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Design and Validation of Hydraulic brake system for Utility Vehicle

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ABSTRACT

The brake system is one of the most important features on all the road vehicles. It must meet manufacturers and Customer requirements in addition to safety standards. This work will analyse automotive braking from vehicle system perspective, emphasizing on legal requirements as well as performance expectations such as Brake pedal effort, Stopping distance and decelerations. The theoretical calculations along with the legal requirements will be verified through the vehicle level validation.

Keywords— **Deceleration, Brake balancing, Adhesion curve**

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I. INTRODUCTION

The highest goal of a good brake system design must be that the vehicle when braking obtains a short braking distance and it does not leave its track and remains steerable. For the solution of this problem, one must consider the dynamics of the braking process. The layout of the braking forces at the front and rear axles for the optimization of the vehicle deceleration.These are essential for different vehicle configurations and loading conditions. The so-called braking dynamics ask first for the optimization of the vehicle deceleration but does not ignore aspects of the braking stability. A vehicle is regarded as stable while braking if its brake system design prevents unwanted vehicle movements automatically, which are either caused by (wrong) actions of the driver or by disturbances of any kind.

In this paper the stability of the vehicle can be achieved through system sizing calculations and the verification is done through vehicle testing.

II. DESIGN OBJECTIVE

The following are the Design objectives, which need to be achieved both in Design calculation as well as in the vehicle validation

1.The brake pedal effort need to be within 50kg under all conditions
2. The designed vehicle has to meet the safety regulations as per IS: 11852 part:3
3.The front wheel has to lock much before Rear wheel; this is achieved by brake balancing.
4. Co-relation between the theoretical and vehicle testing data with the following:
   A.Unladen front V/s Rear pressure
   B.Laden front v/s Rear pressure
   C.Unladen pedal travel v/s Deceleration
   D.Laden pedal travel v/s Deceleration

III. PROPOSED METHODOLOGY

A. Brake system design considerations

In most cases the brake engineer has the following data available when designing the brakes of a vehicle
Empty and loaded vehicle weight
Static weight distribution lightly and fully laden
Wheelbase
Center of gravity height lightly and fully laden
Intended vehicle function
Tire and Rim size
Maximum speed
Braking standard

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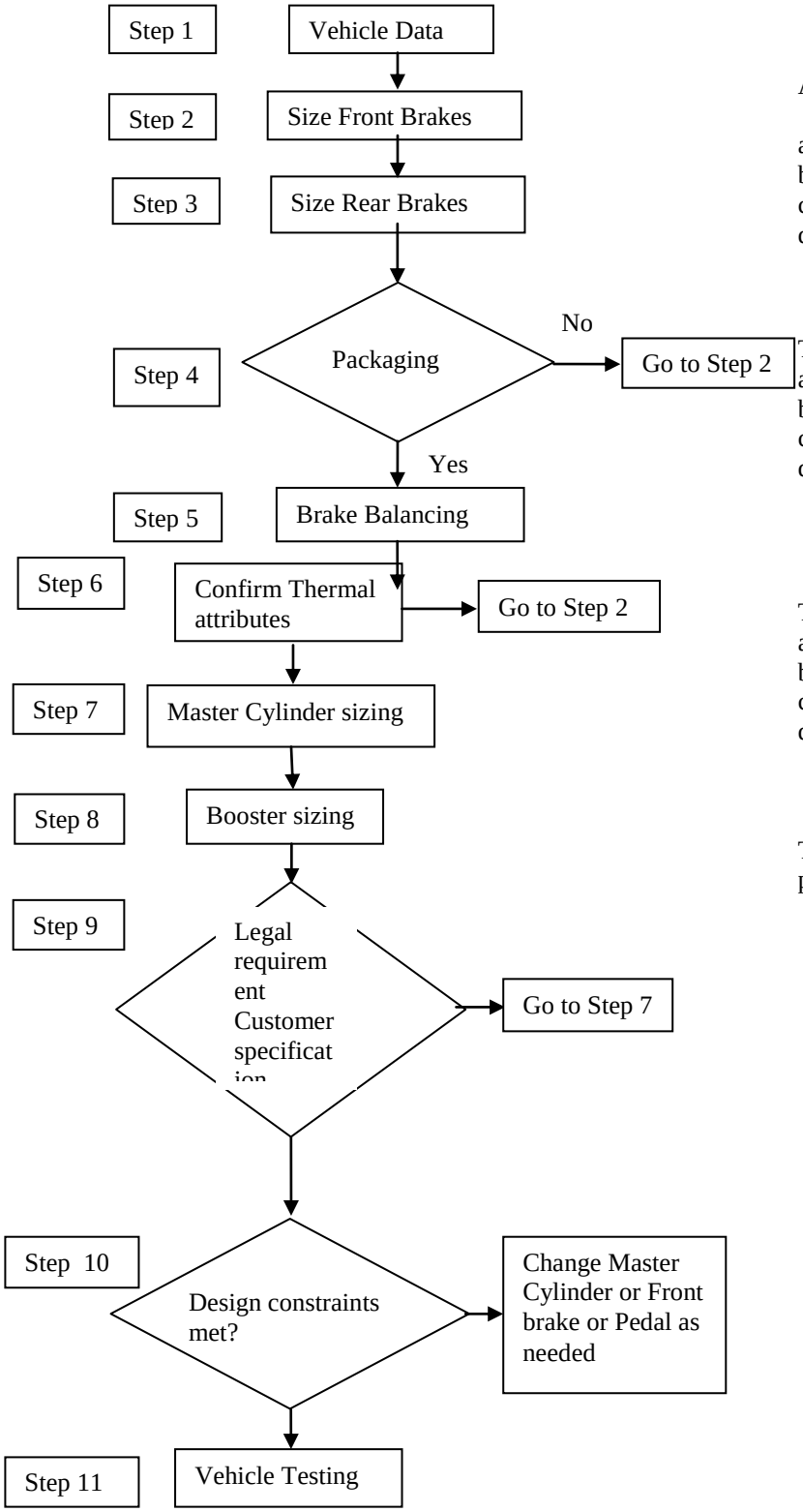
In the fourth step, the pedal assembly and power boost system is designed
In the fifth step, the brake system components must be packagable in the vehicle layout.

B. Flow chart for Brake system Design



C. Step by step procedure for the Brake system design

Step 1: Vehicle Data

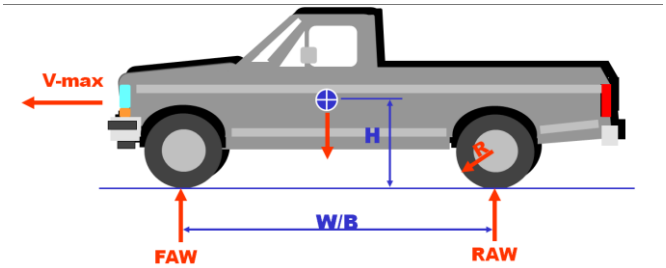


Fig 1

As per Fig 1, the following basic data need to be obtained

a.FAW=Front axle weight
b.RAW=Rear axle weight
c. H =Center of gravity (C.G)
d.W.B = Wheelbase

Step 2: Size Front Brakes

The following inputs are required:
a. Calliper piston diameter
b. Effective radius
c. Pad Mue
d. Application pressure

Step 3: Size Rear Brakes

The following inputs are required:
a. Brake drum diameter
b.Wheel cylinder
c. Brake factor
d. Application pressure

Step 4: Packaging

The below figures 2, 3 and 4 depicts the brake system packaging

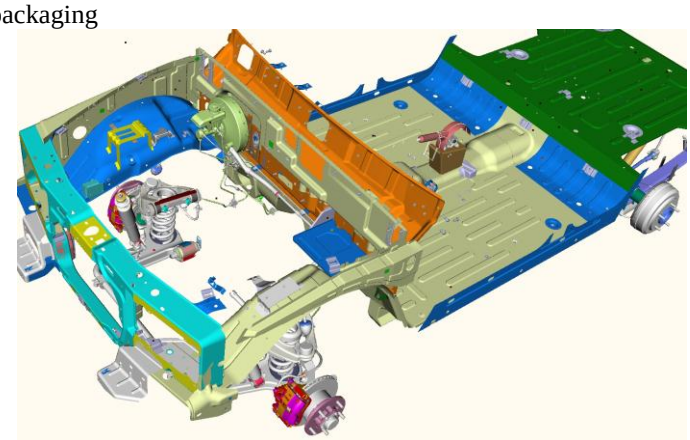


Fig 2: Brake system in vehicle layout

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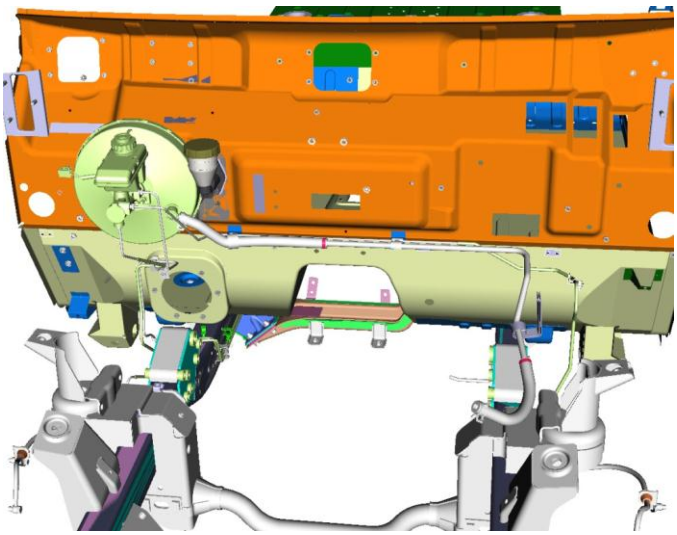

Fig 3: Brake booster packaging

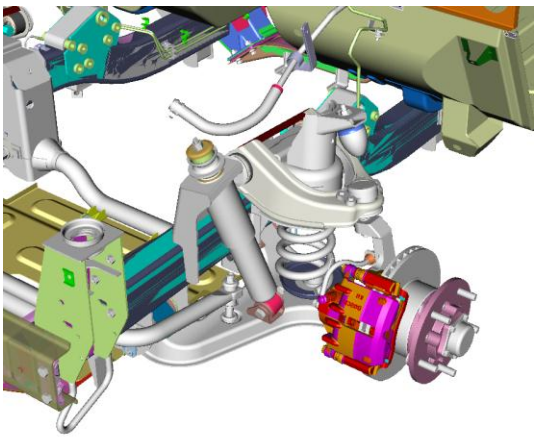

Fig 4: Caliper packaging

Step 5 and 6: Brake balancing

To calculate the front & rear brake contribution, the following
are the formulas

1. Weight @ front =FAW + (m *(C.G/W.B))*Deceleration
2. Weight @ Rear =RAW - (m *(C.G/W.B))*Deceleration
3. Brake force @ front= Deceleration* Weight @ front
4. Brake force @ Rear= Deceleration* Weight @ Rear
5. Ideal torque (kg.mt) = Brake force @ front or rear * Dynamic rolling radius
6. Total drag force=m* Deceleration
7. Total Torque=Ideal torque @ front + Ideal torque @ Rear
8. Total Torque=Tfront + Trear
   = 2*2*Awc*μ*(P-Po)*reff + 2*Awc*B.F *(P-Po)* Reff
9. Percentage contribution of brake for the Front = {(Front Torque/Total Torque)*100}
10. Percentage contribution of brake for the Rear = {(Rear Torque/Total Torque)*100}

Step 6: Thermal attributes

The brakes convert kinetic energy into heat. To determine the energy absorbed. It is to calculate the change in kinetic energy of the vehicle. The change in energy is given by

$\Delta KE=1/2 *m*V^2 +1/2*I*\omega^2$

The energy will be absorbed into that portion of the rotor that is swept by the disc brake pad. We will have to estimate the temperature change of the rotor during the single stop. This is given the equation

$E= m*C_p*\Delta T$

Where,

KE =Kinetic energy

m= mass of the vehicle in kg

V=velocity of the vehicle in m/sec

I= Mass moment of inertia of the front wheel in kg-m²

ω= Angular velocity of the Tire in rad/sec

Cp= Specific heat of the steel=540 J/kg.k

The single stop temperature should not be more than 350 degrees

Step 7 and 8: Master cylinder sizing and Booster sizing

The below formulas are used to find out the force required on the brake pedal to stop the vehicle

1. Force on Master Cylinder (TMC) Piston = (Pressure *TMC Area)/ (TMC efficiency)
2. To find the Booster Input force, the following are the conditions

   a. If, Force on piston ≥ Booster saturation force
   Then, {(Force on piston - Booster saturation force) + Input force at saturation}

   b. If, Force on piston ≤ Booster saturation force
   and Force on piston ≥ Jump in force
   then, {(Force on piston-Jump in force)/(Boost ratio + Threshold force)}

   c. If, Force on piston < Jump in force
   and Force on piston > Threshold force
   then, Threshold force
3. Brake pedal force = (Booster Input force *Pedal ratio)/Pedal efficiency

Step 9 and 10: Legal requirements

The legal requirements as per IS: 11852 part: 3.The Design must meet all the below criteria as shown in below table

TABLE 1

Legal Acceptance criteria as per IS: 11852 part: 3

Test Type	Vehicle speed V Km/h	Stopping distance	Deceleration m/s²	Pedal force Kg
Type P test with engine disconnected	80	≤0.1V +V²/150	>5.8	≤50
Type P test with engine connected	120 =80% Vmax	<0.1V + V²/130	>5	≤50
Secondary braking	80	<0.1V +2V²/150	>2.9	≤50

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The Adhesion -deceleration coefficient for the front & Rear is given by

Adhesion deceleration coefficient for Front
= {(Front actual torque/Ideal front torque)*deceleration}

Adhesion deceleration coefficient for Rear
= {(Rear actual torque/Ideal Rear torque)*deceleration}

The figure 5 and 6 is the adhesion curve both in Unladen and laden, and the importance of this curve is in all the conditions there is only front wheel lock.

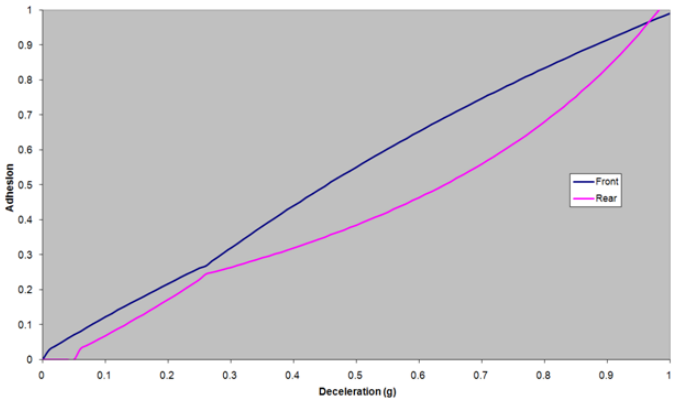

Fig 5 Adhesion-Deceleration Unladen

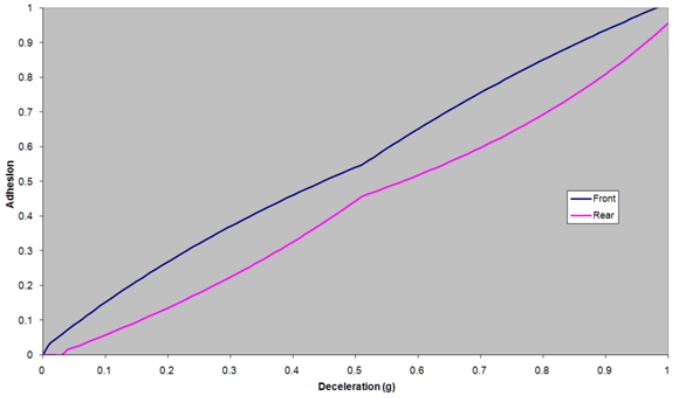

Fig 6 Adhesion-Deceleration Laden

Step 11: Vehicle testing

The following equipments were used for the vehicle testing

1. L-400 optical sensor as shown in fig 7
2. DAS-2 (Data acquisition system) as shown in fig 8
3. Pressure transducer as shown in fig 9
4. Pedal effort gauge as shown in fig 10
5. Pedal travel gauge

Fig-7, L-400 optical sensor

Fig-8, DAS -2

Fig-9, Pressure transducer

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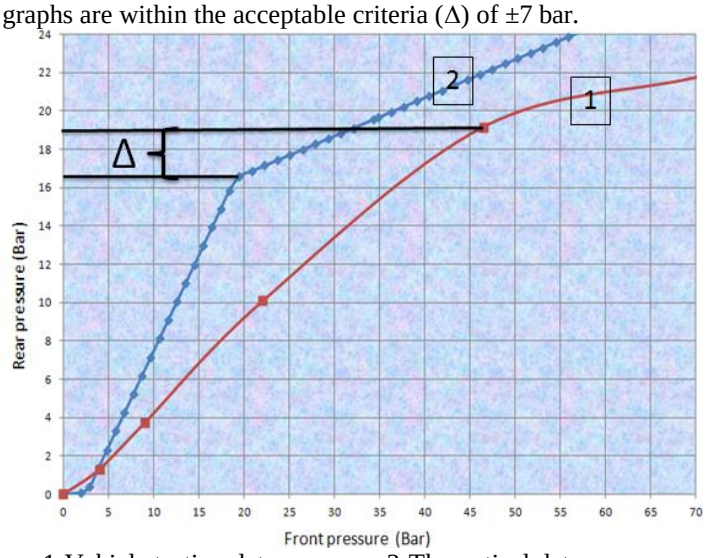
Fig-10, Pedal effort gauge

The vehicle was built to validate the following conditions

a. Unladen Front pressure V/s Rear pressure

A comparative graph of theoretical v/s vehicle testing data has been plotted as shown in fig 11.unladen front pressure is the pressure in the brake pipeline when the vehicle is driven only by driver. In this the cut-in pressure between both the graphs are within the acceptable criteria (Δ) of ±7 bar.

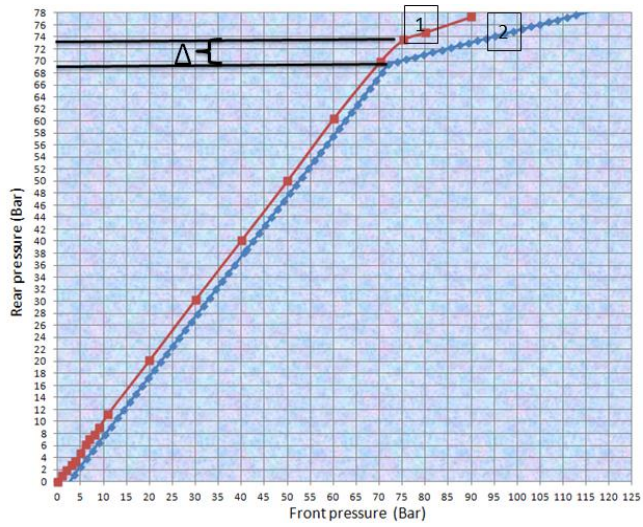


1-Vehicle testing data 2-Theoretical data

Fig 11 Unladen front pressure V/s Rear pressure

b. Laden Front pressure V/s Rear pressure

A comparative graph of theoretical data v/s vehicle testing data has been plotted as shown in Fig 12.The laden front pressure is the pressure in the brake pipeline when the vehicle is fully loaded. In this the cut-in pressure between both the graphs are within the acceptable criteria (Δ) of ±7 bar.



1-Vehicle testing data 2-Theoretical data

Fig 12 Laden front pressure V/s Rear pressure

c. Pedal travel(PT) V/s deceleration(g) Unladen

A comparative graph of theoretical data v/s vehicle testing data has been plotted as shown in Fig 13.The pedal travel is the travel of the brake pedal in order to stop the vehicle. The acceptance criteria is ±10%

% Variation = $(PT_{(Theory)}-PT_{(Actual\ vehicle)}) / (PT_{(Theory)}) * 100$

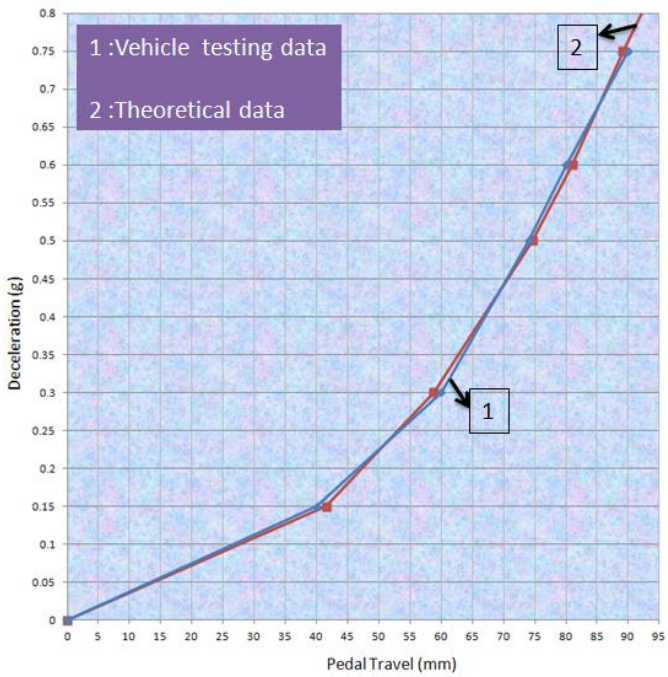


Fig 13 *Pedal travel V/s deceleration (g) Unladen*

d. Pedal travel V/s deceleration(g) laden

A comparative graph of theoretical data v/s vehicle testing data has been plotted as shown in Fig 14.The pedal travel is the travel of the brake pedal in order to stop the vehicle. The acceptance criterion is ±10%.

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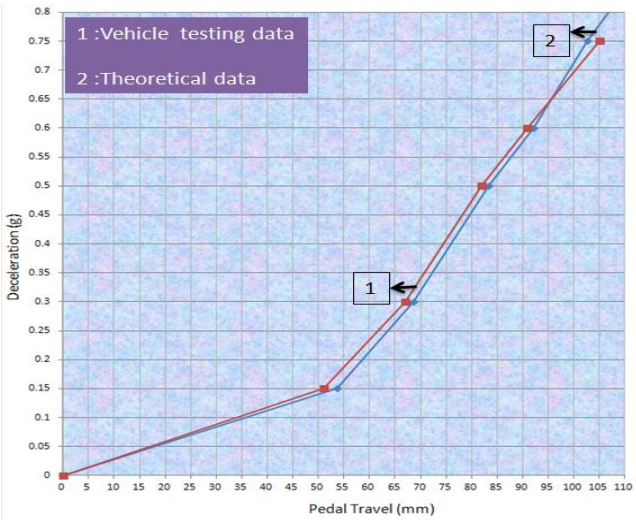

Fig 14 *Pedal travel V/s deceleration(g) laden*

e. Regulation validation

The vehicle was tested in Unladen condition against the specifications mentioned in Table-1, the below results which have evolved out of testing. The Table-2, 3, 4 and 5 are for the Unladen and Table-6, 7, 8 and 9 are for the laden

TABLE 2 (All wheel-Engine disconnected)

All wheel-Engine disconnected			
Spec-Speed 80% Vmax ±5% kmph, PE<50kg, MFDD>5.8 m/s², SD<0.1V+(V²/130)			
PE(Kg)	Speed	MFDD	Remarks
12.98	79.97	6.63	Pass
14.3	79.73	6.95	Pass
14.78	79.45	7.63	Pass

TABLE 3 (Secondary failure –Front only)

Secondary failure(Front only)			
Spec-Speed 80±5% kmph, PE<50kg, MFDD>2.9 m/s², SD<0.1V+(2V²/150)			
PE(Kg)	Speed	MFDD	Remarks
12.98	79.97	6.63	Pass
14.3	79.73	6.95	Pass
14.78	79.45	7.63	Pass

TABLE 4 (Secondary failure-Rear only)

Secondary failure(Rear only)			
Spec-Speed 80±5% kmph, PE<50kg, MFDD>2.9 m/s², SD<0.1V+(2V²/150)			
PE(Kg)	Speed	MFDD	Remarks
13.07	79.45	2.96	Pass
13.1	80	2.98	Pass
12.95	78.37	2.93	Pass

TABLE 5 (Transmission failure-servo failed)

Transmission failure(Servo failed)			
Spec-Speed 80±5% kmph, PE<50kg, MFDD>1.5 m/s², SD≤0.1V+(100/25)*(V²/150)			
PE(Kg)	Speed	MFDD	Remarks
39.45	79.45	3.27	Pass
41.29	80	3.28	Pass
39.1	79.73	3.08	Pass

TABLE 6 (All wheel-Engine disconnected)

All wheel-Engine disconnected			
Spec-Speed 80% Vmax ±5% kmph, PE<50kg, MFDD>5.8 m/s², SD<0.1V+(V²/130)			
PE(Kg)	Speed	MFDD	Remarks
17.91	79.18	6.18	Pass
16.5	79.45	6.25	Pass
14.81	80.27	6.1	Pass

TABLE 7(Secondary failure-Front only)

Secondary failure(Front only)			
Spec-Speed 80±5% kmph, PE<50kg, MFDD>2.9 m/s², SD<0.1V+(2V²/150)			
PE(Kg)	Speed	MFDD	Remarks
11.62	80	4.14	Pass
9.79	79.73	3.33	Pass
8.83	80	3.05	Pass
42.15	80.27	3.31	Pass

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TABLE 8(Secondary failure-Rear only)

Secondary failure(Rear only)			
Spec-Speed 80±5% kmph, PE<50kg, MFDD>2.9 m/s², SD<0.1V+(2V²/150)			
PE(Kg)	Speed	MFDD	Remarks
35.6	79.73	2.99	Pass
35.2	79.18	3.03	Pass
38.67	79.73	3.06	Pass

TABLE 9(Transmission failure-servo failed)

Transmission failure(Servo failed)			
Spec-Speed 80±5% kmph, PE<50kg, MFDD>1.7 m/s², SD≤0.1V+(100/25)*(V²/150)			
PE(Kg)	Speed	MFDD	Remarks
42.89	80	3.37	Pass
43.33	80	3.22	Pass
42.15	80.27	3.31	Pass

The vehicle has met all the critical tests mentioned in IS: 11853 part: 3 regulation

IV. Conclusion

Hydraulic brake system is one of the most important safety features on many road vehicles today; it has met the manufacturer and customer requirements in addition to legal vehicle Safety Standards. With these procedures we were able to analyse the following:

a. The vehicle will stop in any condition within the brake Pedal effort (PE) of 50 kg as shown in table 2 to 9

b. The stopping distances are within the specification as Per IS: 11852 part 3

The figures 9, 10, 11 and 12 shows that the theoretical and testing results are within the acceptance criteria. Calculations necessary to predict brake balance and key System sizing variables that contribute to performance was briefly discussed and the vehicle was fitted with these configurations.

This methodology can be used as a Design manual which intends to cover steps involved.

Acknowledgment

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References

[1] E.Goehring, P Wolsdorf and E.C.Von Glasner "Evaluation of the Brake Force Distribution and its Influence on the Braking performance of Light commercial vehicles" SAE 800523, Page no: 1 to 8

[2] C.H.Pace "Auto-Adjusting Leading/Trailing shoe car Drum Brakes" SAE 790394

[3] Malcolm O. King, Nui wang"New generation Foundation brake developments" SAE 871247

[4] Fred W. Cords, John B.Dale"Designing the Brake system-Step by Step" SAE 760637

[5] Rudolf Limpert "Brake design and safety" SAE publications group 1999

[6] Fred Puhn "Brake Handbook" published by HP books 1985

[7] Paul Oppenheimer "Brake Regulations in Europe" SAE 740313

[8] Automotive vehicles –Brakes and Braking systems part-3 ,Performance requirements and evaluation IS:11852 (Part 3)

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