Pavement Materials & Design

2. Introduction to Traffic Loading

Dr. Hamza Alkuime

1

Definition

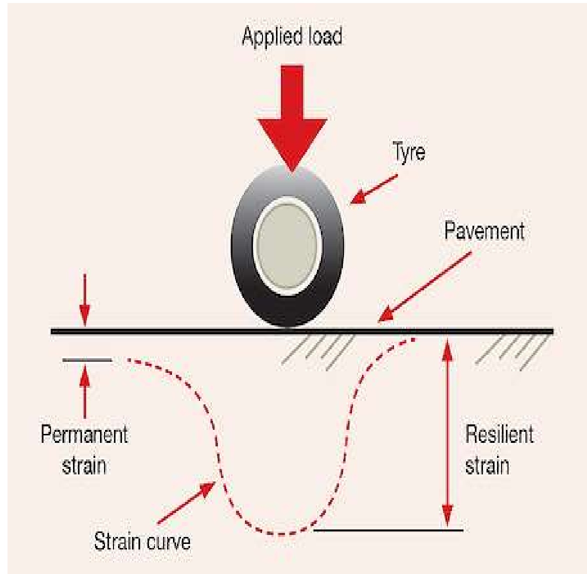
4

4

Introduction to Traffic Loads

Definition

- Traffic loads refer to the forces applied to pavement by vehicles in motion.



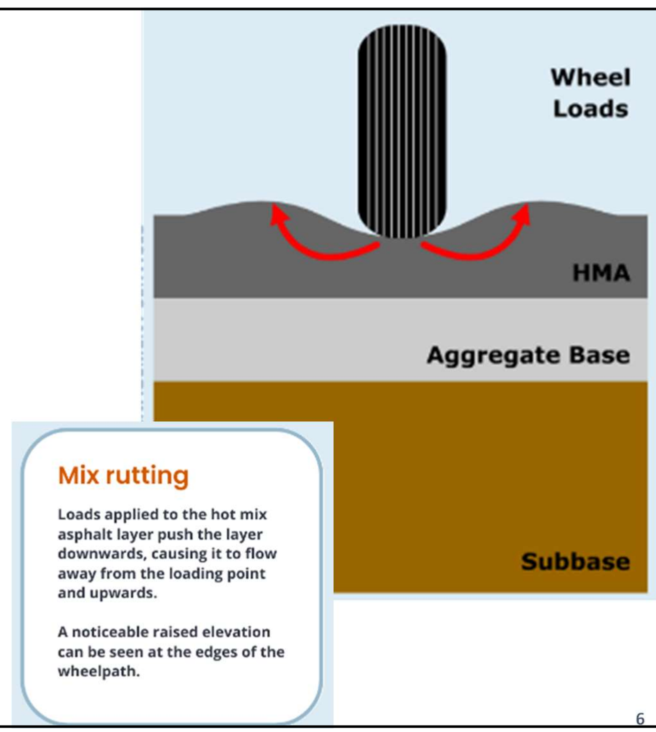
5

5

Traffic Loads

Impact

- Pavement deterioration is caused by the interacting damaging effects of traffic and the environment.
- Traffic loads, primarily those from heavy trucks, cause stresses/strains in pavement structures, whose effects accumulate over time, resulting in pavement deterioration, Such as rutting



6

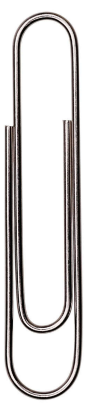
6

Rutting

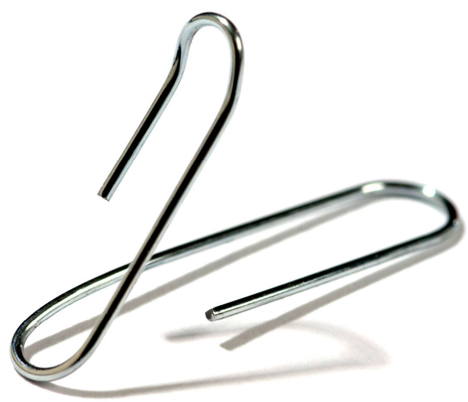
7

7

Permanent deformation !!



Before loading



After X Repetitions of loading

8

8

Traffic Loads

Quantification criteria

9

9

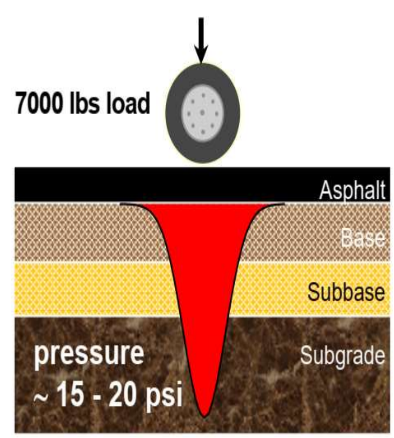
Traffic Loads

Quantification criteria

Pavement Damage depends on weight distribution

Truck traffic loads and their impact on pavements are Quantify using :

1. Vehicle/axle speed
2. Number of truck axles
3. Configuration of these axles
4. Their load magnitude
5. Tire inflation pressure



10

Vehicle/axle speed

Static loading

- The two basic types of loads are static and dynamic
- **Static loading**
  - *implies a sustained loading of the structure over a period of time.*
  - *Generally, static loads are slowly applied such that no shock or vibration is generated in the structure.*
  - *Once applied, the static load may remain in place or be removed slowly.*
  - *Loads that remain in place for an extended period of time are called sustained (dead) loads.*

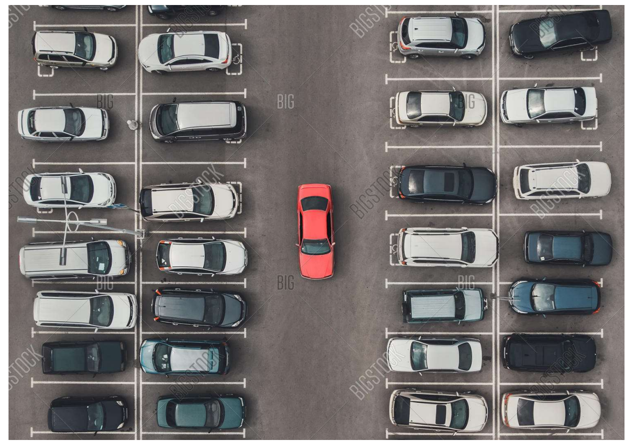
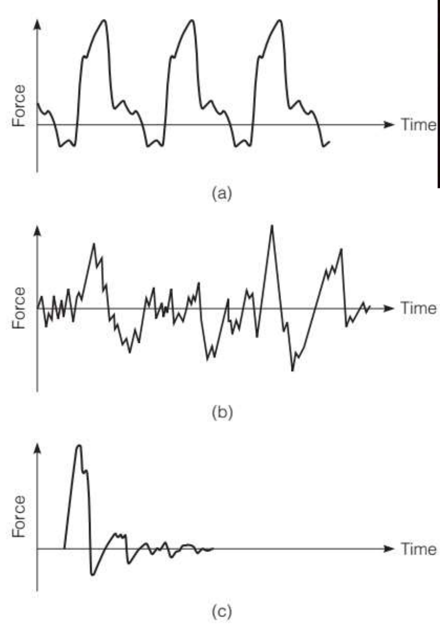


Image source: https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section-5.2.1

Vehicle/axle speed

Dynamic loads

- Dynamic loads
  - *implies Loads that **generate** a shock or vibration `*
- Dynamic loads can be classified as
  - ***Periodic :*** *such as a harmonic or sinusoidal load repeats itself with time*
  - ***Random*** *: the load pattern never repeats, such as that produced by earthquakes*
  - ***Transient load*** *: is an impulse load that is applied over a short time interval, after which the vibrations decay until the system returns to a rest condition*



Types of dynamic loads: (a) periodic, (b) random, and (c) transient

Image source: https://www.open.edu/openlearn/science-maths-technology/science/chemistry/introduction-polymers/content-section-5.2.1

Tire inflation pressure

14

14

Axle and Tire

Configuration

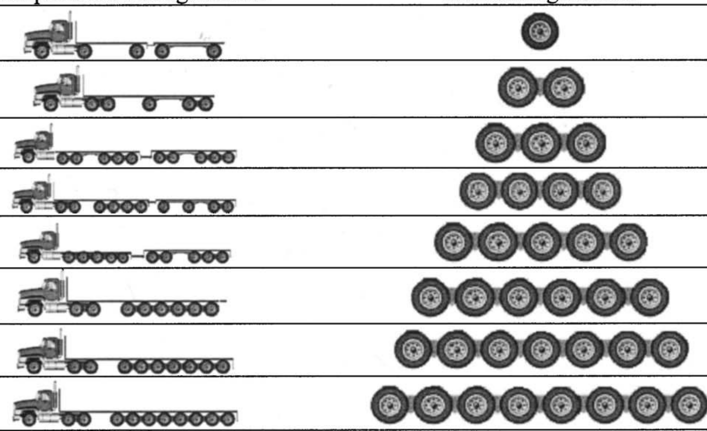
15

15

Axle Configuration

- Axle configuration is defined by the number of
  - Axles sharing the same suspension system
  - the number of tires in each axle

Axle/truck	Example truck configurations	Axle configurations
Single		
Tandem		
Tridem		
Quad		
Five		
Six		
Seven		
Eight		



Single Axle Configuration

Tandem Axle Configuration

18

Tridem Axle Configuration

19

Quad Axle Configuration

20

Tire Configuration

Single Tire

- Typical Load per Tire: 20 - 50 kN

21

Tire Configuration

Dual Tire

- Typical Load per Tire: 40 - 100 kN

22

Tire Configuration

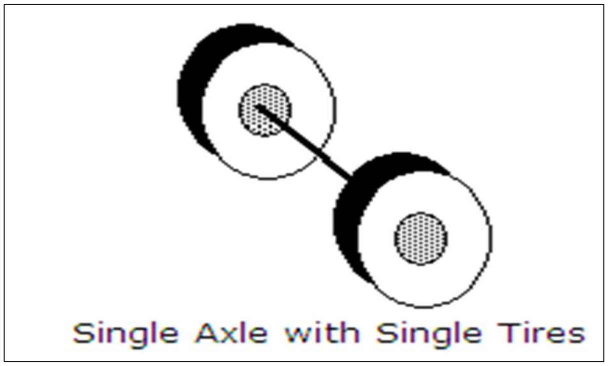
Wide Base Tire

- Description: Extra wide tire designed to replace duals for weight savings.
- Typical Load per Tire: 60 - 100 kN

23

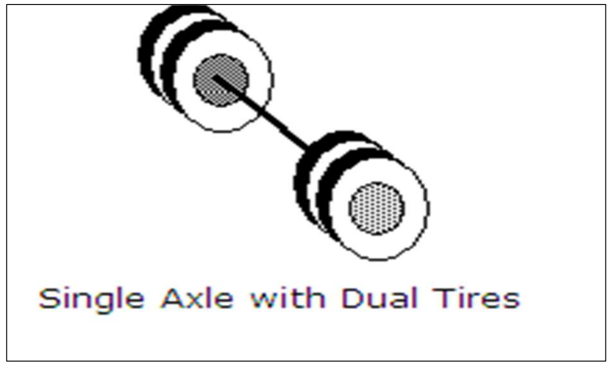
Traffic Load

Typical Axle and Tire Configuration



Single Axle Single Tires

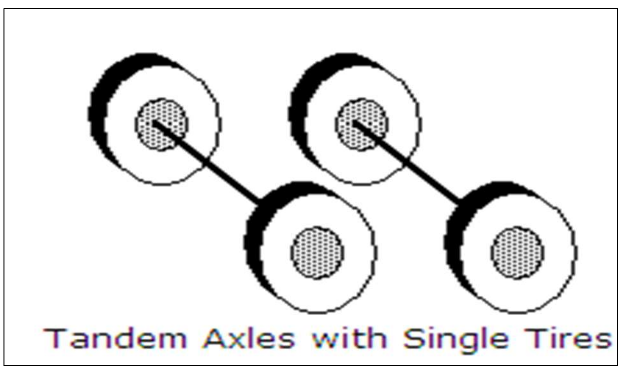
Single Axle Dual Tires



24

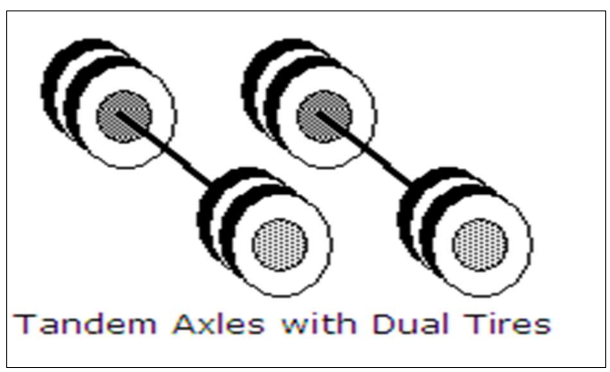
Traffic Load

Typical Axle and Tire Configuration



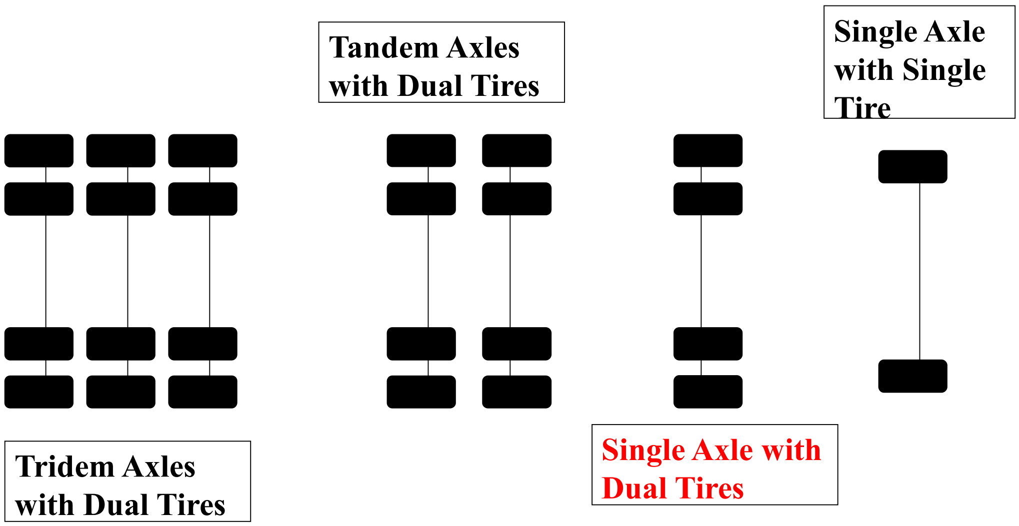
Tandem Axle Single Tires

Tandem Axle Dual Tires



25

Axle Configuration



26

What do you think?

27

What do you think?

Axle Tire Configuration

28

Measurement of Traffic Loads Technology

Weigh-in-motion (WIM) systems

29

29

Weigh-in-motion (WIM) sys

■ Definition

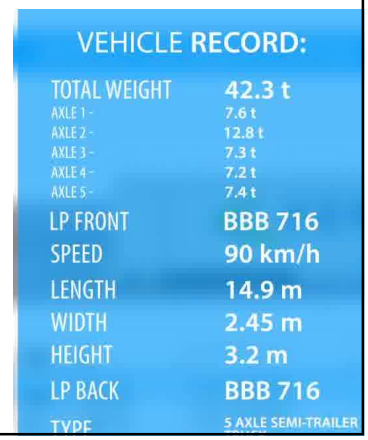
➢ *Weigh-In-Motion (WIM) is a technology used to measure the weight of vehicles as they pass over a sensor at highway speeds, without requiring them to stop.*

■ Main Components:

*1.**Sensors**: Detect and measure the load of vehicles.*

*2.**Data Processing Unit**: Analyzes the collected data.*

*3.**Communication System**: Transmits the data to central servers*



30

Weigh-in-motion (WIM) systems

https://www.youtube.com/watch?v=hQSlOqDGecg

31

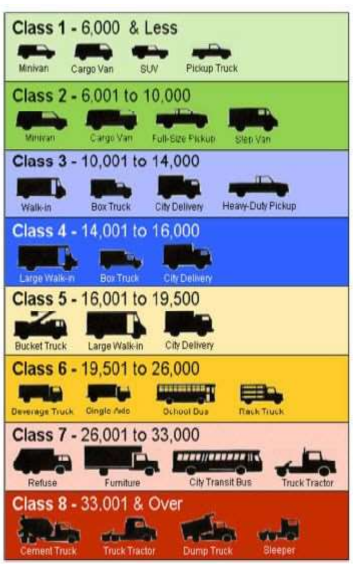
31

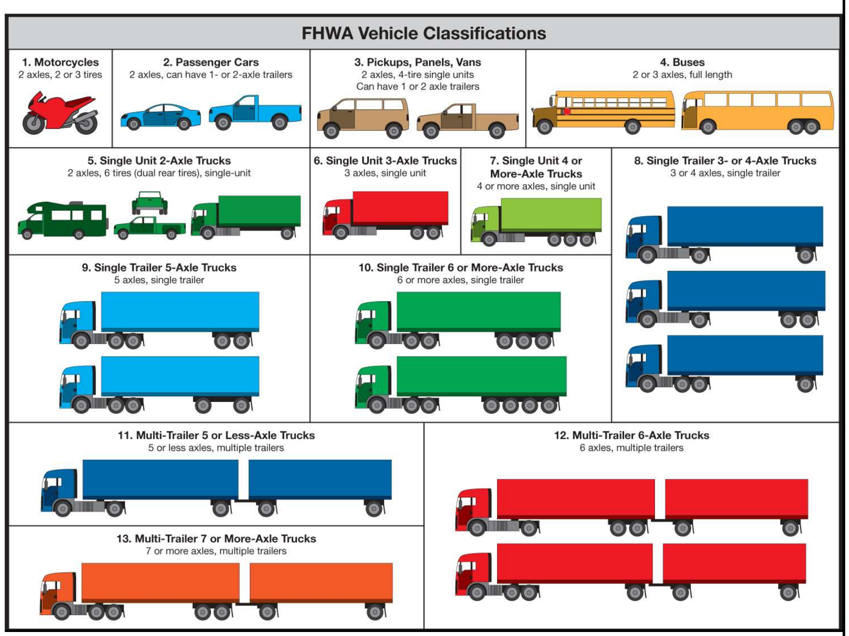
Weigh-in-motion (WIM) systems

https://www.youtube.c

32

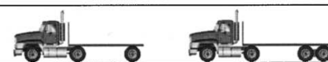
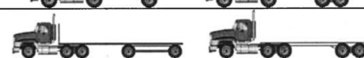
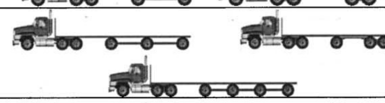
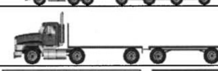
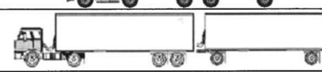
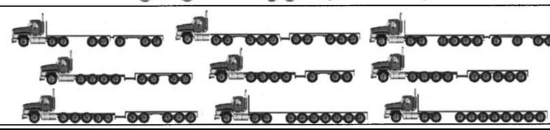
FHWA vehicle classification





33

FHWA vehicle Weigh class

FHWA Class Type	Class Definition	Axle Group	Example truck configurations
5	Two-axle, six-tire, single-unit trucks	1	
6	Three-axle single-unit trucks	1 and 2	
7	Four or more axle single-unit trucks	1, 3 and 4	
8	Four or fewer axle single-trailer trucks	1and 2	
9	Five-axle single-trailer trucks	1and 2	
10	Six or more axle single-trailer trucks	1, 2, 7 and 8	
11	Five or fewer axle multi-trailer trucks	1	
12	Six-axle multi-trailer trucks	1 and 2	
13	Seven or more axle multi-trailer trucks	1, 2, 3, 4, 5, 7and 8	

34

Example of report on traffic classification

Summary report 09/28/2007 11:11:38

Site name : ST000017
Date/Time : From 03/01/2007 00:00 To 06/01/2007 00:00
Period :
Report : Gross weight distribution by classification
Unit : Kip
Class : 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13
Directions : Toward capital Away from capital
Lanes : 0, 2, 4, 6 7, 5, 3, 1

			Classification							
Weight	1	2	3	4	5	6	7	8	9	10
under 5	1165	157384	13162	0	0	0	0	0	0	0
5 to 10	20	35556	69962	0	0	0	0	0	0	0
10 to 15	1	24	1611	199	2318	8	0	2	3	0
15 to 20	0	0	53	430	1026	170	0	22	4	7
20 to 25	0	0	0	498	800	359	1	70	5	20
25 to 30	0	0	0	103	539	244	1	210	84	85
30 to 35	0	0	0	68	340	195	4	243	368	827
35 to 40	0	0	0	45	169	78	2	76	437	2205
40 to 45	0	0	0	20	31	70	0	11	240	666
45 to 50	0	0	0	16	7	73	1	11	110	111
50 to 55	0	0	0	4	0	86	7	4	68	18
55 to 60	0	0	0	2	1	87	9	6	63	31
60 to 65	0	0	0	0	1	30	5	5	38	45
65 to 70	0	0	0	0	0	16	11	4	37	83
70 to 75	0	0	0	1	0	0	23	1	71	84
75 to 80	0	0	0	0	0	0	14	0	116	107
80 to 85	0	0	0	0	0	0	4	0	101	207
85 to 90	0	0	0	1	0	0	0	0	49	519
90 to 95	0	0	0	0	0	0	0	1	15	932
95 to 100	0	0	0	0	0	0	0	0	2	1258
100 to 105	0	0	0	0	0	0	0	1	8	1869
105 to 110	0	0	0	0	0	0	0	0	2	1975
110 to 115	0	0	0	0	0	0	0	0	1	844
115 to 120	0	0	0	0	0	0	0	0	0	248
above 120	0	0	0	0	0	0	0	0	0	69
TOTAL	1186	192964	84788	1387	5232	1416	82	667	1822	12210
%	0.4	64	28.1	0.5	1.7	0.5	0	0.2	0.6	4

35

35

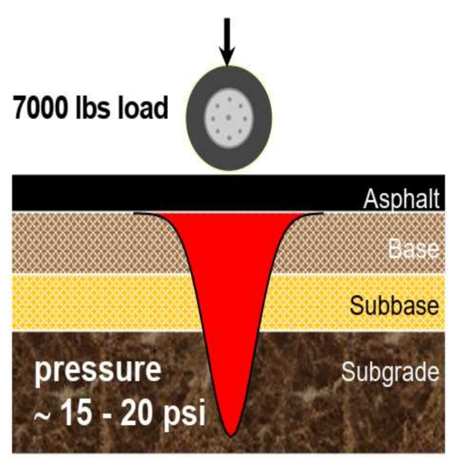
Vehicle, Axle and Tire

Load distribution

Vehicle, Axle and Tire weight

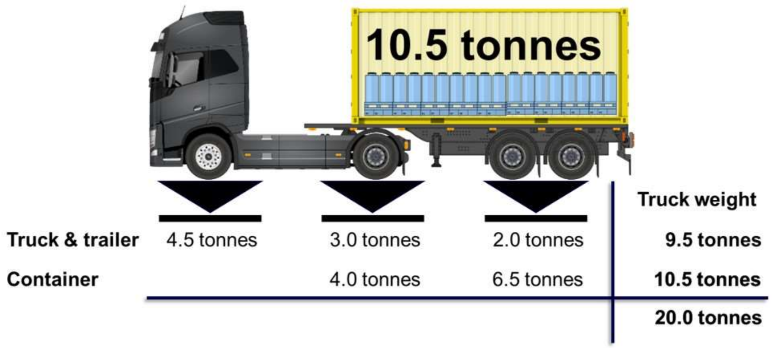
- The axle load distribution depends on the vehicle gross weight and spacing between axles.

				Truck weight
Truck & trailer	4.5 tonnes	3.0 tonnes	2.0 tonnes	9.5 tonnes
Container		4.0 tonnes	6.5 tonnes	10.5 tonnes
				20.0 tonnes



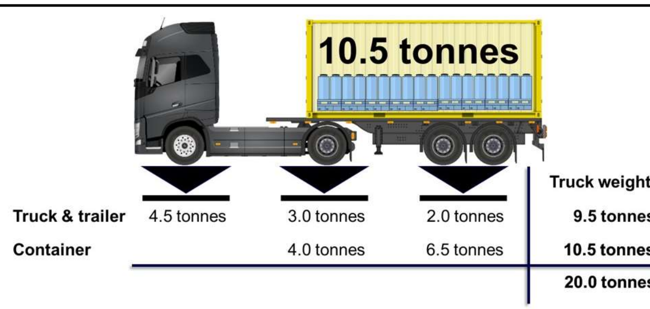
Axle Load distribution

- Tridem axle carries more load with an average weight of when compared with tandem and single axle configurations,
- Tandem axle carries more load than single axle.



Vehicle weight distribution.

Axle loads Vehicle weight



- **Axle Configuration:**
- **Front axle**: Single tire (1 tire total)
- **Second axle**: Single axle with double tires (2 tires total)
- **Tandem axles**: Dual tires (4 tires per axle, 8 tires total)

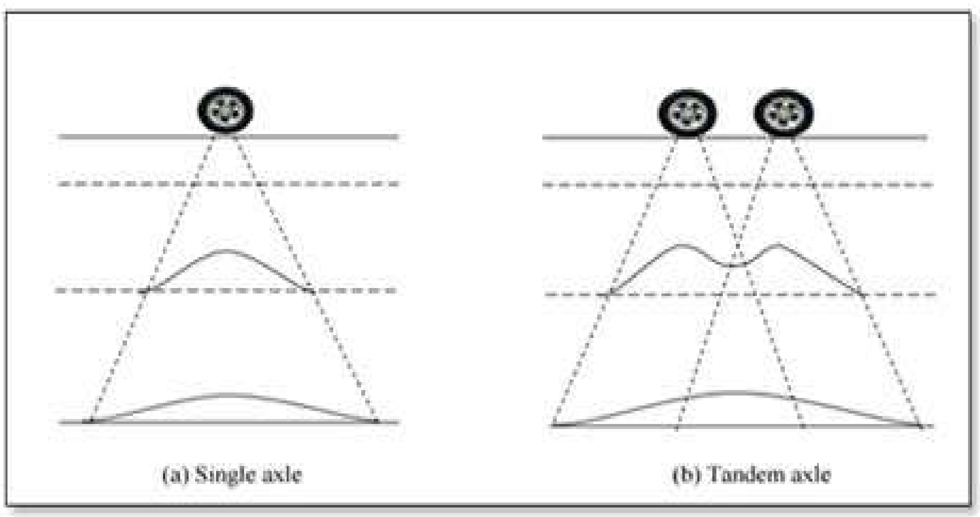
Axle Type	Axle Load (Tonnes)	Number of Tires	Load per Tire (Tones)
Front Axle (Single Tire)	4.5	1	4.5
Second Axle (Double Tires)	3.0	2	1.5
Tandem Axles (Dual Tires)	12.5	8	1.5625

Vertical stress Distribution

40

40

Vertical stress distribution

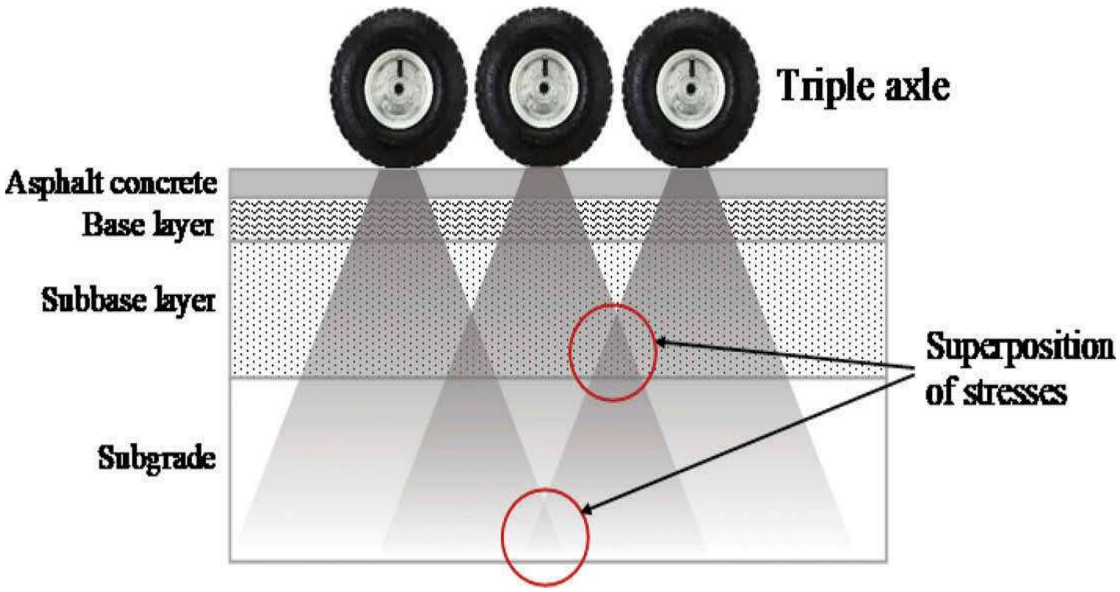


https://www.researchgate.net/publication/326057581_The_study_of_stresses_on_soil_from_roadways_using_plaxis_to_generate_potential_energy_with_piezoelectric

41

41

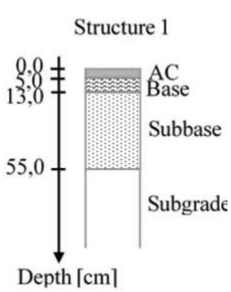
Vertical stress distribution



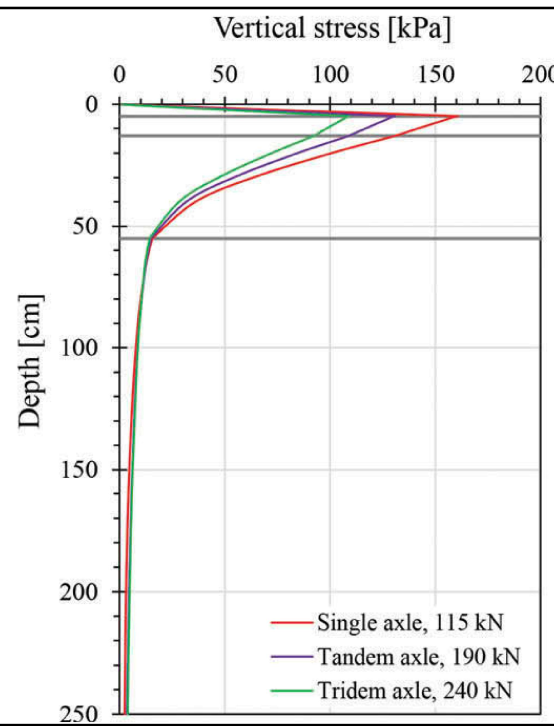
https://www.researchgate.net/publication/355650209_Impact_of_introducing_longer_and_heavier_vehicles_on_the_bearing_capacity_of_pavement_subgrades

42

Vertical stress distribution

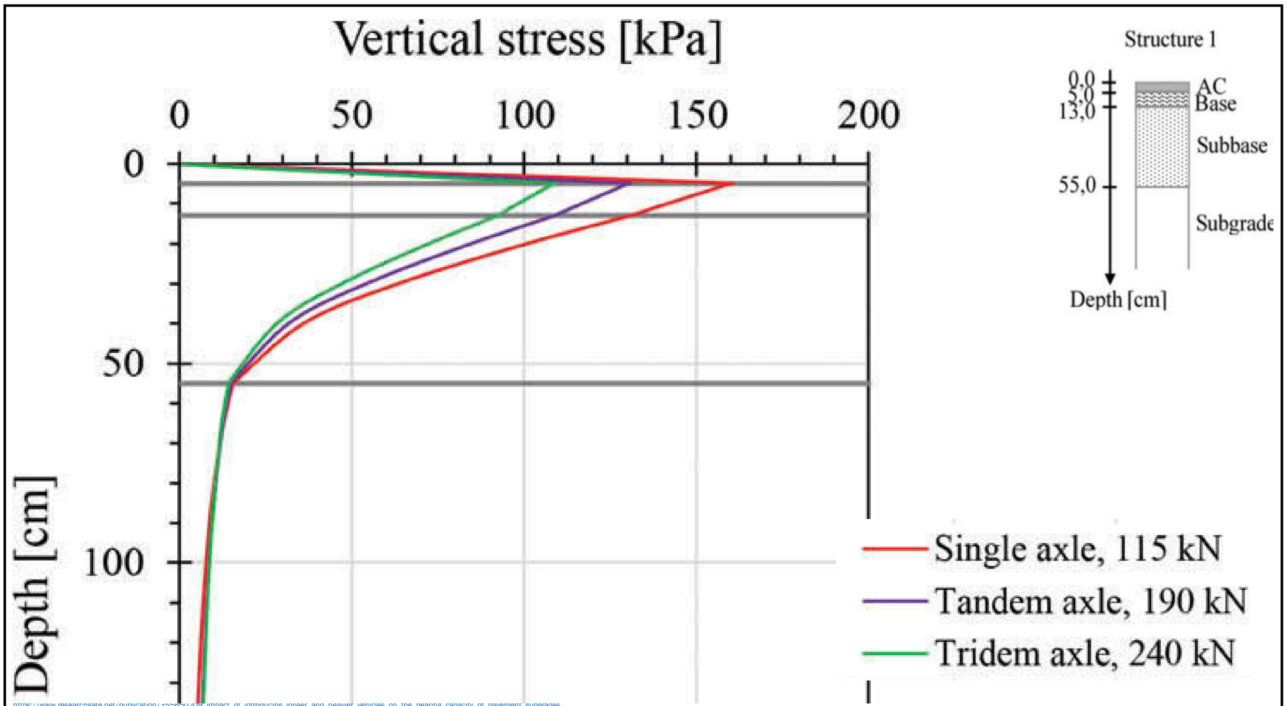


Load case	Axle load [kN]	Number of sub-axles	Tire pressure [kPa]	Distance between the wheels [cm]	Distance between the axles [m]
Single axle	115	1	800	35	-
Tandem axle	190	2	800	35	1.4
Triple axle	240	3	800	35	1.4



https://www.researchgate.net/publication/355650209_Impact_of_introducing_longer_and_heavier_vehicles_on_the_bearing_capacity_of_pavement_subgrades

43



44

44

Traffic Data for Pavement Design Input

45

45

- The collected traffic data must be **summarized** in a format that is suitable for direct input into the pavement design process, ensuring accurate traffic loading estimates for long-term pavement performance analysis.
- Available Approaches:

➢ *ESALs appraoch (AASHTO 1986/1993 Pavement Design Approach)*

➢ *Load spectra (NCHRP 1-37A Pavement Design Approach)*

46

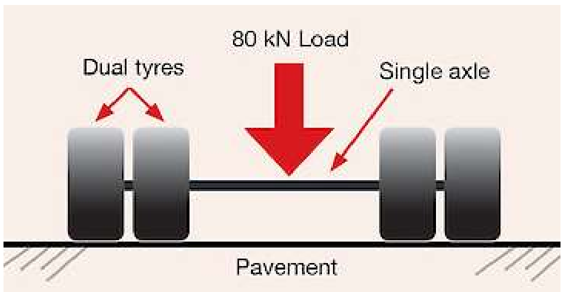
Equivalent Single Axle Load (ESAL)

47

Equivalent Single Axle Load (ESAL)

Idea

- Traffic with different axle loads is simplified by converting them into an equivalent number of standard axles.
  - *Typically, this standard is a single axle with dual tires that has a weight of 18,000 lb (80 KN)*



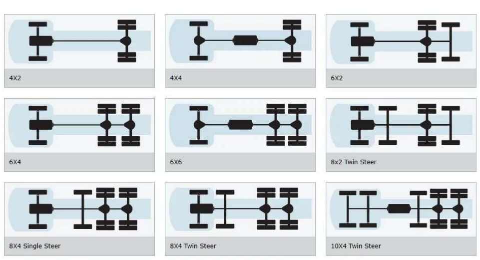
Each repetition of this Standard Axle Load (SAL) will cause a specific damage to the pavement

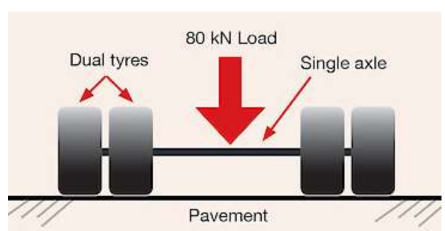
48

48

Equivalent Single Axle Loads (ESALs)

- Convert wheel loads of various **magnitudes** and **repetitions** ("mixed traffic") to an equivalent number of "standard" or "equivalent" loads **based on** the amount the damage they do to the pavement





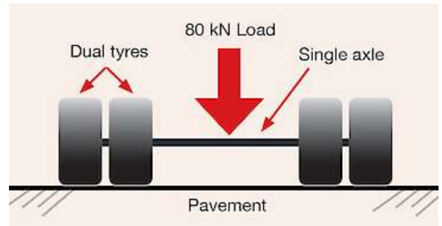
Damage from Mixed Traffic [Different axles and tires combination

= X × [Damage from SAL]

1 ESAL = Damage caused by one SAL

49

Equivalent Single Axle Loads (ESALs)



- Tandem axle (24,000 lb)

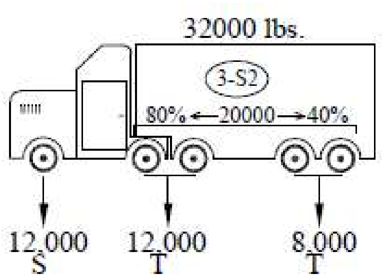
=0.23 × [Damage from SAL]

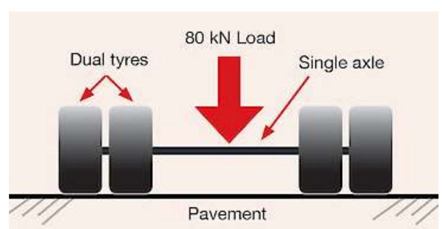
ESALs=0.23

https://www.penndot.pa.gov/ProjectAndPrograms/PostedBondedRoadway/Documents/ESAL-BASED%20COSTS.pdf

50

Equivalent Single Axle Loads (ESALs)





Damage from this vehicle [All axles\ tire combinations]

=X × [Damage from SAL]

$$ESAL = \left(\frac{12{,}000}{18{,}000}\right)^4 + \left(\frac{12{,}000}{33{,}200}\right)^4 + \left(\frac{8{,}000}{33{,}200}\right)^4$$

$$ESAL = 0.198+0.017+0.003$$

$$ESAL = 0.218/veh$$

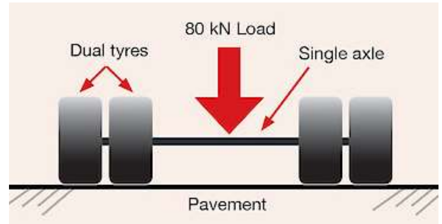
ESAL= 0.218\Veh

https://www.in.gov/indot/files/Multimodal_OverweightLoadsRule_12262013.pdf

ESALs for entire truck = sum of ESALs for each axle

51

Equivalent Single Axle Loads (ESALs)



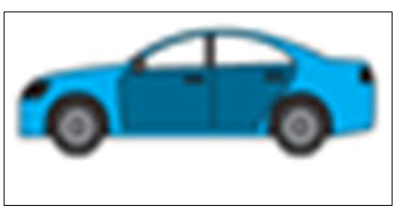
Damage from this vehicle [All axles\ tire combinations]

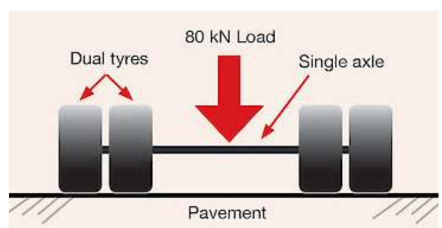
=1.179 × [Damage from SAL]

<u>*ESALs=1.179*</u>

52

Equivalent Single Axle Loads (ESALs)



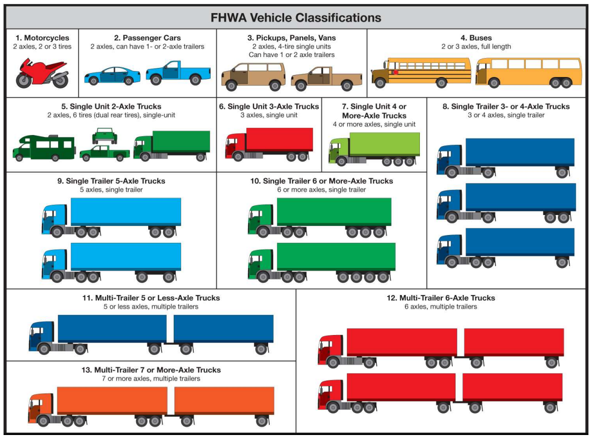


Damage from this vehicle [All axles\ tire combinations]

=0.004 × [Damage from SAL]

<u>*ESAL= 0.004 \Veh*</u>

53



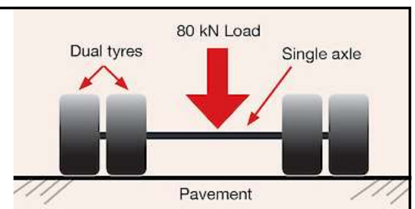
https://www.penndot.pa.gov/ProjectAndPrograms/PostedBondedRoadway/Documents/ESAL-BASED%20COSTS.pdf

TABLE 7.1 Average Initial Truck Factors (ESALs/Truck) by Vehicle Class

VEHICLE CLASSIFICATION			ESAL's	
Line # in DARWin® 3.01	FHWA Class	Corresponding Department Description	Rigid	Flexible
1	1	Motorcycle	0*	0*
2	2	Passenger Cars	0*	0*
3	3	SUV/Pick-up	0*	0*
4	4	BUS Factor	0.24	0.24
5	5	2-axle, 6-tire	0.24	0.24
6	6	3-axle, single unit	1.15	0.82
7	7	4-axle, single unit	7.00	4.50
8	8	3-axle, single trailer	0.60	0.44
9	9	3-axle, multiple axle trailer	1.59	1.00
10	10	6-axle, single trailer	1.42	0.75
11	11	5-axle, multiple trailer	2.40	2.33
12	12	6-axle, multiple trailer	1.42	1.28
13	13	7-axle, multiple trailer	1.42	1.28

*Note: Because motorcycles, passenger cars, and SUV/Pick-up trucks do not significantly contribute to the 18-kip ESALs they are considered negligible and an ESAL/truck factor of 0 is assigned. However, the percent of the ADT in this class must be input into DARWin because the Total Percentage must equal 100.00%. If there are any vehicles that are not large enough to be classified in any of the above classes, they should be grouped with the motorcycle percentage.

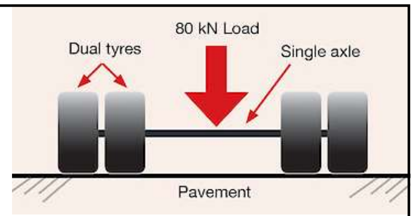
54



Class 7 (Triaxle) = 4.50 ESALs

https://www.penndot.pa.gov/ProjectAndPrograms/PostedBondedRoadway/Documents/ESAL-BASED%20COSTS.pdf

55



Class 9 (Tractor Trailer) = 1.00 ESAL

https://www.penndot.pa.gov/ProjectAndPrograms/PostedBondedRoadway/Documents/ESAL-BASED%20COSTS.pdf

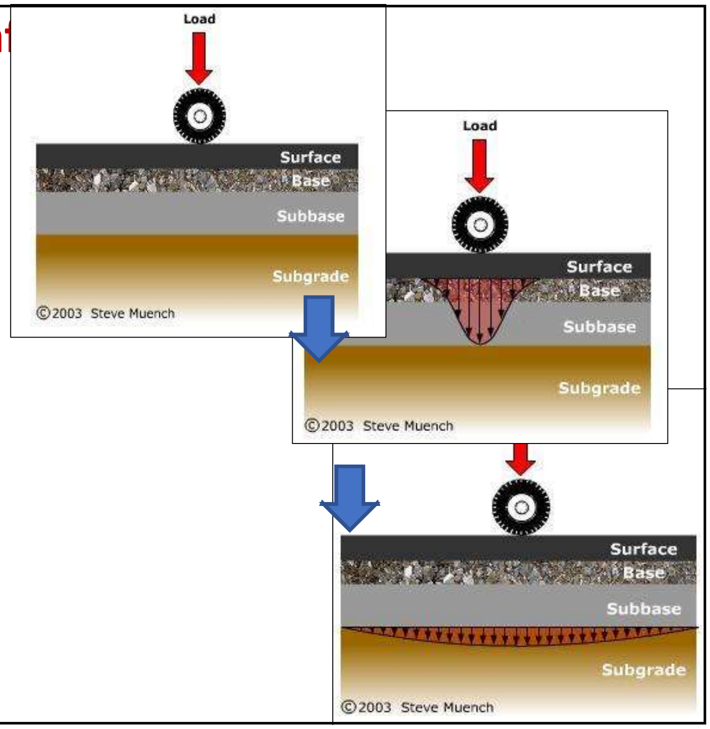
56

Pavement Response to Traffic Loads

57

57

Pavement Response to Traf

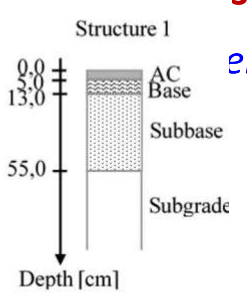


Flexible Pavements

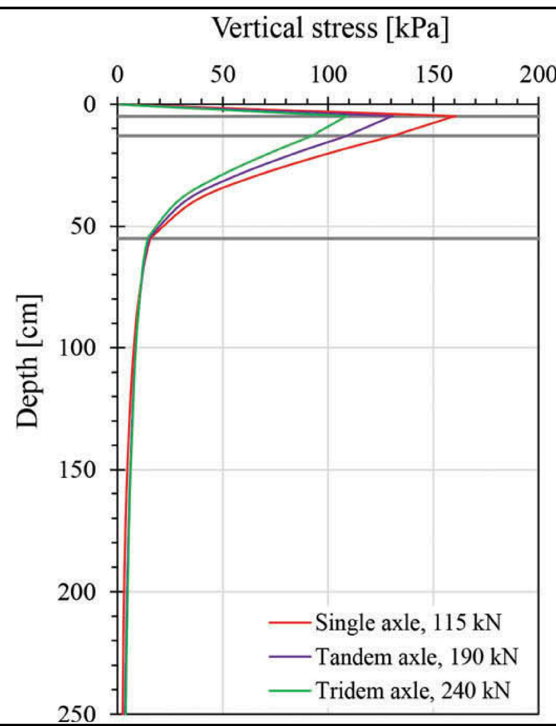
- Load is distributed layer by layer, starting from the surface and spreading through the granular layers below.
- The stress diminishes with depth, as each layer contributes to spreading the load over a larger area.
- **Key Features:**
  - ➢Load distribution depends on the characteristics of each layer, with the subgrade being a critical factor.
  - ➢Flexible pavements exhibit higher deflection under load, as the layers work together to distribute the load.

58

Vertical stress distribution



ements



Load case	Axle load [kN]	Number of sub-axles	Tire pressure [kPa]	Distance between the wheels [cm]	Distance between the axles [m]
Single axle	115	1	800	35	-
Tandem axle	190	2	800	35	1.4
Triple axle	240	3	800	35	1.4

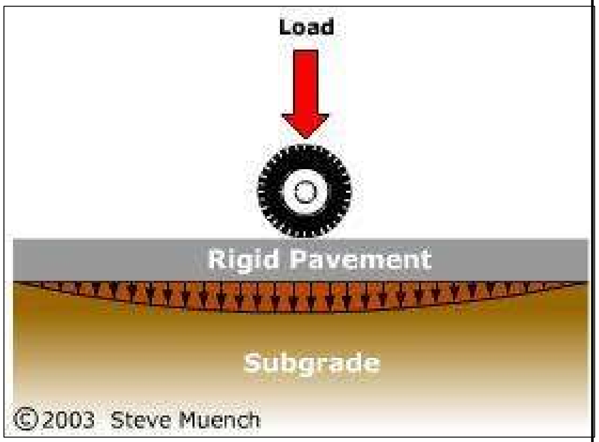
https://www.researchgate.net/publication/355650209_Impact_of_introducing_longer_and_heavier_vehicles_on_the_bearing_capacity_of_pavement_subgrades

59

Pavement Response to Traffic Loads

Rigid Pavements

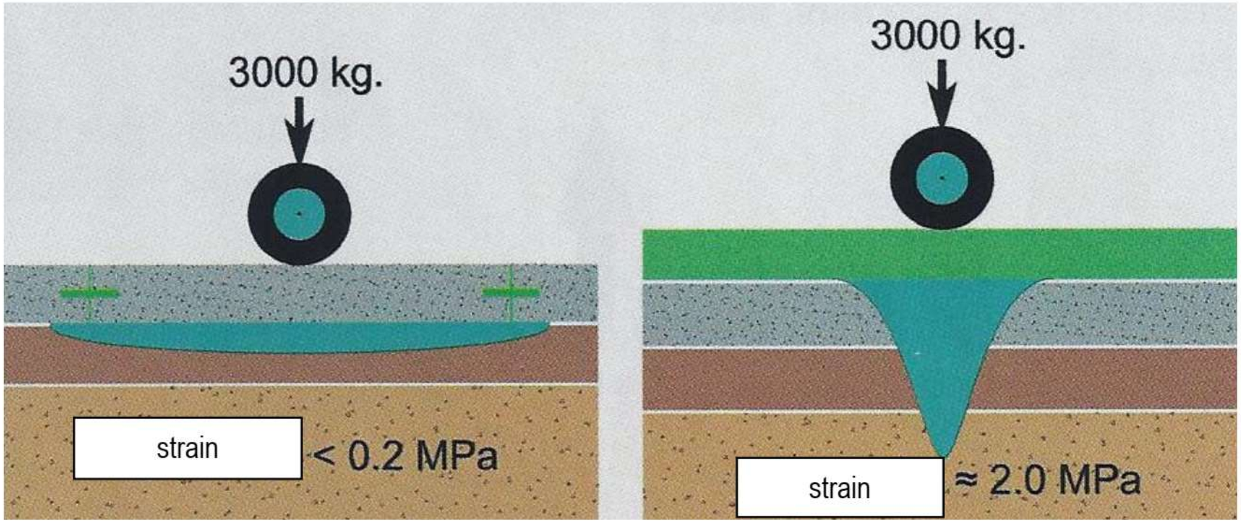
- Load is distributed primarily by the concrete slab itself.
- The slab's stiffness allows it to spread loads over a wide area, minimizing stress on the layers below.
- **Key Features:**
  - ➢The concrete slab carries most of the load, with little reliance on the underlying layers.
  - ➢Rigid pavements exhibit less deflection under load, offering greater structural resilience



60

60

Pavement Response to Traffic Loads



https://www.researchgate.net/publication/273017771_COMPARISON_OF_PAVEMENT_STRUCTURES_IN_TUNNELS

61

61

Asphalt Mixture design

62

62

TABLE 6.1 ***Superpave Aggregate Consensus Requirements***

20-Year Design ESALs[a] (in millions)	Coarse Aggregate Angularity (Percent), minimum[c] AASHTO T 335 (CAA)		Uncompacted Void Content of Fine Aggregate Angularity (Percent), minimum AASHTO T 304 (FAA)		Sand Equivalent (Percent), minimum AASHTO T 176 (SE)	Flat and Elongated[c] (Percent), maximum ASTM D4791 (F&E)
	≤ 100 mm[f]	> 100 mm[f]	≤ 100 mm	> 100 mm[f]		
< 0.3	55/-	-/-	-[d]	-	40	-
0.3 to < 3	75/-	50/-	40[e]	40	40	10
3 to < 10	85/80[b]	60/-	45	40	45	10
10 to < 30	95/90	80/75	45	40	45	10
≥ 30	100/100	100/100	45	45	50	10

NOTES:

a Design ESALs are the anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years and choose the appropriate N levels

63

63

Marshall Method Criteria[1]	Light Traffic[3] Surface & Base		Medium Traffic[3] Surface & Base		Heavy Traffic[3] Surface & Base	
	Min	Max	Min	Max	Min	Max
Compaction, number of blows each end of specimen	35		50		75	
Stability[2], N (lb.)	3336 (750)	–	5338 (1200)	–	8006 (1800)	–
Flow[2,4,5], 0.25 mm (0.01 in.)	8	18	8	16	8	14
Percent Air Voids[7]	3	5	3	5	3	5
Percent Voids in Mineral Aggregate (VMA)[6]	See Table 7.3					
Percent Voids Filled With Asphalt (VFA)	70	80	65	78	65	75

NOTES:

1. All criteria, not just stability value alone, must be considered in designing an asphalt paving mix.
2. Hot mix asphalt bases that do not meet these criteria when tested at 60°C (140°F) are satisfactory if they meet the criteria when tested at 38°C (100°F) and are placed 100 mm (4 inches) or more below the surface. This recommendation applies only to regions having a range of climatic conditions similar to those prevailing throughout most of the United States. A different lower test temperature may be considered in regions having more extreme climatic conditions.
3. Traffic classifications
   Light Traffic conditions resulting in a 20-year Design ESAL $< 10^4$
   Medium Traffic conditions resulting in a 20-year Design ESAL between 10^4 and 10^6
   Heavy Traffic conditions resulting in a 20-year Design ESAL $> 10^6$