Syllabus

- Concrete Pavements. Prof Sixtus Kinyua Mwea
- Airfield pavements. Prof Sixtus Kinyua Mwea
- Principles of runway design. Prof Sixtus Kinyua Mwea
- Evaluation of pavements. Prof FJ Gichaga
- Strengthening of pavements. Prof FJ Gichaga
Design of Concrete Roads

Å Kenyan Method
Å South African Method
Introduction

Although their construction cost may be higher than asphalt pavements, once properly built, however, their maintenance costs are potentially significantly lower. Their lifecycle costs could be lower.

Philippines they comprise over 75%.

Chile, concrete road building is firmly established.
Introduction

Å Lately been renewed interest in concrete for use on heavily trafficked roads.
Å In August 2006 about 4km of dual carriageway (Mbagathi Way) in Nairobi was reconstructed with a concrete.
Å In March 2007 the Gilgil weighbridge facility near Naivasha, 200m long by 22m wide, was reconstructed with a concrete pavement.
Å The performance of these two projects is currently being monitored.
Introduction

Advantages

- Concrete is safer than asphalt roads because it increases visibility, especially at night.
- The reflects heat energy better than asphalt, which will be beneficial to the passage of vehicles in hot climates.
- Less energy for propulsion than asphalt. Fuel savings between 10-20% are indicated.

Disadvantages

- Traffic noise
- Difficulty of repairing concrete roads compared to asphalt.
Introduction

We shall describe types of concrete pavements, their components and functions.

Factors influencing the design process and selection of pavement type, and

Design procedure for the pavement type, slab reinforcement and joint details.
Characteristics

- The strength derived mainly from the concrete slab action
- Concrete is a rigid material and design objective is to ensure
  - i) Stresses imposed by traffic and induced by thermal expansion and contraction can be endured by the concrete without it fracturing.
ii) Account for stresses due to variation in temperature.

- Spacing of Expansion and contraction joints, are determined by the temperature variation range.

- Small temperature fluctuations, joints can be quite widely spaced

- Hotter climates there are large fluctuations of temperature and special attention to joint design and spacing.

iii)
Characteristics

A Skid resistance of concrete
- Adequate at construction
- Maintained at regular intervals
Characteristics

BEFORE SUNRISE

Slab temperature

0°C

15°C

Slab dished

Joints open

MID AFTERNOON

Slab temperature

0°C

60°C

20°C

Slab hogged

Joints closed
Types

PAVEMENT TYPES

The principal types of concrete pavements usually implemented for roads are:

- Undowelled skewed jointed plain (unreinforced) concrete pavements;
- Dowelled square jointed plain (unreinforced) concrete pavements;
- Continuously reinforced pavements,
- Rolled cement concrete pavements.
Types

CROSS - SECTION TERMINOLOGY

PAVEMENT TERMINOLOGY

JOINTED PLAIN CONCRETE PAVEMENT

CONTINUOUS REINFORCED CONCRETE PAVEMENT
Subgrade

- Material below the subbase
- Or the possible drainage layer
- Includes insitu material,
- Or Fill
- Or Improved subgrade.
## Subgrade

<table>
<thead>
<tr>
<th>Subgrade</th>
<th>CBR Range (%)</th>
<th>Stiffness Modulus (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>2 - 5</td>
<td>20</td>
</tr>
<tr>
<td>S2</td>
<td>5 - 10</td>
<td>50</td>
</tr>
<tr>
<td>S3</td>
<td>10 - 15</td>
<td>80</td>
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<tr>
<td>S4</td>
<td>15 - 20</td>
<td>100</td>
</tr>
<tr>
<td>S5</td>
<td>20 - 30</td>
<td>120</td>
</tr>
<tr>
<td>S6</td>
<td>&gt;30</td>
<td>150</td>
</tr>
</tbody>
</table>
Drainage layer

- Water enters the pavement through the joints and cracks
- Loss of supporting strength
- Non-uniform subgrade support.
- Mud-pumping
- The erosion can reach the bottom of the slab, causing lack of support.
Drainage layer

Specify a suitable drainage
Layer to be under the subbase
To be continuous through the shoulder up to the ditches or
Longitudinal drains under footpaths.
### Crushed Stone

<table>
<thead>
<tr>
<th>Grading</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum aggregate size</td>
<td>75 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>Sieve (mm)</td>
<td>% by weight passing</td>
<td></td>
</tr>
<tr>
<td>75</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>63</td>
<td>-</td>
<td>-</td>
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<tr>
<td>50</td>
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<td>37.5</td>
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<td>75-100</td>
</tr>
<tr>
<td>20</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>35-65</td>
<td>55-75</td>
</tr>
<tr>
<td>6.3</td>
<td>25-50</td>
<td>30-55</td>
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<td>2</td>
<td>10-20</td>
<td>10-25</td>
</tr>
<tr>
<td>1</td>
<td>2-10</td>
<td>-</td>
</tr>
<tr>
<td>0.425</td>
<td>0-5</td>
<td>2-10</td>
</tr>
<tr>
<td>0.075</td>
<td>-</td>
<td>0-3</td>
</tr>
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</table>

### Stone Requirements

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>LAA max.</td>
<td>45</td>
</tr>
<tr>
<td>ACV max.</td>
<td>32</td>
</tr>
<tr>
<td>SSS max.</td>
<td>20</td>
</tr>
<tr>
<td>FI max.</td>
<td>35</td>
</tr>
<tr>
<td>CR min.</td>
<td>30</td>
</tr>
</tbody>
</table>
Subbase

- Provides uniform support to the concrete slab
- Provide best possible resistance to prevent erosion under traffic and environmental conditions.
- Needed when subgrade cbr is less than 15
  - adequate for in-situ stabilised soils with lime and/or cement,
  - when in cut with rock formation
Subbase

- The subbase can be
  - dense graded asphalt for base
  - dry lean concrete
    - This is the same as lean concrete for flexible pavements
Separator

A lean-concrete subbase develops shrinkage cracks.

A These cracks can reflect in the concrete slab,

A Introduce interlayer de-bonding

   ï Application of a bond-breaking separator laid on the surface of the lean concrete

   ï Provides a smooth surface to receive the slab
Separator

- either:
  - a bitumen emulsion with a little fine sand
  - a polythene sheet, 125 microns thick,

- Also prevents water loss at the base of the concrete slab during the beginning of its hardening and limits thus the warping of the slab near the joints and corners.
Concrete slab

Concrete slab is a mix of coarse aggregates and fine aggregates, cement, water and additives (plasticizer).

Manufactured in plant and placed on the subbase between fixed forms.

The minimum compressive strength of the concrete to be at least 35 Mpa

- BS EN 13877-1: 2004 concrete pavement
- BS EN 13877-2 Functional requirements
Joints

• Contraction joints result from shrinkage of the concrete during its hardening, random cracks can appear in the slab.
• It is best practice to saw transverse and longitudinal joints with regular intervals in the after concrete sets.
• Then the cracks will concentrate on these joints.
Joints

Off-set and positioning of longitudinal and transverse contraction joints

Undowelled Skewed Jointed Plain Concrete

Dowelled Square Jointed Plain Concrete
Joints

Continuous Reinforced Concrete Pavement
Expansion joints

- Provided when the concrete pavement abuts with a permanent structure like a bridge or culvert. Normally these joints
- Meant for relieving expansion pressure when the slabs abut against unyielding structure
- Transverse and longitudinal joints must be sealed to be waterproof.
Expansion joints

Products usually used are either:
- hot applied sealants;
- cold applied sealants;
- pre-moulded joints.
Dowels

Å Transfer of load across the transverse joints,
   ï in combination with the coarsest aggregates
   ï Alone only as soon as the interlock by the coarse aggregates becomes insufficient because of the shrinkage of the concrete
   ï The wear of these aggregates over time.
Dowels

- Should not induce stresses in the concrete due to

- Movements of the slabs resulting from.
  - temperature effects,
  - moisture movements.

- They must thus be able to slip freely into their housing.

- Are smooth, with the ends of a fine layer of bituminous or plastic product.
Dowels

Contraction Joint with dowel bar

Transverse expansion joint
Tie bars

Å Longitudinal joints separate the lanes,
Å They crack and the slabs tend to move away
Å Tie bars made of deformed bars are therefore provided to hold the slabs together.
Å The rods are protected from corrosion by painting with bituminous paint.
Å These tie rods are placed at the mid height of concrete slabs.
Continuous Reinforcement Concrete Pavement

 Å Longitudinal reinforcements in the CRCP is to distribute the cracking caused by shrinkage of the concrete
 Å Not structural
 Å Crack spacing will be approximately one meter
 Å Their opening is small
Continuous Reinforcement Concrete Pavement

Å Longitudinal reinforcement are deformed bars
Å Placed parallel to the pavement axis
Å At mid-thickness of the slab.
Å The transverse reinforcements are used to support the longitudinal reinforcements
Å And provided at right angle to the longitudinal joints
Continuous Reinforcement Concrete
Pavement

Sample of CRCP reinforcement with transverse support (inlay project)
Surface Texture

For friction and skid resistance
Done soon after surface is finished and before it hardens

types of textures
Micro-texture is dependent on the
Type of aggregates used in the concrete whereas
Macro-texture can be created by steel bristle brush, tinning, burlap drag etc.
Surface Texture

- The popular methods of texturing
  - texturing with steel bristles;
  - texturing with tines
  - exposed aggregates;
  - texturing with nylon or coir brush;
  - burlap drag.
Surface Texture

- Longitudinal tining rake
- Longitudinal tine texturing
- Surface Mortar Being Washed Away to Expose Aggregate
- Finished Exposed Aggregate Surface
Rolled Cement Concrete

- No dowels, reinforcements
- Pavement is a relatively stiff mixture of aggregate (maximum size usually not higher than 20 mm), cement and water, which is compacted by vibratory rollers.
- A minimum compressive strength of 30 MPa is generally specified.
- Blended in a mixing plant into a zero slump concrete.
- Placed in layers not greater than 250 mm compacted thickness by paving machine.
Rolled Cement Concrete

- Final compaction sometimes provided by rubber tire rollers.
- The pavement is cured to provide a hard and durable surface carrying traffic directly on the finished surface.
- Wearing course is not normally used, although a surface dressing or a thin asphalt concrete overlay can be added.
Design Considerations – Traffic

Â Axle load distribution of the traffic is assessed
Â Traffic surveys will is conducted
Â An axle load survey is also conducted
Â All axles including  are weighed separately and converted to an equivalent
Â The number of standard 80 kN axles (ESAL), using the Equivalent Factor relationship
Design Considerations – Traffic

Å Initial average daily number of ESAL is evaluated
Å Expected daily number of commercial vehicles for new alignments are estimated.
Å The initial daily number of standard axles is assessed (t1).
Å Select annual growth rate (i) and a design period (N, 30 years for concrete pavements)
\[
T = 365t1 \left( \frac{(1 + 0)^N}{1} - 1 \right)
\]

The cumulative number of ESAL, \( T \) over the design period \( N \) (in years) is then obtained.

Determine the traffic class.
Equivalent Standard Axles

A Convert all the single axle loads to Equivalent Standard Axles

\[ EF = \left( \frac{Ls}{80} \right)^{4.5} \]
## Traffic Classification

<table>
<thead>
<tr>
<th>Traffic Level</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>0</td>
<td>250,000</td>
</tr>
<tr>
<td>T2</td>
<td>250,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>T3</td>
<td>1,000,000</td>
<td>3,000,000</td>
</tr>
<tr>
<td>T4</td>
<td>3,000,000</td>
<td>10,000,000</td>
</tr>
<tr>
<td>T5</td>
<td>10,000,000</td>
<td>25,000,000</td>
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<tr>
<td>T6</td>
<td>25,000,000</td>
<td>60,000,000</td>
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<td>T7</td>
<td>60,000,000</td>
<td>100,000,000</td>
</tr>
<tr>
<td>T8</td>
<td>100,000,000</td>
<td>150,000,000</td>
</tr>
</tbody>
</table>
## Subgrade classification

<table>
<thead>
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<td>10 - 15</td>
<td>80</td>
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<tr>
<td>S4</td>
<td>15 - 20</td>
<td>100</td>
</tr>
<tr>
<td>S5</td>
<td>20 - 30</td>
<td>120</td>
</tr>
<tr>
<td>S6</td>
<td>&gt;30</td>
<td>&gt;150</td>
</tr>
</tbody>
</table>
STRUCTURAL DESIGN METHOD

A catalogue of structures for concrete pavements is established by adapting the method developed by the French Central Laboratory of Bridges and Roads.

The specific Kenyan situations taken into considered are the types of roads, their traffic pattern and the characteristics of materials in use in this country.
Å stresses and strains within the structure with each **passage of load** are calculated using Burmister’s model,
Å coefficients of correction, determined to take account of specificities of concrete pavements, such as discontinuities, edge and corner effects and heat gradients
Å The model provides the strain (\(\varepsilon\)) and stress (\(\sigma\)) fields present at any point in the mass.
Admissible values for these stresses or strains correspond to the maximum level of loading of cumulative traffic before being subjected to a given level of damage.

The design account for reliability associated with the type of subgrade and the type of road characterized by the expected traffic during the design period.

This represents the probability of failure of the pavement for the number of repetition of the equivalent axle.
For cemented materials the formula adapted to the Kenyan conditions is

$$\sigma_{t \text{ allowable}} = \sigma_6 \times (0.173 \times N \text{ ESAL} \times 10^{-6}) \times b \times K_r \times K_s \times K_c \times K_d$$

For bituminous materials the formula adapted for the Kenyan conditions is

$$\varepsilon_{t \text{ allowable}} = \varepsilon_6 \times (0.069 \times N \text{ ESAL} \times 10^{-6}) \times b \times K_r \times K_s \times K_c$$
σₐₜ allowable = Allowable direct tensile stress in the bottom of cemented layer at the end of the design period;
σ₆ = Average direct tensile strength after laboratory fatigue tests of 106 repetitions of equivalent axle.
N ESAL = Cumulative number of standard axles during the design life
⁻¹/b = Exponent of the fatigue curve beyond 106 loading repetitions (for Cement Concrete⁻¹/b = 16, for Lean Concrete –¹/b = 14, for Dense Bitumen Macadam –¹/b = 5, for Rolled
Cement Concrete –¹/b = 14 )
\( Kr \)

\( Kr \) = Risk coefficient of failure admitted at the end of the design life (Reliability) according to the expected traffic volume. takes also into account the risk percentage retained and the standard deviation \( St \) on the thickness of the slab, which varies with the construction method of its support. The values of this coefficient vary from
Kr values

Å Kr
Å Cement concrete  .704-.84
Å Lean concrete     1
Å Rolled cement concrete  .704-.789
Ks, Kc, Kd values

Å Takes account of variation of subgrade strength
Å 0.833-1
Å Kc
Å Adjustment as a result of differences between model and insitu conditions = 1.5
Å Kd
Å Adjustment to take effect of edges joints and temp variations = .588-1.0
5.3 FATIGUE LAW CURVES USED FOR CALCULATIONS OF ALLOWABLE STRESSES IN THE CONCRETE SLAB

![Graph showing fatigue law curves for different conditions.](Image)
Lecture 2

1) SPECIAL FEATURES OF CONCRETE PAVEMENTS

2) DESIGN OF STEEL REINFORCEMENT BARS

3) STANDARDS PAVEMENT STRUCTURES FOR NEW ROADS
SPECIAL FEATURES

Å JOINTS
Å The spacing between transverse contraction joints depend on the thickness of the slab.

<table>
<thead>
<tr>
<th>Å Slab Thickness</th>
<th>Joint Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Å ( mm )</td>
<td>( m )</td>
</tr>
<tr>
<td>Å 0 to 200</td>
<td>4.00</td>
</tr>
<tr>
<td>Å 200 to 300</td>
<td>4.50</td>
</tr>
<tr>
<td>Å 300</td>
<td>+ 5.00</td>
</tr>
</tbody>
</table>
The transverse joints of undowelled skewed jointed pavements are tilted 15°.
The transverse joints of dowelled square jointed pavements are perpendicular.
The longitudinal joint is placed between each lane, outside the road markings area.
Depth of sawing: 1 / 3 to 1 / 4 of the thickness of the slab.
JOINT DESIGN:

Details of contraction joints (Hot or Cold poured Sealant)

Transverse Joint: W = 8 to 10 mm
Longitudinal Joint: W = 6 to 8 mm
Details of expansion joint

Details of contraction joints (Pre-moulded)
SLAB DETAILS ADJACENT TO ABUTMENT OF STRUCTURES

- Cement concrete slabs expand during hot season & result in the building up of horizontal thrust on adjoining bridge structures.

- An anchor beam is provided in the terminal slab.

- The terminal slab also is reinforced to strengthen it.
A typical arrangement of anchor
Not needed for culverts with fill on top.
Typical Details of Anchor Beam and Terminal Slab
TRANSITION BETWEEN CONCRETE PAVEMENT AND FLEXIBLE PAVEMENT

At the interface of rigid and flexible pavement, at least 3m long reinforced buried slab should be provided. The details are shown in the diagram.
DESIGN OF STEEL REINFORCEMENT BARS

The dowels are smooth round bars complying with standard BS EN 13877-3: 2004,
Installed at the square transverse joints to enable load transfer.
Parallel to the pavement axis and at mid-thickness of the slab.
The steel must be at least grade Fe-S 235. Dimensions and spacing are indicated below:
Slab thickness Dowel diameter Dowel length Dowel spacing
# DOWEL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Diameter</th>
<th>Length</th>
<th>Spacing</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 mm</td>
<td>20 mm</td>
<td>400 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>160 to 200 mm</td>
<td>25 mm</td>
<td>450 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>210 to 280 mm</td>
<td>30 mm</td>
<td>450 mm</td>
<td>300 mm</td>
</tr>
<tr>
<td>290 to 350 mm</td>
<td>40 mm</td>
<td>500 mm</td>
<td>400 mm</td>
</tr>
</tbody>
</table>
TIE BARS

Tie bars apply to Dowelled Square Jointed Slabs.
The ties are installed at longitudinal joints in order to keep the joint closed; the loads are transferred by interlocking of the sections of adjacent concrete strips.
Placed at mid-thickness of the slab.
TIE BARS

Å Steel Fe-E 400 according to standard BS EN 10027-1: 2005.

Å At least 600 mm long.

Å The cross section area of the ties per metre length of longitudinal joint is given by the formula:
TIE BARS

\[ S = \left( f \times l \times P \right)/L_s \]

- \( f \) coefficient of the concrete on the subgrade taken equal to 1.5;
- \( l \) is the width separating the tied joint from the nearest edge;
- \( P \) is the weight per m2 of the slab;
- \( L_s \) is the working stress in the steel, taken as equal to 75% of the elastic limit.

The diameter of the tie bars is based on the cross section \( S \) so that they are spaced at intervals of between 700 mm to 1 metre.
LONGITUDINAL REINFORCEMENTS OF CONTINUOUS REINFORCED SLABS

• distribute the shrinkage of the concrete;
• and limit shrinkage cracks from opening.

They are located in a plane parallel to the slab surface:
• above the neutral fibre (mid-thickness of the slab), in the area compressed under traffic loads;
• below 80 mm from the slab surface, in order to avoid corrosion.
LONGITUDINAL REINFORCEMENTS OF CONTINUOUS REINFORCED SLABS

The ratio $p$ of the steel to the concrete sections depend

- on adhesion between the two materials,
- the grade of the steel
- tensile strength of the concrete.

For reinforcement complying with standard BS EN 10027-1 : 2005, the steel must be at least grade Fe-E 400, in which case ratio $p$ is equal to:
LONGITUDINAL REINFORCEMENTS OF CONTINUOUS REINFORCED SLABS

$\Delta p \% = 0.67 \ ( ft / 3.3 )$

$\Delta ft$ being the average indirect tensile strength in MPa of the concrete at 28 days (or 56 days for a slow-setting cement).

$\Delta$ The diameter of the reinforcements must be between 12 and 16 mm.
The following nine charts provide the thicknesses of the subbases and the concrete slabs depends on

- The type of subgrade
- Type of traffic
STANDARDS PAVEMENT STRUCTURES

Å Undowelled Skewed Jointed Plain Concrete Slab overlying a Lean Concrete subbase
Å (Chart CC1)
Å - Dowelled Square Jointed Plain Concrete Slab overlying a Lean Concrete subbase
Å (Chart CC2)
Å Continuous Reinforced Concrete Slab overlying a Lean Concrete subbase
Å (Chart CC3)
STANDARDS PAVEMENT STRUCTURES

Å - Undowelled Skewed Jointed Plain Concrete Slab overlying a DBM subbase
  (Chart CC4)

Å - Dowelled Square Jointed Plain Concrete Slab overlying a DBM subbase
  (Chart CC5)

Å - Continuous Reinforced Concrete Slab overlying a DBM subbase
  (Chart CC6)
STANDARDS PAVEMENT STRUCTURES

Å - Undowelled Skewed Jointed Plain Concrete Slab overlying a Drainage Layer
   (Chart CC7)

Å - Dowelled Square Jointed Plain Concrete Slab overlying a Drainage Layer
   (Chart CC8)

Å - Plain Rolled Cement Concrete
(Chart RCC)
CC1 Undowelled Skewed Jointed Plain Concrete

- Undowelled Skewed Jointed Plain Concrete
- Separator
- Lean Concrete for Base
- Drainage Layer
- Subgrade
- S1 class is unsuitable and must be improved

CONSTRUCTION PROCEDURES

- Concrete Slab: Fixed Form, Slip Form Paver preferably
- Lean Concrete: Paver and Rollers
- Drainage Layer: Grader and Rollers
CC1 Undowelled Skewed Jointed Plain Concrete

ADVISIED SHOULDER ARRANGEMENTS

- Separator
  - Lean Concrete
  - Drainage Layer
  - Subgrade

Fixed form paving

- Separator
  - Lean Concrete
  - Trenching
  - Drainage Layer
  - Subgrade

Slip form paving

2/24/2012
CC1 Undowelled Skewed Jointed Plain Concrete
A separation membrane is required between subbase and concrete slab,

- To reduce the friction between the slab and the subbase in JUCP and JRCP pavements,
- Inhibits the formation of mid-slab cracks.
- Also reduces the loss of water from the fresh concrete

- The minimum thickness of the polythene sheet shall be 2.6 mm.
- For CRCP pavements, a bituminous spray should be used on the subbase,
A Capping thickness design chart

![Capping thickness design chart](chart.png)
Concrete Slab Thickness and Reinforcement

- The minimum thickness of concrete pavement for JUCP and JRCP pavement is 150 mm.
- For CRCP pavements the minimum thickness is 200 mm.
Jointed Unreinforced Concrete Pavement (JUCP)

Fig 6.2 presents the design thickness of JUCP concrete slab calculated from the design traffic ESAs.

It assumes the presence of an effective lateral support to the edge of the most heavily-trafficked lane, such as a shoulder with a pavement structure able to carry occasional loads.
If this shoulder is absent, an additional slab thickness is required, and this additional thickness can be determined from Fig. 6.3.

JUCP pavements have no reinforcements for crack control. However, the longitudinal and transverse joints are provided with reinforcements. The joint details are discussed in a previous section.

The minimum thickness of concrete pavement for JUCP is 150mm
Concrete Slab Thickness and Reinforcement

- Jointed Reinforced Concrete Pavement (JRCP)
- The thickness of JRCP concrete slab calculated from the design traffic ESAs.
- Reinforcement steel is used between joints for crack control.
- Same figure as that of JUCP is used to determine the longitudinal reinforcement in terms of mm2/m for a design thickness of concrete slab.
- Several alternate combinations of thickness of concrete slab and amount of reinforcement can be compared.
Concrete Slab Thickness and Reinforcement

- With no effective lateral support provided by the shoulder adjacent to the most heavily trafficked lane, an additional slab thickness is required and can be determined using Figure 6.4.
- Add transverse reinforcement, if required, for ease of fixing the longitudinal reinforcement.
- In that case, reinforcement shall be provided at 600 mm spacing and consist of 12 mm diameter steel bars.
- The minimum thickness of concrete pavement for JRCP pavement is 150 mm.
Concrete Slab Thickness and Reinforcement

- **Continuously Reinforced Concrete Pavement (CRCP)**
  - CRCP pavements withstand severe stresses induced by differential movements.
  - Relatively high percentages of steel and no joints except for construction joints and some expansion joints.
  - Since the pavement contains very few joints it is generally smooth riding
  - It is potentially a low-maintenance pavement.
Concrete Slab Thickness and Reinforcement

- The minimum and maximum spacing recommended for longitudinal steel is 100 mm and 220 mm respectively.
- The percentages are 0.5-0.7%.
- For a traffic volume up to 100M ESAs, the thickness of CRCP concrete slab shall be 200mm.
Concrete Slab Thickness and Reinforcement

Å The diameter of the bars should not exceed 20 mm and the center-to-center.
Å If required, transverse reinforcement shall be provided to control the width of any longitudinal cracks that may form.
The diameter of the bars should not be less than 12 mm and the maximum center-to-center spacing of the bars should not be greater than 750 mm.

Transverse reinforcement is normally required only for ease of construction.

It may be omitted except where there is a risk of differential settlements.
As with JUCP and JRCP pavements, in the absence of effective shoulder support adjacent to the most heavily trafficked lane, the additional slab thickness required can be determined using Fig 6.3.

For CRCP pavements the minimum thickness is 200 mm. Hence, the designer should carefully assess the necessity and requirements for such pavements, depending on the design traffic volume.
Concrete Slabs constructed on old Asphalt Pavements: ‘whitetopping’

American Concrete Association on ‘whitetopping’, or overlaying asphalt roads with concrete.

The support given by the existing pavement + subgrade must be taken into account in the thickness design of the concrete slab.
Nomograms which can be used to estimate the Westergard modulus of subgrade reaction, or k-value, on top of the existing pavement are in next slide.

Next slides for asphalt on granular base and on a cement-treated base.

Asphalt thickness is the residual asphalt remaining after milling of the old surface.
Slab design thickness
- old asphalt road on cement-treated base
For Traffic Classes T5? and upwards concrete slab thicknesses ranging from 200mm to 300mm should be satisfactory.

For Traffic Classes T4 and below, concrete slab thicknesses between 130mm and 180mm would be appropriate.
Å Slab design thickness
   old asphalt road on granular base
Tutorial exercise:

- Get the AASHTO Pavement Design Guide 1993 or any other design guide.
- Make a more scientific approach to thickness design

- To be handed in and to be graded
Construction issues

- There are labour-intensive methods employing a minimum of mechanical plant.
- Use of mechanical spreaders and finishers with the side-forms being placed to correct line and level.
- Mechanization there are slip-form pavers in which the side forms are carried on the machine with wire guidance, or lasers, to secure correct line and level.
- Increasing mechanization makes high output possible and good surface finish, but complicates the installation of joints and reinforcement.
Labour Intensive works

- A rotating drum mixer and vibrating tamper bar
- A Timber side forms. Coarse and fine aggregates are apportioned using wooden gauge-boxes,
- A Water is added by volume, using the slump cone test to control workability.
- A alternate bays constructed on each successive day, facilitating the installation of joints and accurate location of dowell bars.
- A labour intensive works can be effective under strict supervision
Medium mechanisation works

Å Ready-mixed concrete should be discharged into a mobile hopper from which the concrete is drawn off into wheelbarrows and raked into an even profile.

Å An additional 10 to 15% of the finished slab thickness is required to allow for compaction.

Å Compaction can be carried out using vibratory equipment, either pokers or vibrating screens working on the side forms.
High mechanisation works
Slip-form pavers are the ultimate in the ingenuity of machinery manufacturers but require an enormous effort and investment to mobilise.

Roller-compacted concrete pavements
Mechanical spreaders adapted by increasing the compactive effort of the vibrating screen.
The compaction process is completed by using steel-wheeled rollers, and joints are cut into the completed concrete.
The concrete mixtures are of low workability, with low water:cement ratios.
Surface finish
A rough surface of the finished concrete is required to give adequate skid resistance
achieved by cutting closely spaced (at 2cm spacings) grooves in the hardened concrete.
The grooves may be cut in the longitudinal direction or transversally, the advantage of the latter being that it assists drainage, although being much noisier.
The noise created by grooved concrete roads is an issue.
Concreting in hot climates

- High temperatures increase the rate of hydration of cement.
- Concrete begins to harden rapidly after mixing so that it can become difficult to spread and compact.
- Rapid early gain in strength can be accompanied by shrinkage and cracking of the concrete with the result that the subsequent gain in strength is much lower than with concrete cured at a lower temperatures.
Concrete cured in damp conditions at 20°C, gain of about 40% in compressive strength is obtained between 7 and 28 days, a slight increase afterwards.

Concrete cured at 50°C there is likely to be little gain in strength between 7 and 28 days, likelihood of weakening afterwards because of the shrinkage cracks that will have developed.
Workability during concrete laying can be increased by adding more water but to maintain the concrete strength, more cement is the required.

Air entraining agents can be used to improve workability and chemical compounds are available to retard the concrete setting, e.g. sugar, but it should be confirmed that their use is not detrimental to the concrete hardening.
The most effective measures involve keeping the concrete components as cool as possible before mixing, protecting the surface of the concrete from the sun if possible and keeping the concrete damp for the first 7 days.
Maintenance and repair

- Keep joints sealed against the entry of water, particularly where there are large daily or seasonal temperature changes.
- Another problem are loose surface stones.
- They can cause spalling of the concrete at the edges of joints.
- Joints on concrete roads should be inspected yearly and loose stones removed.
- Fresh sealing compound may also be required in the joints.
Joints that have become badly spalled can be repaired by cutting out and replacing the damaged concrete but this is a specialised skill and may only be worthwhile on new concrete roads.

Restoring transverse grooves in concrete surfaces worn smooth can be done but an alternative is to provide a bituminous surface dressing. Use of polymer-modified bitumen may assist in obtaining a more durable result.
Mud-pumping may occur at the joints of more heavily trafficked roads, indicating structural inadequacies in that there is no provision for water to drain away beneath joints.

Deterioration can be arrested by drilling holes and placing fresh concrete in the defective foundation.
References

• Design Manual for Roads and Bridges (DMRB), Volume 7 (Pavement Design); IAN 73/06 (Foundation Design); HD29 (Surveys & Investigations); HD30 (Maintenance Assessment Procedure); HD32 (Maintenance of Concrete Roads)
• Also:  [Website Link]
  [Website Link]
• Cement & Concrete Association. Australia, Concrete Roads Manual 1997
• AASHTO Pavement Design Guide 1993
• Whitetopping-State of the Practice: American Concrete Association, 1998
• Road Building in the Tropics: HMSO State of the Art Review 9, Millard, 1993
Appendix A: South African Design Method

Å Five basic steps.
Å Estimating the traffic loads and volumes.
Å Assessment of slab support conditions
Å Joint design and load transfer mechanism
Å Calculation of the concrete slab thickness
Å Estimating the traffic loads and volumes
Estimating the traffic loads and volumes

- Figure 2.1
- Conversions of the total load on a combination of axles to equivalent 80 kN axles for different axle groupings.
- EG the total tandem axle with dual wheels is 150 kN, the equivalent load on dual wheel axles for that particular axle configuration is 88 kN.
- The equivalent no of 80 kN axles can then be calculated from

\[ E_{80} = \left( \frac{P}{80} \right)^n \]
Where

- \( E_{80} \) = equivalent number of 80 kN axles on dual wheel
- \( P \) = is the equivalent load on a single axle dual wheel
- \( n \) = damage factor (4.2 for the South African code, 4.5 for the TZ code)

In this way after an axle survey and subsequent traffic analysis the total number of equivalent 80 kN to be expected can be determined and used as input in Figure 2.5.
Assessment of slab support conditions

Degree of support that the subgrade will provide to the pavement, the stiffness of the support is expressed in terms of stiffness modulus

Determined in the laboratory by doing a triaxial test or similar test under repeated loading.

The stiffness value obtained using this method is the resilient modulus and not the subgrade of modulus reaction, \( k_o \).
Å In the case the top layer is stabilized the stiffness can be obtained from a relationship of unconfined compression value and the stiffness modulus as shown on Figure 2.2.

Å In the case of a subbase sitting on a subgrade Figure 2.3 can be used for obtaining an equivalent slab support.
FIGURE 2.2
Determination of stiffness modulus of stabilised materials
FIGURE 2.3
Determination of equivalent slab support stiffness
Joint design and load transfer mechanism

The more critical stresses usually develop in the vicinity of the cracks or joints in the pavements. It is imperative that load transfer at joints or cracks should be considered in the design of concrete pavements. Load transfer is best explained in the relative joint movement when a 40kN transverses across a joint or crack.
Figure 2.4 shows the how to determine the influence on load transfer caused by changes in bar spacing, bar size, aggregate size and joint spacing. For normal concrete pavements variables such as slab length, aggregate size, dowel spacing etc is specified.

These are normally 4.5 metre spans, 37.5 mm maximum aggregate and 22 mm bars spaced at 600mm centres. If these parameters are changed then Figure 2.4 is used to determine the relative joint moment for incorporation into Figure 2.5.
FIGURE 2.4
Effect of load transfer devices on relative movement
Appendix A: South African Design Method

Calculation of the concrete slab thickness

The concrete thickness is determined from Figure 2.5. The input is the loading in terms of equivalent 80 kN axle loads. The appropriate resilient modulus (MPa) is intersected. The assumption here is that there will be a limited loss of support over 600 mm resulting from erosion settlement, and curling of the slab.
The thickness is derived by considering the relative movement of joints or cracks. The suggested relative movements values for a plain jointed concrete pavement (PJCP), dowel jointed pavements and continuously reinforced concrete pavement (CRCP) are shown on the Figure.

These suggested values assume that standard 37mm aggregate is used and that joints are sealed and that normal wear and tear occurs at the interface between steel bar and concrete as well as between aggregate within the joints or cracks.
FIGURE 2.5
Design of concrete pavement thickness