Powering, Load Distribution & Braking of a Dump Truck

Kamasani Bujji Babu
Assistant Manager
Department of Research & Development
BEML Ltd., Mysore, Karnataka, India

Abstract— powering i.e. how to calculate the power required for a dump truck, what are the factors to be considered while deciding the power requirement and then select an engine which will provide sufficient power to dump truck. Load distribution i.e. how much load is coming on the front axle and rear axle when the truck is in moving on horizontal surface with zero % gradient. Also we will discuss the load distribution on front & rear axles when the dump truck is climbing a gradient and when the dump truck coming along the downhill. Weight transfer between the axles while climbing a gradient and while coming down through a downhill. This load distribution dictates the design of mainframe, wheel base distance, dump body design and selection of tires of a rigid dump truck. Braking i.e.in braking we will discuss about the stopping distance calculation as per ISO 3450 for rigid dump trucks and the actual measured stopping distance of a dump truck. Conditions for measuring the stopping distance of a dump truck, Effects of driver's reaction, gradient, speed and brake response on the stopping distance and the brake ratio generally used in the dump trucks. Braking is very important in safety point of view.

Key words: Load distribution, powering, Braking, Powering a Dump Truck

I. Introduction

Dump truck is an earth moving machinery widely used in mining sector like coal mining, iron ore mining, bauxite mining etc. Various sizes of dump trucks are available based on the amount of payload that carries ranging from 30 metric tons to 400 metric tons. Up to 240 metric tons we have mechanical dump trucks. 240 metric tons and above we have electrical dump trucks (both AC & DC drives) are available because of various advantages of electric drive.

II. Powering a Dump Truck

While designing a dump truck, the selection of prime mover is an utmost important. If the engine selection goes wrong then the entire project will go in vain. Hence it is important to learn the factors to be considering while calculating the power requirement for a dump truck.

Consider that we need to design a dump truck which carries a payload "P" on a predefined gradient say 12% with some desired speed say V= 10kmph.

Then the unladen weight of the truck needs to approximately arrive as "K" which includes mainframe, dump body, front & rear suspension, tires, operator cabin, engine& transmission, front axle& rear axle, fuel & hydraulic tank and the connecting tubes, hose assemblies.

Then the Gross Vehicle Weight (GVW) as W can be arrived as sum of the unladen weight of the dump truck plus the payload weight.

GVW (W) = unladen weight (K) + Payload (P)

Various loads/forces need to overcome in order to move the dump truck on the gradient with some desired speed.

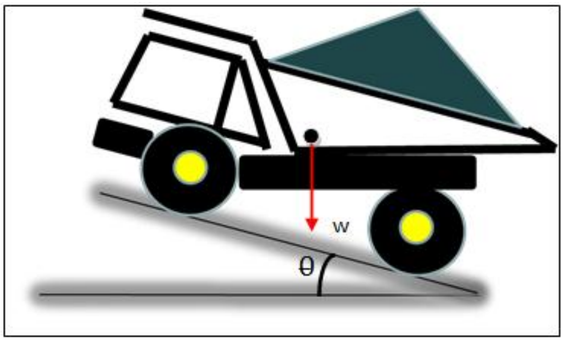


Fig. 1: Dump truck on a gradient

Since the truck is standing on a gradient, it should overcome the resistance offered by it and is called as grade resistance R_g. Also the tires of the dump truck are in contact with the haul road, which contributes to the rolling resistance R_r.

When the truck is moving with certain velocity then the aerodynamic drag will come into picture because of the frontal area and this is called aerodynamic resistance R_a.

From the above it is clear that the total forces that the dump truck needs to overcome in order to move on a gradient with certain speed is equal to sum of the Grade resistance, rolling resistance and aerodynamic resistance.

Total resistance(R)=Grade Resistance (R_g) + rolling resistance (R_r) + Aerodynamic resistance (R_a)

III. Various Resistances/Loads Acting on the Dump Truck

W = Weight of the dump truck including payload (GVW) acting at the Center of gravity (C.G)

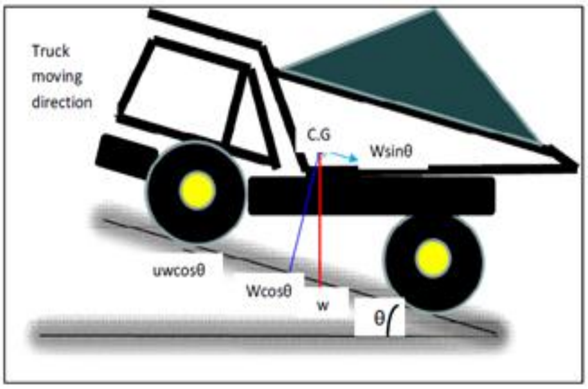


Fig. 2: Loads acting on dump truck

A. Calculation of Grade Resistance:

From the above, it is clear that the load $W\sin\theta$ is acting in the opposite direction to the vehicle moving direction.

Hence this load should be overcome by the prime mover/engine.

Therefore the grade resistance is given by R_g =WsinQ

B. Calculation of Rolling Resistance:

When the tires are resting on the haul road, there exists a friction between the tire & the haul road with co-efficient of friction m

Considering the coefficient of friction m as 0.02 between the tire and the haul road.

Rolling resistance is the frictional force existing between the tire and the haul road

Rolling resistance R_r= mWcosQ

Here m=0.02 and when Q is small cosQ approximately equals to 1.

Therefore rolling resistance R_r= 0.02 x W x1

$$R_r = \frac{2}{100} \text{ x W}$$

$$R_r = 2\% \text{ W}$$

Hence this load also should be overcome by the prime mover/engine.

C. Calculation of Aerodynamic Resistance:

When a truck is moving with velocity V, then there will drag force acting on the dump truck due air obstructing to the frontal area A

V= dump truck speed on gradient

A= frontal area of the truck (width X height of the truck)

r= is the density of air; 1.2253 kg/m^3

Then the drag force is given by

$$R_a = \frac{1}{2} x r x v^2 \text{ x A}$$

Therefore the total resistance R = R_g + R_r + R_a

Hence the power required to move the dump truck on the gradient at desired speed is given by;

Power required P = R X V (watts)

Note:- Nm/s = watt

1 hp = 746 watts

Now add up the power required to drive the implement hydraulic pumps, A.C compressor, engine fan etc.,

Then we will arrive at the power required for a dump truck.

IV. LOAD DISTRIBUTION ON A DUMP TRUCK

The load distribution on front and rear axle is not uniform in a dump truck; normally more load will be imposed on the rear axle when compared to the front axle.

The Static loads on front & rear axle on a horizontal ground can be calculated using simple leverage principle as follows.

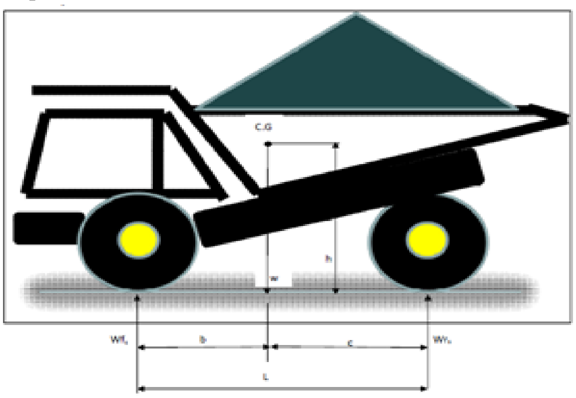


Fig. 3: Load distribution on front & rear axle on plainl haul road

W = GVW of a dump truck

C.G = center of gravity

L = Wheel base

b = Distance from front axle to C.G location

c = Distance from rear axle to C.G location

h = height from the ground to the C.G location.

Wf_s = Static load on the front axle

Wr_s = Static load on the rear axle.

When a dump truck is standing on the horizontal haul road, it will be stable without any unbalanced forces on front & rear axles.

Hence the moment due to various forces on the front and rear axles are zero.

Taking moment with respect to front axle and equating to zero

$$Wf_s \text{ x } 0 + W \text{ x } b - Wr_s \text{ x } L = 0$$

$$Wr_s = W \text{ x } \frac{b}{L}$$

Taking moment with respect to rear axle and equating to zero

$$W_r \text{ x } 0 + W \text{ x } c - Wf_s \text{ x } L = 0$$

$$Wf_s = W \text{ x } \frac{c}{L}$$

The static loads acting on axles are given by

On front axle: $Wf_s = W \text{ x } \frac{c}{L}$

On rear axle: $Wr_s = W \text{ x } \frac{b}{L}$

V. ON GRADIENT HAUL ROAD

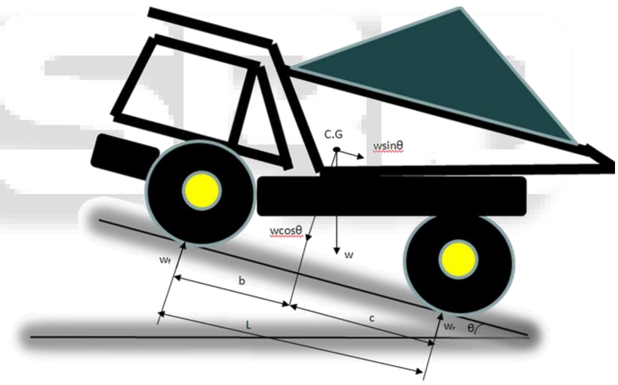


Fig. 4: Load distribution on front & rear axle on gradient haul road

Wf = Load on the front axle

Wr = Load on the rear axle

Q = Gradient in degrees

When a dump truck is standing on a up gradient haul road, it will be stable without any unbalanced forces on front & rear axles in vertical direction.

Hence the moment due to various forces on the front and rear axles are zero.

Taking moment with respect to front axle and equating to zero

$$-\text{Wf x } 0 + \text{w}\cos\theta \text{ x b} - \text{Wr x L} + \text{W} \sin\theta \text{ x h} = 0$$

$$W_r = \frac{W}{L} (\text{b} \cos\theta + \text{h} \sin\theta)$$

Taking moment with respect to rear axle and equating to zero

$$\text{Wr x } 0 - \text{w}\cos\theta \text{ x c} + \text{Wf x L} + \text{W} \sin\theta \text{ x h} = 0$$

$$W_f = \frac{W}{L} (\text{c} \cos\theta - \text{h} \sin\theta)$$

The loads acting on axles when the dump truck on up gradient is given by

On front axle: $W_f = \frac{W}{L}$ [c $\cos\theta -$ h $\sin\theta$]

On rear axle: $W_r = \frac{W}{L}$ [b $\cos\theta +$ h $\sin\theta$]

VI. ON DOWNHILL HAUL ROAD

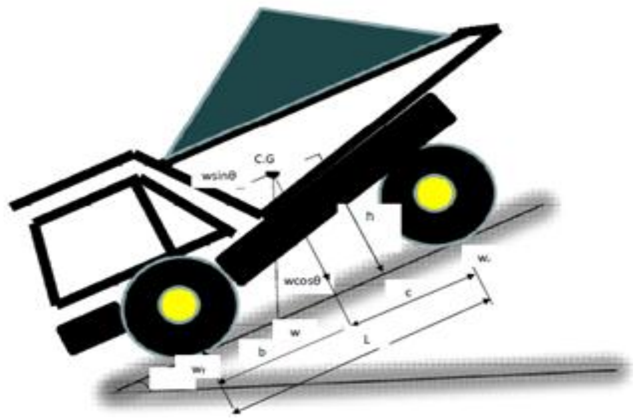


Fig. 5: Load distribution on front & rear axle on gradient haul road

When a dump truck is coming on a down gradient haul road called downhill, it will be stable without any unbalanced forces on front & rear axles in vertical direction.

Hence the moment due to various forces on the front and rear axles are zero.

Taking moment with respect to front axle and equating to zero

W_f x 0 + W sinθ x h - Wcosθ x b + W_r x L = 0

$W_r = \frac{W}{L}$ [b $\cos\theta - h\sin\theta$]

Taking moment with respect to rear axle and equating to zero

W_r x 0 + W sinθ x h + Wcosθ x c + W_f x L = 0

$W_f = \frac{W}{L}$ [c $\cos\theta + h\sin\theta$]

The loads acting on axles when the dump truck on down gradient (downhill) is given by

On front axle: $W_f = \frac{W}{L}$ [c $\cos\theta + h\sin\theta$]

On rear axle: $W_r = \frac{W}{L}$ [b $\cos\theta - h\sin\theta$]

The load distribution in different cases are tabulated below

Load on the axles	On Plain Haul road	On Up Gradient haul road	On down gradient haul road
Front Axle	Wf_s = W x $\frac{c}{L}$	$W_f = \frac{W}{L}$ [c $\cos\theta - h\sin\theta$]	$W_f = \frac{W}{L}$ [c $\cos\theta + h\sin\theta$]
Rear Axle	Wr_s = W x $\frac{b}{L}$	$W_r = \frac{W}{L}$ [b $\cos\theta +$ h $\sin\theta$]	$W_r = \frac{W}{L}$ [b $\cos\theta - h\sin\theta$]

From the above it is clear that the load transfer will happen towards rear when the dump truck is moving on a up gradient.

Similarly load transfer will happen towards front side when the dump truck when it is coming on a down gradient.

When Q is small, cosQ = 1; sinQ= Q in radians.

Then the load distribution chart can be simplied as follows

Load on the axles	On Plain Haul road	On Up Gradient haul road	On down gradient haul road
Front Axle	Wf_s = W x $\frac{c}{L}$	$W_f = \frac{W}{L}$ [c $- h \times \theta$]	$W_f = \frac{W}{L}$ [c $+ h \times \theta$]
Rear Axle	Wr_s = W x $\frac{b}{L}$	$W_r = \frac{W}{L}$ [b + h x θ]	$W_r = \frac{W}{L}$ [b $- h \times \theta$]

VII. BRAKING OF DUMP TRUCK

Braking a dump truck is an important safety feature required to stop/slow down the dump truck while negotiating a curve, while other Heavy Earth Moving Machinery (HEMM) comes in the way of the dump truck, also to stop the dump truck for loading, dumping.

The different types of braking combinations provided on a dump truck are

1) Service brake - stopping and holding
2) Retarder brake - energy absorbing brake to control speed
3) Emergency brake -used for stopping is service brake fails
4) Parking brake - used to hold a stopped vehicle stationary

VIII. SERVICE BRAKE OF A DUMP TRUCK

Service brake is used for stopping and holding a dump truck. ISO 3450 gives the service brake stopping distance requirements for various earth moving machinery including articulated dump trucks, loaders & rigid dump trucks.

As per ISO 3450 the service brake stopping distance requirements for a rigid dump truck whose unladen weight is more than 32,000 kg is given by an empirical formula.

$$S = \frac{V^2}{48-2.6xa}$$

Where

S = Stopping distance in meters

V = Velocity of the dump truck in kmph

a = Gradient of the test track as percentage

A. *Velocity V:*

For service brake testing as per ISO 3450, the velocity V should be at least 50±3 kmph or maximum surface speed If the dump truck maximum speed is less than 50kmph.

B. *Gradient a:*

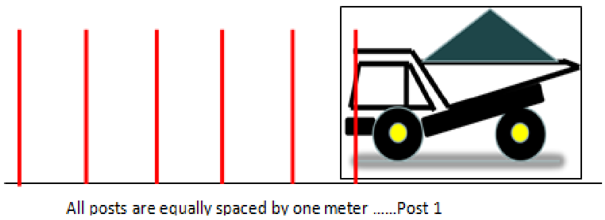
The test course shall have a down gradient 9±1% in the direction of travel of the dump truck.

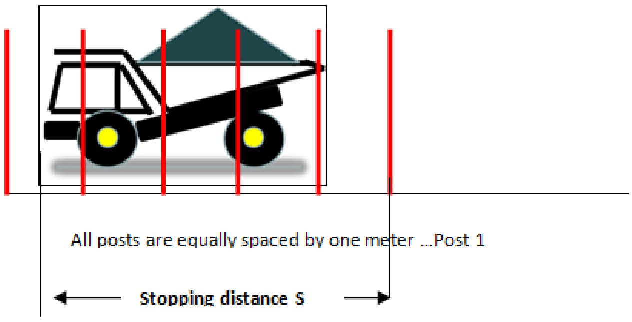
For service brake testing, the dump truck should be loaded with payload as specified by the manufacturer.

IX. SERVICE BRAKE TEST PROCEDURE

Service brake stopping distance test is carried out by with load by means of 5 stopping tests at 10-20 min interval between the tests.

Series of poles are kept at 1m distance apart(around 30 posts), the driver depress the service brake when the dump truck reaches the first post, then the stopping distance is measured from the first post to the dump truck stopped position.





X. FACTORS AFFECTING THE STOPPING DISTANCE

Stopping distance of the dump truck depends on the following

1) Drivers reaction
2) Brake response
3) Gradient
4) Load
5) Speed

Driver's reaction; If there is delay in applying the service brake, then that delay leads to increase in stopping distance.

After depressing the brake pedal by the driver, there exists a delay in applying the brake to the full force. If this delay is more than it leads to increase in stopping distance.

Gradient; down gradient in the direction of dump truck travel leads to increase of stopping distance on the other hand up gradient in the direction of travel shortens the stopping distance.

Load; if load is more than the specified payload then the stopping distance will increase. If load is less than the specified payload then it gives a shorter stopping distance value which is not reliable Speed; If the speed is less than the test speed specified as per ISO 3450, shorter stopping distance values will be recorded which gives false values.

The graph shows the stopping distance variation if the vehicle speeds & gradient changes.

[Calculated using $S = \frac{V^2}{48\text{-}2.6xa}$]

From the above we can note that the stopping distance increases by four times when the speed becomes double.

If the gradient doubles, the stopping distance also doubles approximately.

Note:- The gradient mentioned above is the down gradient along the direction of travel of the dump truck.

Example: stopping distance calculation for a dump truck whose unladen weight is more than 32,000 kg running with speed 40 kmph(max. speed) on 9% gradient test track is calculated as per ISO 3450

$$S = \frac{V^2}{48\text{-}2.6xa}$$

$$S = \frac{40x40}{48-2.6x9} = 65.0 \text{ mts}$$

But if we conduct a test as per ISO 3450 test procedure, the stopping distance will be somewhere around 25- 35 mts which is almost half of the value.

Hence ISO 3450 stopping distance formula gives minimum criteria for brake performance, but the actual performance of the brake must be more affective to avoid accidents in the mines.

Hence Brake ratio is the right criteria to decide the performance of braking system on a dump truck.

$$\text{Brake ratio} = \frac{\text{brake force exerted by wheels}}{\text{vehicle weight}}$$

The brake force exerted by the wheels results in a linear (in line of travel) retardation of the vehicle. This force is generated by the wheel brakes exerting a braking torque (measured in Nm), which will be applied to the outside of the wheel and tire.

Brake ratio generally expressed as percentage. Ex: 35 % brake ratio.

$$\text{Also Brake ratio} = \frac{\text{brake force exerted by wheels}}{\text{vehicle weight}}$$

$$= \frac{\text{vehicle weight x retardation}}{\text{vehicle weight xacceleration due to gravity}}$$

$$\text{Brake ratio} = \frac{\text{Retardation}}{g}$$

XI. INSTRUMENTED BRAKE TESTING

Instrumented brake testing involves the usage of electronics in measuring the brake ratio. Single axial accelerometer is used to determine the retardation of a dump truck when the service brake is applied.

Generally a good brake ratio varies within a range of 35-45 % for a dump truck.

XII. CONCLUSIONS

Powering of the dump truck is very important factor in design & development of a dump truck. If the engine selection goes wrong then huge amounts of efforts of the engineers and technicians, money will go waste.

Load distribution of the dump truck when the dump truck is on plain haul road, on up gradient and downhill are important to consider while designing a dump truck since these load transfers from front to rear axle and vice versa leads to safety issues of the personnel, equipments working near by the dump trucks.

Braking is another important feature of a dump truck that needs to understand by the designers while designing a dump truck.

REFERENCES

[1] Jaroslav J. Taborek. Mechanics of vehicles.
[2] Barry Robinson MBE, OPERC Chief Examiner. Guidance on Brake Testing for rubber-tyred vehicles operating in quarries, open cast coal sites and mines.
[3] ISO 3450 third edition 1996-04-01.Earth-moving machinery-Braking systems of rubber-tyred machines-systems and performance requirements and test procedures.
[4] Thomas. D. Gillespie. Fundamentals of Vehicle Dynamics