Semnan University
Faculty of Mechanical Engineering

دانشکده مهندسی مکانیک

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درس طراحی سیستم های شاسی خودرو

Vehicle Chassis Systems Design

Chapter 3 – Braking Performance
Class Lecture

❑ **CONTENTS:**

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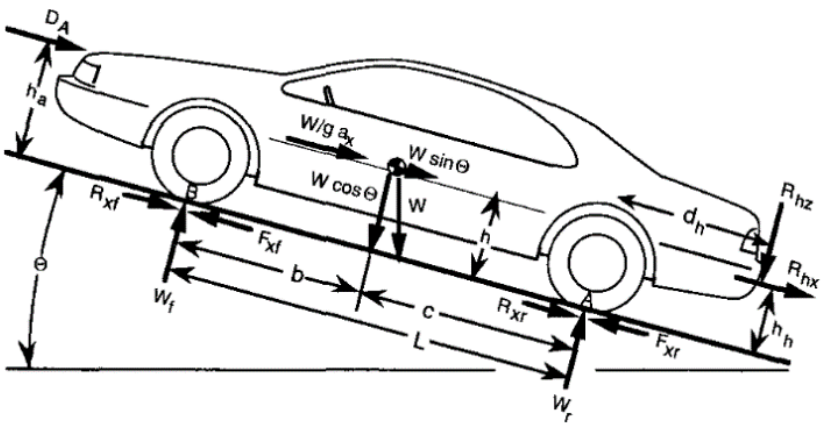
BASIC EQUATIONS

- The general equation for braking performance:
  - Newton's Second Law for the x-direction

$$M\, a_x = -\frac{W}{g} D_x = -F_{xf} - F_{xr} - D_A - W \sin\Theta$$



W = Vehicle weight
g = Gravitational acceleration
D_x = $-a_x$ = Linear deceleration
F_{xf} = Front axle braking force
F_{xr} = Rear axle braking force
D_A = Aerodynamic drag
Θ = Uphill grade

BASIC EQUATIONS

- Constant Deceleration:

$$D_x = \frac{F_{xt}}{M} = -\frac{dV}{dt}$$

F_{xt} = The total of all longitudinal deceleration forces on the vehicle (+)

V = Forward velocity

- This equation can be integrated:

$$\int_{V_o}^{V_f} dV = -\frac{F_{xt}}{M}\int_0^{t_s} dt \rightarrow V_o - V_f = \frac{F_{xt}}{M} t_s$$

BASIC EQUATIONS

- Relationship between velocity and distance:

$$\rightarrow \quad \frac{V_o^2 - V_f^2}{2} = \frac{F_{xt}}{M} X$$

X = Distance traveled during the deceleration

- Deceleration to full stop ($V_f = 0$):
  - X: Stopping Distance, SD $\rightarrow$ $SD = \dfrac{V_o^2}{2\dfrac{F_{xt}}{M}} = \dfrac{V_o^2}{2 D_x}$
  - t_s: Stopping Time $\rightarrow$ $t_s = \dfrac{V_o}{\dfrac{F_{xt}}{M}} = \dfrac{V_o}{D_x}$

BASIC EQUATIONS

- Deceleration with Wind Resistance:
  - The aerodynamic drag on a vehicle is dependent on vehicle drag factors and the square of the speed.

$$\sum F_x = F_b + C\,V^2$$

F_b = Total brake force of front and rear wheels

C = Aerodynamic drag factor

$$\int_0^{SD} dx = M \int_{V_0}^{0} \frac{V\,dV}{F_b + C\,V^2}$$

$$SD = \frac{M}{2C} \ln \left[\frac{F_b + C\,V_0^2}{F_b} \right]$$

BASIC EQUATIONS

- Energy/Power:
  - The energy and/or power absorbed by a brake system

$$\rightarrow \quad \text{Energy} = \frac{M}{2}\left(V_o^{\,2} - V_f^{\,2}\right)$$

$$\rightarrow \quad \text{Power} = \frac{M}{2}\,\frac{V_o^{\,2}}{t_s}$$

BRAKING FORCES

- Rolling Resistance:
  - Rolling resistance always opposes vehicle motion

$$\rightarrow \quad R_{xf} + R_{xr} = f_r (W_f + W_r) = f_r W$$

  - The parameter "f_r" is the rolling resistance coefficient.
  - The total force is independent of the distribution of loads on the axles (static or dynamic).
  - Rolling resistance forces are nominally equivalent to about 0.01 g deceleration.

BRAKING FORCES

- Aerodynamic Drag:
  - The drag from air resistance is proportional to the square of the speed.
  - At low speeds it is negligible.
  - At normal highway speeds, it may contribute a force equivalent to about 0.03 g

- Driveline Drag:
  - The engine, transmission, and final drive contribute both drag and inertia effects to the braking action.
  - Whether or not driveline drag aids in braking depends on the rate of deceleration.

BRAKING FORCES

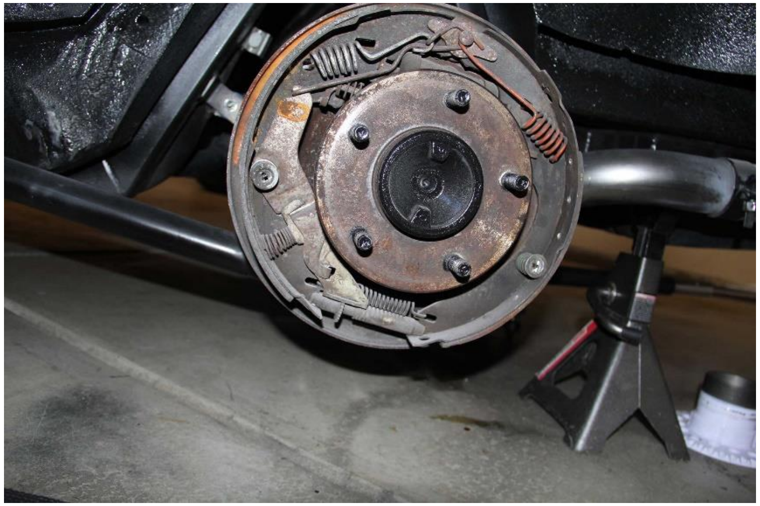
- Grade:
  - Road grade will contribute directly to the braking effort, either in a positive sense (uphill) or negative (downhill).

$$\rightarrow \quad R_g = W \sin \Theta \cong W \Theta$$

  - A grade of 4% (0.04) will be equivalent to a deceleration of ± 0.04 g

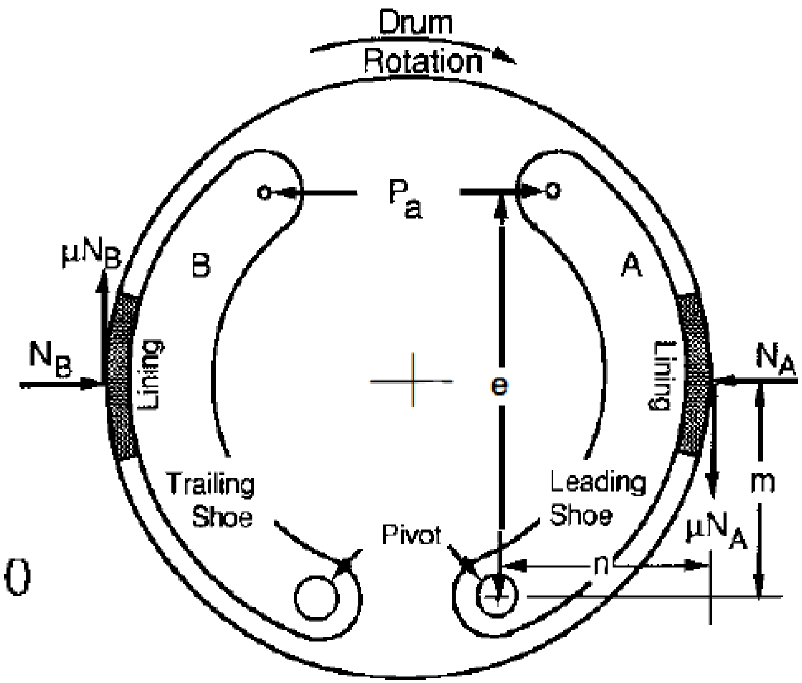
BRAKING FORCES

- BRAKES
  - Automotive brakes in common usage today are of two types:
    - ✓ Drum Brake
    - ✓ Disc Brake



BRAKING FORCES

- Brake Factor:
  - Mechanical advantage that can be utilized in drum brakes to minimize the actuation effort required.
  - Some of torques about P:

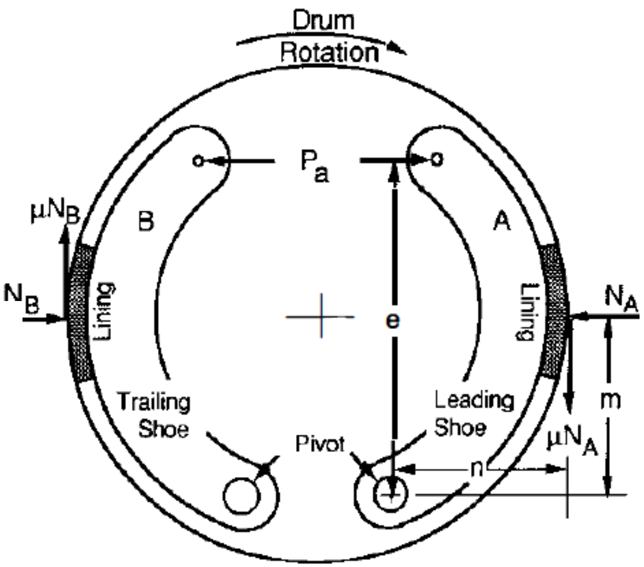


$$\Sigma M_p = e\,P_a + n\,\mu\,N_A - m\,N_A = 0$$

e = Perpendicular distance from actuation force to pivot
N_A = Normal force between lining A and drum
n = Perpendicular distance from lining friction force to pivot
m = Perpendicular distance from the normal force to the pivot

BRAKING FORCES

- The friction force developed

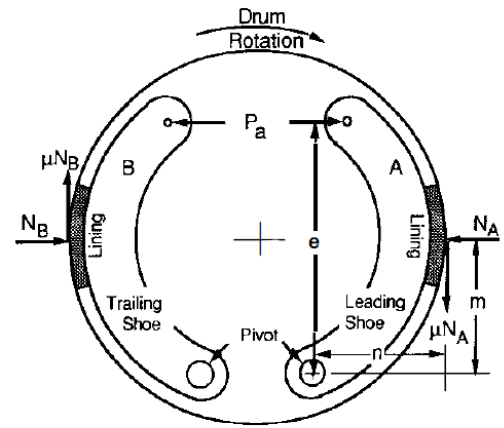


$$F_A = \mu N_A \quad \text{and} \quad F_B = \mu N_B$$

$$\frac{F_A}{P_a} = \frac{\mu e}{(m - \mu n)} \quad \text{and} \quad \frac{F_B}{P_a} = \frac{\mu e}{(m + \mu n)}$$

- The shoe on the right is a "leading" shoe.

BRAKING FORCES



- The friction force developed
  - The shoe on the right is a "leading" shoe.
  - The moment produced by the friction force on the shoe acts to rotate it against the drum and increase the friction force developed.
  - Shoe B is a trailing shoe configuration on which the friction force acts to reduce the application force.
  - By using two leading shoes, two trailing shoes, or one of each, different brake factors can be obtained.

BRAKING FORCES

- Brake torque performance can be measured in the laboratory using an inertial dynamometer.
  - It can he difficult to predict accurately over all conditions

$$\rightarrow T_b = f\,(P_a, \text{Velocity}, \text{Temperature})$$

$$\rightarrow F_b = \frac{(T_b - I_w \alpha_w)}{r}$$

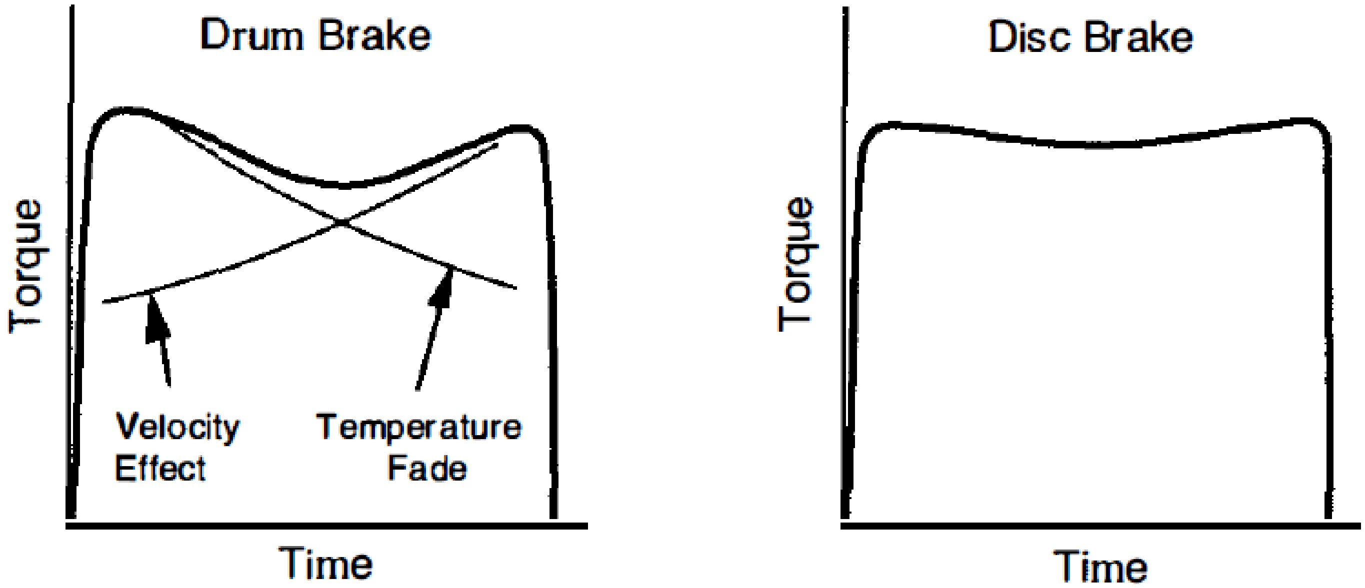
r = Rolling radius of the tires
I_w = Rotational inertia of wheels (and drive components)
α_w = Rotational deceleration of wheels

  - Neglecting the wheels:

$$\rightarrow F_b = \frac{T_b}{r}$$

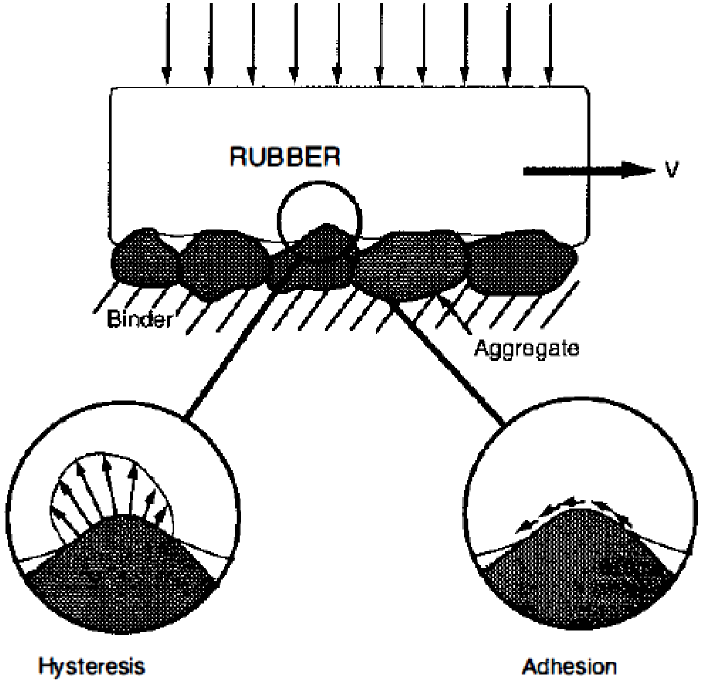
BRAKING FORCES

- Brake torque performance



TIRE-ROAD FRICTION

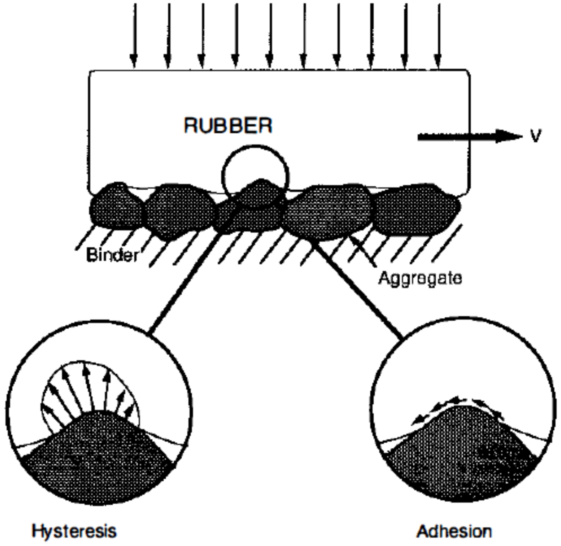
- The brake force limit: frictional coupling between the tire and road
  - There are two primary mechanisms
    - ✓ Surface adhesion (intermolecular bonds between the rubber and the road surface)
    - ✓ Hysteresis (energy loss in the rubber as it deforms when sliding)



TIRE-ROAD FRICTION

- The adhesion component is the larger of the two mechanisms on dry roads, but is reduced substantially when the road surface is contaminated with water.

- Bulk (or hysteretic) friction is not so affected by water on the road surface, thus better wet traction is achieved with tires that have high-hysteresis rubber in the tread.

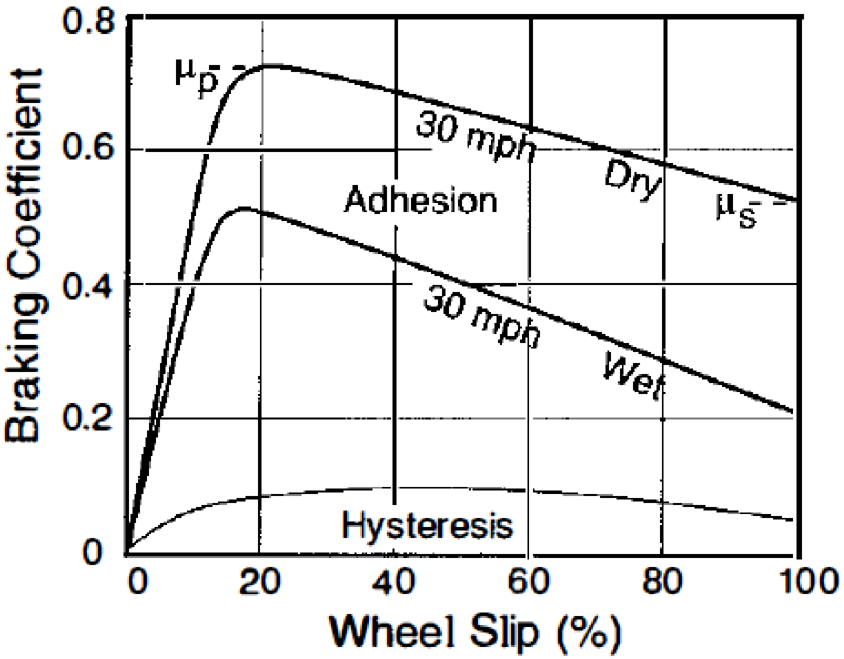


TIRE-ROAD FRICTION

- Both adhesive and hysteretic friction depend on some small amount of slip occurring at the tire-road interface.

$$\text{Slip} = \frac{V - \omega r}{V}$$

V = Vehicle forward velocity
ω = Tire rotational speed (radians/sec)



TIRE-ROAD FRICTION

- Other Parameters:
  - Velocity
    - ✓ On dry roads, both peak and slide friction decrease with velocity.
    - ✓ Under wet conditions, even greater speed sensitivity prevails because of the difficulty of displacing water
  - Inflation Pressure
    - ✓ On dry roads, peak and slide coefficients are only mildly affected by inflation pressure.
    - ✓ On wet surfaces, inflation pressure increases are known to significantly improve both coefficients
  - Vertical Load
    - ✓ Increasing vertical load is known to categorically reduce normalized traction levels (F_X/F_Z) under both wet and dry conditions.

FEDERAL REQUIREMENTS FOR BRAKING PERFORMANCE

- Automotive Safety:
  - Federal Motor Vehicle Safety Standard (FMVSS)
  - FMVSS 105
    - ✓ Establishing braking performance requirements for vehicles with hydraulic brake systems
  - FMVSS 121
    - ✓ Establishing braking performance requirements for vehicles with air brake systems

BRAKE PROPORTIONING

- Lockup reduces the brake force on an axle, and results in some loss of ability to control the vehicle.
- Preferred design is to bring both axles up to the lockup point simultaneously.
- For :

$$W_f = \frac{c}{L} W + \frac{h}{L} \frac{W}{g} D_x = W_{fs} + W_d$$

$$W_r = \frac{b}{L} W - \frac{h}{L} \frac{W}{g} D_x = W_{rs} - W_d$$

W_{fs} = Front axle static load

W_{rs} = Rear axle static load

$W_d = (h/L)\ (W/g)\ D_x$ = Dynamic load transfer

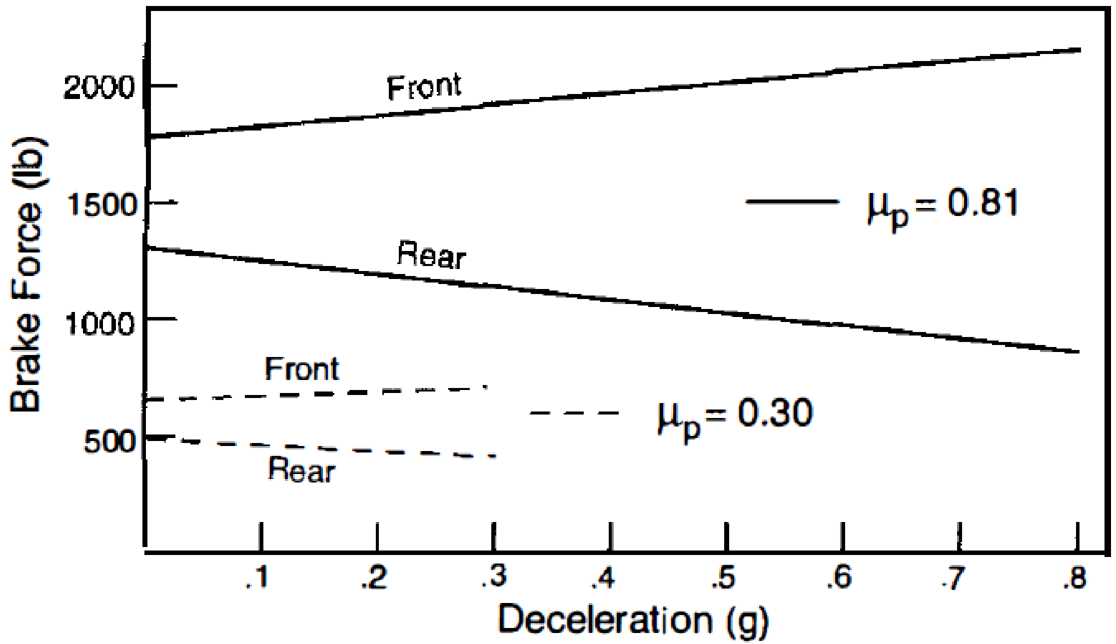
BRAKE PROPORTIONING

- The maximum brake force on each axle:

$$F_{xmf} = \mu_p W_f = \mu_p \left(W_{fs} + \frac{h}{L}\frac{W}{g} D_x\right)$$

$$F_{xmr} = \mu_p W_r = \mu_p \left(W_{rs} - \frac{h}{L}\frac{W}{g} D_x\right)$$

μ_p = Peak coefficient of friction



BRAKE PROPORTIONING

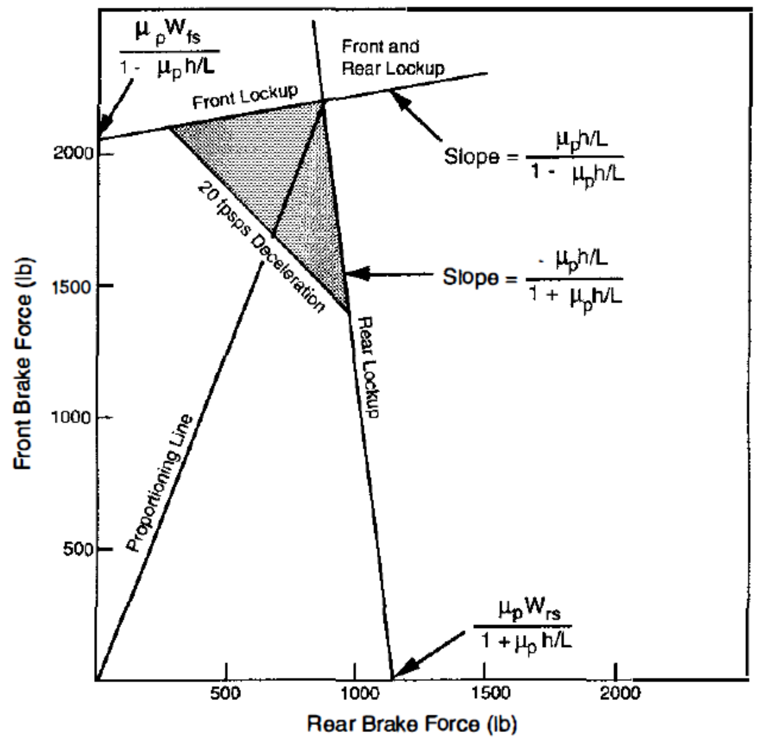
- Also the deceleration is a function of the total braking force imposed on the vehicle

$$D_x = \frac{(F_{xmf} + F_{xr})}{M} \qquad F_{xmf} = \frac{\mu_p \left(W_{fs} + \frac{h}{L} F_{xr} \right)}{1 - \mu_p \frac{h}{L}}$$

$$D_x = \frac{(F_{xmr} + F_{xf})}{M} \qquad F_{xmr} = \frac{\mu_p \left(W_{rs} - \frac{h}{L} F_{xf} \right)}{1 + \mu_p \frac{h}{L}}$$

BRAKE PROPORTIONING

- "Brake proportioning“
  - Relationship between front and rear brake forces determined by the pressure applied to each brake and the gain of each



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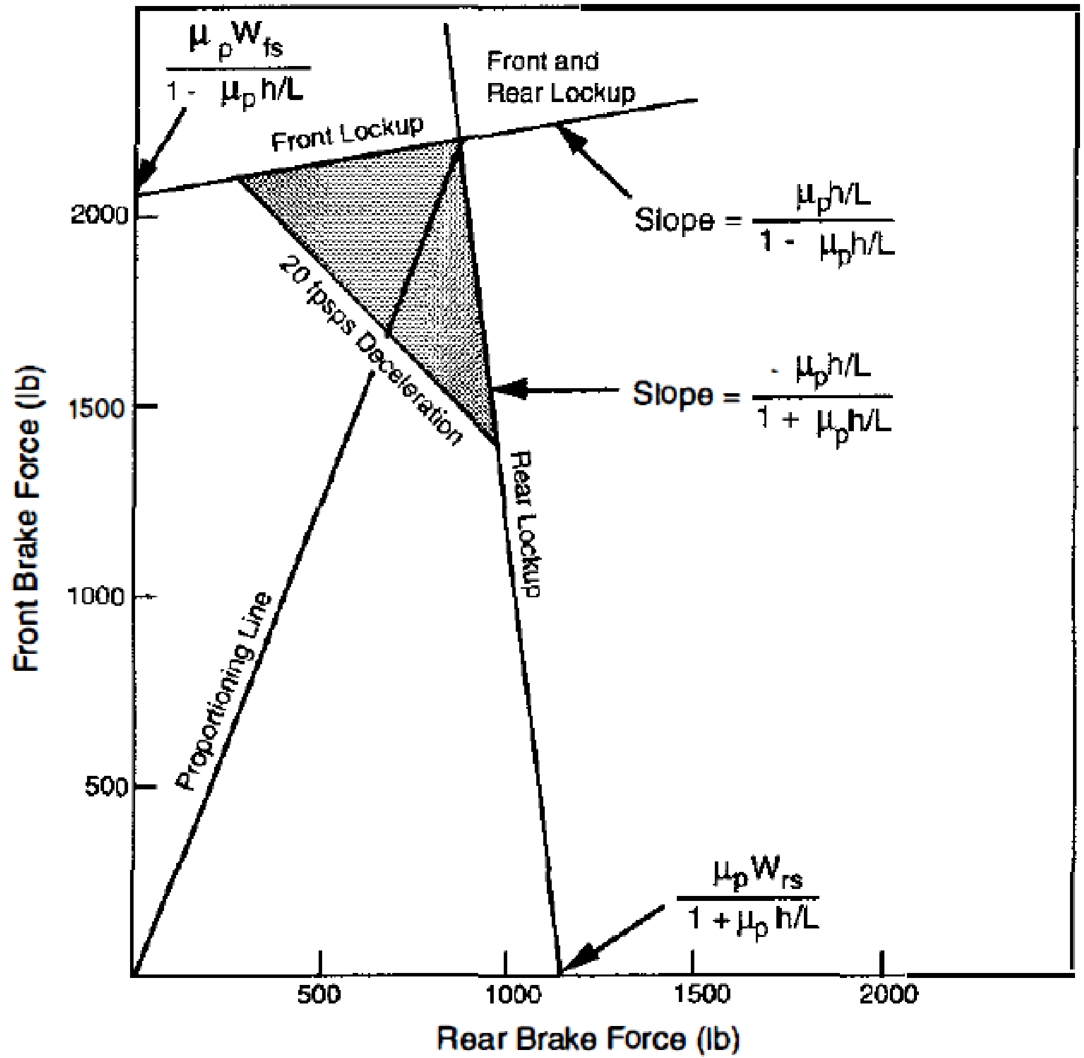
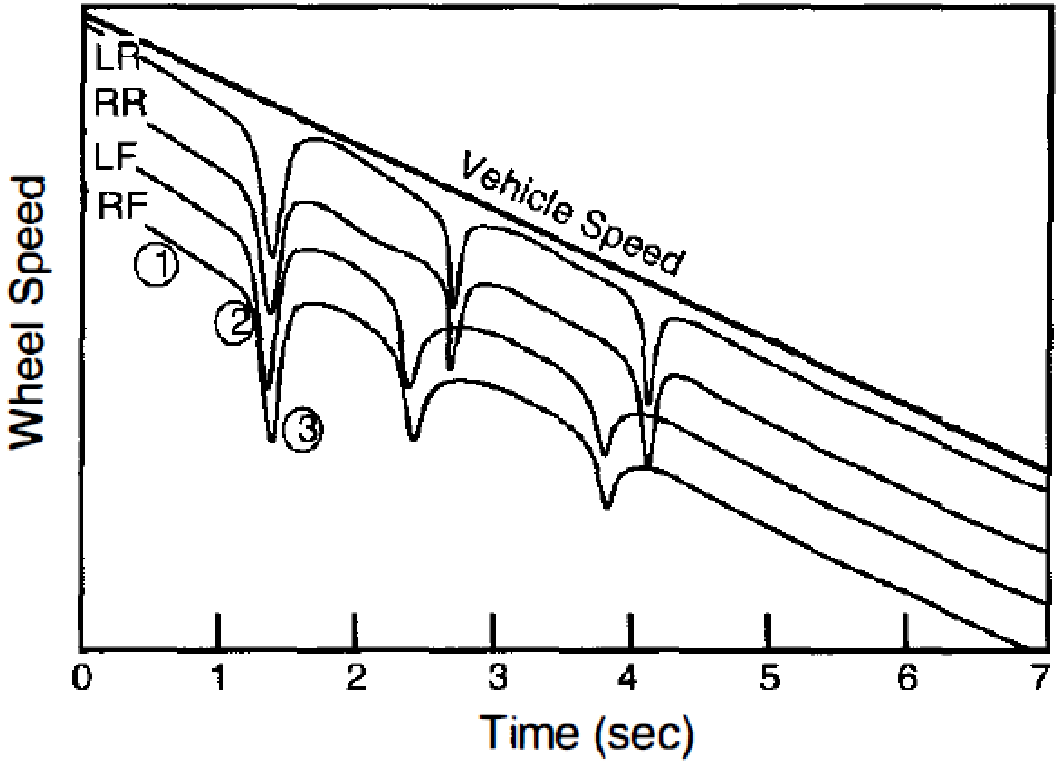
BRAKE PROPORTIONING

- "Brake proportioning“



ANTI-LOCK BRAKE SYSTEMS

- Anti-lock systems (ABS):
  - Sense when wheel lockup occurs, release the brakes momentarily on locked wheels, and reapply them when the wheel spins up again.



BRAKING EFFICIENCY

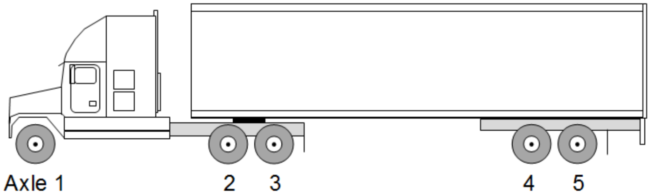
- Braking efficiency, η_b :
  - Ratio of actual deceleration achieved to the "best" performance possible on the given road surface
  - The best performance any vehicle can achieve is a braking deceleration (in g's) equivalent to coefficient of friction between the tires and the road surface

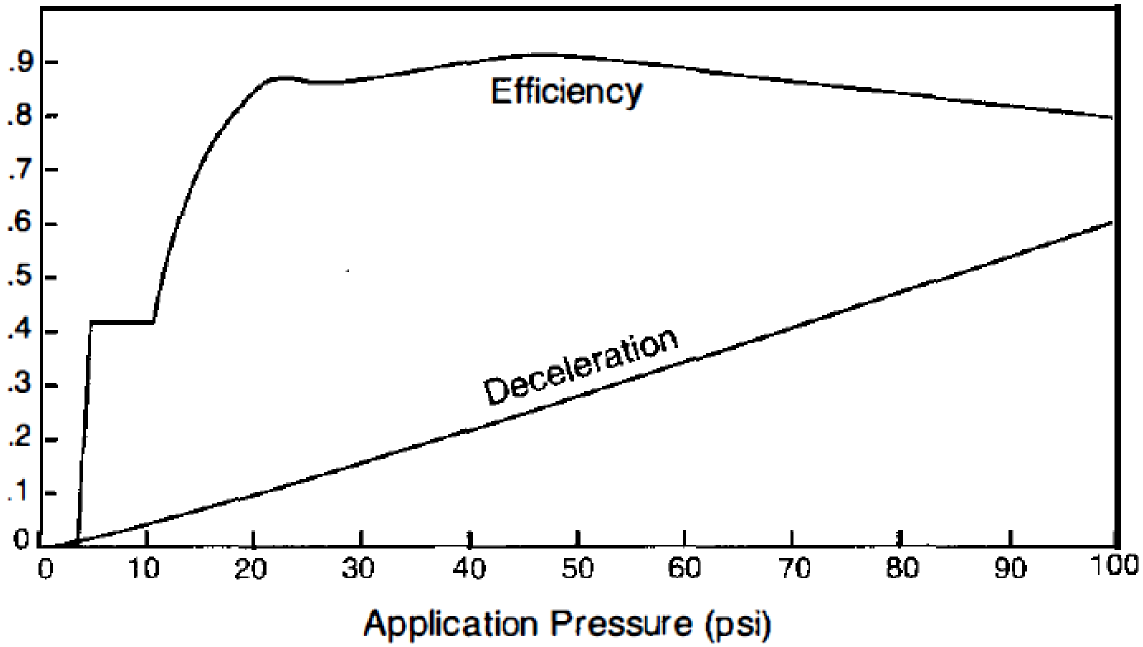
$$\eta_b = \frac{D_{act}}{\mu_p}$$

  - Braking efficiency is a useful method for evaluating the performance of brake systems, especially on heavy trucks where multiple axles are involved.

BRAKING EFFICIENCY

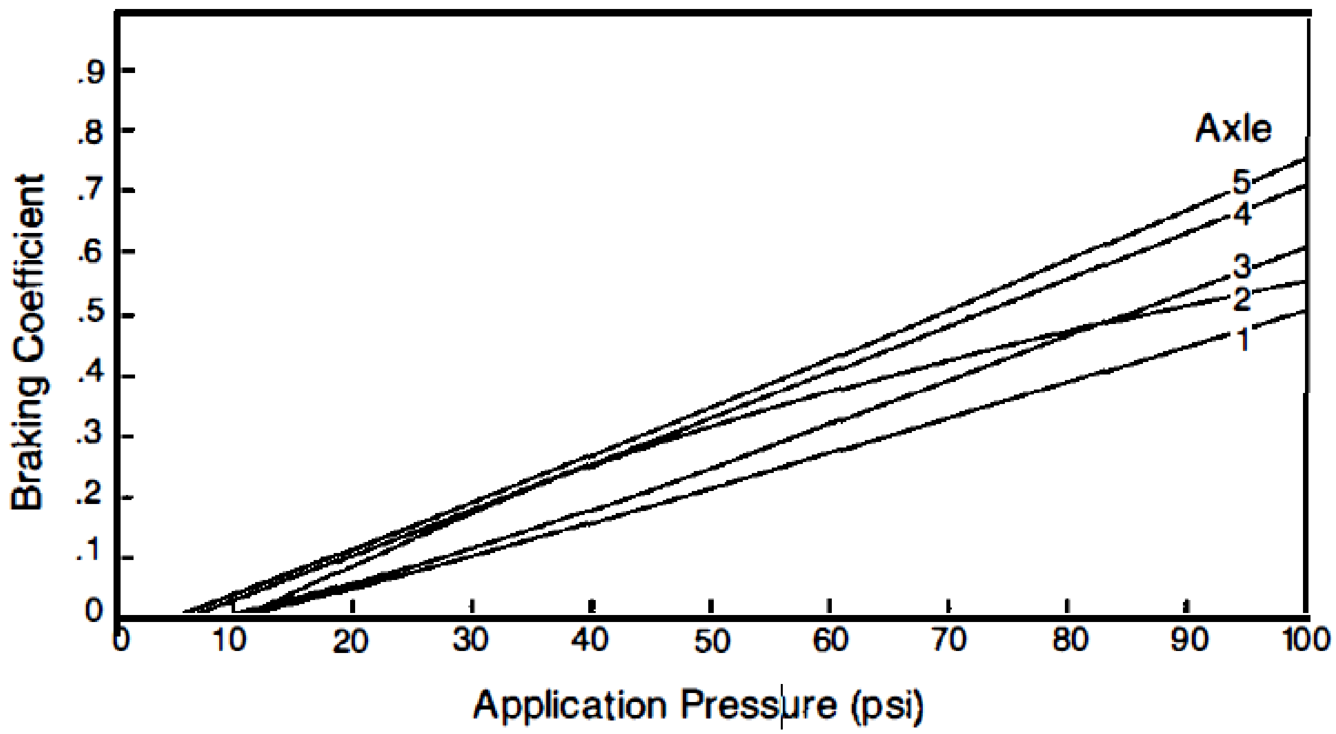
- Braking efficiency calculated for a five-axle tractor semitrailer:





BRAKING EFFICIENCY

- Contributions to braking from individual axles:



PEDAL FORCE GAIN

- Ergonomics:
  - The ease with which the driving public can optimally use the braking capabilities