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Dynamic Load Analysis of Mine-Truck Using Multibody Dynamic Analysis Method

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Abstract: Vehicle load distributed on front & rear axle assembly during various working conditions is one of the most important factors influencing working performance and service life of drive axle assembly. The dynamic load on axle assembly is higher compared to the rated load because of variations in vehicle speed and road surface conditions. Early failure of structural components is caused because of higher dynamic reaction forces due to uneven road profiles. The dynamic load calculation of axle assembly is presented in this paper for a Mine-truck with various road conditions and vehicle speeds. The road load conditions consist of grade, bump & path hole. Mine-truck with payload capacities of 63 Ton is considered for the study. The behaviour of vertical force is calculated for different vehicle speeds (3 - 12 km/hr.) of the machine on the front & rear axle assembly during running conditions. Multi-body dynamic Analysis tool ADAMS is used for this study. ADAMS helps to study the dynamics of moving parts and load distribution throughout mechanical systems during motion. The Mine-truck3D model was created with the help of computer-aided design (CAD) software. Major units of Mine trucks are considered to prepare 3D models like Cabin-engine mass, Bucket, front axle assembly, rear Axle assembly & tires. Multi-body vehicle models are prepared in simulation software ADAMS by importing 3D models prepared by computer-aided design (CAD) software. This provides guidelines for selecting dynamic load factors while designing structural parts of the vehicle.
Keywords: Dynamic load factor, Mine Truck, Multibody dynamic Analysis, Drive Axle, Road Profile.

I. INTRODUCTION

The axle assembly is the main load-carrying member of the off-highway vehicle. Vehicle load distributed on front & rear axle assembly during various working conditions is one of the most important factors influencing working performance and service life of drive axle assembly. Load distribution on the wheel is based on its operating condition [1]. Reaction force on one wheel is a key parameter that is used for the design of a vehicle. This one-wheel load depends on gross vehicle weight (GVW), speed, wheelbase, and Centre of gravity location of the vehicle. The dynamic load on axle assembly is higher compared to the rated load because of variations in vehicle speed and road surface conditions. The road condition of the Mines is severe with path holes, sand, and gravel. Figure 1 shows Typical Coal mine road conditions.

The mining dump truck runs all year round on the terrible mine road, which is prone to need higher performances than the general highway vehicle, such as stiffness, strength, and fatigue life [2]. This study is useful to avoid the early failure of the Mine-truck axle by determining the dynamic load coming on the wheel due to road surface roughness.

Fig 1 – Typical Coal Mine Road Condition

Joubert et al. (2020) presented a study on semi-analytical & full analytical methods to predict the vehicle frame loads using Multibody Dynamic simulation, considering the single-wheel ramp, downhill ramp & hard braking conditions on vehicles using SimPack^{TM} [2]. Lu et al. (2009) reported a Numerical and experimental investigation on a stochastic dynamic load of a heavy-duty vehicle, Analysis of dynamic load is carried out with the help of software ADAMS [3]. Cheli et al. (2011), mentioned a study on Tire-road contact forces determined through finite element analysis (FEA) and verified through experimental tests, vehicle dynamics results are significantly affected due to Tire-road contact forces [4]. Zheng et al. (2014), reported the Failure analysis of the Mining dump truck frame, considering the various path holes, obstacles, slope and curves on the bumpy road by combing the FEA, as well as static and dynamic testing [5]. Zhang et al. (2021), reported a practical approach to estimating the vertical tire forces of a multi-axle truck for dynamic control. MATLAB/Simulink and Trucksim software are used, which can simulate a real truck used in the heavy vehicle industry [6]. Guan et al. (2018) reported the use of MSC ADAMS software for pavement design based on a multi-rigid-body dynamics model to calculate the force & displacements [7]. Mi et al. (2012) used the finite element method and multibody dynamic analysis to predict the fatigue life of mining dump trucks. Multibody dynamic analysis & finite element analysis are done by combined use of software ADAMS, SolidWorks, Hyper mesh, and MSC. Fatigue [8].

The present research work is different from the above-cited works. The overall objective of this research is to calculate the dynamic load on the vehicle axle assembly, considering the effect of speed, and road condition with a 63Ton payload capacity of Mine-trucks. The dynamic load on front and rear axle assembly is calculated for various road conditions and a 63-ton payload capacity truck.

Vertical tire forces are essential in vehicle modelling and dynamic control. Two types of methods, i.e., a direct measurement and an estimation, can be used to evaluate the vertical tire forces. The costs of a direct measurement are high, whereas the estimation method requires more sensors to ensure the accuracy, in this research vertical dynamic load on the vehicle is calculated by using the virtual model in MSC.ADAMS [9].

Figure 2 shows the side view of the Mine Truck. Major units of the Mine Trucks are material carrying bucket, engine and cabin, Front Axle assembly and rear Axle assembly. The bucket is located at the rear of the truck. The engine & cabin is in front of the truck. The payload placed on the bucket is transferred to the ground through the Front & rear axle assembly of the truck.

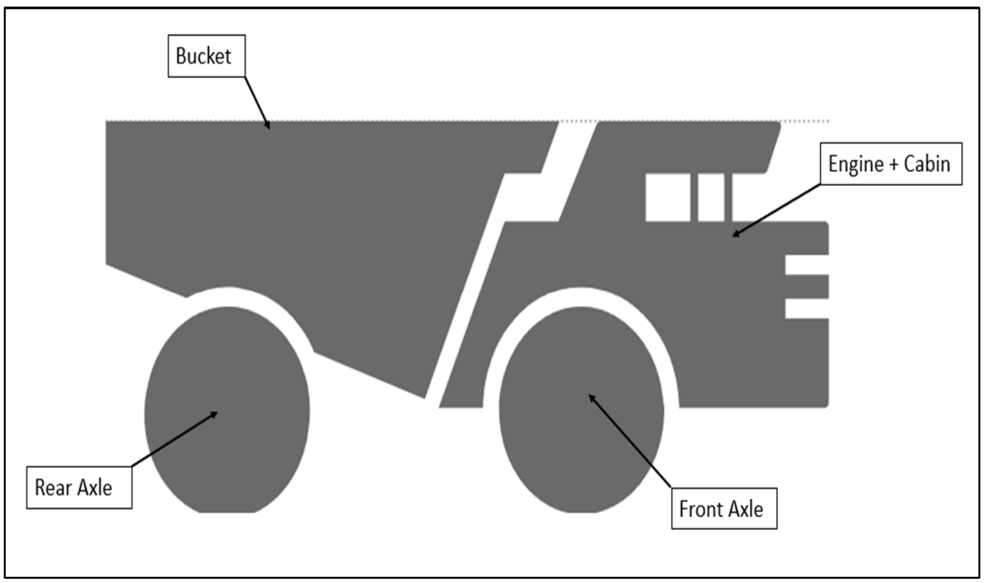

Fig 2 – Side View of Mine Truck.

A parametric virtual prototype of a Mine-truck is created in the simulation package MSC.ADAMS [9]. ADAMS helps to study the dynamics of moving parts, and load distribution throughout mechanical systems during motion. A mine-truck with a payload capacity of 63 Tons is used for analysis. Vehicle speeds ranging from 3 to 12 km/hr are used. Various road conditions like ramps, path holes, and cross bumps are used for analysis. A moving vehicle is a complex nonlinear vibration system with multiple degrees of freedom, but a simplified model is used to perform analysis because our objective is to calculate only wheel reaction forces during the moving condition, besides Mine-truckdoes not have any suspension linkages like leaf springs or Dampers to absorb the shock from the road surface.

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II. MATERIALS AND METHODS

A. Underground Mine-truck specifications:

Specifications of 63T payload capacity A Mine-truck is used to perform multibody dynamic analysis, key Parameters of the truck according to payload capacity are listed in below Table 1, (Sandvik, 2022) [10].

Table 1 – Technical Specifications of Mine-Truck

Truck	
Pay Load Capacity (Ton)	63
Empty Vehicle weight (kg)	48,440
Gross vehicle weight (kg)	111,440
Wheelbase (mm)	5650
Static Tire rolling Radius (mm)	979

B. Modelling of Truck

Mine-truck 3D model has been created with the help of computer-aided design (CAD) software. Major units of Mine-truck are considered to prepare 3D models like Cabin-engine mass, Bucket, front axle assembly, rear Axle assembly & tires. The overall dimensions of the mine truck are considered from the product brochure (Sandvik, 2022) [10]. Multi-body vehicle model has been prepared in simulation software ADAMS by importing a 3D model prepared by computer-aided design (CAD) software. The densities of each unit of Mine trucks are adjusted to match the Front axle and Rear axle assembly load with the brochure. This is used as an empty vehicle model for further multibody dynamic analysis. Bucket density adjusted to consider external payload on Mine Truck. It is assumed that extra payloads are equally distributed over the bucket.

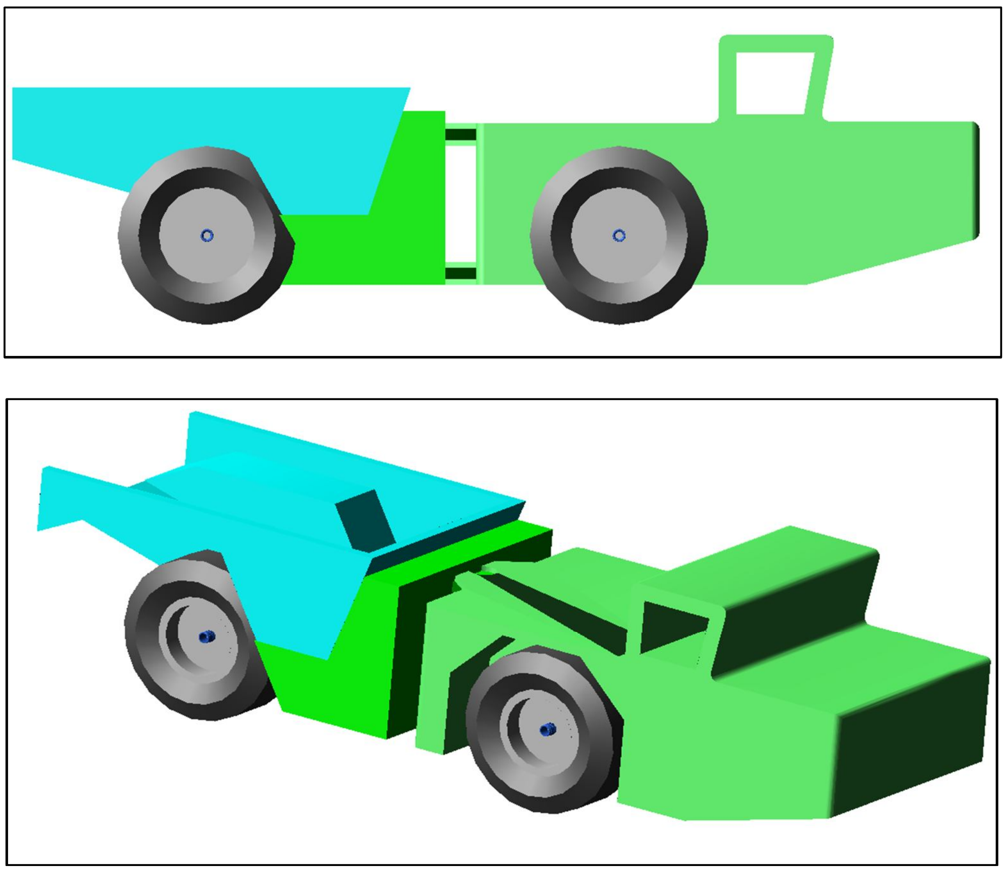

Fig. 3 – Simplified 3D Multi-Body Vehicle Model of 63-Ton Mine Truck.

The Front axle and rear axle are attached to the Cabin & bucket through fixed joint respectively. The revolute joint is used to connect the Tire & axle.

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C. Modelling of tire & Road Profiles:

The Tire of Mine-truck acts as a suspension device between the vehicle & road surface which absorbs the shock from the road. Tire is a very critical parameter in the multibody dynamic analysis because of its variable stiffness. Tire stiffness depends on the inflation pressure, material (rubber) properties, type & configuration [3]. ADAMS Fiala Tire (FT) is selected from the standard library of ADAMS [11]. The Fiala Tire model is a physical tire model in which the tire carcass is modelled as a beam on an elastic foundation in the lateral direction. The tire belt ply or buffer layer is simplified as a section beam acting under concentrated load. The model is very simple and does a fair job of representing general tire force and moment curves, which is verified by experiments by ADAMS [11]. The main advantage of the ADAMS Fiala Tire (FT) is that only a few parameters are required, The vertical stiffness and damping of the tire are specified as input parameters. Tire size and dimensions are selected from Mine-truck specifications for preparing tires in the simulation software ADAMS.

During the vehicle life, dynamic forces caused by the road roughness produce dynamic stresses and these forces lead to fatigue failure of axle, which is the main load carrying part of the assembly. Therefore it is vital that the axle resist against the fatigue failure for a predicted service life [12].

The road condition of the Mines is severe with path holes, sand, and gravel. This is because of the unpaved mine road surface [5]. Generally, any vehicle during its operation goes through grade, path hole & bump conditions. Various road surface designs are prepared to consider the effect of grade, path hole & bump during simulation. Figure 4 shows the top view of the Road surface model inside the simulation software ADAMS. 3D road format is created in ADAMS. It consists of path holes, bumps & grades. Path holes and bumps are located at alternate distances so that both wheels of the same axle will not have hurdles at the same time. This simulates severe load conditions. Path holes and bumps simulate the condition of big pits and gravels of actual mines. Figures 5, 6 and 7 show cross-sections of cross-path holes, cross bumps, and grades respectively. Table 2 shows the Basic dimensions of the road surface

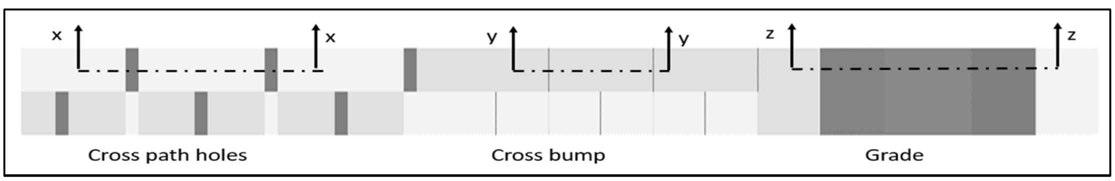

Fig. 4 - Top View: Road Surface Slong with Cross Paths holes, Cross Bump & Grade.

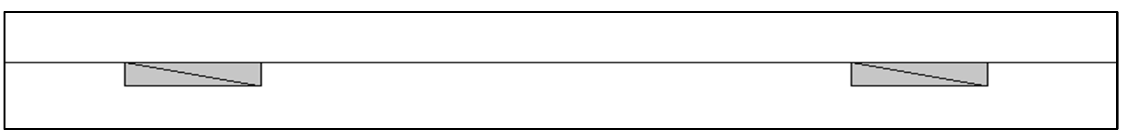

Fig. 5 - Side View (Section X-X): Road Surface with Cross-Path holes.

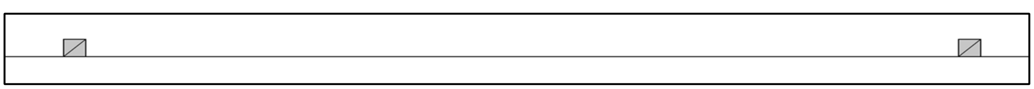

Fig. 6 - Side View (Section Y-Y): Road Surface with Cross bump

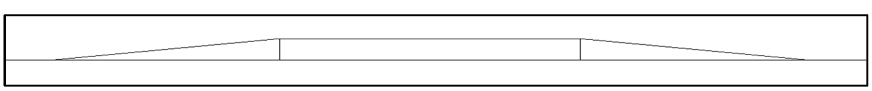

Fig. -7 Side View (Section Z-Z) Road Surface with Grade.

Table 2 –Basic Dimension of the Road Surface

Road surface	Dimension
Grade (Deg)	8
Cross bump (mm)	150 (W) X 50 (D) X 2500 (L)
Cross path holes (mm)	1500 (W) X 100 (D) X 2500 (L)

W – Width, D-Depth and L-Length

The selected Mine-truck model is analyzed in simulation software ADAMs with the speed variation of 3km/hr., 6 km/hr., 9 km/hr. & 12 km/hr. respectively to find out the dynamic wheel reaction forces. Maximum wheel reaction force is taken from results and used for further dynamic load factor calculations.

Dynamic load factor (G):

Dynamic Load factor (G) is calculated as follows:

$$Dynamic\ load\ factor\ (G) = \frac{Laod\ in\ dynamic\ condition}{Nominal\ load\ in\ static\ condition}$$

Load in dynamic condition: Reaction force on the wheel of the vehicle during running condition.
Nominal load in Static condition: Reaction force on the wheel when the vehicle is travelling over plane road surface or in stationery condition.

III. RESULTS & DISCUSSION

A. *Verification of Multi-body vehicle model:*

The multi-body vehicle model is verified for front axle assembly load & rear axle assembly load before performing analysis on various road surface conditions prepared.

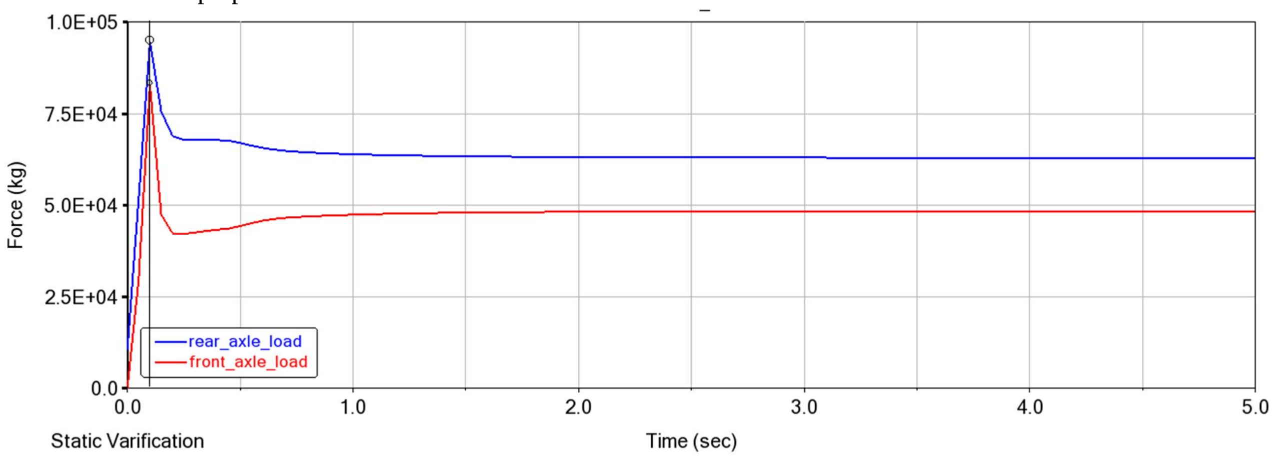

Fig 8 - 63 Ton Mine-Truck Front & Rear Single Wheel Reaction Load

Front Axle Load = 48,200 kg
Rear Axle Load = 63,000 kg

Figure 8 shows the results of the multibody model running on a plane surface. Reaction force on the front axle & rear axle is shown in kg.

Table 3 shows a comparison of multibody dynamic simulation verification results with actual specifications. Minor deviations of 0.6 % and -0.1 % were observed compared to actual specifications.

Table 3- Results comparison

Load on Axle assembly	Specification	Results	% Deviation
Front (kg)	48520	48200	0.6%
Rear (kg)	62920	63000	-0.1%

B. *Dynamic Load Calculation through multi-body vehicle model*

The vehicle model 63 Ton payload is analyzed on various road surface conditions shown in Figure 4 with the speed of 3 km/hr, 6 km/hr, 9 km/hr & 12 km/hr after verification of the multi-body vehicle model.

Figure 9 shows the reaction load calculated for the 63-ton payload vehicle model with speed of 12 km/hr. The vehicle ran first through the grade road surface, bump surface & path hole surface respectively. Maximum reaction load is extracted & used to calculate the Dynamic Load factor (G) for each road surface condition.

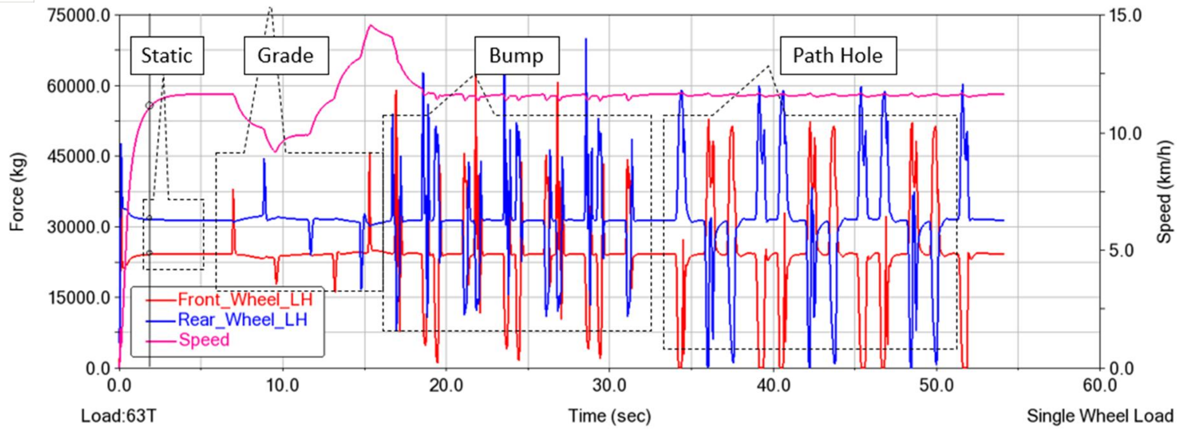

Fig. 9: Front & Rear axle assembly dynamic load (63 Ton Payload with 12km/h)

Table-4- Dynamic Load factor Front & Rear axle assembly dynamic load (63 Ton Payload with 12km/hr)

		Static	Grade	Bump	Path Hole
Front axle	One side Wheel Load-kg	24213	45872	60652	52803
	Dynamic Load factor	1.0	1.9	2.5	2.2
Rear axle	One side Wheel Load-kg	31485	54027	70031	60347
	Dynamic Load factor	1.0	1.7	2.2	1.9

Table 4 shows the Dynamic Load factor (G) calculated for the front & rear axle of 63 Ton payload vehicle. maximum Dynamic load factor is 2.5 & 2.2 for the front & rear axle respectively.

C. Analysis results

Dynamic Load factor (G) is calculated by taking the ratio of axle assembly level reaction force from simulation to axle assembly rated load value of brochure. Dynamic load factor versus speed is plotted for 63T Payload Mine-truck for various road conditions.

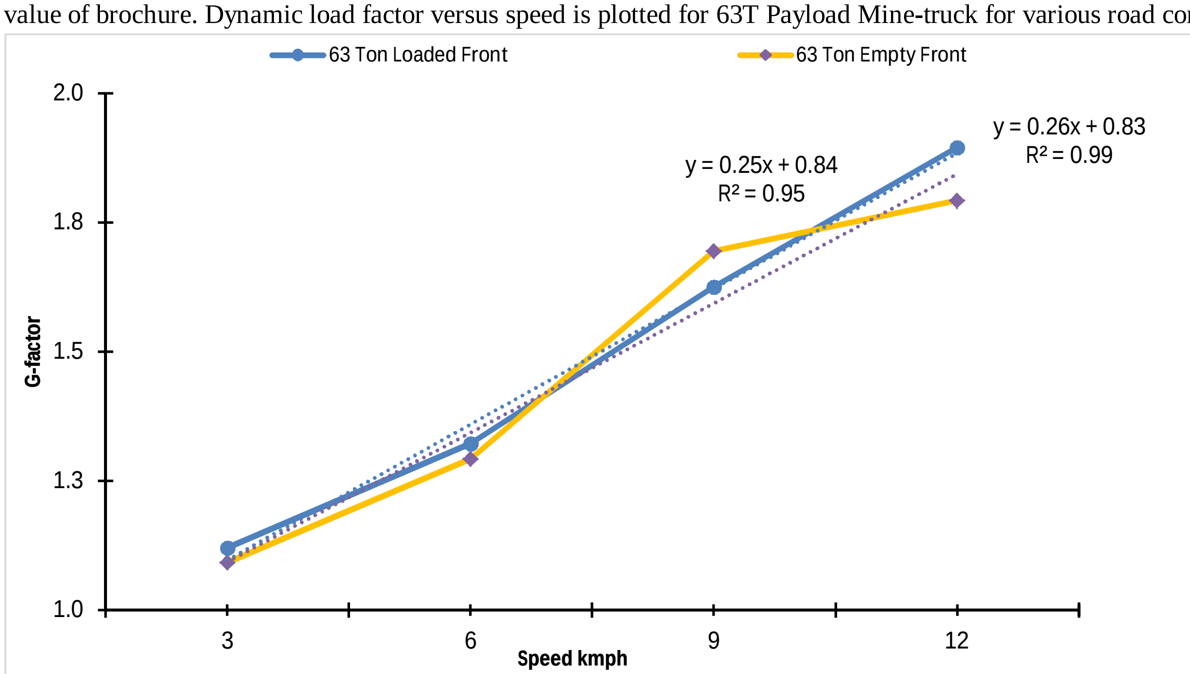

Fig. 10: a) Front axle dynamic load factor vs. speed (Empty/Loaded Vehicle - **Grade**)

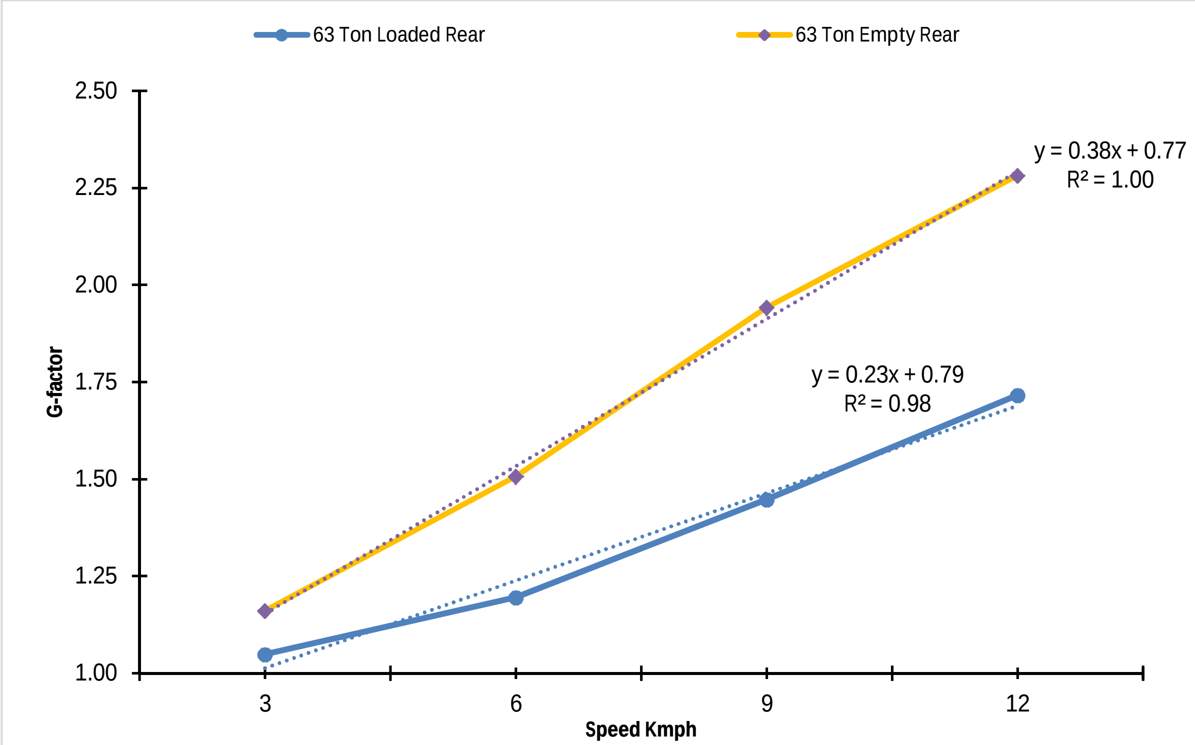

Fig. 10: b): Rear axle dynamic load factor vs. speed (Empty/Loaded Vehicle - **Grade**)

Figure 10 (a) and (b) shows the Dynamic load factor of front and rear axle assembly plotted against different speeds for empty & loaded conditions, and vehicle travel on Grade. The dynamic load factor of both front and rear axle assembly increases with an increase in speed. A linear correlation equation is shown in the respective plot. Dynamic load factor values for the front axle for empty & loaded conditions are identical with grade road conditions. Dynamic load factor values for rear axle empty trucks are higher than loaded truck conditions. Dynamic load factor values for the rear axle are higher compared to the front axle.
Dynamic load factor values of empty vehicles are higher compared to loaded vehicles. This is because loaded vehicle behaviour is less dynamic compared to empty vehicles.

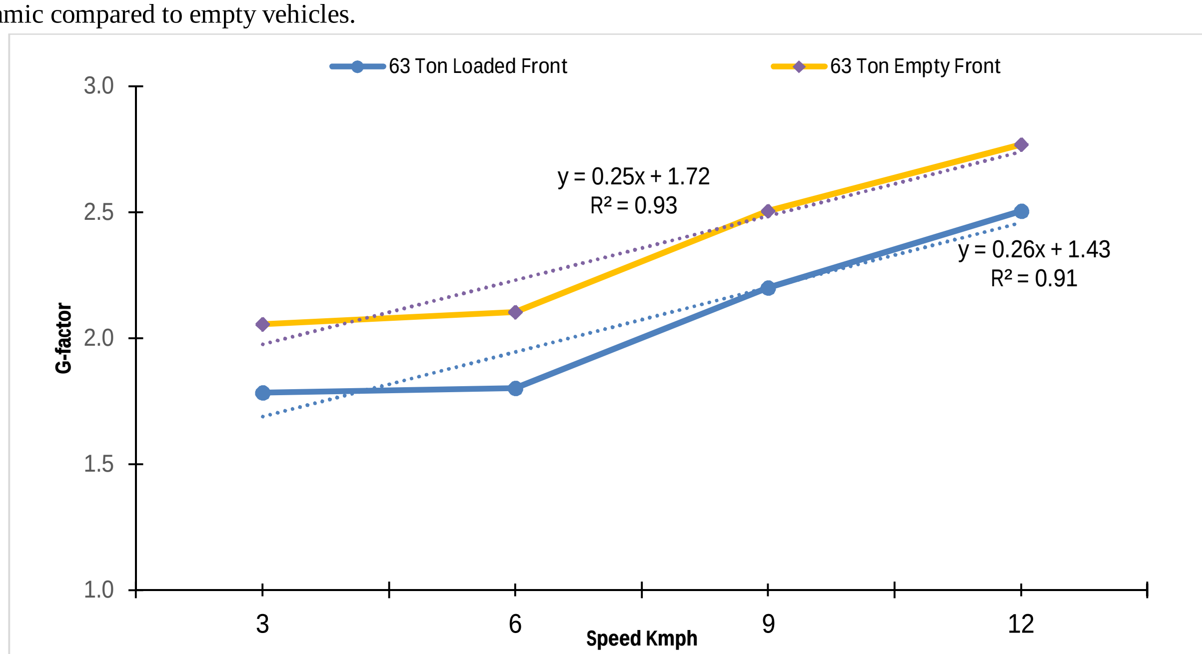

Fig. 11: a) Front axle dynamic load factor vs. speed (Empty/Loaded Vehicle - **bump**)

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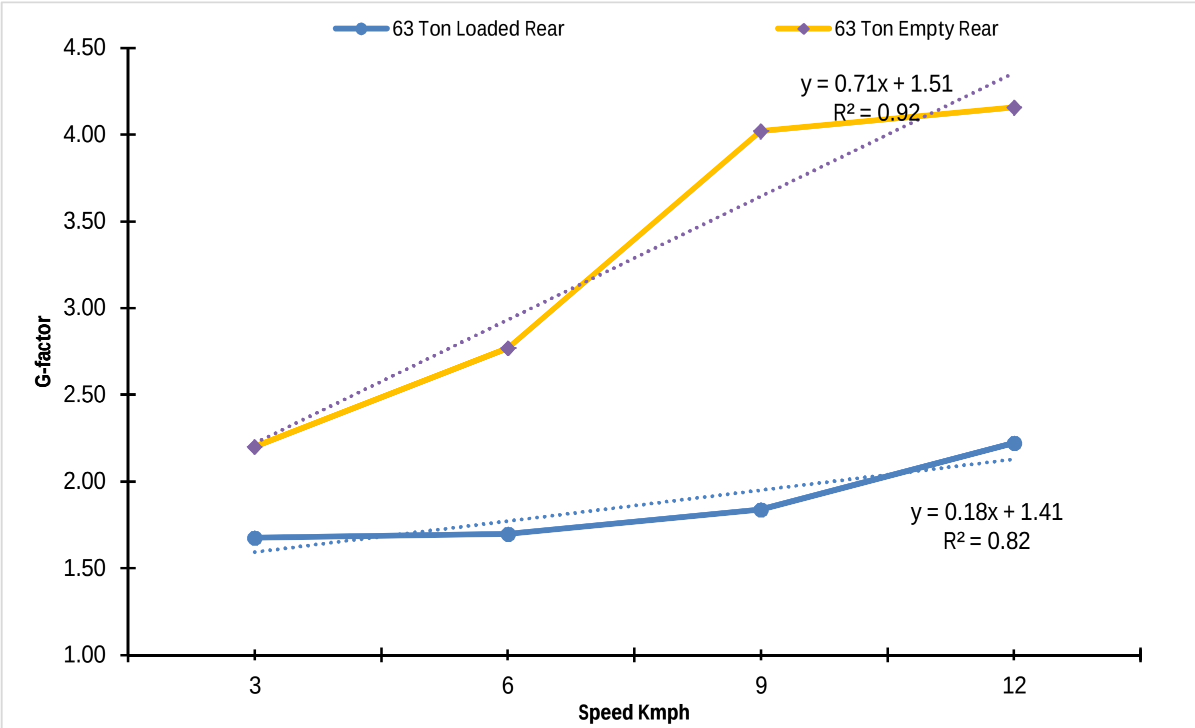

Fig. 11: b) Rear axle dynamic load factor vs. speed (Empty/Loaded Vehicle - **bump**)

Figure 11 (a) and (b) shows the Dynamic load factor of front and rear axle assembly plotted against different speeds for empty & loaded vehicle travel on the bump. The dynamic load factor of both front and rear axle assembly increases with an increase in speed. The linear correlation equation is shown in the respective plot. Dynamic load factor values for the front axle for empty & loaded condition is parallel with bump road condition. Overall dynamic load factor values for the rear axle are higher compared to the front axle.

Dynamic load factor for rear & front axle with empty truck is higher compared to loaded vehicle. This is because loaded vehicle behaviour is less dynamic compared to empty vehicles.

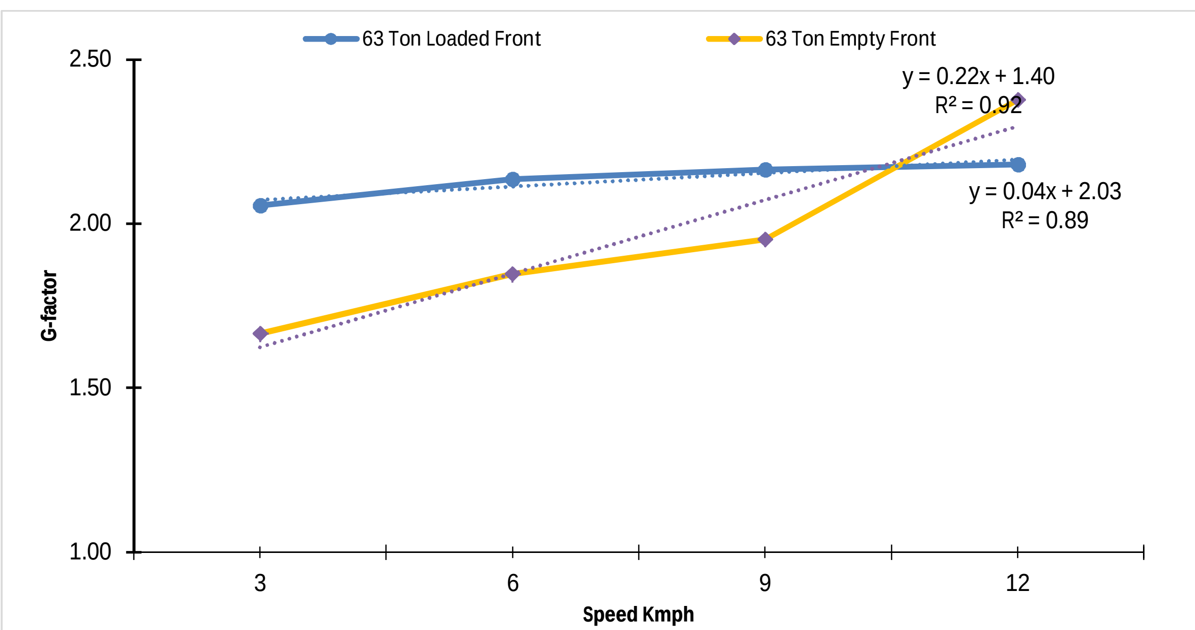

Fig. 12: a) Front axle dynamic load factor vs. speed (Empty/Loaded Vehicle - **path hole**)

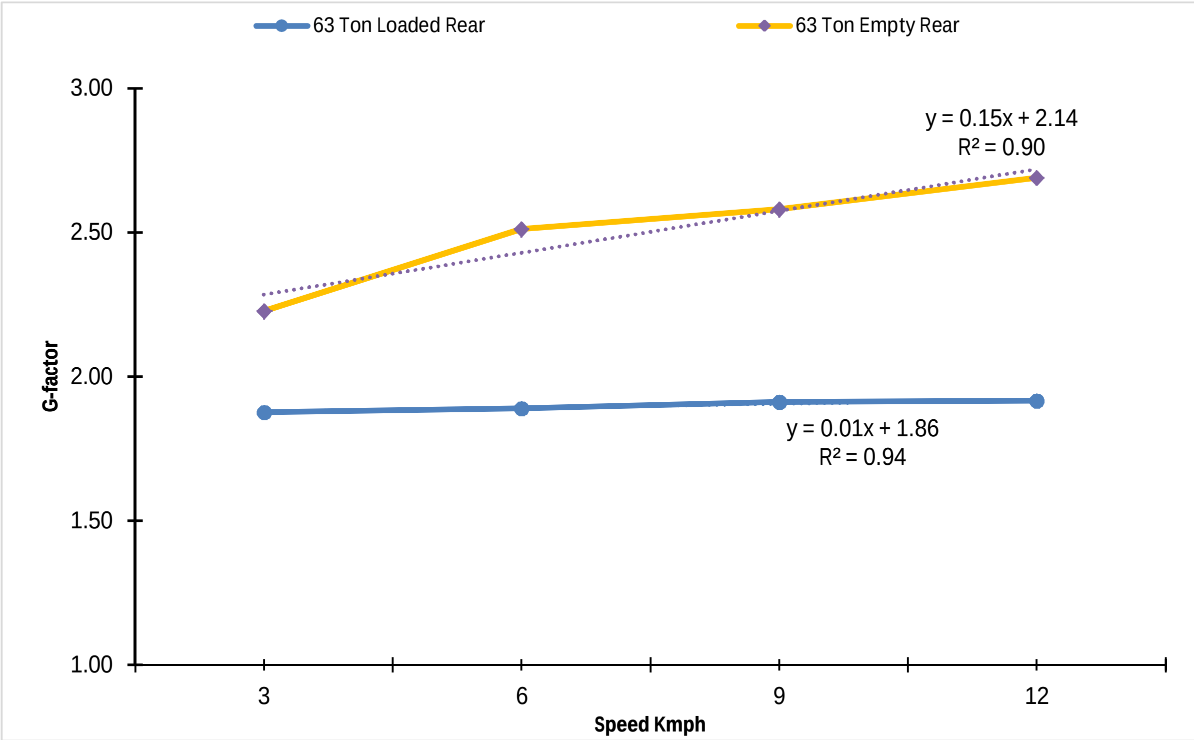

Fig. 12: b) Rear axle dynamic load factor vs. speed (Empty/Loaded Vehicle - **path hole**)

Figure 12 (a) and (b) shows the Dynamic load factor of front and rear axle assembly plotted against different speeds for empty & loaded conditions, vehicle travel on path hole. The dynamic load factor of both front and rear axle assembly increases with an increase in speed. A linear correlation equation is shown in the respective plot. Overall Dynamic load factor values for the rear axle are higher compared to the front axle. The dynamic load factor for the rear axle with the empty truck is higher compared to loaded vehicles. This is because loaded vehicle behaviour is less dynamic compared to empty vehicles.

Further Dynamic Load factor (G) is compared for different speeds with Grade, Path hole & bump road surface, considering the empty & loaded condition of 63T Mine-truck.

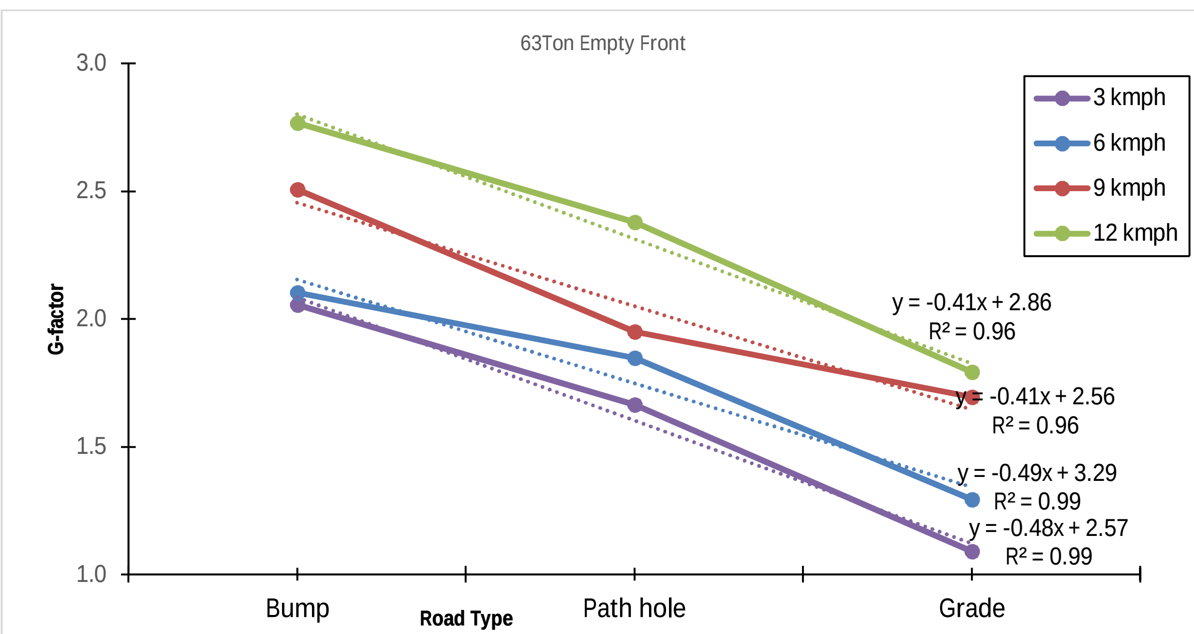

Fig. 13: a) Front axle dynamic load factor vs. road type (**Empty Vehicle**)

Figure 13 (a) shows the Dynamic load factor of the front axle assembly for an empty truck plotted against road type for different speeds, The Dynamic load factor is less for low speed & high for higher speed for all road surfaces. Dynamic load factor for bump road conditions is higher for all speeds while it is low for Grade surfaces.

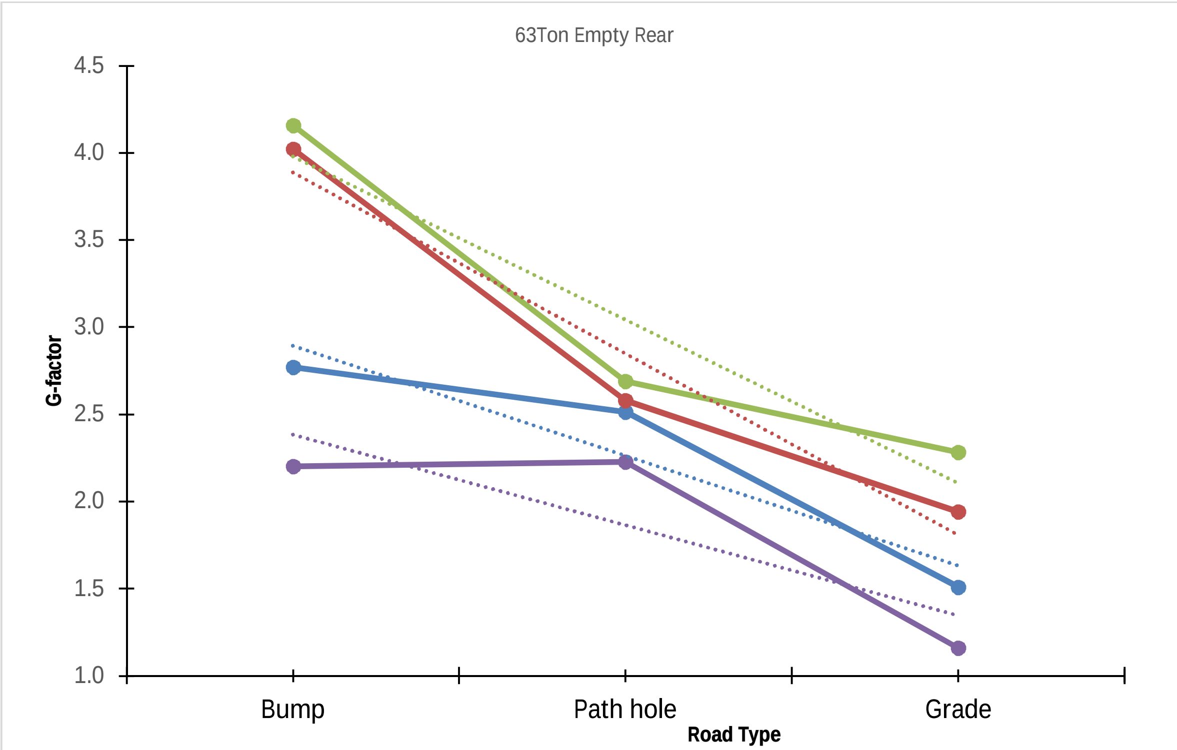

Fig. 13: b) Rear axle dynamic load factor vs. road type (Empty Vehicle)

Figure 13 (b) shows the Dynamic load factor of rear axle assembly for empty vehicles plotted against road type for different speeds, The Dynamic load factor increases with the speed for all road surfaces. Dynamic load factor for bump road conditions is higher for all speeds while it is low for Grade surfaces.

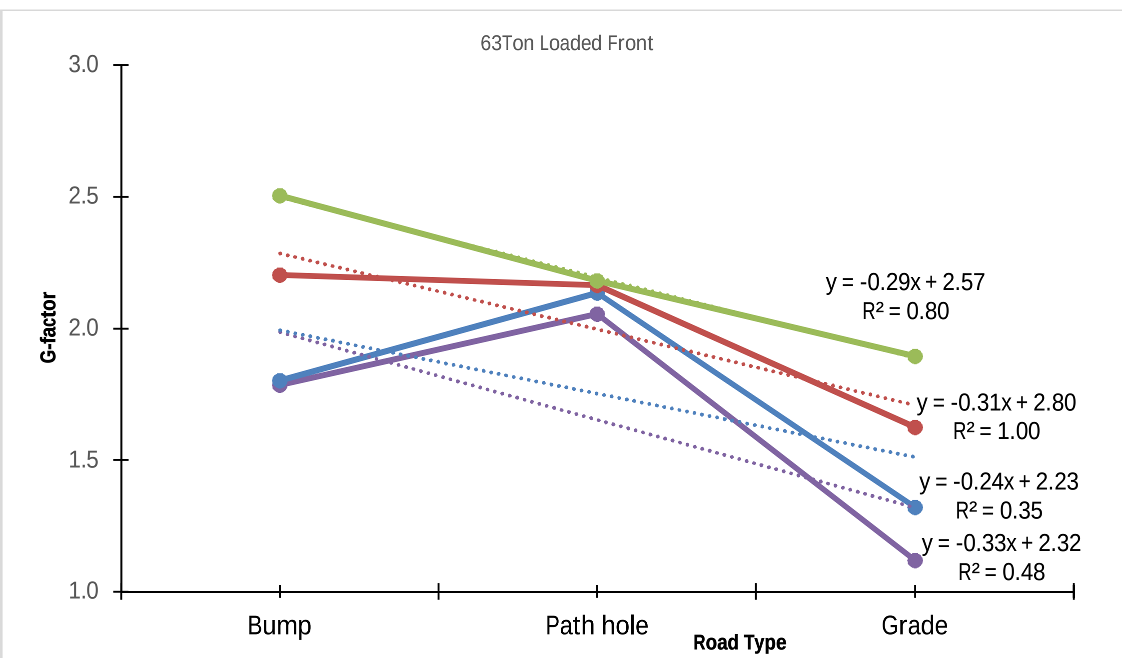

Fig. 13: c) Front axle dynamic load factor vs. road type (**Loaded Vehicle**)

Figure 13 (c) shows the Dynamic load factor of rear axle assembly for empty vehicles plotted against road type for different speed, The Dynamic load factor is increasing with the speed for all road surfaces. The dynamic load factor for Path hole condition is identical for all speed.

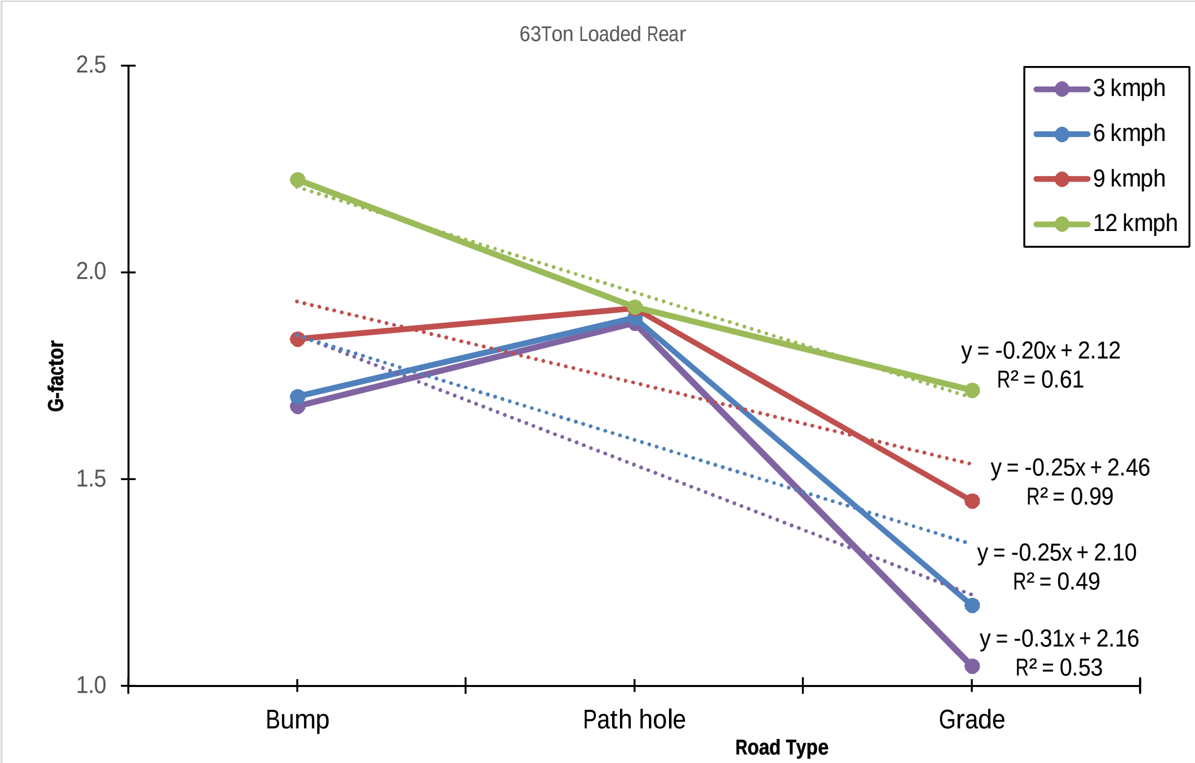

Fig. 13: d) Rear axle dynamic load factor vs. road type (**Loaded Vehicle**)

Figure 13 (c) shows the Dynamic load factor of rear axle assembly for empty vehicles plotted against road type for different speeds, Dynamic load factor is increasing with the speed for all road surfaces. Dynamic load factor for the Path hole condition is identical for all speed.

IV. CONCLUSIONS

1) Dynamic Load factor of a Mine-truck increases as speed increases.
2) Linear correlation equations are developed which can be used to calculate the G-factor at any speed of a Mine-truck for respective road surface conditions.
3) Dynamic load factor values in the case of
4) the front axle is higher compared to the rear axle assembly while the truck is travelling over a graded road surface. This is because of the dynamic effect of centre of gravity of a truck while travelling on graded road surface.
5) Dynamic load factor values of empty vehicles are higher compared to loaded vehicles. This is because, loaded vehicle behaviour is less dynamic compared to empty vehicles, also due to the uncertain body bounce generated by the truck.

V. ACKNOWLEDGMENT

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Conflict of Interest statement:
On behalf of all authors, the corresponding author states, the authors have no financial or proprietary interests in any material discussed in this article.

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