


Fig. 1.14. Self propelled scraper.

The problem of loading by a pusher is overcome by the third type of scraper known as self-loading or elevating scrapers. These are twin engine scrapers and can work completely independently of all other plants. It does not need a pusher. To make them more effective and competitive with dump trucks, some of the manufacturers are producing three axle-scrapers of 40 cubic meter pay loads. However, these have certain limitations, firstly, the elevator cannot load particularly free flowing sands or handle rock infested soils. Secondly pay loads are restricted because of the additional weight of the loading elevator and its drive system. Thirdly, increase in loading time, the inability to obtain a full load, indicates that for powerful units a pusher is still required.

Construction

A self-propelled or motorised type scraper has following main parts :

(*i*) **Bowl.** The bowl is a pan to hold the scraped dirt. It is hinged at the rear corners to the rear axle inside the wheels, and is capable of tilting down for digging or ejecting. The bowl size is specified to indicate the size of the scraper.

(*ii*) **Cutting edge.** The bowl has a cutting edge attached at the bottom.The cutting edge is lowered into the dirt to make a shallow cut.

(*iii*) **Apron.** This is a wall in front of the bowl, which opens and closes to regulate the flow of the earth in and out of the bowl. This can open or closes in carrying position as well.

(*iv*) **Tail gate or ejector.** These are the rear of the pan which is capable of forward and backward movement inside the bowl. During loading it remains at its rear wall, while moves forward to help in ejecting the load during dumping.

All these items are controlled by the hydraulic system. Movements of these parts are controlled hydraulically. In hydraulic system, oil pressure works in the double acting rams provided separately for bowl, apron, and tail gate. The flow of oil in these rams is controlled by valves.

Specification of a Scraper

Usually the capacity of a scarper is given in terms of cubic metres struck and cubic metres heaped. Struck capacity of a scraper is the actual volume enclosed by the bowl and apron, struck off by a straight line passed along the top edge of the side plates. In other words it is the volume of the material levelled with the top edges of the bowl. Heaped capacity is the sum of the struck capacity and the volume enclosed by the four plates at a 1 : 1 slope extending upward.

The other important specifications of the scraper are type of excavator *i.e.* towed type or self-propelled or self-loaded ; two or three axle scraper, number of engines *i.e.* one or two engines ; horsepower of the engine at the flywheel ; pusher required with the scraper ; track-type or wheel type ; pay load capacity ; size of the tyres etc.

Operation

Operation of a scraper is described hereunder for an earth work application :

(*i*) **Loading or digging.** Operator moves to the cut with the ejector at the rear and the apron raised approximately to 40 cm. The bowl is then lowered to the desired depth of cut, increase engine speed, move forward in first gear keeping optimum depth of cut. When the bowl is full, the apron is closed and the bowl is then raised.

(*ii*) **Transporting.** The bowl is transported in high gear in raised position to provide sufficient clearance. During transporting, apron should be fully closed to prevent loss of the material, and the ejector should remain in the rear position.

(*iii*) **Unloading.** Unloading in a scraper is also termed as 'dumping and spreading'. The bowl should be positioned to spread the material to the desired depth during this operation. A partial opening of the apron during the initial unloading will help in even spreading. For wet and sticky material, the apron should be raised and lowered repeatedly until the material behind it is loosened and drops out of the bowl. Then the ejector is moved forward to push the remaining material out of the bowl at a uniform rate.

When the dump is complete, the tail gate is fully retracted, the apron dropped and the 'bowl' raised to transporting position. The finishing touch during spreading is done by grading it with the cutting edge, and the unit then hurries back and starts next cycle.

In hydraulic system the operations as described above are effected through oil pressure working in double-acting rams, usually two for apron and one for tail gate.

For better efficiency in the scraping operations following points should be taken care of :

(*i*) Depth of cut should commensurate with the power available for the cut.

(*ii*) Keep the haul roads maintained.

(*iii*) Pushers should utilise their waiting time in dressing the cut.

(*iv*) Loading operation should be carried out downhill wherever possible.

(*v*) Excessive turning of a pusher should be avoided, and scraper pusher balance should be maintained.

Economics of Scraper Operation

To examine the economics of scraper operation two main factors need detailed consideration, they are : material and haulage distance.

(*i*) **Material.** Scrapers can conveniently be used in all types of soils, like sand, gravel, silt, loam, clay and their mixtures.

(*ii*) **Haulage distance.** It is generally seen that for very short distances say 50 to 100 metres, a bulldozer is most economical earth moving equipment, whereas a scraper is most economical when the haulage distance is less than, say, 1500 metres and more than 100 metres.

Number of Scrapers per Pushdozer

For attaining the maximum hauling capacities, wheel type tractor-pulled scrapers need the assistance of pushdozers during loading to reduce the loading time. Similarly crawler-type tractor pulled scrapers, which are claimed to be self loading can also be loaded by means of push dozers. If the use of push dozer is found to be econom ical *i.e.* the increase in production is sufficient enough to pay back the cost of the tractor dozer, it is better to use it.

When pusher dozer is used, it is desirable to match the number of pushers with the number of scrapers. Waiting of any one, reduces its efficiency and increases the production cost. The cycle time for a pusher includes the time required to load one scraper plus the time needed to move into position to load another scraper. It depends on the conditions in the loading pit, sizes of the pusher and scrapers and loading method.

Following formula should be used to determine the number of scrapers that a push dozer can serve :

$$\text{Number of scrapers served} = \frac{\text{Cycle time for Scraper}}{\text{Cycle time for Pushdozer}}$$

1.8.1. Elevating Scraper

Scrapers described earlier depends upon a pusher tractor for loading, the elevating scraper is self loading one in addition to self propelled capabilities. It is similar to a conventional scraper except that its apron has been replaced by an 'elevator', also known as 'ladder'. This ladder is made up of chains with buckets bolted to it. The chain is rotated by power independent of the travel of the scraper. It has a variable speed and also reversing of the chain and buckets is possible. Loading of this scraper is done by forcing incoming earth over the cutting edge and subsequently ladder will carry it up into the bowl. They are capable of

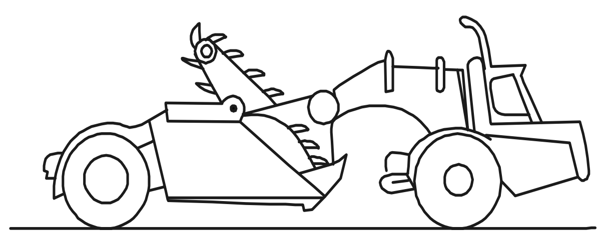


Fig. 1.15. Elevating scraper.

loading most materials except rock and boulders which are too large to pass between the cutting edge and the elevator buckets, and cohesive material with high moisture content.

By using elevating scraper, cost of a pusher and its operator is eliminated. Elevating scrapers also have very good finishing ability, and hence very useful in preparing final layer of earth work in road or airfield construction work.

The operating cost and maintenance cost of the elevating scraper is higher by nearly 30% as compared to that of conventional scrapers. Due to dead weight of the loading mechanism, its transportation efficiency is reduced.

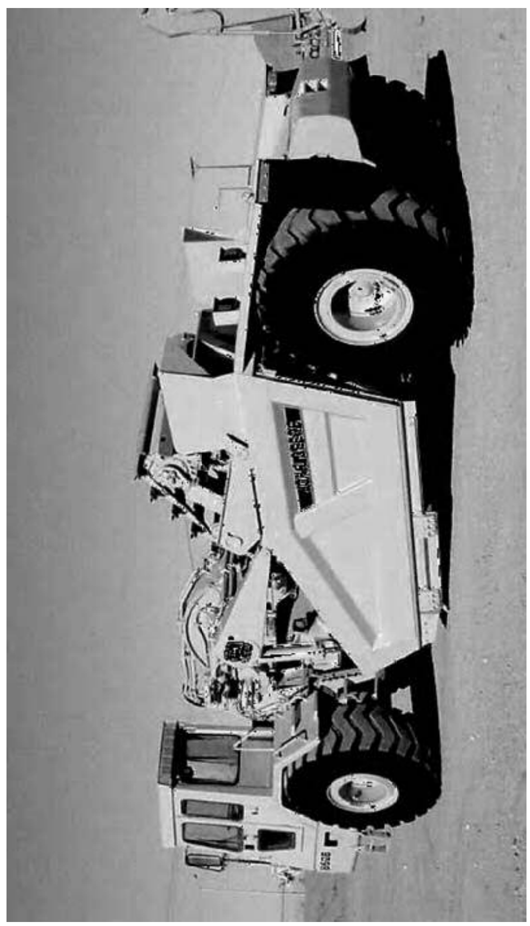


Fig. 1.16. Elevating scraper (courtesy : John deere).

Operation

Operation of an elevating scraper is described hereunder. The working cycle is similar to that of conventional scraper.

(*i*) **Loading.** For making a cut, the bowl is first lowered to a depth which can permit the elevator and tractor to operate at high and constant engine speed. The cut will force material towards the bowl and elevator buckets will sweep the material into the bowl. The elevator has 4 forward and one reverse speed. Soft surfaces like, sand, silt and topsoil are dug and loaded at high speeds. Low speeds are used for loading tough materials, like, hard clay etc. When the bowl is fully loaded, stop the elevator to avoid sweeping of the material from the face of the load and also to avoid spilling over to sides of the bowl.

(*ii*) **Transporting.** When the scraper is loaded, the elevator should be stopped and bowl is raised until it clears the ground, move the scraper and raise the bowl further during travelling. Transport the material to the place of dumping.

(*iii*) **Unloading.** The bowl is lowered to allow the desired depth of the spread. With the machine in motion, the ejector floor is opened, thus allowing the bowl to unload itself and the loading edge of the ejector floor will strike off the unloaded material in the bowl, in a smooth and even layer.

When unloading is complete, the bowl can be raised, ejector floor is closed and the scraper is returned for the next cycle.

Optimising the Scraper Production

Following are the some of the suggestions which will increase the scraper production :

(*i*) Construct and maintain smooth haul roads for faster and safer travel with less driver fatigue.

(*ii*) Depth of cut should be according to the type of soil being handled.

(*iii*) Use ripper teeth in hard or abrasive materials for easy loading. While ripping a rock, the depth ripped should be more so as to leave a loose layer of material under the tracks and tyres to provide good traction and reduced wear.

(*iv*) Where possible, loead-ing be done in down grade.

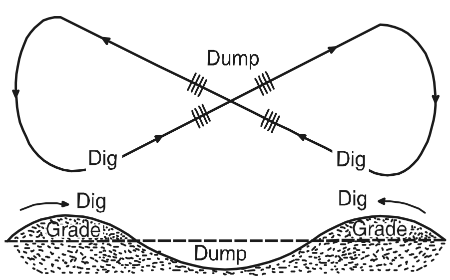


Fig. 1.17. Figure-8 method of loading and hauling.

(*v*) To increase stability of the scraper during travel, carry the bowl as close to the ground as possible.

(*vi*) If necessary, pre-wetting of the soil is done so that soil is reasonably moist, since some soils will load more easily when they are moist.

(*vii*) Whenever possible, plan the work to eliminate all avoidable turns. For example, 'Figure 8' loading, hauling, and unloading can be used to great advantage. By using this method, only two turns are required while two full loads are delivered, whereas normally two turns are required for each load.

(*viii*) Dumping should be done in an orderly pattern in the lifts of desired thickness so that compaction equipment work in an effective manner.

(*ix*) A spotter should always be employed to eliminate confusion and traffic congestion and coordinate the movement of scrapers for spreading the soil in the fill and that of compacting equipment.

Advantages of Elevating Scrapers

Following are the main advantages of elevating scrapers :

(*a*) Better loading ability in loose free flowing materials.

(*b*) Good finishing ability.

(*c*) Can be operated independently.

(*d*) Smooth and complete unloading of bowl by reversing the elevator rotation.

(*e*) Pusher tractor dozer is not required.

(*f*) Addition of ripper teeth to the cutting edge permits self loading in hard compacted material.

(*g*) Pulverising and mixing action by the elevator places material in uniform and homogeneous state for compaction.

Special Types of Scrapers

Other than the tractor towed, motorised, and elevating scrapers explained earlier, following are the other types of scrapers :

(*i*) **Tandem Scrapers.** In this type of scraper two bowls are attached to a single prime-mover unit. It gives higher capacity per cycle.

(*ii*) **Twin Engine Scrapers.** This type of scraper has two engines with single bowl. This has the advantages of, (*a*) greater acceleration due to higher power, (*b*) higher speeds under sever conditions, (*c*) less chances for getting struck.

(*iii*) **Multi-engine Multi-Bowl Scrapers.** This is the combination of the above two ideas. In these scrapers power is supplied to each wheel. These are generally self loading ; number of axles varies between 3 to 6, number of bowls 3, capacity upto 80 cu m. This eliminates the need for a pusher.

Output of Scrapers

Output of scrapers depends upon the following main factors :

(*i*) Size and mechanical condition of the scraper.

(*ii*) Hauling distance.

(*iii*) Condition of the haul road.

(*iv*) Characteristics of soil and work area.

(*v*) Efficiency.

Heaped capacity of scraper out of the two scrapers having more length or width and less height is higher even if the struck capacity is same.

Output of a scraper in bank-volume/hour.

$$= \text{Optimum loose volume loaded/trip} \times S \times \frac{60}{t} \times \text{Efficiency}$$

where, S = Swell factor

and t = Cycle time/trip in minutes.

Cycle Time for a Scraper

Cycle time for a scraper is the time required for loading, hauling to the fill, dumping, and returning back to the loading position. This cycle time is divided into : (*i*) Fixed time, which includes loading, dumping, turning, accelerating, retarding. These elements are reasonably constant under uniform operating conditions. Generally time study data of such elements are available for three type of conditions, namely favourable, average and unfavourable conditions. (*ii*) Variable time, which includes hauling and returning; it depends on the distance travelled and the average speed of the vehicle. This time is generally required to be determined.

1.9. LOADERS

A bucket is attached to the arms and capable of being raised, lowered and dumped through mechanical or hydraulic controls. The loaders having bucket in the front, known as 'Front-end loaders' are very common. The loaders are versatile, self propelled equipment mounted either on crawler or wheel-type running gear. These loaders are fitted with front mounted general-purpose bucket operated through hydraulic rams, with which they dig, scoop, lift, transport, carry, dump or load ino hauling units, bins, hoppers, conveyors and stockpiles. With the help of additional front and rear mounted attachments these can doze, scrap, grub, fork-lift, trench, grade, ditch rip, clamp, and winch. Applications of a loader vary from handling coal, sugar, sand, salt, stone etc. to earth moving and digging work in quarries.

Types of Loaders

Loaders are of the following types :

(*a*) Crawler loaders (*b*) Wheel loaders.

Crawler Loaders

Crawler track types are generally preferred for digging and loading jobs where ground conditions are poor and low pressure characteristics are required, and are preferable for applications involving rock and sharp stony ground as there is no possibility of tyre damage. These are best employed for short moves between loading and dumping points. These should be transported from one site to another after loading on the trailers.

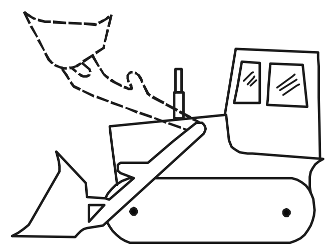


Fig. 1.18. Crawler loader

Wheeled Loaders

As a result of the development of more capable power trains (axles and tires), there was a steady trend towards wheel loaders at the expense of crawlers. Protective chains for tires, that considerably increases tire operating life, even in quarry applications, additionally favoured the wheel loader against the rather more difficult to manoeuvre crawler.

Wheeled loaders are generally four wheel drive. However, for handling light jobs on good ground conditions two-wheel drive variants are also used. Four wheel drive loaders are generally used for construction job, whereas, two wheel drive loaders are used for bulk handling of coal, cement, fertilizer etc. into hoppers and trucks.

From manoeuvrability point of view, wheel loaders are of following type :

(*i*) Articulated type (Pivot steer).

(*ii*) Rigid frame-two wheel steer or all wheel steer.

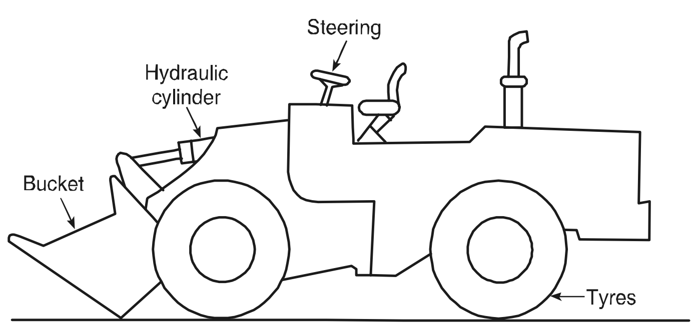


Fig. 1.19(*a*). Line diagram of wheel loader.

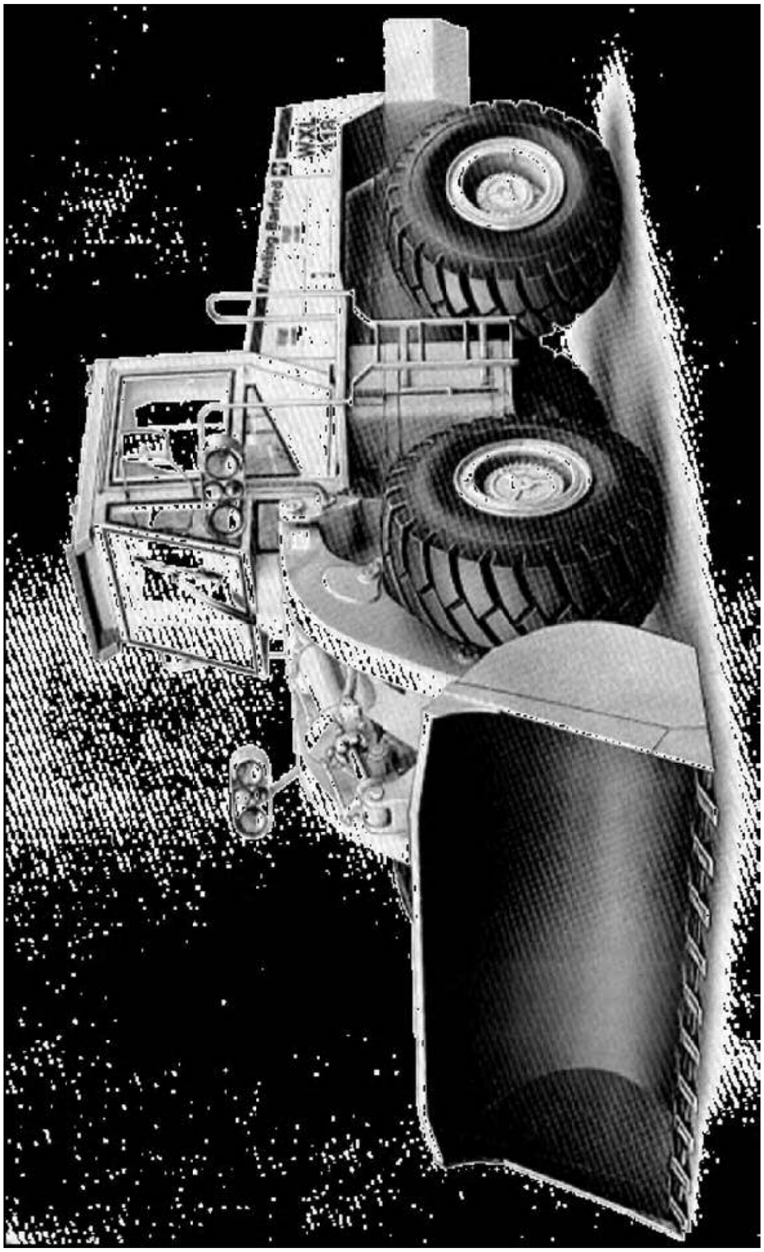
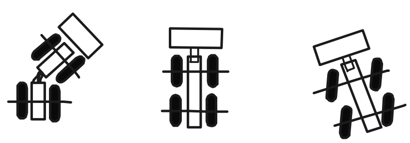


Fig. 1.19(*b*). Wheel loader with bucket of 4.8 cu m.
(courtesy : Aveling Barford)

(*i*) **Articulated type of loaders.** This type of loader is hinged in the middle of the front and rear axles, as shown in the Fig. 1.20(*a*). Due to their operational characteristics and capability of working in limited space and short turning radius, resulting higher speed of work, these have become very popular. Because of the advantage of quick manoeuvring and thereby easier spotting of loads, less rolling resistance on turns, better mobility on soft surface, these loaders give better performance and high productivity. The articulation permits the loader to pivot 30-45 degree either side of the centre.

(*ii*) **Rigid frame type-loaders.** These are comparatively cheaper than articulated frame type of loaders. With this type of loader sometimes operators misjudge hopper or truck body width and therefore he has to manoeuvre back and forth before dumping. Rigid frame loaders are of two types, namely two wheel steer and all wheel steer. By designing all wheel steer loader, manoeuvrability is gained along with the advantages of rigid frame construction. In all wheel steer loaders, operator can switch from 4 wheel to 2 wheel steer or *vice-versa* by using a lever. On stockpile operations, all wheel steering allows the operator to align the bucket in the pile quickly to ensure a heaped load in the minimum possible time. While moving on the roads operator can set his loader on front steer only and then handles it like a normal road vehicle.



(*a*) (*b*) (*c*)

Fig. 1.20. Types of loaders :

(*a*) Articulated

(*b*) Rigid frame-two wheel steer

(*c*) Rigid frame 4 wheel steer.

Construction

As we have discussed earlier, articulated frame type of wheel loaders are very common in consruction engineering, hence these are discussed here. The loader is consisting of two frames, the front frame and the rear frame, interlinked by means of a vertical centre pivot. The front frame of the equipment carries drivers seat, bucket's hydraulic rams etc., whereas the rear frame carries the engine assembly, transmission assembly and the hydraulic tank. The power is transmitted from the engine to the front and rear axle through a torque convertor and power shift transmission assembly by means of propeller shafts. The loaders have two stage hydraulic system, one for hoisting or lifting the bucket through raising the lift arms with hydraulically-operated rams, and another for the dumping through dump arms which are operated by another set of arms.

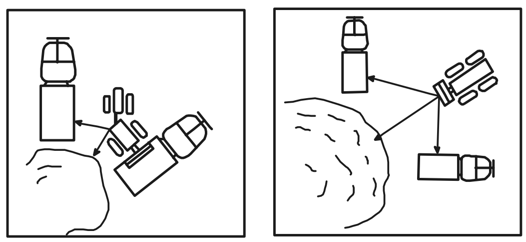
The hydraulically actuated loader lift mechanism is located infront of the operator for safety reasons. Lift control provides raise, hold, lower and float positions. Bucket control has roll-back, hold and dump positions. Additional hydraulic controls are also proided for optional attachment.

Applications

Loaders with its general purpose bucket and with additional attachment can be used for :

(*i*) Loading the dump trucks in querries, mines and industries.

(*ii*) Loading the material in the hopper of crushers, conveyors etc.



(*a*) (*b*)

Fig. 1.21. Loading arrangement with (*a*) Articulated, (*b*) Rigid frame loaders.

(*iii*) Loading the waste material, clearing debris.

(*iv*) To move bulky objects. (*v*) Removing snow.

(*vi*) Clearing the areas. (*vii*) For forklifting.

(*viii*) For dozing, trenching, ripping etc. with the help of suitable attachments.

Thus the loader is a very useful equipment and is used in mining, quarrying, industrial work in addition to the construction engineering works.

Modern Trends in Wheel Loaders

Wheel loader is the most widely used piece of construction equipment. From mundane road pitching jobs to billion-dollar dams, in tiny quarries, and vast open cast mines, it is the indispensable tool.

While users keep finding new jobs for wheel loaders, most still spend much of their lives advancing and reversing from stock pile or bank to truck or hopper making nearly 1000 or so directional changes per shift. Both semi-automatic and fully automatic power shifts are now in the market. On the semi-automatic models, the transmission will shuttle between two gears—first and second or third and fourth—depending on the speed selected. The fully automatic version just requires the operator to set the travel direction, and the transmission handles all the gear changing.

Few models have come into the market, on which, the hydraulic transmission works through a three-speed power shift gear box, providing infinitely variable speed upto more than 35 km/hr in top gear. The electro-hydraulically selected gear ratios and travel direction can be selected under full power. A unique feature is the multi-function level that controls all bucket, gear selection, and travel direction functions. The system allows the operator to keep one hand on the steering wheel at all times, greatly enhancing safety.

Fig. 1.22. Coal, being loaded by wheel loader.

New trends is towards installing new attachments for other applications without changing basic form of the loader. The quick change coupler allow buckets and other implements to be swapped in seconds. Optional hydraulic circuits to power jack hammers, grinding and cutting discs, pumps, and other tools capable of operating with hydraulic motors are also available.

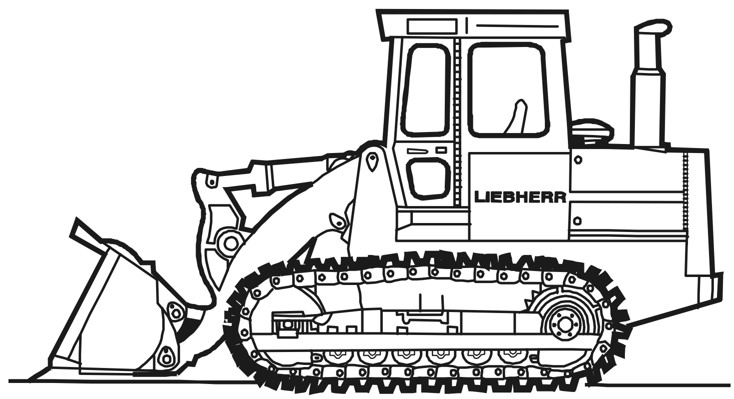
Developments in wheel loaders are also meeting the demands of customers for improved noise protection, delux seats, electronic equipment, air conditioning and better layout of the machine.

Equipment manufacturers are trying for more efficient power train and hydraulic systems. The quantity of fuel needed per cubic metre of earth handled has declined. Tyre wear is being controlled by differential locks and rear axle disconnects for road travel, and still search for better and better version is still going on.

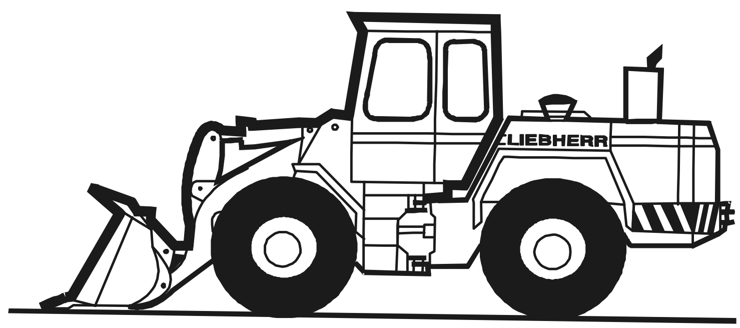
Operations

Loaders are used to carry out following main operations :

(1) **Loading.** Loading operation is the main operation performed by the loaders. Loading consists of scooping, lifting, turning and dumping



(*a*)



(*b*)

Fig. 1.23. Loaders : (*a*) Crawler (*b*) Wheeled, types.
(Courtesy : Liebherr)

materials such as sand, gravel and crushed materials from stockpiles, bank or construction site into the hauling units. For better output the bucket should be filled full and the number of hauling units deployed for the work should be such that there is no waiting time for the loader and there should not be more than one hauling unit in the Queue.

(2) **Hauling.** Wheel loaders are excellent for moving loose materials over short distances to dump into hauling units, hoppers, conveyors, bins or any other place of work in the construction sites.

A *cycle time* for a loader consists of the following :

(*a*) Time for scooping, lifting and dumping the bucket along with time required for changing the directions and taking the turns.

(*b*) *Hauling time.* It is the travel time for load carrying and empty returning. Generally the high reverse speeds reduce the returning time enabling the reduction in cycle time and thus more work in one hour.

(3) **Excavating.** Crawler loaders and heavy duty wheel-loaders are excellent for many excavation jobs, like basement digging etc. With excavator attachment it can also handle several other types of excavation works. These loaders can excavate as well as lift the excavated material and dump it into trucks or on the stockpiles. In case surface is hard for excavating and scooping, the earth ripper or sacrifier attachment is mounted on the rear of the loader to loosen such surface. The operator can then easily dig and load the material into bucket for removal.

(4) **Clearing.** Loaders can scoop up and load the debris of demolished buildings into hauling units. They also knock down small and temporary buildings ; loaders are also used for clean up the areas after snow-storms, tornadoes, floods etc. A grubber blade attachment is used in place of bucket for large-scale clearing work. Thus the loaders are the first equipment to prepare the site for building and construction operations; and also the last equipment in order to backfill, spread, level and top up with selected good soil for grass and landscaping.

Attachments

Following are the main attachments which can be fitted to a wheel loader :

(*i*) **Back filling attachments.** Backfilling can be done with the bucket of this attacment when used with the loader.

(*ii*) **Fork lift attachment.** An industrial fork lift when attached with a loader gives more stability, more tractive power and greater clearance than with a normal fork lift truck.

(*iii*) **Side bucket attachment.** Side dump bucket is used to load snow for removal when work is required to be carried out in tight area.

By reducing the manoeuvring time, production in boosted by using this attacment.

(*iv*) **Sweeping attachment.** A sweeping attachment can be fitted to a wheel loader for general cleaning of roads and parking area in the industries.

(*v*) **Multipurpose bucket.** A multipurpos or four-in-one bucket can be used as a dozer, scraper, clamshell and general purpose loading. The multipurpose bucket is much heavier than the general purpose bucket, and therefore a loader equipped with it will generally need more counter-weight for the same operating load rating.

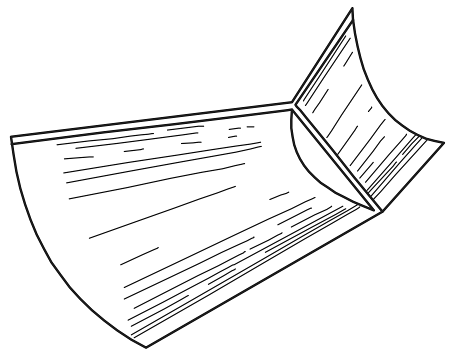
(*vi*) **Ripper-scarifier attachment.** These are mounted on rear of the loader to loosen hard surfaces such as compacted earth ; hardpan, shale, slate, decomposed rock ; to tear up old brick, asphalt or broken concrete pavement, that do not readily yield to direct bucket loading.

Fig. 1.24. Loader with Stacking rake attachment.

(*vii*) **Miscellaneous other attachments.** A large number of attachments for specialised jobs are also available for fitting to the loaders. Some of these are pipe laying attachments, wooden log or concrete pipe handling attachments, pole handling attachments, boom for loader crane set-up.

(*viii*) **Stacking Rake.** Stacking rakes are designed for follow-up clearing, racking and piling after trees and brushes have been cut by other attachments. The teeth are curved and of extra long length to carry a full load up into the fine line pile or windrow.

(*ix*) **Snow removal attachment.** Snow-removal V-plow is normally used for high speed plowing of snow on long stretches of highway, airport runways and places where there is ample room to throw the snow.



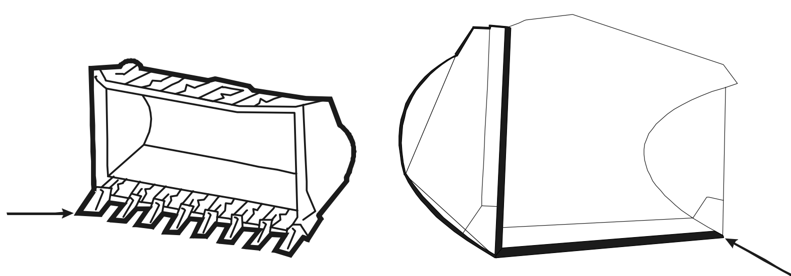
1.25. Snow removal attachment.

(*x*) **Protective chains.** These chains offer the protection for wheel loaders where tires are exposed to sever wear, cuttings, and sudden failures due to punctures. Typical applications for the use of these chains would be in quarries, mines, or heavy rock.

Teeth for Loader Buckets

Loader buckets have following types of teeth.

(*i*) Weld-on flush mounted shank assemblies, which are useful in medium duty applications where a level grade or floor must be maintained. This can withstand normal break out forces and remain secure to the bucket cutting edge. This design allows the maintaining of a level grade since the shank is welded to the top of the bucket cutting edge leaving the tooth flush with the bucket bottom.



(*a*) (*b*)

1.26. Buckets with (*a*) teeth and (*b*) cutting edge.

(*ii*) Weld-on shank can be used in any application where teeth are going to be used 100% of the time because of the economical advantage over Bolt-on teeth.

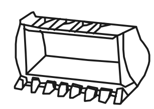
(*iii*) Bolt-on heavy duty shank assemblies designed with recessed holes on top and bottom protect bolt heads and nuts from material wear.

(*iv*) Bolt-on teeth can be used for temporary digging in hard coal, shale or compacted materials etc. These teeth can easily be removed when they are not needed or when smooth grade work or clean-up work is required.

Fig. 1.27. Coal being loaded in a dumper.

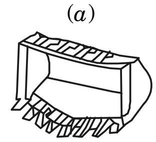
Loader Buckets and Their Application

(*i*) **Standard bucket (Fig. 1.28 a).** This is most univesally used loader attachment and can be used in particularly every type of material encountered during earthmoving operations. Applications of this bucket includes loading, excavation, scraping and level grading.



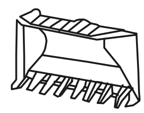
(*a*)

(*ii*) **Rock bucket (Fig. 1.28 b).** It is designed primarily for quarry operations and is very rugged. To achieve good penetration it has a V-shaped cutting edge. This V-shaped cutting edge also enables the operator to concentrate breakout forces on one point.



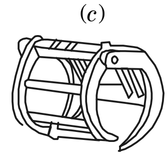
(*b*)

(*iii*) **Side dump bucket (Fig. 1.28 c).** This is designed for loading operations in extremely confined quarters, such as subway tunnel, etc. It is available with the opening on either or both sides, material is dumped to the side.



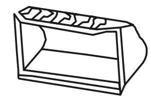
(*c*)

(*iv*) **Log grapples (Fig. 1.28 d).** This is designed for log loading operations. It consists of a loading fork and a hydraulically powered clamp, keeping the logs from shifting or rolling out.



(*d*)

(*v*) **Stockpile bucket (Fig. 1.28 e).** This performs best when loading relatively light and non-cohesive materials. It weighs less than a standard bucket and offers greater volumetric capacity. Since it is used in stockpile environment, it is not equipped with teeth.



(*e*)
Fig. 1.28. Loader Buckets.

Fig. 1.29. Wheel loader with log grapple attachment

1.10. OUTPUT OF LOADERS

Hourly production in m^3/hr (Q) = $q \dfrac{3600}{C} \times \text{Efficiency}$

where, q = production per cycle (m^3)

= Heaped Capacity × Swell factor × Bucket factor.

and C = Cycle time (in secs)

Bucket Factor

Bucket factor vary from 1.0 to 0.4 depending upon the height of bench, nature of fragmentation, efficiency of the bucket mechanism, operator's skill. Loading conditions affect the bucket factor as mentioned in the table given below :

	Loading conditions	*Bucket factor*
(*i*) Easy :	Digging and loading from stockpiles or from where no-digging power is required and the material which can be heaped in bucket. Sand, sandy soil with a moderate moisture.	1.0 to 0.8
(*ii*) Average :	Digging and loading from stock piles which is more difficult to penetrate and scoop but which make nearly a fully heaped bucket. Dry sand or only soil, clayey soil, clay, unscreened gravels or digging and loading of soft gravels directly from hill.	0.8 to 0.6
(*iii*) Difficult :	Digging and loading of finely crushed stones, hard clay, gravelly sand, clay etc. with high moisture content. It is difficult to fill the bucket with these materials.	0.6 to 0.5
(*iv*) Very difficult :	Loading of bulky, irregular shaped or rugged rocks, blasted rocks, boulders, sand mixed boulders, soils which can not be scooped up into the bucket.	0.5 to 0.4

Cycle Time

Cycle time is the time required for loading into the bucket, swing time (loaded), travel time (loaded), dumping, back swing and travel time (with empty bucket). The swing time (loaded) and back swing are generally termed as manoeuver time.

To determine the number of loads per hour the loader cycle time must be known combining these above mentioned timings, which are governed by the following factors :

(*a*) **Loading time**

Material	*Minutes*
(*i*) Uniform aggregates	0.03 – 0.05
(*ii*) Moist, mixed aggregates	0.04 – 0.06
(*iii*) Wet loam	0.05 – 0.07
(*iv*) Roots, large rocks, soil	0.05 – 0.20
(*v*) Extremely cohesive material	0.10 – 0.20

(*b*) **Travel Time.** In loader operation, travel time is a combination of haul and return travel. For estimating the travel time manufacturer's chart is used.

(*c*) **Swing time** is the time required for moving the bucket from one position to another keeping the height same. This time depends on the degree and speed of swing and the skill of the operator. Swing times are generally adopted as below :

Degree of swing	*Swing time, in seconds*
45° to 90°	4—7
90° to 100°	5—8

(*d*) **Dumping time** is the time required for unloading the bucket, and depends on the proper spotting of transport equipment, and the operator's skill. Dumping at a fixed area requires 5 to 8 seconds, while at an area not fixed requires 3 to 6 seconds.

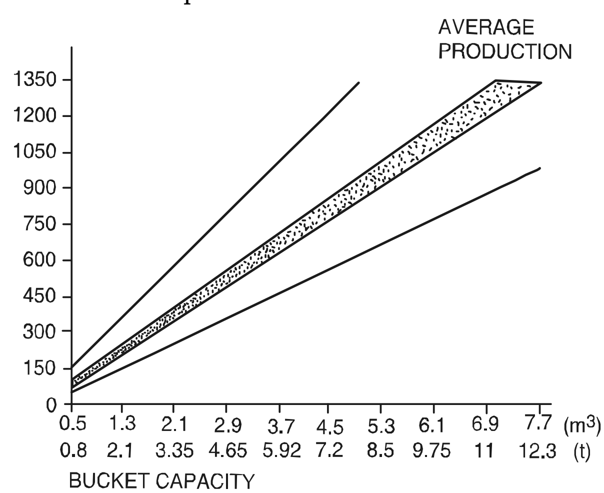


Fig. 1.30. Wheel loader production in t/hr.

Wheel Loader Production. Fig. 1.30 gives a range of production likely to be achieved with a particular size of bucket, depending upon the cycle time. The chart is drawn considering the density of material as 1.8 tons/m^3

Loader Capacity

For general purpose, loaders with bucket sizes varying between 1.4 to 2.8 cubic metres are commonly used. However loaders upto 18 cu metres are also available for light materials handling. Engines with power ranging between 65 to 250 B.H.P. are generally available. Capacities of the buckets are indicated by the struck capacity as wsell as heaped capacity. The crawler loaders use rock bucket for use in rocky, consolidated soils and are generally used for movements upto 50 metres (as compared to that of 300 metres in wheel loaders). Articulation permitting 90° rotation of the bucket (45° to each side of the centre line) is available in most wheel loaders.

Increasing Loader Production

Loader production can be increased by adopting following methods :

(*a*) **Blasting.** Loosening of rock by blasting results in good fragmentation which permits faster digging, greater payloads due to fewer voids, and also helps in increased crusher production with lesser strains. Loosening of rock by blasting also reduces the danger of rock slides while the loader is in operation.

(*b*) **Helping the Loader by a Dozer.** Loader production can be increased if it is spared from digging and collecting the material. These operations if performed by a dozer, the loader is then allowed to concentrate only on loading functions resulting in increased production. This is possible if either the quantum of work is very heavy or a dozer working in the area is not fully occupied.

(*c*) **Planning the work.** Locating the dumpers, and place in the stockpile from where it takes the material for loading greatly effect the loading cycle time. This should be carried out in such a way that cycle time is kept minimum. During idle time *i.e.* when it is not loading, the loader should be used to work a stockpile, clean the area in order to save the tyres of hauling units. If idle time is long, it can be used to maintain haul roads and other jobs which can be performed by the loader including those with special attachments.

1.11. BELT LOADERS

Belt loaders consist of a cutting edge and a conveyor belt, which either discharge excavated earth on the side of the belt loader or crosses machine towards the rear to load into the carriers located there. The material cut by the blade is thrown over the lower end of the conveyor belt to carry it over to discharge into the hauling units or thrown to the side into windrows. Generally soft materials are handled by these loaders.

Fig. 1.31. Portable swivelling belt loader. (courtesy :

The material thus poured into the hauling units does not damage by the body of hauling units, which is likely in loading by front end loaders due to extreme shock while dumping. Conventional loading may produce voids, whereas loading by belt conveyors ensures elimination of voids. The belt loaders are more productive and suitable for large production work.

These belt loaders are suitable for soft surfaces, and very helpful in down the hill dozing work. These can be used only where quantum of work is high and to keep loader busy. A sufficient number of dozers are required to feed the earth excavated for loading by loaders, if surface is hard.

The belt loaders are ideal for quick, efficient and economical loading of loose and free flowing materials (say upto 65 mm size), like sand, gravel, earth, quarry aggregates etc. from heaps into trucks as shown in the Fig. 1.31, and 1.32. It has bucket elevator, belt conveyor and trolley forming a well-balanced portable unit. The bucket-elevator scoops up the material from heap and passes it on to the belt-conveyor, which in turn carries it into the truck. The bucket-elevator can swivel over and thus covers a large portion of the heap without moving the trolley. The trolley can also move backwards and forwards and turn sideways. It can thus approach every section of the heap. The bucket elevator and trolly are provided with a separate prime mover for each one.

Following are the essential requisites for using a belt loader :

(*i*) Belt loader is economical only for large quantities.

(*ii*) Cycle time on long hauls can be cut sharply by fast loading.

(*iii*) Belt loading is economical only when closing distance between

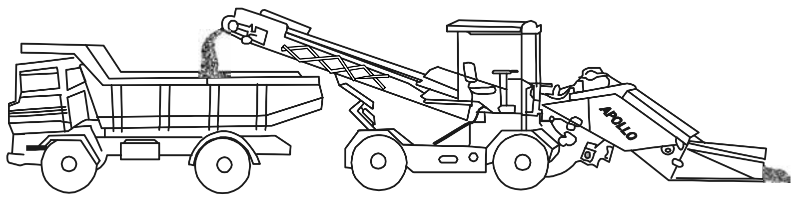


Fig. 1.32. Appollo force feed loader loading the material into the dumper. Mold board collects the material of all kinds such as milled pavement, material behind road planers, sand, gravel aggregates etc. through blades driven hydraulically.

the dozers and belt loader trap is less than 150 metres. In order to keep the loader busy, as many as six dozers, depending upon dozer size, pushing capacity, length of push, belt loader capacity and capacity of the hauling units, are deployed.

1.12. EXCAVATORS

Excavators are basically digging machines, having following three main components.

(*a*) An undercarriage to give mobility. This may be crawler track mounted or wheel mounted.

(*b*) A superstructure with operator's cabin mounted on either a slew ring to traverse through 360° or on a rigid frame.

(*c*) Hydraulically articulated boom and dipper arms with bucket.

Hydraulic excavators are now becoming more and more popular and these enjoy various advantages. This can be fitted with various multipurpose attachments for various earthmoving jobs, like, laying pipes, removing trees, excavating drains, general earth moving jobs of cleaning areas, loading etc. The hydraulic system is very productive and efficient due to its mobility and lightness and lower maintenance costs, and hence contributing towards popularity. A most important advantage is the hydraulic wrist action of the excavator which directs the bucket teeth at their most efficient angle during digging operation. The hydraulic system also contributes for the smooth, shock-free operation during digging and traction. The hydraulic controls are easy to operate and respond quickly.

Mechanical or cable operated excavators are of either 'Hoe' type or 'Shovel' type. In 'Hoe' equipments the bucket opening faces towards the machine and the bucket is pulled towards the machine and are used for excavation below the standing level of the machine like, excavation of house and building foundations ; trenches for irrigation, sewerage, cables, gas and oil pipe lines ; maintenance and cleaning of rivers, canals and irrigation channels. Whereas in shovel the bucket opening faces away from the machine and the bucket is pushed away from the machine and is used for excavating or loading operations above or on the standing level of the machine *i.e.* for excavating of rock or earth ; loading of material like earth, coal, aggregate etc. 'Hoe' and 'Shovel' are described separately in this book in the chapter on 'Shovels and Cranes'.

Types of Excavators

Excavators are of following four types based on the type of carriers on which they are mounted :

(*a*) Crawler mounted excavator.

(*b*) Truck mounted excavator.

(*c*) Self propelled excavator.

(*d*) Excavators mounted on barge or rail.

(*a*) **Crawler Mounted Excavator.** These excavators are mounted on the crawler system and are very suitable for carrying out large works in rough terrain. Crawler excavators have following main characterisics :

(*i*) Can be used for work on soft or wet grounds.

(*ii*) Can be used on sharp rocks or other adverse conditions.

(*iii*) These can climb steep grades (even upto 40 per cent).

(*iv*) Requires very less turning space.

(*v*) Have very less speed for travelling.

(*vi*) Can be shifted from one site to another only on trailers.

(*b*) **Truck Mounted Excavators.** These excavators are mounted on truck chasis and has following main characteristics :

(*i*) High road speed and mobility is the main advantage.

(*ii*) Lower stability over sides and hence require counter-weight or outriggers.

(*iii*) Require more operating space.

(*iv*) Tyres or outriggers give high ground pressure and hence it requires firm and smooth operating locations.

(*v*) Have two engines and two cabs, separately for truck chasis and excavator.

(*c*) **Self Propelled Excavators.** These excavators are self proeplled and has rubber tyres. The main characteristics are :

(*i*) Medium travel speed generally between 10 to 30 km per hour.

(*ii*) Has one engine and one cab for control by one operator.

(*d*) **Excavators on Barge or Rail.** These excavators are mounted on barge or rail to carry out work of excavation in water or near railway line respectively.

Excavator Capacity

Excavators of sizes between 0.5–4 cubic metre bucket capacity are commonly used for various excavation purposes.

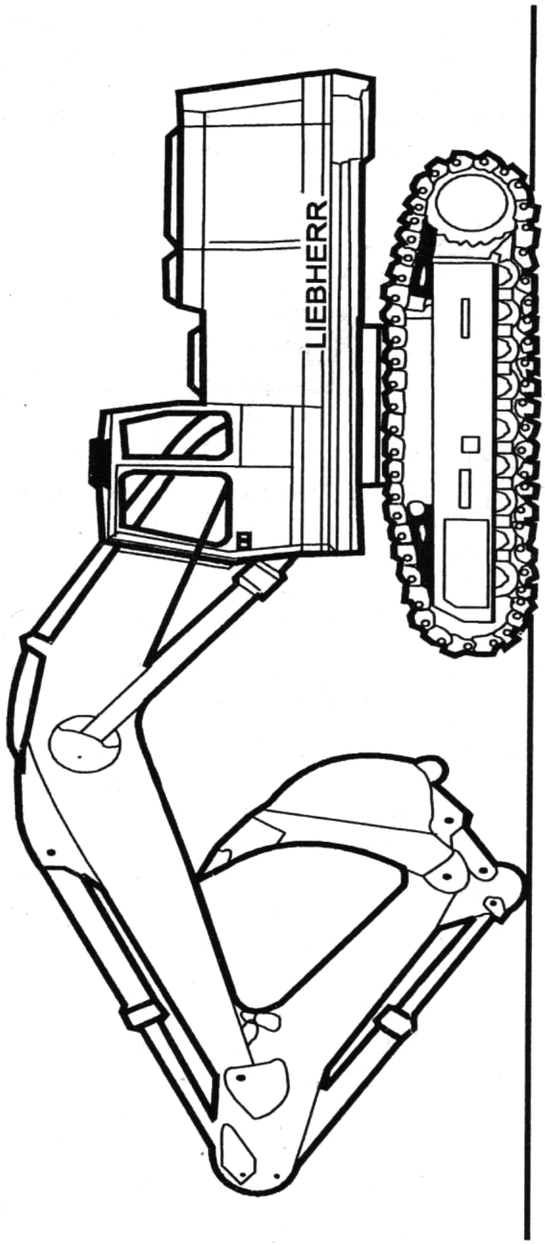


Fig. 1.33. Hydraulic Excavator (Courtesy : Liebherr).

1.13. HYDRAULIC EXCAVATORS

Hydraulic actuated excavators have rotating superstructures which are somewhat different from those of the cable-actuated machines like back hoe, power-shovel, dragline and clamshell (explained in next chapter). However, attachments of backhoes, straight line telescopic hoes, and telescopic boom lift cranes are available for mounting on hydraulic-actuated exvacator. This increases the suitability, applicability and popularity of hydraulic excavators.

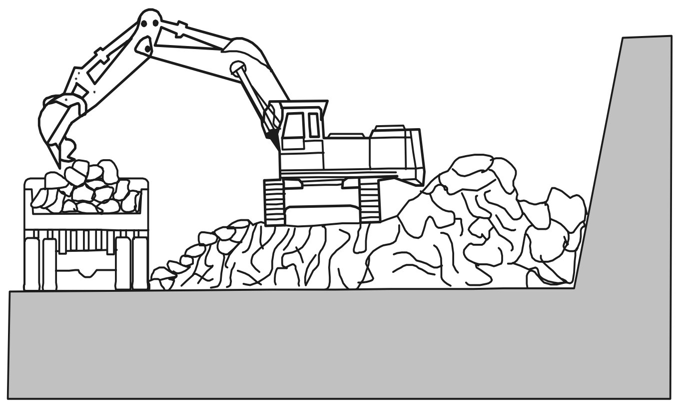


Fig. 1.34. Hydraulic excavator in loading operation
(Courtesy : Liebherr)

The various digging actions are powered by hydraulic cylinders and motors and are controlled by hydraulic valves or variable-stroke pumps. The hydraulic excavator has the advantages that its digging forces do not tend to lift the bucket out of a deep trench, as does the cable pull on a cable-powered hoe. But hydraulic excavators need slightly larger engine as compared to that of cable operated, because hydraulic pumps are slightly less efficient than gear and chain drive, and also due to pressure drop in line and valve.

Hydraulic excavators are troubled by gradual erosion of pumps and valves from fine dirt or by sudden failures due to large metal particles in the oil flow. Oil filteration is therefore very important. Care should also be taken that, foam or air must not be pulled into the pumps because air even in minute quantities can soon destroy a pump.

Now-a-days hydraulic excavators of various sizes upto 30 m^3 bucket capacity and 1730 kW engine output are available. These large sized, heavy hydraulic excavators are mostly used in exploitation of raw materials, open cast mining, for loosening and loading of large material quantities, and where transport vehicles of adequate size can be economically employed.

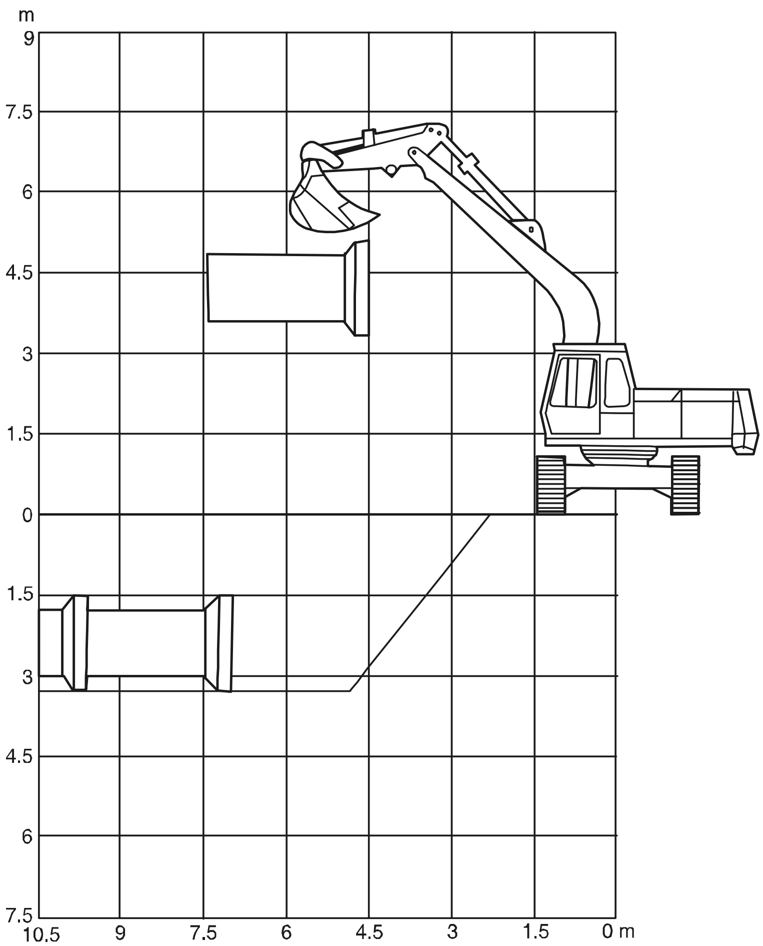


Fig. 1.35. Pipe laying by hydraulic excavator (courtesy : Liebherr).

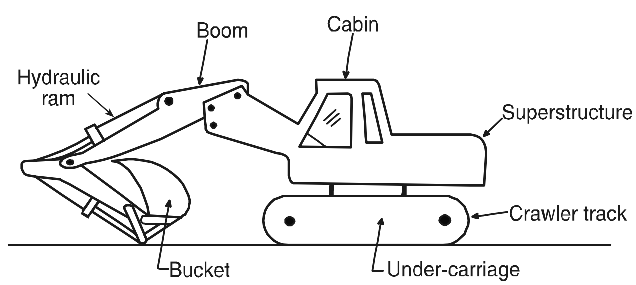


Fig. 1.36. Hydraulic excavator.

Output of Excavators

Hourly Production in m^3/hr (Q)

$$= q \times \frac{3600}{C} \times \text{Efficiency}$$

where, q = Production per cycle (m^3)

C = Cycle time (sec)

Production per cycle (q) = $q_1 \times s \times k$

where, q_1 = Heaped capacity as per specifications of the excavator

s = Swell factor

k = Bucket factor, and is considered between 0.4 to 1.0 depending on difficult to easy digging and loading conditions.

Cycle time, is the time required for excavation, swing, dump and back swing. Where excavating time depends on digging depth and surface to be digged. Swing time depend on the degree and speed of swing and the skill of operator. Dumping time depends upon the proper spoting of transport vehicle and the skill of the operator.

Cycle Time = Excavating time + 2 × swing time + dumping time

Excavating time is the time required for excavation and depends on digging depth and other digging conditions as indicated below :

Digging depth	*Time in seconds, for digging conditions*			
	Easy	*Average*	*Difficult*	*Very difficult*
0—2 m	6	9	15	26
2—4 m	7	11	17	28
4 m and above	8	13	19	30

Bucket Fill Factors

Bucket fill factors depend on the material to be excavated. Following table indicates these factors for different materials :

	Material	*Bucket fill factor*
(*i*)	Soft Clay	1.00 to 1.10
(*ii*)	Earth and loam	0.90 to 1.05
(*iii*)	Bank gravel and sand	0.90 to 1.00
(*iv*)	Uniform aggregates	0.80 to 0.90
(*v*)	Hard clay	0.75 to 0.85
(*vi*)	Rock	
	(*a*) Well blasted	0.60 to 0.75
	(*b*) coarsely blasted	0.40 to 0.60

Optimizing Excavator Production

As we know that for increasing the excavator production, loading cycle should be reduced. Therefore, following are the some of the suggestions which will increase the excavator production, by adopting ideal backhoe applications, as shown in Fig. 1.37.

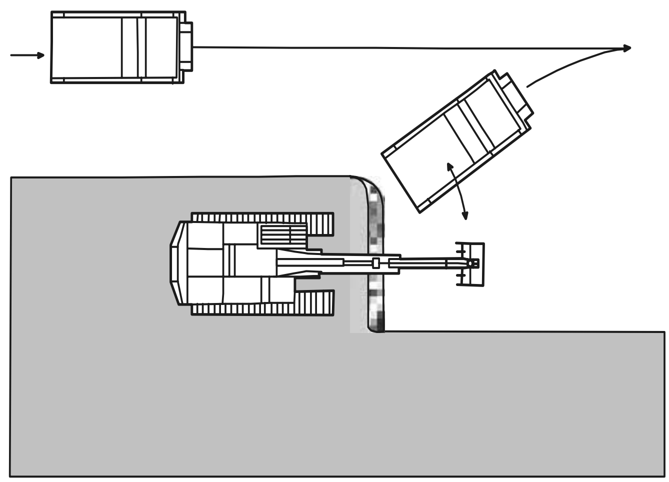


Fig. 1.37 (*a*). Short swing angles and low material hoisting.

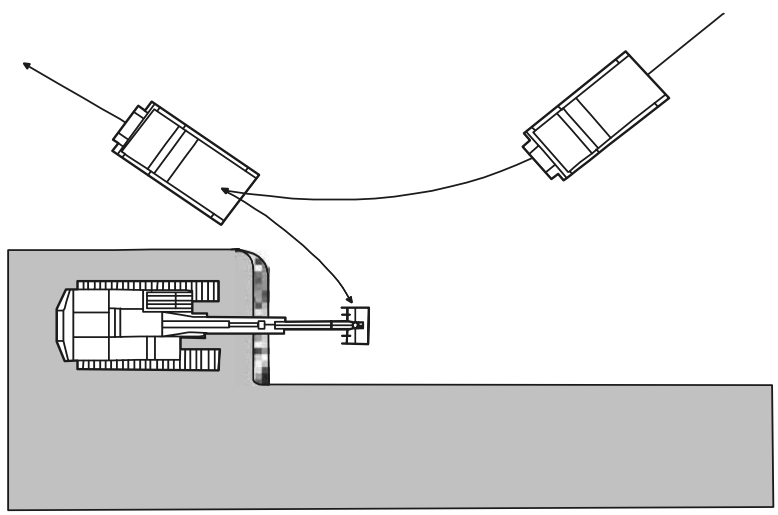


Fig. 1.37 (*b*). Fastest possible truck exchange for high hourly production.

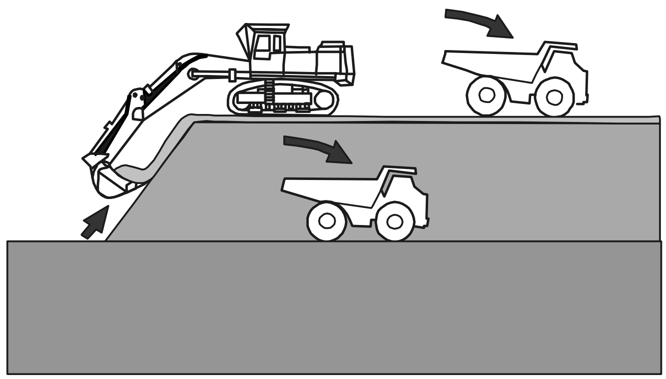


Fig. 1.37 (*c*). Loading trucks "downstairs" and "upstairs" for highest possible production output..

Latest Developments in Excavators

Latest development in excavator is to provide an attachment having a chain trencher. This attachment can be fitted within 15-20 minute replacing the bucket and improves the excavator output when digging narrow trenches for cable and small diameter pipeline installations. The chain's carbide-tipped can also handle quite rocky ground.

This type of excavator with trencher attachment have advantage of easy access over self-propelled trencher. Another advantage is that, it is economical for a company having intermittent requirement for trenching equipment.

Technical data for smallest and biggest excavators manufactured by a world leading manufacturers M/s LIEBHERR are given hereunder.

(*a*) **Specifications**

S. No.	*Criteria*	*Data for model*		
		A 900 B	*R 900 B*	*R 994*
1.	Operating weight	12—13 tons	14.9—16.0 tons	200 tons
2.	Bucket capacity	0.14—0.9 m^3	0.14—0.9 m^3	9—17 m^3
3.	Engine Output	68 H.P.	68 H.P.	990 H.P.
4.	Rate R.P.M.	2000	2000	1800
5.	Fuel tank capacity	222 lit	222 lit	2500 lit
6.	Maximum travel speed	20 km/hr (wheeled)	1.7 km/hr (crawler)	2.4 km/hr (crawler)

Contd...

Contd...

S. No.	Criteria	*Data for model*		
		A 900 B	*R 900 B*	*R 994*
7.	Tyre size	1000 × 20	—	—
8.	Wheel base	2.5	—	—
9.	Ground Pressure	—	0.26-0.43 kg/cm2	1.74 kg/cm^2
10.	Overall length with boom	—	7.5 m	16.8 m
11.	Maximum dumping height	5.1—6.0 m	4.9—5.8 m	10.8 m
12.	Maximum reach at ground level	7.4—9.3 m	7.5—9.3 m	15.3 m
13.	Maximum digging depth	4.5—6.5 m	4.7—6.7 m	8.5 m
14.	Maximum cutting	7.4—8.35 m	7.2—8.0 m	15.8 m

Fig. 1.38. Hydraulic excavator in Trenching operation.

(*b*) **Lift Capacities**

Trend for lifting capacities for different heights and reaches for 3 models of excavators are indicated below.

Model. A 900 B (wheeled).

Height	*Outrigger configuration*	*Reach*		
		3 m	*4.5 m*	*6.1 m*
6.1 m	(*a*) Without		2.9 T	1.8 T
	(*b*) With		3.3 T	2.6 T
3 m	(*a*) Without		2.5 T	1.6 T
	(*b*) With		3.8 T	2.4 T
1.5 m	(*a*) Without		2.3 T	1.5 T
	(*b*) With		3.6 T	2.3 T
Ground level	(*a*) Without		2.3 T	1.5 T
	(*b*) With		3.6 T	2.3 T
– 1.5 m	(*a*) Without	4.3 T	2.3 T	1.5 T
	(*b*) With	5.8 T	3.5 T	2.3 T
– 3 m	(*a*) Without		2.3 T	–
	(*b*) With		2.3 T	–

Fig. 1.39. Side shift backhoe hydraulic excavator to dig a straight wall trench on either side of tractor centre.

Fig. 1.40. Fixed pivot backhoe hydraulic excavator in trenching application.

Fig. 1.41. Hydraulic excavator with clamshell bucket

1.14. EXCAVATOR-LOADERS

Excavator-loaders sometimes also known as backhoe-loaders, are basically digging and loading machines, and comprise following main components :

(*a*) A tractor with two- or four-wheel drive.

(*b*) A rear mounted digging arm and hydraulically operated excavator bucket, able to slew through a 180° arc.

(*c*) A front mounted loader arm assembly with loader bucket.

Excavator end is used for side tipping : excavating of house and building foundations, trenches or irrigation ; sewerages, gas and oil pipe line work ; and also for irrigation channel cleaning and maintenance. Whereas the loader end is used for loading and rehandling of materials such as excavated soil, aggregates, coal etc.

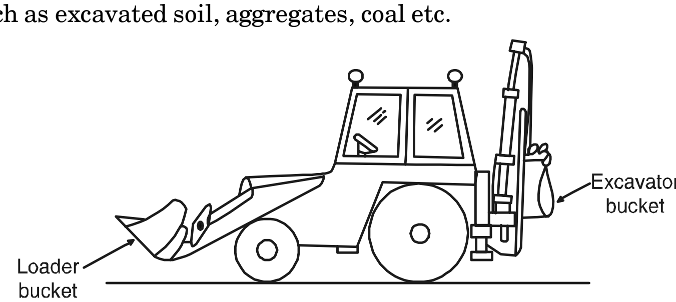


Fig. 1.42. Excavator-loader.

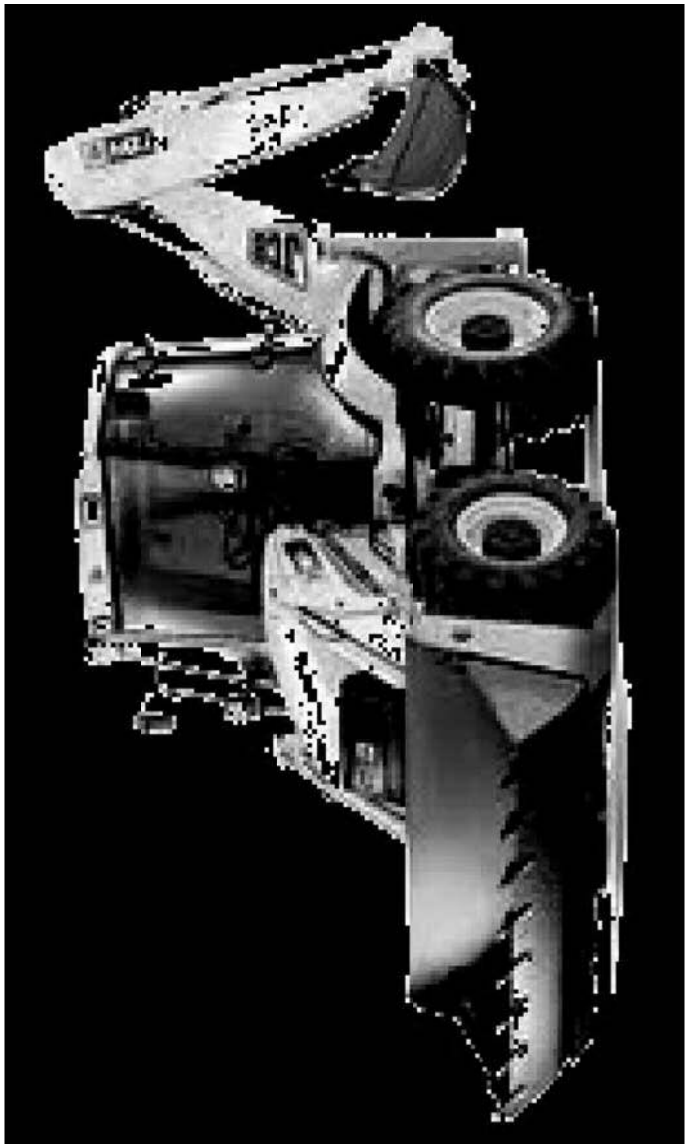


Fig. 1.43. Wheeled loader cum excavator.

Excavator-loader can be made even more useful by using hydraulically operated attachments for road breakers, pumps, pole planters, winches, crane hook and boom etc.

Fig. 1.44. Wheeled backhoe-loader.

Excavator-Loader for Civic Utility Works

Excavator-loader is a versatile equipment, since in addition to the standard excavator and loader buckets, a vast range of special purpose attachments like the forklift,the rock breaker, the ripper, the jib crane, the ditch clearing bucket, can be provided. With these attachments the excavator loader can be used for handling numerous tasks of our cities, including laying of water pipelines, trenching, with crane attachments load canbe lifted and pipes can be lowered into the trench, backfilling can be done, ground can be levelled, can collect and load garbage, can be used in road maintenance works, can be used on hot mix and crushing plants for loading of gravel and stone.

Hydraulic Milling Cutters

Fig. 1.45(*a*). Milling cutter fitted with hydraulic excavator.

Fig. 1.45(*b*). Milling cutter.

The hydraulic milling cutters can be mounted to an excavator in lieu of bucket. The milling cutter mainly consists of a gearbox and a pair of transverse cuttingheads (as shown in Fig. 1.45 *b*) which are fitted with round shank picks. It is driven by a hydraulic motor which is fed with pressure oil from the excavator hydraulics. An adopter is required for attachment to the excavator. For operating the hydraulic milling cutter with an excavator, the control of the hydraulic motor for the milling cutter is installed at the operator's panel.

Applications

The hydraulic milling cutters are suited for cutting natural rocks, concrete, asphalt, masonary and other similar materials for :

(1) *Tunneling and Mining* : Heading, profiling, mineral extraction etc.

(2) *Demolition* : Pinpointed demolition, Partial demolition while safeguarding the remaining structure.

(3) *Road construction* : Asphalt cutting.

(4) *Hydraulic Engineering*: Lowering of navigable waterways. Milling of culverts in river beds.

(5) *Civil Engineering* : Trench milling, foundation milling.

Due to versatility, the unparallel line of extensions, booms, intermediate booms and demolition sticks assures optimal performance at every phase of the job. Changing of attachements can be done quickly using pins and quick couplings. The versatility also allows the loading of debris. Due to quick assembly and disassembly with minimum effort, the result is significant time and expense reduction. Quick couplings connect the high-pressure hydraulic lines between the basic boom and intermediate boom.

1.15. BUCKET-WHEEL EXCAVATOR

Bucket wheel excavator consists of a digging wheel having buckets can be adjusted vetically by means of hydraulic rams. The wheel is mounted on a boom, having a conveyor belt on which this wheel discharges. This boom together with digging wheel and conveyor can swing through a complete 360° circle by rotating on the crawler-mounted or wheel mounted undercarriage. A second conveyor, which is colinear, with the first, receives material from the first conveyor. Although the discharge point of the first is fixed relatively to the loading point of the second conveyor. The second conveyor can be hydraulically slewed through an arc of 180° and can be raised and lowered hydraulically to accommodate receiving hauling units of varying heights.

The power for each of the conveyor, digging wheel, the crawlers and to rotate the superstructure is provided by individual electric motors. These motors, inturn are driven by the main prime-mover. Single operator controls all the functions of the excavator from the cabin.

Bucket wheel excavator of various sizes ranging from 200 cu m to 11000 cu m/hr are manufactured. Wheels of diameter upto 15 metres are manufactures for excavation. This type of wheel excavator is generally used for mining work.

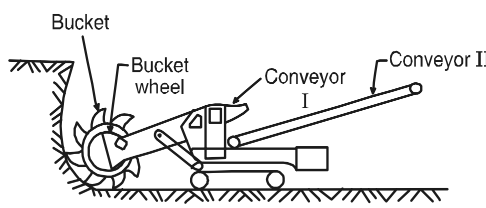


Fig. 1.46. Bucket wheel excavator.

1.16. SNOW-CLEARING EQUIPMENT

Clearance of snow from construction sites and access roads was earlier done through specialised and expensive machines. It is now possible by converting standard construction machinery into economical and effective units for the removal of snow. This is done by providing special attachmenets. An attachment for cutting and blowing the snow is provided with a tractor and can be inter-changed with the angle-dozer etc. The snow blowers have a capacity of 1000 to 2400 tons/hr depending upon the tractor's horsepower. The blowers have either a single or dual hydrostatic motor input to power the single stage, dual impeller design, and does not require any auxiliary engine. The dual fans are combination of cutters and blowers with 12 wear resistant and hardened steel teeth to provide a milling effect on frozen and hard packed snow.

1.17. TRENCHING MACHINES

These machines are used for digging trenches at a faster rate and with proper control of depths and widths, and are capable of digging any type of soil except rock. They are available in various sizes for digging trenches of various depths and widths. These are generally crawler mounted having large range of speeds to permit the selection of the most suitable speed for any job conditions, ranging from canal excavation to laying cables.

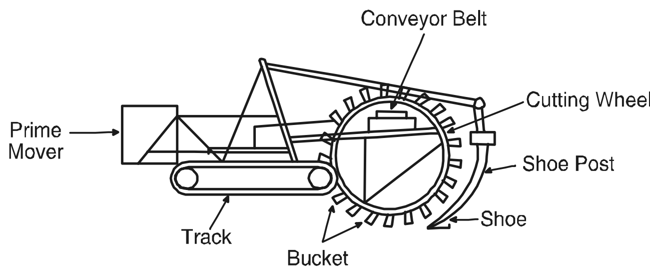


Fig. 1.47. Trencher.

Trenching machines are of two types, namely wheel trenchers and ladder trenchers and are described hereunder :

(A) Wheel-Trenchers

Trenchers are the equipments used for excavating trenches or ditches of variable width and depth. The trenches of width upto 12 metres and depth upto 3 metres can be excavated in one pass with the trenchers available now-a-days. A trencher consists of : (*a*) self-propelled tractor or carrier fitted with either crawler type or wheel-type running gear ; (*b*) an excavating device consisting of several buckets on the periphery of a wheel or several cutters attached to a chain for digging and discharging continuously : (*c*) a means of conveying the excavated material to either side of the excavated trench and depositing it in windrows.

Wheel trenchers are most common type of excavators. Excavating member of these wheel trenchers consist of a pair of circular rims whose outside diametes are connected by U-shaped buckets or cutters. The wheel is turned by a chain drive which connects to the power source. The wheel turns in a direction with the buckets travelling away from the carrier in the top position when discharging material, and toward the carrier at the bottom of their travel while digging. The buckets or cutters on the wheel perform the work of excavation while travelling upward. When the wheel reaches the top position, the excavated material drops from the buckets on the conveyor and discharges alongside the trench to form windrow, keeping some clearance between the windrow and the edge of the trench. The wheel trenchers are very suitable equipment for digging canals and other trenches.

The trenches may be for water, gas and oil pipe lines, telephone cables, drainage and sewers. These provide for digging with positive control over depths and widths of trenches and needs minimum efforts for finishing. These can dig any type of soil except rock, and are available in various sizes for digging trenches of varying depths and widths.

Selection of trenchers

The selection of a trenching equipment depend on the job conditions, depth and width of the trench, type of soil, disposal of excavated earth, availability of ground water.

(B) Ladder-type Trenching Machines

In these machines buckets are provided with chain links on ladder type frame or boom. By providing extensions to these ladders and by adding more buckets, it can dig trenches upto 10 meter depth. These machines are used where depth of trench required is more than 3 metres. Width of the trench can be increased by installing shaft mounted side cutters on each side of the boom. As the bucket travel up the underside of the boom, they bring out earth & unload it on a belt conveyor which discharges this excavated earth along either side of the trench like wheel type trenching machines.

The ladder turns about two pivot points in its elliptical path. This makes for a flatter, more compact arrangement, and the depth of excavation is not restricted by wheel diameter. For slit trenching, there is chain line which carries cutting blades along its periphery like a chain saw. The blades are available in different lengths depending upon the width of the trench desired. For hard ground like concrete or rock-studed ground, tungsten carbide teeth are used.

Advantages in Using a Trencher

By using a trencher following advantages can be achieved :

(*a*) It is faster and cheaper method of trenching.

(*b*) It digs only as much as is necessary. A 10-cm pipe can be installed in a 15 cm wide slot cut by a trencher.

(*c*) It is a continuous process and is not like that of back-hoe excavator *i.e.* dug-lift-dump.

1.18. WORKING CONDITIONS FOR OPTIMUM UTILISATION OF H.E.M. EQUIPMENT

In addition to the availability of spares, proper maintenance and operating skill, optimum utilisation of Heavy Earth Moving Equipment depends upon actual working conditions. Factors related to working conditions are discussed hereunder :

(*i*) **Proper Fragmentation.** Fragmentation of the rock piece should be appropriate so that bucket is filled fully.

(*ii*) **Ripping.** The rock should be loose enough otherwise rippers should be used so as to enable it to be loaded by front end loader.

(*iii*) **Capacity to match the specific gravity of rock.** Dumpers and loader buckets have capacity in terms of tonnes of the rock carried by them. In order to utilise full capacity, it should be sufficient in size so as to load it fully in terms of weight. A dumper meant for iron ore if used for coal, will utilise only 1/3rd of its capacity.

(*iv*) **Proper Height for Excavation.** Excavator/shovels has optimum digging heights, therefore these should be used in such a way that excavation is always carried out for optimum heights.

(*v*) **Manoeuvrability.** Excavating area should be managed in such a way that minimum time is wasted in manoeuvrability.

(*vi*) **Gradient.** The hauld road should not have too much gradient.

(*vii*) **Condition of Hauled Roads.** In order to save time in haulage, the haul road should be properly maintained. Properly maintained road means free from unevenness, sharp bends, ruts, ditches, boulders etc. lying on the road, with sufficient road width. The road should be maintained by sprinkling water, compacting and using the motor grader. This saves from the dust and allows the vehicle to move with more speed. Large projects have permanent haul roads. The increase in efficiency, less break down and more production due to less cycle time prove this as economical.

QUESTIONS

1. Justify the statement, "Tractor is a basic equipment for earth moving machinery". Describe its construction in brief.

2. List out applications of a bulldozer.

3. Describe 'dozing' and 'ripping action by bulldozers.

4. Describe construction and working of scrapers.

5. Describe construction and working of elevating scraper. Differentiate it with conventional scrapers.

6. Illustrate various applications of loaders. Mention merits and demerits of wheel loaders and crawler loaders.

7. What is an excavator ? Describe working of a hydraulic excavator. Mention its applications.

8. Write short notes on :

(*a*) Use of scraper as a construction equipment,

(*b*) Trenching machines.

9. Explain the relative advantages and disadvantages of a 'crawler tractor' and a 'wheel tractor'.

10. What are the operations that can be performed by bulldozers ? Describe briefly the procedure for clearing of an area with bulldozer.

11. Discuss the factors which influence the output of earth moving machinery.

12. What is a tractor ? For what purposes it is used ?

13. What factors influence the selection of a tractor ? Explain in brief.

14. How the power is supplied to the dozers ?

15. Write a note on the blades of a dozer.

16. What is meant by rock ripping ? How the rippability of rocks is determined ?

17. What is a scrapper ? Discuss dozer pulled scrapers.

18. Give the classification of scrappers and discuss them in brief.

19. Explain different types of ripper attachments with sketch.

20. Write short notes on :

(*a*) Types of dozer blades (*b*) Output of bulldozer

21. How would you calculate the output of rippers? How would you increase the ripping production from a dozer?

22. Suggest methods for increasing the scraper production.

23. Write short notes on the following :

(*a*) Advantages of elevating scrapers.

(*b*) Cycle time for a scraper. (*c*) Articulated type of loaders.

(*d*) Loader applications.

24. Explain different types of wheel loader attachments.

25. Explain different types of loader buckets and their applications.

26. How would you calculate loader output? Suggest methods for increasing the loader production.

27. Explain the following in brief :

(*a*) Belt loader (*b*) Types of excavators.

(*c*) Output of excavator.

28. What is an excavator-loader? Explain various applications of excavator-loader.

29. Explain the following in brief :

(*a*) Bucket-wheel excavator. (*b*) Snow-clearing equipment.

(*c*) Wheel-trenchers.