Rigid and Flexible Pavements

A flexible pavement is a layered system—typically featuring a hot-mix asphalt surface over progressively coarser granular base and sub-base layers—designed to distribute vehicle loads via a grain-to-grain mechanism into the subgrade. The top asphalt layer bears the highest stresses, which attenuate down through the layers, and its flexibility allows slight deformation under rolling loads . Common in urban and rural roads due to lower initial cost, ease of construction, and quick opening to traffic, flexible pavements typically last around 15–30 years but require more frequent maintenance—such as patching, sealing, or overlay—to address rutting, cracks, and weather-related damage .

In contrast, a rigid pavement is a concrete slab—often Portland cement or reinforced—placed directly on a sub-base or prepared subgrade. Thanks to its high flexural stiffness, it distributes loads across the slab via slab-action mechanisms, allowing it to “bridge” minor subgrade irregularities with minimal deflection. Though initially about 20–30 % more expensive and requiring joints and curing time before traffic can use it, rigid pavements are highly durable, with service lives commonly exceeding 30 years, and have lower maintenance requirements—limited mainly to joint sealing and occasional crack repairs

Plain concrete without reinforcement may be employed to construct concrete bases. This is referred to as simple concrete rigid pavement. Reinforced concrete may be employed to construct rigid pavements. For the purpose of expansion or contraction, joints may be longitudinal or transverse.

Differences between rigid and flexible pavements

Figure 1: Flexible pavements

Flexible
Asphalt
Continuous
Low initial cost

Figure 2: Rigid pavements

Flexible
Asphalt
Continious
High initial cost

High maintenance costs Last shorter, 5 – 10 years	High maintenance costs Last shorter, 10 – 15 years

Structural components of rigid pavements

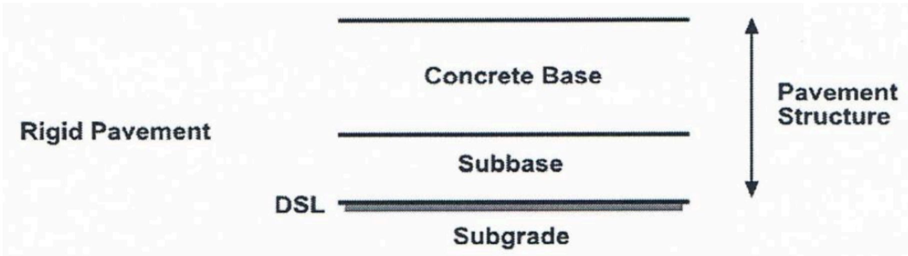

Figure 3: layout of structural components of rigid pavement.

It is recommended to provide a lean not bound cement subbase (LSC) under the base of a rigid pavement. To provide flexibility and material tolerance.

Rigid pavement

- Since rigid pavement is made of cement concrete, it is not bendable like flexible pavement; it resembles a concrete slab.
- Because the pavement slab is made of concrete that is strong enough to support traffic loads, the pavement is known as rigid.
- Its flexural strength allows it to function as a bridge and beam over any little surface defects.
- The concrete surface must offer a comfortable and smooth ride and have strong skid resistance in all weather situations because traffic runs directly on top of the slab or base.
- Because of their great compressive strength, rigid pavements tend to disperse the load over a sizable soil area.

Subbase of a rigid pavement

For one or more of the following reasons, a lean or bonded concrete subbase is advised beneath a concrete base:

to minimize "pumping" at joints and slab edges and prevent erosion beneath the base To offer consistent support beneath the pavement to improve load transfer across joints and lessen joint deflection (particularly in the absence of additional load transfer devices, like dowels). to aid in the management of high-volume-change subgrade soils' swelling and shrinking.

Types of rigid pavements

The principal types of concrete pavements are:

- Jointed Plain (unreinforced) concrete pavements (JPCP)
- Jointed reinforced concrete pavements (JRCP)
- Continuously reinforced concrete pavements (CRCP)
- Steel fibre reinforced concrete pavements (SFCP)
- Prestressed concrete pavement (PCP)

Jointed plain concrete pavement (JPCP)

- PCPs are plain cement concrete pavements constructed without reinforcement .

- Cement concrete is placed in the form of slabs on sub-base or prepared subgrade.
- In JPCPs, longitudinal and transverse joints are provided to accommodate shrinkage and thermal cracking due to temperature and moisture changes.
- Traffic load is transferred from slab to slab through particle interlocking and dowel bars.
- Tie bars are used to hold the faces of two adjacent slabs in contact.
- Transverse joint spacing is selected such that temperature and moisture stresses do not produce intermediate cracking between joints.

Joints in jointed plain concrete pavement (JPCP)

Rigid pavements are placed on prepared subgrade or subbase in the form of slabs with the provision of joints.
Two types of joints are used in concrete pavements:

- Longitudinal joint
- Transverse joints

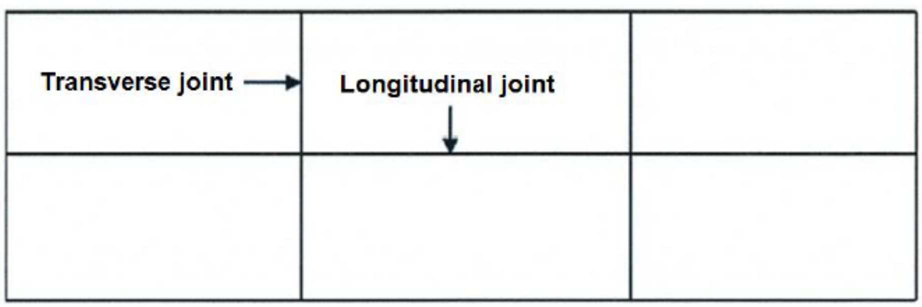

Figure 4: Types of joints

Tie and Dowel Bars

- Tie bars are used along the longitudinal joint to hold the slabs together.
- Dowel bars are used to allow the shrinkage and thermal expansion and contraction as well as load transfer from one slab to another.

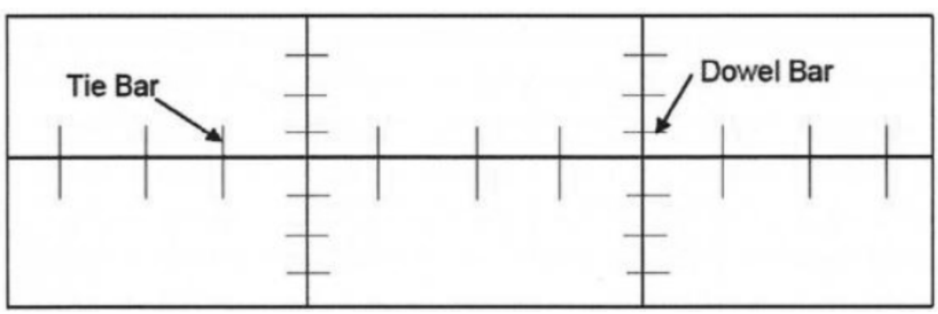

Figure 5: Tie and dowl bars loactions

Joints in rigid pavement

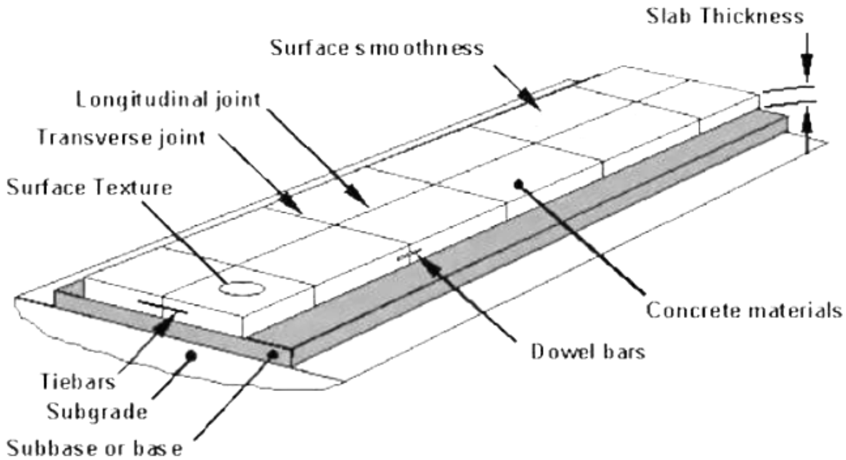

Figure 6: Rigid pavements diagram components.

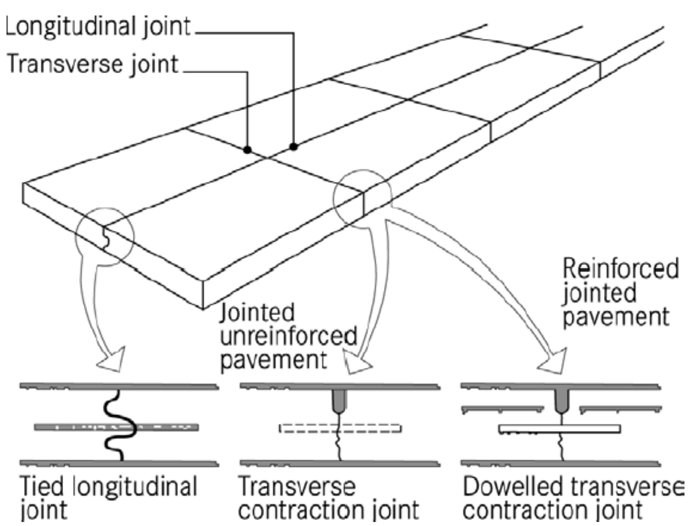

Figure 7: Rigid pavements joints diagram.

Transverse joints in rigid pavement

There are three types of transverse joints in rigid pavements:

- Contraction joint
- Expansion joint and
- Construction joint

Another type of joint is also used in rigid pavements in some particular situations which is called Isolation joint

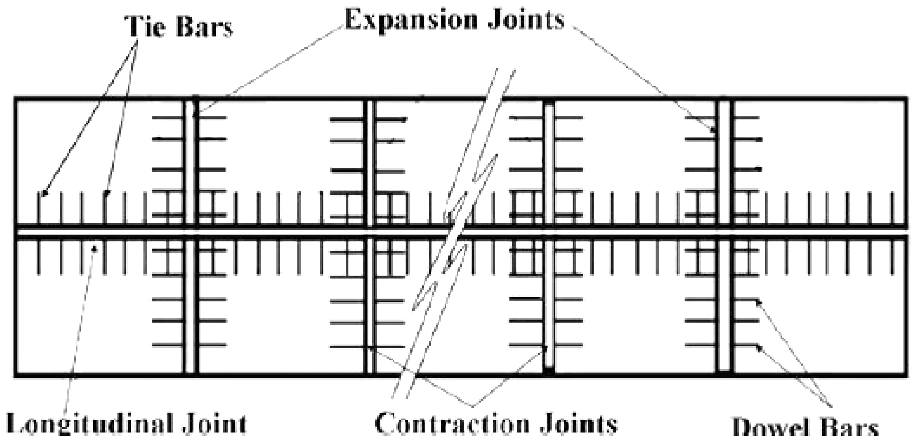

Figure 8: isolation joints on rigid pavements

Expansion joint in rigid pavement

- During the hot season of the year, rigid pavements expand due to overall increase in temperature of the pavement.
- Similarly, during cold season rigid pavements contract.
- Therefore, in order to accommodate the variation in length of the rigid pavement, expansion joints are provided in the transverse direction of the rigid pavement at fairly long intervals, after a number of contraction joints.
- An expansion joint is placed at a specific location to allow the pavement to expand without damaging adjacent structures or the pavement itself.
- The expansion joints are formed through joints across the full depth of the slab with about 20 mm gap between the two slabs.
- Thus the concrete pavement slab is separated across the expansion joint and therefore there is no load transfer across the expansion joint, resulting in weak cross section of cc pavement across these joints.
- In order to strengthen these locations of the concrete pavement slab and to provide load transfer across the expansion joint, suitable steel 'dowel bars ' are designed and installed during construction.
- Preformed filler usually is a nonabsorbent, non reactive, non extruding material made from a foam rubber or a bitumen- treated fiber board. After the concrete hardens, cut and remove about 20 mm of the filler below the slab surface to allow space for joint sealant

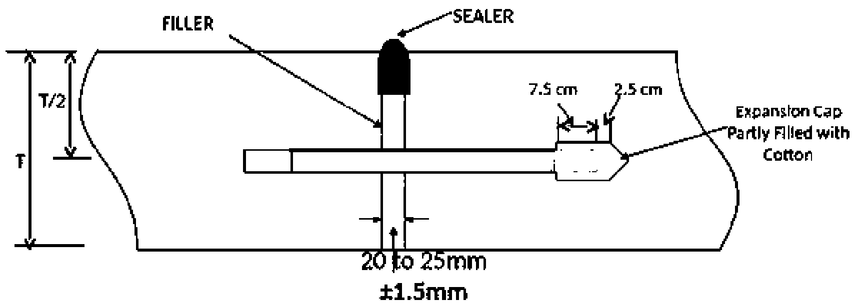

Figure 9: Dowel connection and expansion joints

- Random cracking is mitigated by the installation of contraction connections in concrete slabs.
- During the initial curing period of the pavement, contraction joints are created by cutting grooves of a width of at least 3 mm and a depth of approximately 25 to 30% of the pavement thickness. This process results in the formation of a fine shrinkage fracture below each groove at the weakened section.
- Steel reinforcement may be implemented across the contraction joints to prevent the widening of fine shrinkage fractures.
- The deformation stresses that are generated as a result of the temperature differential between the top and bottom of the concrete pavement slab are partially alleviated by contraction joints that are closely spaced.
- Curling (warping) tension in the pavement is caused by the temperature differential between the top and bottom of the slab.
- The top surface of the slab will expand and the bottom surface will contract if the temperature of the upper surface is higher than that of the bottom surface. This will result in compressive stress at the top and tensile stress at the bottom, and vice versa.

Contraction Joint in rigid pavement

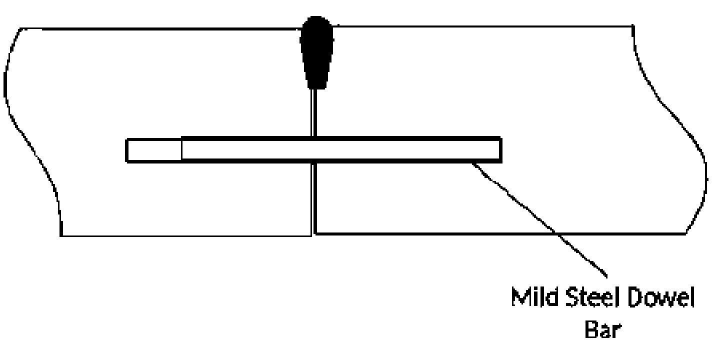

Figure 10: Dowels are 3 to 5 mm wide cut to ⅓ or ¾ depths, placed ½ depth covered with thin plastic sheeting for ⅔ lengths.

Construction joint in rigid pavement

- During the construction of rigid pavements when the concreting work is stopped at the end of the day or concrete paving is suspended due to any other reason, a construction joint is formed.
- As the construction joints are formed as through joints across the full depth of the slab, it is necessary to provide suitably designed dowel bars for load transfer.
- As far as possible it is advisable to merge the construction joint with an expansion joint by suspending the work at the nearest expansion joint so that the dowel bar system will be available for load transfer.
- Dowel bars at contraction joints shall be provided to increase service life under heavy trafficable load.
- Macimum spacing of contraction joints to be 4.5 m

Rigid pavement design system

Step 1 Select the type of rigid pavement

1. Plain (jointed unreinforced) concrete pavements (PCP)
2. Jointed reinforced concrete pavements (JRCP)
3. Continuously reinforced concrete pavements (CRCP)
4. Steel fibre reinforced concrete pavements (SFCP)
5. Prestressed concrete pavement

Factors affecting the selection of the above types are:

1. Traffic loadings, i.e. design traffic
2. Areas of application
3. Availability of materials
4. Availability of funds
5. Importance of pavement
6. Design culture

Step 2 Decide the criteria 'with or without shoulder'

- Incorporation of concrete shoulders is considered in rigid pavement design procedure.
- Concrete shoulders enhance the pavement performance and enable a lesser base thickness to be adopted.
- Two types of shoulders are considered: Integrated shoulder, structural (tied) shoulder.

Integral concrete shoulders: They are made up of the same concrete and are the same thickness as the base pavement, and are cast integrally with the base pavement with a minimum width of 600 mm.

Structural concrete shoulders:

- A structural shoulder is connected with a tied corrugated joint and has a minimum width of 1.5 m

- A tied concrete shoulder is made up of the same concrete and is the same thickness as the base pavement. It is formed, de-bonded and tied to the base pavement.

Step 3 Determine the type and thickness of subbase:

- The purpose of the subbase is to provide uniform support to the base concrete layer and provide sufficient resistance to prevent erosion of subbase material under traffic and environmental conditions.
- Only lean concrete subbase (LCS) or bound subbases are recommended for the heavy traffic levels
- Lean concrete subbase has a characteristic 28-day compressive strength of not less than 5 MPa and is designed to have low shrinkage, typically less than 450 με

- Bound subbase includes cement stabilised crushed rock (with cement, lime, fly ash, blast furnace slag), dense graded asphalt, or rolled lean concrete (dry concrete).
- Based on the predicted number of heavy vehicle axle groups over the design period, the minimum subbase thickness and type is determined from Table

Table 1: Minimum subbase requirements for rigid pavements

Design Traffic (HVGA)	Subbase type
Up to 10^6	125 mm bound
Up to 5×10^6	150 mmm bound or 125 mm LCS
Up to 1×10^7	170 mm bound or 125 mm LCS
Greater than 1×10^7	150 mm LCS

Base thickness design:

- Information is required on both axle group types, and the distribution of each axle group type and the number of repetitions of each axle type/load combination expected to use the pavement during its design life.
- The calculated base thickness should then be rounded up to the nearest 5 mm.
- The design base thickness is the greater of the calculated base thickness (including rounding) and the minimum base thickness from Table 9.7 for different base types and traffic volumes.

Base Thickness design procedure:

- A trial design base thickness is selected and the total fatigue and erosion damage is calculated for the entire traffic volume and composition during the design period.
- If either fatigue or erosion damage exceeds 100%, then the trial thickness is increased and the design process is repeated.

- The design thickness is the least trial thickness which has a total fatigue less than or equal to 100% and a total erosion damage less than or equal to 100%.

Step 4 Determine effective subgrade strength

Research work and experience has identified that there is an increase in effective subgrade strength with the use of bound and lean concrete subbase. Figure 11 is used to determine the increase in strength for use in the base thickness design.

Given subgrade CBR = 5% For 150 mm LCS, effective subgrade strength is 75%.
Similarly, Subgrade CBR = 4% For 125 mm bound, effective subgrade strength is 18%.

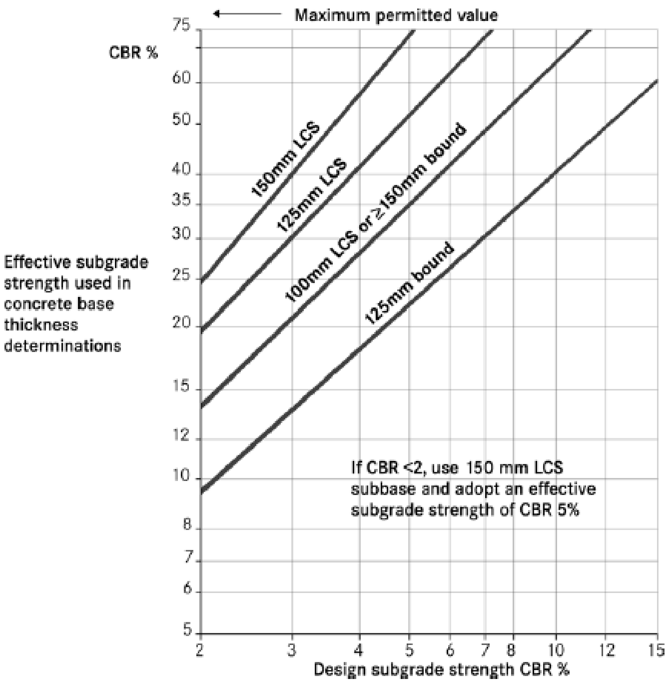

Figure 11: Graph of design subrage strength with respect to California bearing ration (CBR)

Step 5 select 28 days flexural strength of the concrete base

- Flexural strength is the property of concrete that indicates its ability to withstand a flexural or bending load.
- The critical stresses within a concrete pavement under the action of wheel loads are flexural rather than compressive. Flexural strength, therefore, is normally used for thickness design.
- Typically, the 28 day flexural strength is 3 – 5 MPa.
- The minimum concrete flexural strength for concrete pavements with design traffic of 106 HVAG or more, is 4.5 MPa at 28 days
- Therefore, flexural strength of concrete is considered to be, fc = 4.5 MPa.

Step 6 Select desired project reliability and hence the load safety factor

- In the design procedure, the axle group loads are multiplied by a Load Safety Factor (LSF) to obtain Design load.
- The load safety factors used in design are derived from the values in Table 2 according to the desired project reliability for a specified pavement type.

Table 2: Load safety factor L_{sf} for rigid pavement type

Pavement Type	80%	85%	90%	95%	97.5%
PCP	1.15	1.15	1.2	1.2	1.35
Dowelled and CRCP	1.05	1.05	1.1	1.2	1.25

Step 7 Select trial base thickness

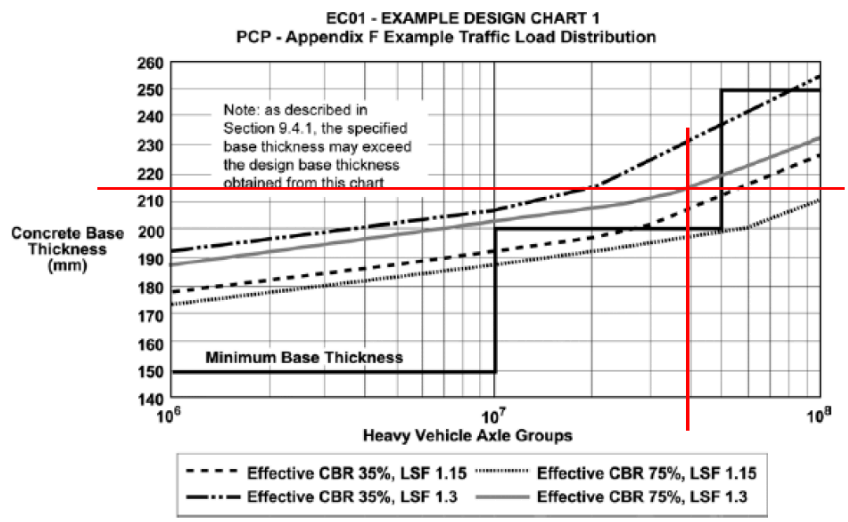

Figure 12: Example esign chart plain concrete pavements without dowelled joints for combinations of tow effective subgrade strengths and two load safety factors

Step 8 Calculate the expected load repetitions of each axle group load of each axle group type

Expected load repetitions of an axle group load of an axle group type is calculated as:

$$ELR = Proportion\ of\ loads \times proportion\ of\ axle\ group \times design\ traffic\ (HVAG)$$

Table 3: Proportion of axle group

SAST	TAST	SADT	TADT	TRDT	TOTAL
39.3%	0.9%	19.1%	25.9%	14.8%	100%

Table 4: Proportion of loads

Axle group laad (kN)	% of axle group type
10	0.2804
20	7.827
30	15.46
40	15.71

50	29.94
60	23.29
70	6.502
80	0.7943
90	0.1087
100	0.0354
110	0.0174
120	0.0174
130	0.0174
Total	100%

Example:

In pavement design, it's essential to estimate the number of heavy axle load repetitions over a structure's design life to assess potential damage. In your exercise, $Design\,Traffic\ =\ 4\times10^{7}\ HVAG$ (Heavy Vehicle Axle Groups). The calculation:

With a 30 kN load, these are "expected load repetitions" of SAST. This indicates how many axles of this kind with a 30 kN load have passed a pavement segment during the course of the design life.

Yields the expected load repetitions (ELR) for a 30 kN axle load on a Standard Axle Group Type (SAST). This means that over the design life, approximately 2.43 million 30 kN axle passes are anticipated.

Using Miner's cumulative damage hypothesis—a foundational concept in fatigue and erosion analysis—each axle passage contributes a fraction of damage, and the damage accumulates linearly until failure. In rigid pavements, this translates to flexural stress (fatigue) and corner deflection/pumping (erosion). In flexible pavements, repeated bending induces subsurface fatigue cracking.

So, the figure 2,430,312 repetitions becomes the starting point to calculate Fatigue Damage (based on slab-edge stresses) and Erosion Damage (from corner deflections), using appropriate damage exponents and stress/load relationships per PCA or AASHTO-style mechanistic models. This paves the way for evaluating and designing pavement thickness and materials to resist that cumulative damage.

$ELR\ for\ SAST\ that\ carries\ a\ load\ of\ 30\ KN\ =\ (39.3/100)\times(15.46/100)\times4\times10^{7}\ HVAG\ =\ 2430312$

Calculation of 'expected load repetitions' of SAST

<u>Table 5: single axle/single tyre (SAST)</u>

Axle group load (kN)	Proportion of loads (%/100)	Proportion of axle group (%/100)	Design traffic (HVAG)	Expected repetitions
130	0.000174	0.393	40 000 000	2735
120	0.000174	0.393	40 000 000	2735

110	0.000174	0.393	40 000 000	2735
100	0.000354	0.393	40 000 000	5565
90	0.001087	0.393	40 000 000	17088
80	0.007943	0.393	40 000 000	124864
70	0.06502	0.393	40 000 000	1002114
60	0.2329	0.393	40 000 000	3661188
50	0.2994	0.393	40 000 000	4706568
40	0.1571	0.393	40 000 000	2469612
30	0.1546	0.393	40 000 000	2430312
20	0.07827	0.393	40 000 000	1230404
10	0.002804	0.393	40 000 000	44079

The axle load value and the corresponding expected repetitions are then transferred to columns 1 and 3 of the thickness calculation sheet as shown below in the thickness calculation sheet.

Table 6: values for single axle tyre group (SAST)

			Equivalent Stress Fatigue analysis	**0.751**	**Erosion factor Erosion analysis**	**1.865**
Axle group load (kN)	Design load (kN)	Expected repetitions	Allowable repetitions	Damage (%)	Allowable repetitions	Damage (%)
130	169.0	2735	2974	91.96	162052	1.69
120	156.0	2735	11812	23.15	269239	1.02
110	143.0	2735	47245	5.79	483605	0.57
100	130.0	5565	192228	2.84	977194	0.57
90	117.0	17088	1808199	0.95	2419503	0.71
80	104.0	124864	Unlimited	0.00	9462726	1.32
70	91.0	1022114	Unlimited	0.00	978333565	0.10

Step 9 Calculate allowable repetition in fatigue distress mode using equation (1) and (2)

- From the project traffic load distribution, obtain the highest axle load for the SAST axle group and determine the allowable repetitions in terms of fatigue using equations 26 and 27.
- Load distribution in step 8 shows that the highest axle load for the SAST axle group is 130 kN. Therefore, it should be started from 130 kN.
- Design load is calculated by multiplying axle group load by Load Safety Factor (LSF).

Two distress modes are considered in rigid pavement design system: Fatigue and Erosion distress modes.

Fatigue distress mode

Flexural fatigue cracking of the pavement base:

Allowable load repetitions (Nf) for a given axle load are calculated using Equation (1) and (2).

(1) $log(N_f) = \left[\frac{0.9719 - S_r}{0.0828}\right] when\ S_r > 0.55\ N_F = allowable\ load\ repetition = UNLIMITED\ when\ S_r < 0.45,$

(2) $N_f = \left[\frac{4.258}{S_r - 0.4325}\right]^{3.268}$ $when\ 0.45 \le S_r \le 0.55$ (3) $S_r = \frac{S_e}{0.944 f_{cf}}\left[\frac{PL_{SF}}{4.45F_1}\right]^{0.94}$

$S_e = equivalent\ concrete\ Stress\ (MPa)$

$f_{cf} = design\ characteristic\ flexural\ strength\ at 28\ days\ (MPA), P = \ Axle\ group\ (kN)$

$L_{SF} = load\ safety\ factor, F_1 = \ load\ adjustment\ for\ fatigue\ due\ to\ axle\ group$

$= 9\ for\ single\ axle\ with\ single\ tyres)(referred\ to\ SAST\ axle\ group)$

$= 18\ for\ single\ axle\ with\ dua;\ tyres\ (SADT)$

$= 18\ for\ tandem\ axle\ with\ single\ tyres\ (TAST) = 36\ for\ tandem\ axle\ with\ dual\ tyres\ (TADT)$

$= 54\ for\ triaxle\ with\ dual\ tyres\ (TRDT) = 72\ for\ quad\ axle\ with\ dual\ tyres\ (QADT)$

(4) $log(F_2 N_e 0 = 14.524 - 6.777\left[max(0, \left(\frac{PL_{SF}}{4.45F_4}\right)^2 \frac{10^{F_3}}{41.23} - 9\right]^{0.103}$

$S_e or\ F_3 = a + \frac{b}{D} + c.ln(E_f) + d/D^2 + e.[ln(E_f)]^2 + f.ln(E_f)/D + g/D^3 + h.[ln(E_f)]^3 + i.[ln(E_f)^2/d + j.$

Step 10 Calculate the ratio of the expected fatigue repetitions (step 8) to the allowable repetitions (step 9).

Table 7: single axle/single tyre (SAST)

Axle group load (kN)	Design load (kN)	Exceptional repetitions	Equivalent stress 0.751 Fatigue analysis Allowable repetitions	Damage (%)	Erosion factor 1.865 Erosion analysis Allowable repetitions	Damae (%)
130	169.0	2735	2974	91.96	162052	1.69

$Percentage\ fatigue = (2735\ /\ 2974)\ x\ 100 = 91.96\%$

Step 11 Determine from equation 4 the allowable number of receptions for erosion for the highest axle load for the SAST axle group $Ne = 162052\ for\ axle\ group\ load\ 130\ kN\ for\ SAST$

Step 12 Calculate the ratio of the expected erosion repetitions (Step8) to the allowable repetitions (Step 11)

$Ne = 162052\ for\ axle\ group\ load\ 130\ kN\ for$
$SAST\ Percentage\ fatigue = (2735\ /\ 162052)\ x\ 100 = 1.69\%$

Step 13 Repeat step 9 to 12 for each axle group up to a load level whether the allowable load repetitions exceed 108, at which point further load repetitions are not deemed to contribute to pavement distress.

Step 14 sum the percentage failure for all relevant loads of this axle group type. Similarly, sum the percentage erosion for all relevant loads of this axle group type.

Step 15 Repeat step 9 to 14 for each axle group type (i.e. SADT, TAST, TADT, TRDT and QADT).

Steph 16 Sum the total fatigue and total erosion damage for all axle group types

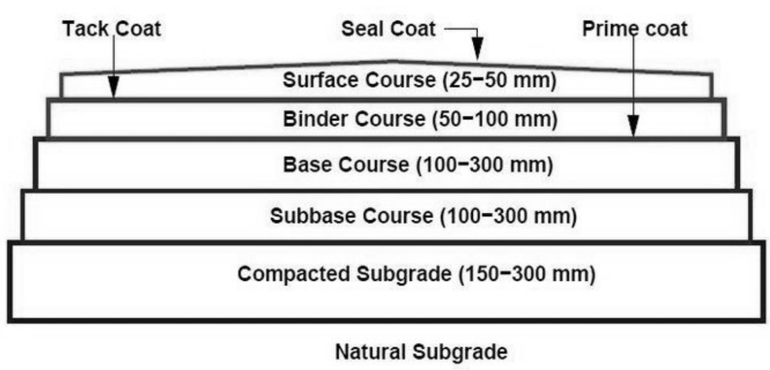

Figure 13: Different layers of road infrastructure

Table 8: Road Design for High traffic volume

Surface Type	Surface thickness
Asphalt wearing course	40 mm
Asphalt Binder course	80 mm
Base course	150 mm
Subbase course	180 mm
Compact subgrade	220 mm

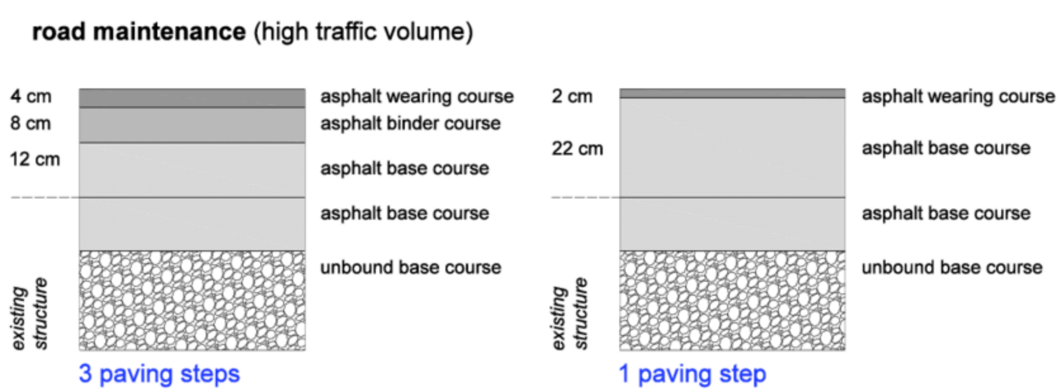

Figure 14: different courses for paving steps