B.Sc - Road & Railway Design I. *Lecture 9.*

FLEXIBLE & RIGID PAVEMENTS – ROAD DRAINAGE

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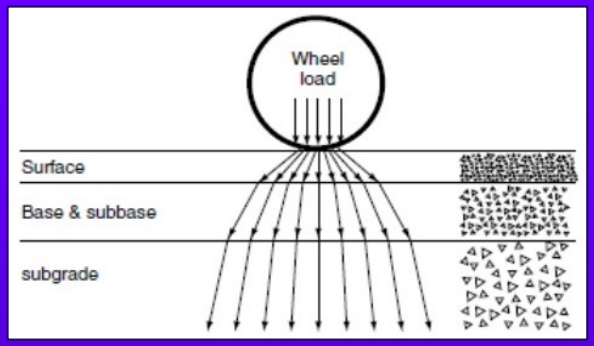
WHAT IS A PAVEMENT?

- Pavement is the actual travel surface especially made durable and serviceable to withstand the traffic load commuting upon it
- Pavement grants friction for the vehicles thus providing comfort to the driver and transfers the traffic load from the upper surface to the natural soil



- A multi layer system that distributes the vehicular loads over a larger area; i. e. a structure consisting of superimposed layers of selected and processed materials whose primary function is to distribute the applied vehicle load to the subgrade
- A structure which separates the tires of vehicles from the underlying foundation, including all structural layers resting on the original ground

FUNCTIONS OF A PAVEMENT

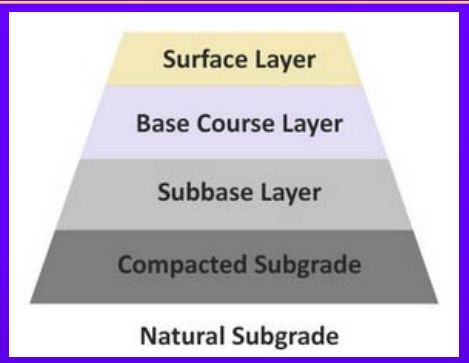
- Reduce and distribute the traffic loading so as not to damage the subgrade
- Provide vehicle access between two points under all-weather conditions
- Provide safe, smooth and comfortable ride to road users without undue delays and excessive wear & tear
- Meet environmental and aesthetics requirement
- Limit noise and air pollution
- Reasonable economy

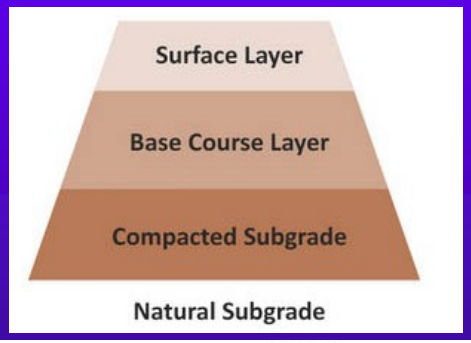
REQUIREMENTS OF PAVEMENT STRUCTURE

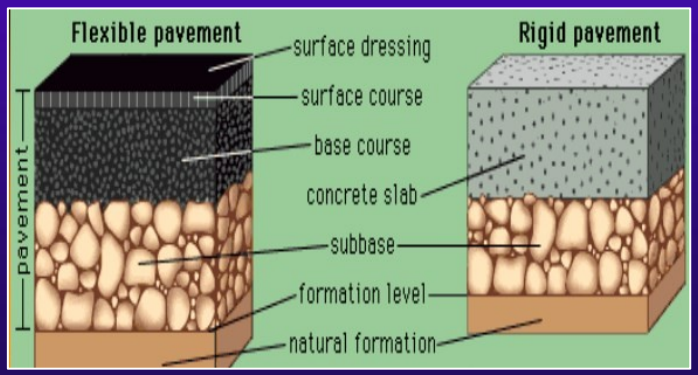
- Sufficient thickness to spread loading to a pressure intensity tolerable/bearable by subgade
- Sufficiently strong to carry imposed stress due to traffic load
- Sufficient thickness to prevent the effect of frost susceptible subgrade
- Pavement material should be impervious to penetration of surface water which could weaken subgrade and subsequently pavement
- Pavement material should be non-frost susceptible
- Pavement surface should be skid resistant

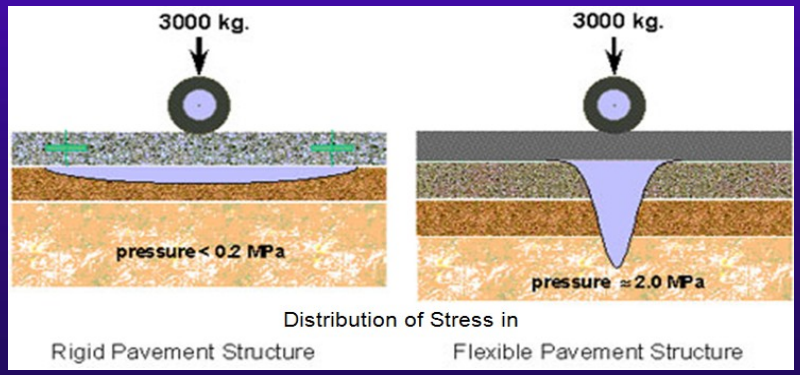
CLASSIFICATION OF PAVEMENTS

- **By function:**
  - Airport pavements
  - Road pavements
  - Street and parking area pavements
  - Bycicle road and footway pavements
- **By structure:**
  - Flexible pavements (asphalt concrete)
  - Rigid pavements (cement concrete)
  - Composite pavements
  - Macadam pavements (without binder)



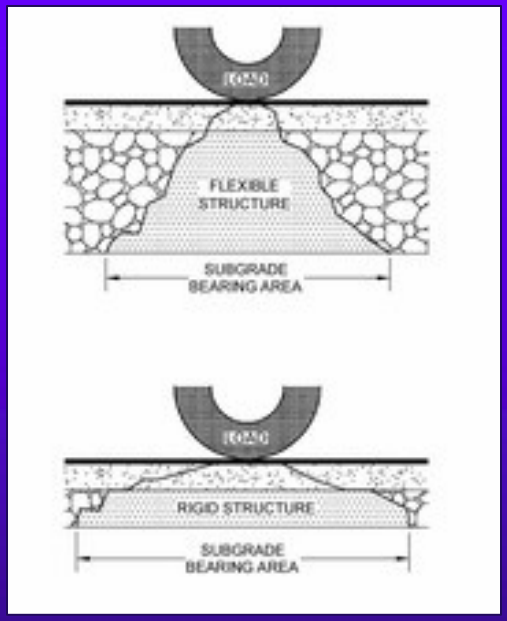




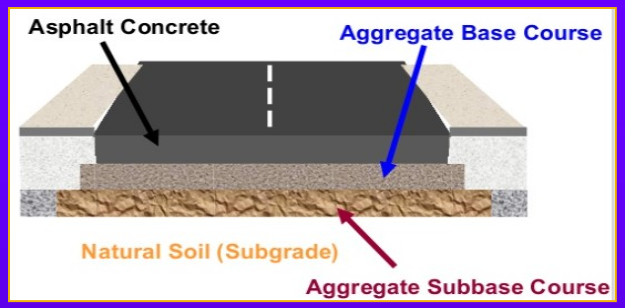


FLEXIBLE PAVEMENTS

- Flexible pavements consists of layered Hot Mix Asphalt (HMA), are so named because the total pavement structure deflects, or flexes under loading
- A flexible pavement structure is typically composed of several layers of different materials, built/laid down separately
- Each layer receives the loads from the above layer, spreads them out, then passes on these loads to the next layer below
- Thus, the further down in the pavement structure a particular layer is, the less load (in terms of force per unit area) it must carry
- In order to take maximum advantage of this property, material layers are usually arranged in order of descending load bearing capacity with the highest load bearing capacity material (and most expensive) on the top and the lowest load bearing capacity material (and least expensive) at the bottom



STRUCTURE OF FLEXIBLE PAVEMENT 1



- ***Surface Course*:**
  - this is the top layer and the layer that comes in contact with traffic loads and normally contains the highest quality materials
  - it provides characteristics such as friction, smoothness, noise control, rut and shoving resistance and drainage (to prevent the entrance of excessive quantities of surface water into the underlying base, sub-base and subgrade)
  - it is sometimes subdivided into two layers:
    - the upper *Wearing Course* is the layer in direct contact with traffic loads (it is meant to take the brunt of traffic wear and can be removed and replaced as it becomes worn)
    - the underlying *Intermediate, or Binder Course* distributes load
- ***Base Course*:** this is the layer directly below the surface course and generally consists of durable aggregates (either stabilized or un-stabilized) that will not be damaged by moisture or frost action, thus it provides additional load distribution and contributes to drainage and frost resistance

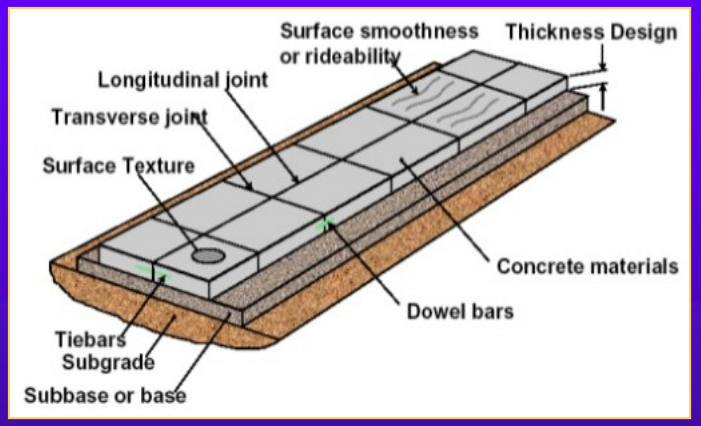
STRUCTURE OF FLEXIBLE PAVEMENT 2

- ***Sub-base Course*: this is the layer (or layers) between the base course and the sub-grade; it functions primarily as structural support, but it can also:**
  - **Minimize the intrusion of fines from the sub-grade into the pavement structure**
  - **Improve drainage**
  - **Minimize frost action damage**
  - **Provides a working platform for construction**
- **It generally consists of lower quality materials than the *Base Course,* but better than the *Sub-grade Course* soils**
- **It is not always needed or used (for example, a pavement constructed over a high quality, stiff sub-grade may not need the additional features offered by a sub-base course so it may be omitted from design)**
- ***Sub-grade Course*: this is the material (soil) upon which the pavement structure is placed - in most cases the top of natural ground or compacted embankment fill; the quality of sub-grade can often be the overriding factor in pavement performance**

TYPES OF HMA SURFACE COURSE

RIGID PAVEMENTS

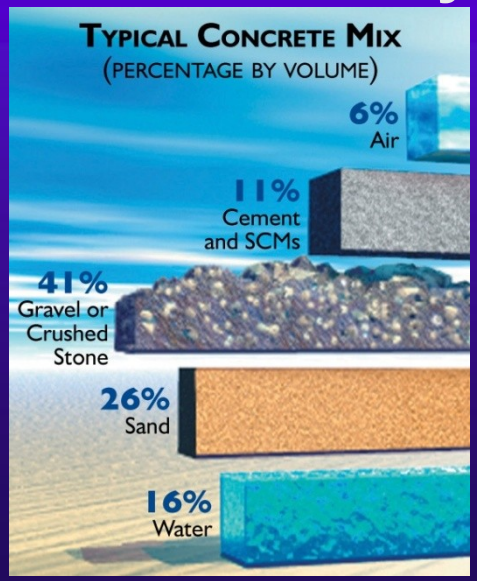
- *Rigid pavements* does not deform under stress i. e. deflects very little under loading due to the high modulus of elasticity of their surface course, which contain sufficient beam strength to be able to bridge over the localized sub-grade failures and areas of inadequate support
- Load is transmitted through beam action of slab in rigid pavements which reduces the stress concent-ration and distributes the reduced stresses uniformly to the area under the slab



- Concrete – air entrained increases resistance to frost damage and de-icing salt corrosion
- Reinforcement – may be bars or mesh; continous rigid pavements have heavy reinforcement, while in non-continuous rigid pavements joints are used to allow for thermal movement
- Includes a ‘filler’ and surface sealant; laid as a single layer

WHAT IS CEMENT CONCRETE?

- Construction material; mixture of portland cement, water, aggregates and in some cases, admixtures
- The cement and water form a paste that hardens and bonds the aggregates together
- Strong, durable, versatile and economical construction material, adaptable to a wide variety of uses
- Composition of cement concrete:
  - Cement (artificial or natural)
  - Water (preferably clean)
  - Aggregates (sandy gravel, crushed stone)
  - Chemical admixtures (influencing curing time and strength)

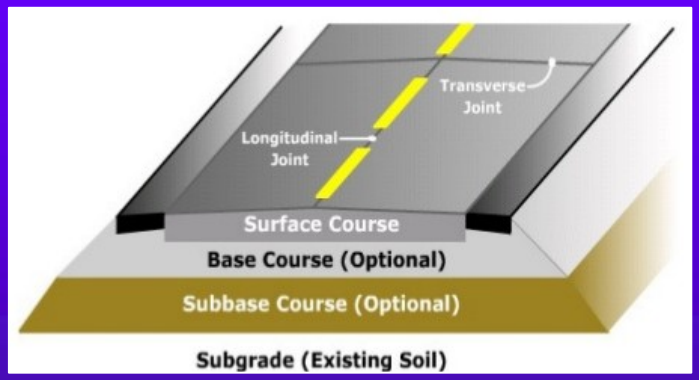


COMPOSITION OF CEMENT CONCRETE

- Cement is a crystalline compound of calcium silicates and other calcium compounds having hydraulic properties; it is considered hydraulic because of their ability to set and harden under or with excess water through the hydration of the cement's chemical compounds or minerals
- The strength and other properties of concrete are highly dependent on the amount of water and the maximum water-cement ratio (in road construction the latter is generally around 45%; for LCB around 60%)
- Aggregates occupy 60 to 80 percent of the volume of concrete; all aggregates must be essentially free of silt and/or organic matter
- Materials (powder or fluids) that are added to the concrete to give it certain characteristics not obtainable with plain concrete mixes; admixture dosages are less than 5% by mass of cement, and are added to the concrete at the time of batching/mixing
- All concrete structures will crack to some extent, due to tensile stress induced by shrinkage or stresses occurring during setting or use

STRUCTURE OF RIGID PAVEMENTS 1

- Rigid pavement structure is composed of a Portland Cement Concrete (PCC) S*urface Course* built on top of either the sub-grade or an underlying base course
- *Surface course* is the top layer in contact with traffic loads, it consists of the reinforced or continuously reinforced concrete slabs; it provides characteristics such as friction, smoothness, noise control and drainage and it serves as a waterproofing layer to the underlying base, sub-base and sub-grade



- The surface course can vary in thickness but is usually between 150 mm (for light loading) and 300 mm (for heavy loads and high traffic volumes)

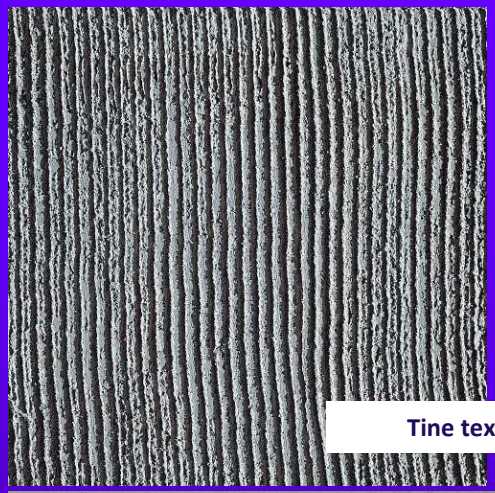
STRUCTURE OF RIGID PAVEMENTS 2

- *Base Course* is the layer directly below the PCC layer and generally consists of aggregate or stabilized sub-grade; it provides:
  - Additional load distribution
  - Contributes to drainage and frost resistance
  - Uniform support to the pavement and
  - A stable platform for construction equipment
- *Base Courses* are usually constructed out of
  - Crushed aggregates (a common option since the early 1900s)
  - Stabilized aggregate or soil - *cement treated bases* (CTB-s) can be built to as much as 20-25%; while *lean concrete bases* (LCB-s) can be built to as much as 25-50% of the surface course strength
  - Dense-graded HMA (in situations where high *base stiffness* is desired)
  - Permeable, or open graded HMA (in situations where high base stiffness and *excellent drainage* is desired)

STRUCTURE OF RIGID PAVEMENTS 3

- *Sub-grade* provides support to the overlying concrete slab; if it is of good quality then slab can be laid over it without providing sub-base otherwise (if it is extremely poor), a sub-base layer should be incorporated
- For design purpose the only thing to know about sub-grade is its classification and the unit pressure coming from slab to sub-grade should be calculated for its selection; however, it must be resistant to moisture damages
- The choice between flexible or rigid pavement is based mainly on technical & economic arguments, but heavily influenced by the competition between oil and cement industries as well

TYPES OF PCC SURFACE COURSE



Tine texturing

Diamond grinding and grooving

Concrete Renew with a broom finish

Brushed concrete surface

COMPARISON OF PAVEMENTS

FLEXIBLE PAVEMENT

- Deformation in the sub grade is transferred to the upper layers
- Design is based on load distributing characteristics of the component layers
- Have low flexural strength
- Load is transferred by grain to grain contact
- Have low completion cost but repairing cost is high
- Have short life span *(high maintenance cost)*
- Surfacing cannot be laid directly on the sub grade but a sub base is needed
- No thermal stresses are induced as the pavement have the ability to contract and expand freely
- That Is why expansion joints are not needed
- Strength of the road is highly dependent on the strength of the sub grade
- Rolling of the surfacing is needed
- Road can be used for traffic within 24 hours
- Force of friction is less
- Damaged by oils and certain chemicals

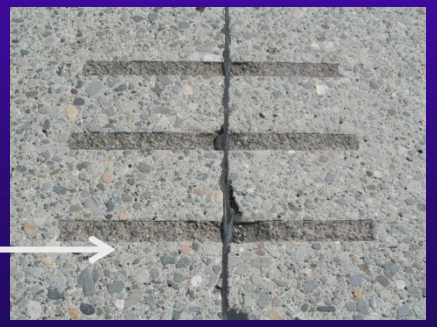
RIGID PAVEMENT

- Deformation in the subgrade is not transferred to subsequent layers
- Design is based on flexural strength or slab action
- Have high flexural strength
- No such phenomenon of grain to grain load transfer exists
- Have low repairing cost but completion cost is high
- Life span is more as compare to flexible pavements *(low maintenance cost)*
- Surfacing can be directly laid on the sub grade
- Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete
- Thats why expansion joints are needed
- Strength of the road is less dependent on the strength of the sub grade
- Rolling of the surfacing in not needed
- Road cannot be used until 14 days of curing
- Force of friction is high
- No damage by oils and greases

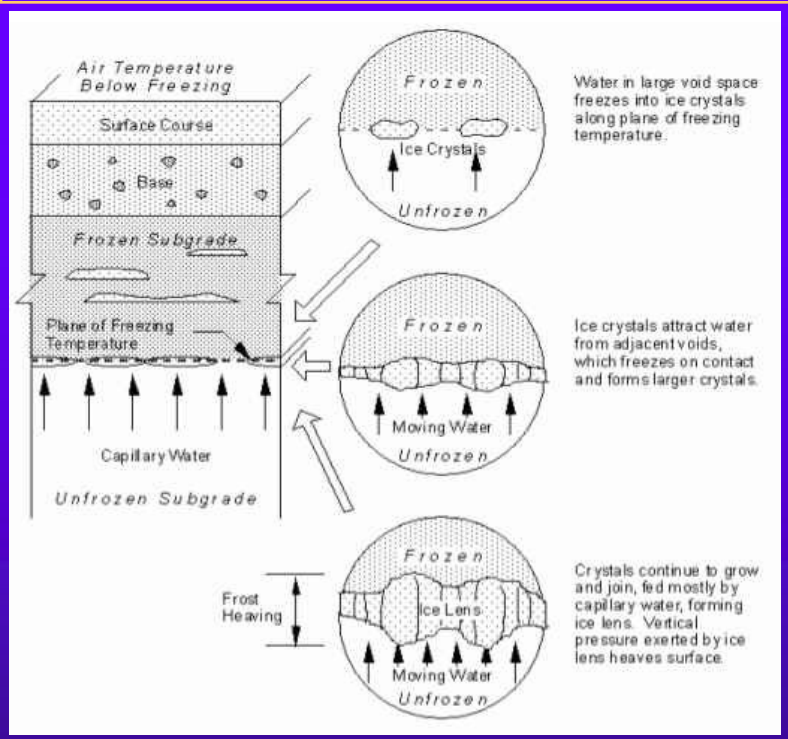
TYPES OF PAVEMENT FAILURE

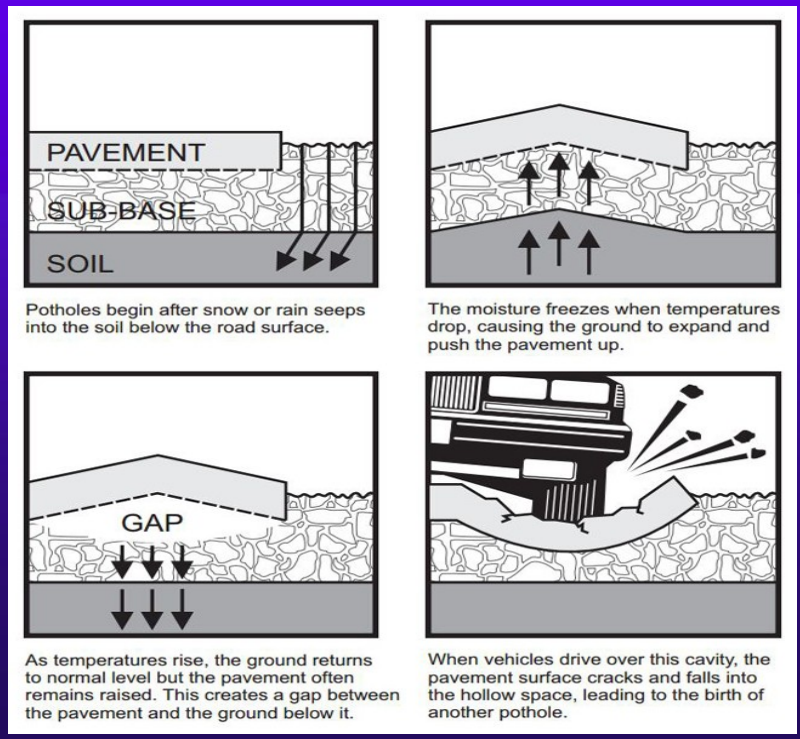
- Flexible Pavements
  - Fatigue (alligator) Cracking
  - Rutting
  - Thermal (block) Cracking

- Rigid Pavements
  - Fatigue Cracking
  - Pumping or erosion
  - Others: faulting, spalling, joint deterioration

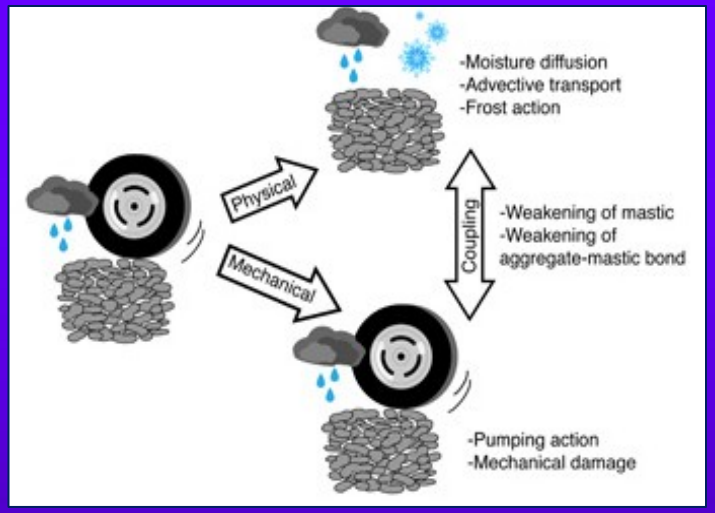


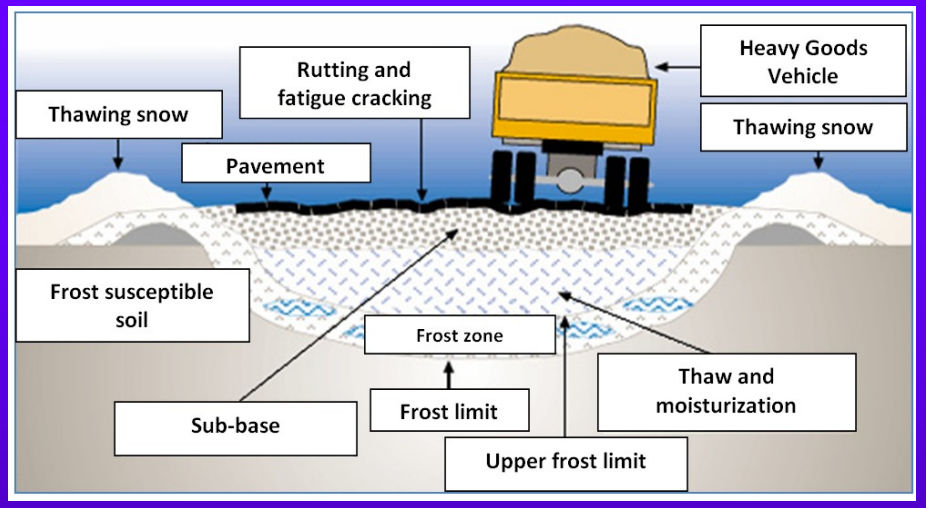
FREEZE-THAW DAMAGE





SNOWBREAK DAMAGE





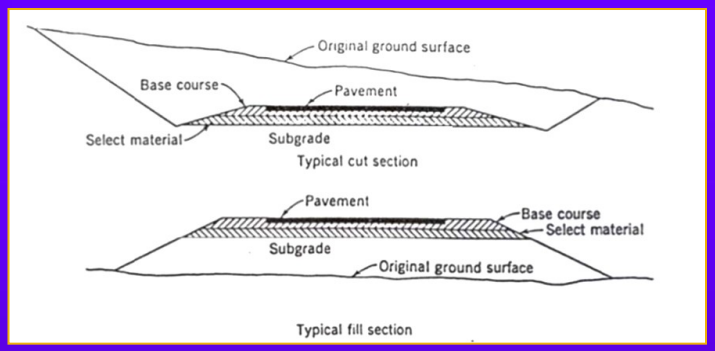
IMPORTANCE OF DRAINAGE

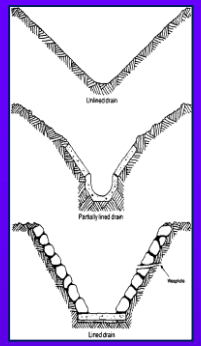
- Water on or under the roadway is the *single most significant cause of damage* to the roadway
- Problems related to water include rutting, cracking, potholes, erosion, washouts, heaving, flooding and premature failure of the roadway
- To prevent these problems and help ensure a roadway achieves its designed *service life*, an appropriate *drainage system* is planned
- A good drainage system includes several elements, all of which must function properly and be well maintained:
  - Surface drainage
  - Subsurface drainage
  - Culverts, ditches and gutters

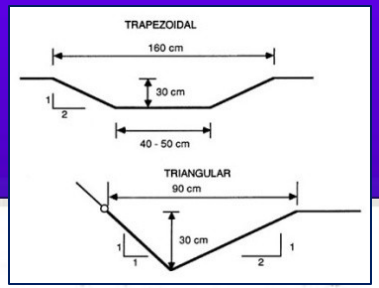
SURFACE DRAINAGE

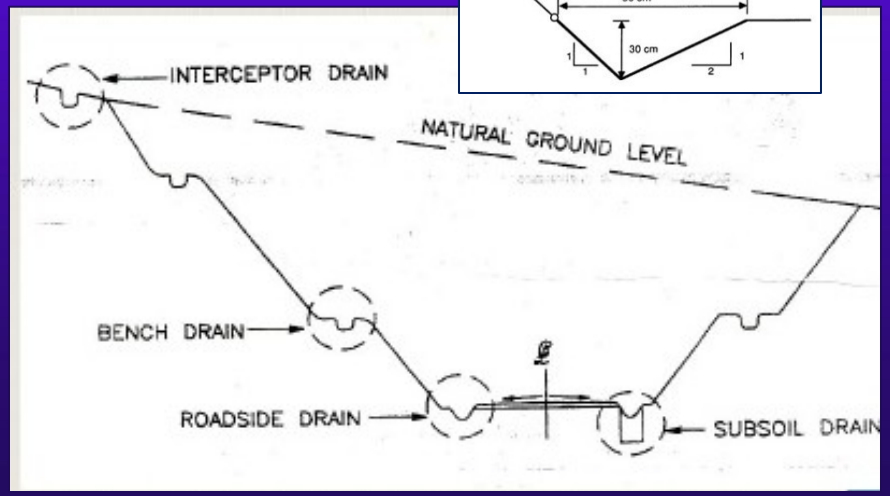
- It deals with the drainage of *storm water runoff* from the road surface & the surfaces adjacent to the roadway
- Several elements can be used to intercept or capture this runoff and facilitate its safe discharge to an appropriate receiving location
- After falling onto road surfaces, rainfall runoff drains to the lowest point and in moving across the road surface forms a layer of water of varying thickness - this water can be a hazard to the motorist: splash and heavy spray are thrown up by moving vehicles *reducing visibility*, whilst the water on the pavement *reduces friction* between the tires and road surface
- Design of the elements for this runoff must adequately cater for the safety and convenience of road users, including pedestrians and protect adjacent properties and the road pavement from damage

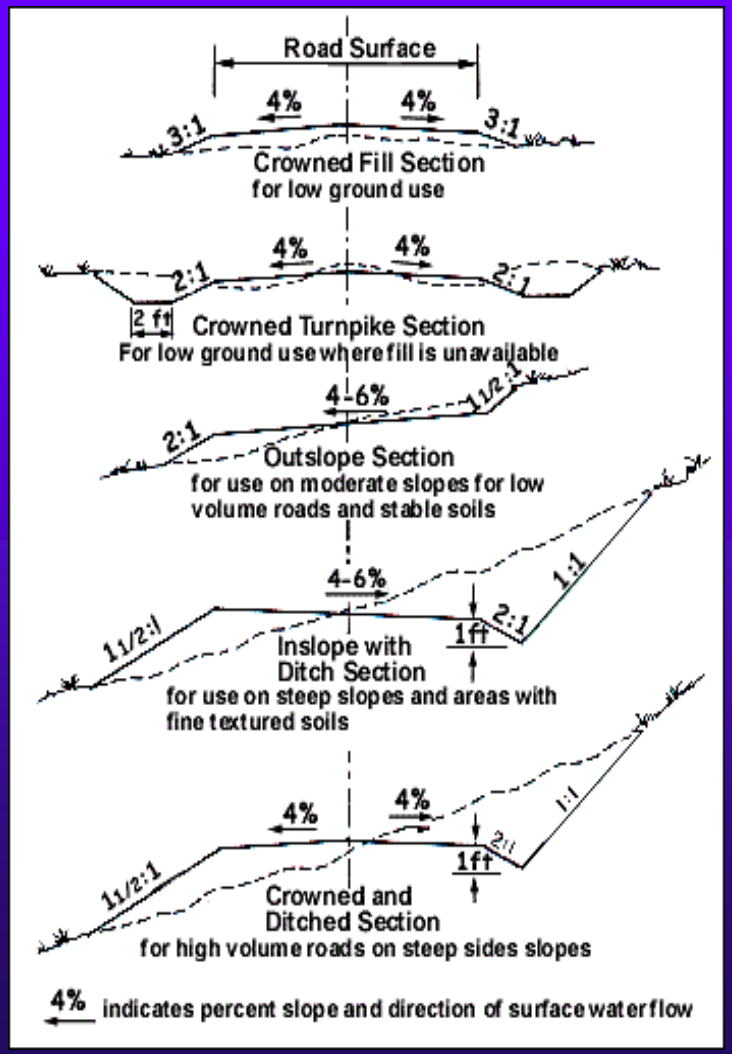
NOMENCLATURE GUIDE











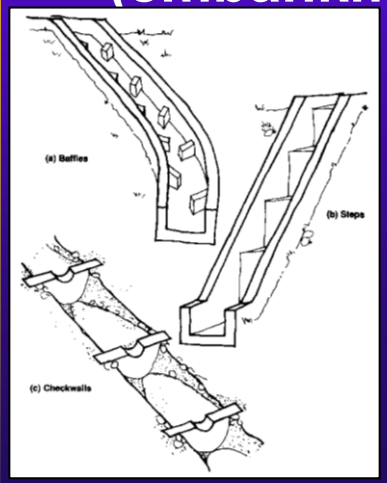
DITCHES

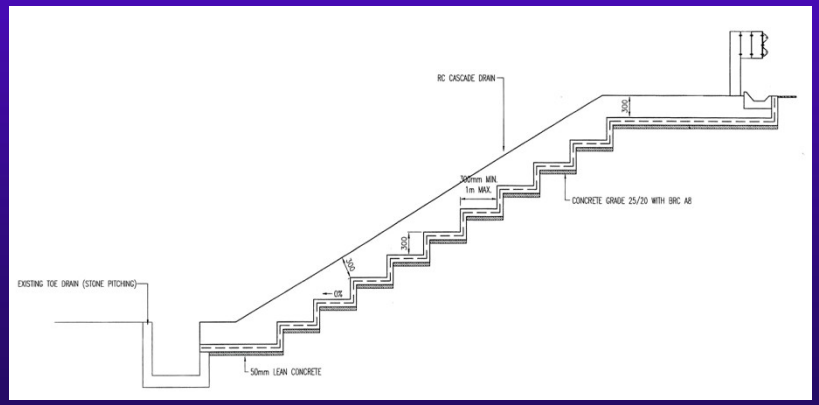
- Ditches (unpaved or paved) collect water runoff from the road surface
- A well- maintained, smooth- flowing ditch will be free of heavy vegetation (tall grass, trees, cattails, etc.) and standing water, with enough grade (min 2.5%) to ensure self-cleaning and continuous flow of water
- Ditches with flat percent-of-grade allow residue or debris to settle and fill in the ditch - if sediment accumulates, water may erode a new path *outside* of the ditch area



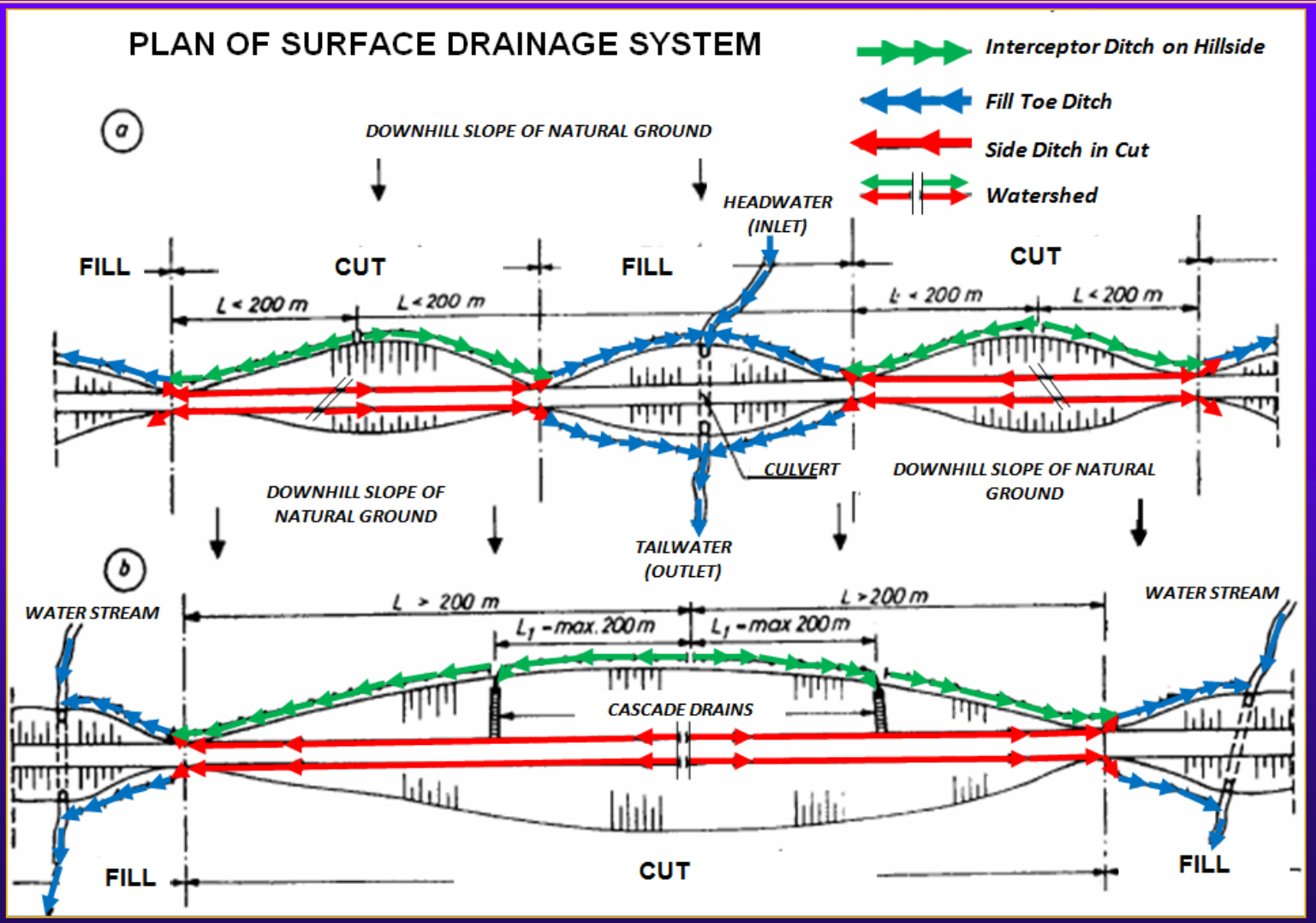

CASCADE DRAINS

- They are built to divert water from a *slope*, leading it in a controlled way through *baffles* built into to slow down (reduce the kinetic energy of) the flow
- Typical elements of surface drainage slopes of high (>3.0 m) fill sections (embankments) of motorways





SURFACE DRAINAGE SYSTEM



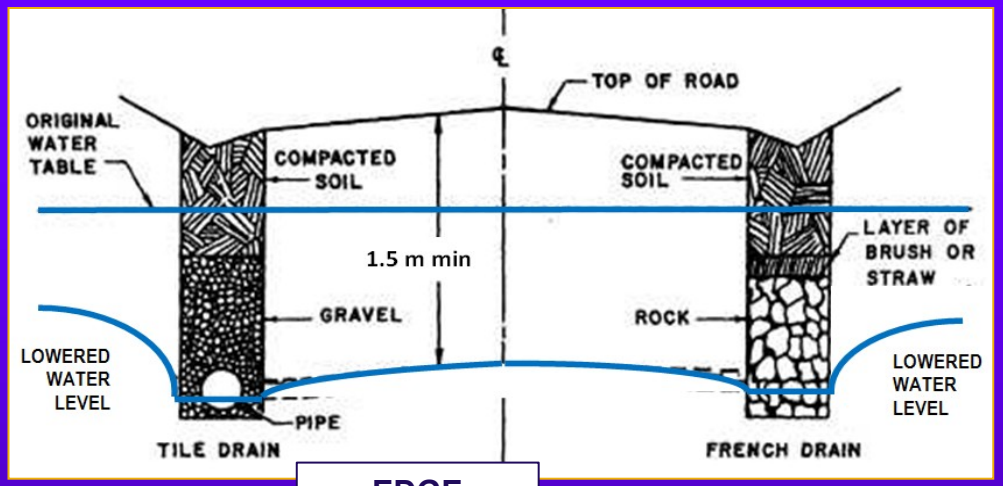
SUBSURFACE DRAINAGE

- Carries water from beneath the pavement to appropriate drainage features, like ditches or storm drains
- The purpose of subsurface (or subsoil) drainage is to control the moisture content of the pavement and the surrounding material in order to maintain pavement strength and serviceability throughout the design life
- The design and installation of subsurface or subsoil drains beneath / adjacent to road pavements is essential where groundwater or seepage is considered to be present
- Subsurface drainage systems are generally installed in a road either to remove water from the subgrade and pavement materials or to intercept water before it reaches the road structure
- The elements of subsurface drainage include sub-drains (under-drains and edge drains)

UNDER-DRAINS

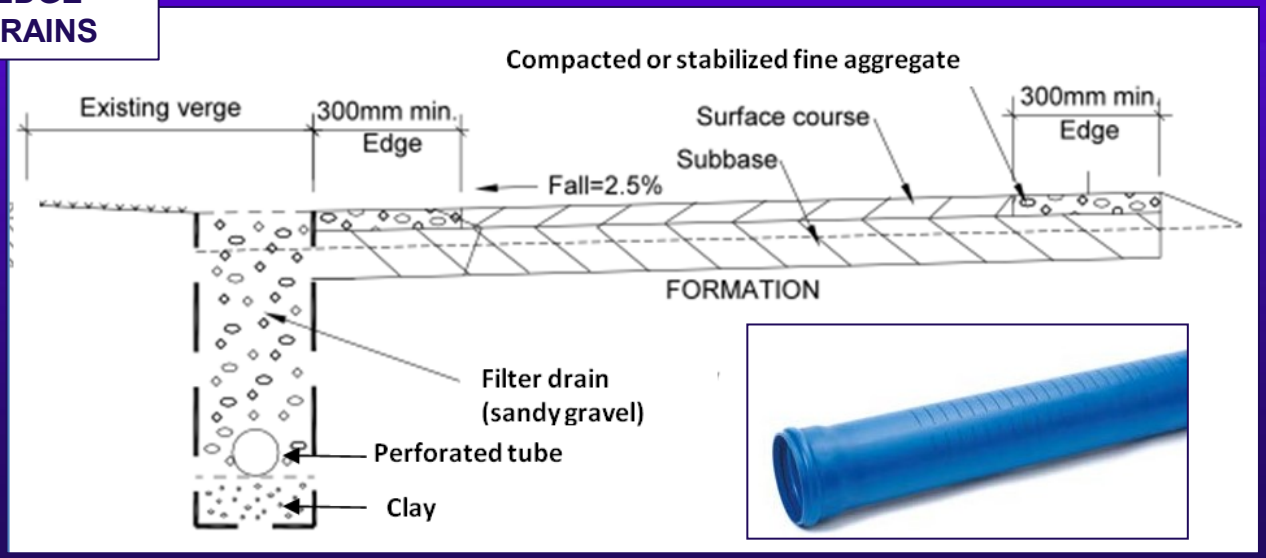
- A well-maintained system of transverse and longitudinal *drainage pipes* effectively intercepts and carries water out of the granular layer
- *Under-drains* carry water from the granular drainage layer to edge drains, while *edge drains* are installed under shoulders or ditches, longitudinally adjacent to the pavement
- *Edge drains* are constructed during roadway construction where a perforated pipe is installed in a trench parallel to the roadway, which is then backfilled with an open-graded aggregate:
  - Caps of impervious soil are placed on top of edge drains to prevent surface water from draining into them
  - Filters may be used to prevent fine-grained soil from clogging the open-graded aggregate or the pipe itself
  - Water from the under-drains is collected in a non-perforated edge drain pipe that discharges into a roadside ditch or a storm sewer system

EDGE DRAINS



EDGE DRAINS

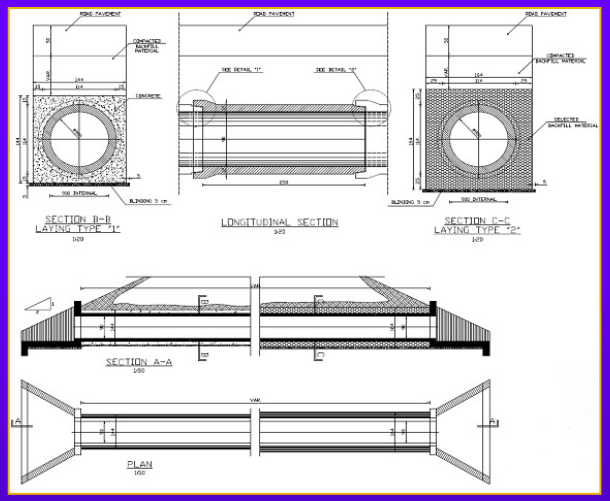
UNDER DRAINS

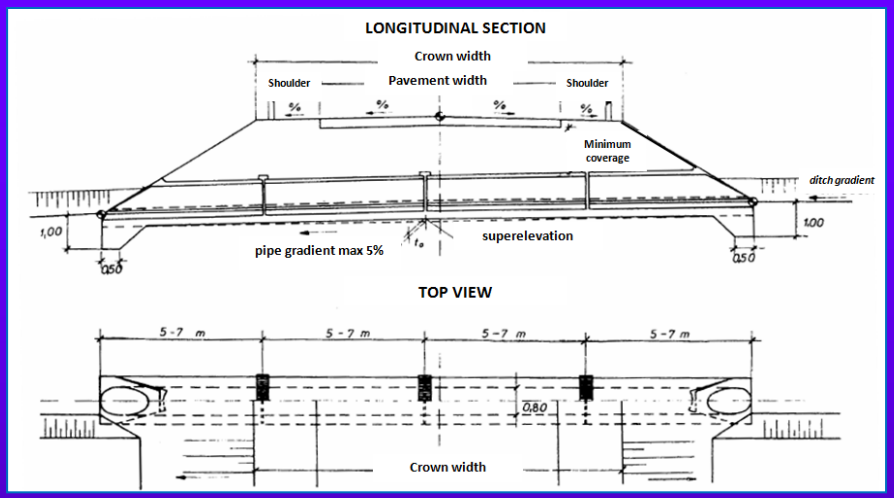


CULVERTS

- Culverts provide drainage under driveways, roads, slopes, and adjacent areas
- Their grade and direction should conform as closely as possible to that of the water they are carrying
- They are built from tubular or angular precast concrete elements or from corrugated metal (steel pipes)
- Culverts are well maintained when
  - the flow line and the design slope from inlet to outlet still exist
  - no sections have settled and all joints are tight and not separated
  - the curtain walls are not exposed, and
  - the downstream channel has not started to erode

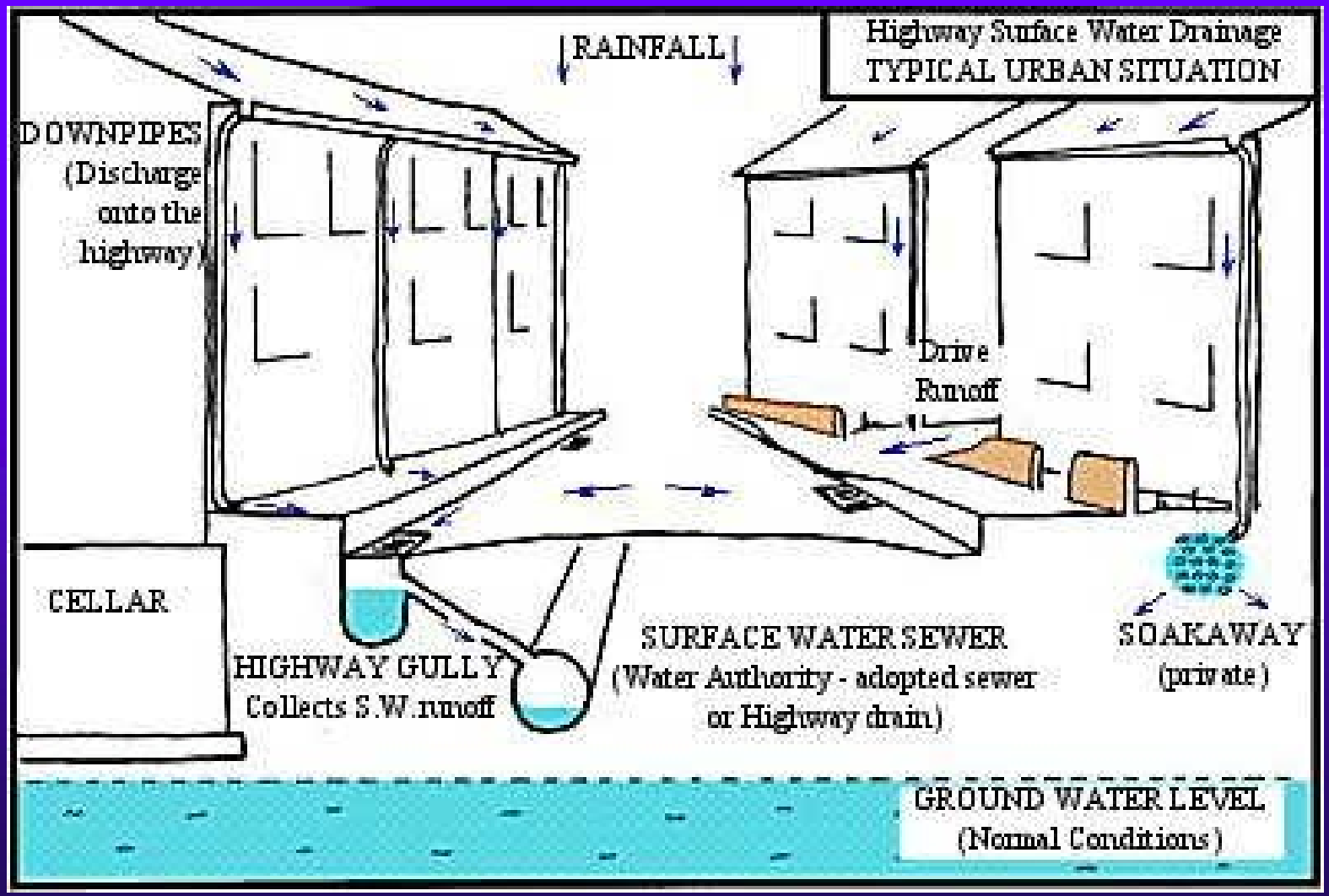
CULVERTS


SECTION B-B
LAYING TYPE "1"
LONGITUDINAL SECTION
SECTION C-C
LAYING TYPE "2"
SECTION A-A
PLAN


LONGITUDINAL SECTION
Crown width
Shoulder
Pavement width
Shoulder
Minimum coverage
ditch gradient
1,00
pipe gradient max 5%
superelevation
1,00
0,50
0,50
TOP VIEW
5 - 7 m
5 - 7 m
5 - 7 m
5 - 7 m
0,80
Crown width

STORMWATER DAMAGING MOTORWAY (M1/HUNGARY; 2010)

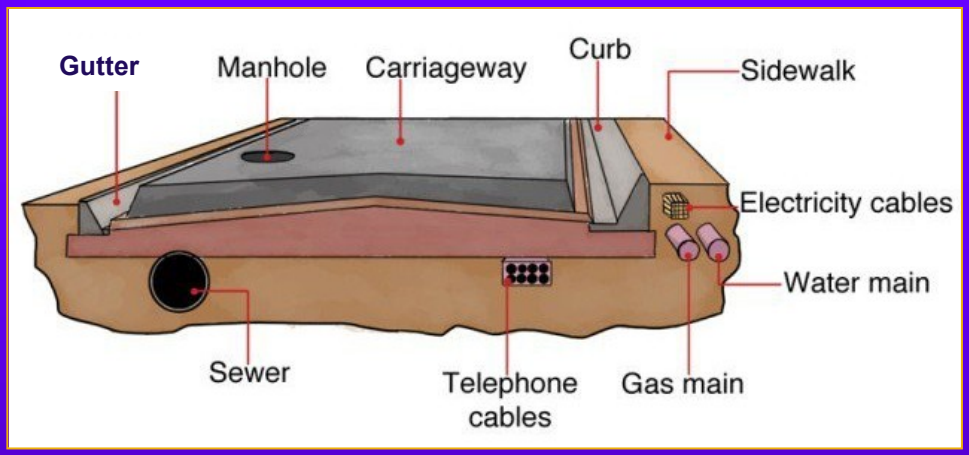
URBAN ROAD DRAINAGE 1

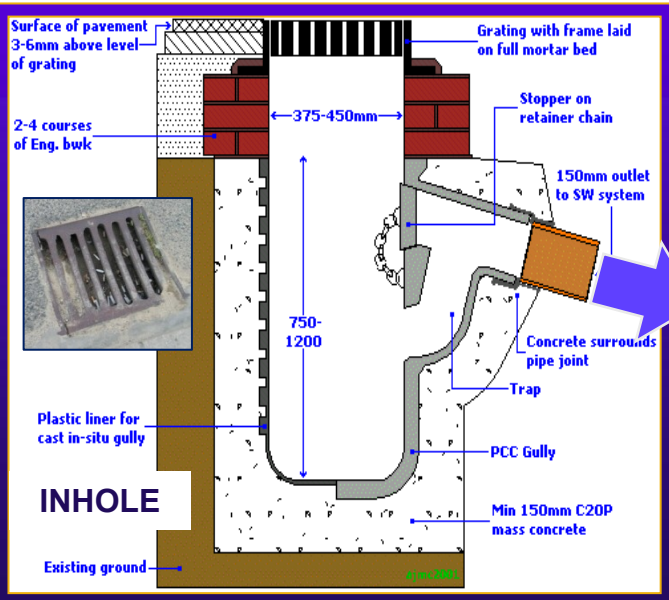


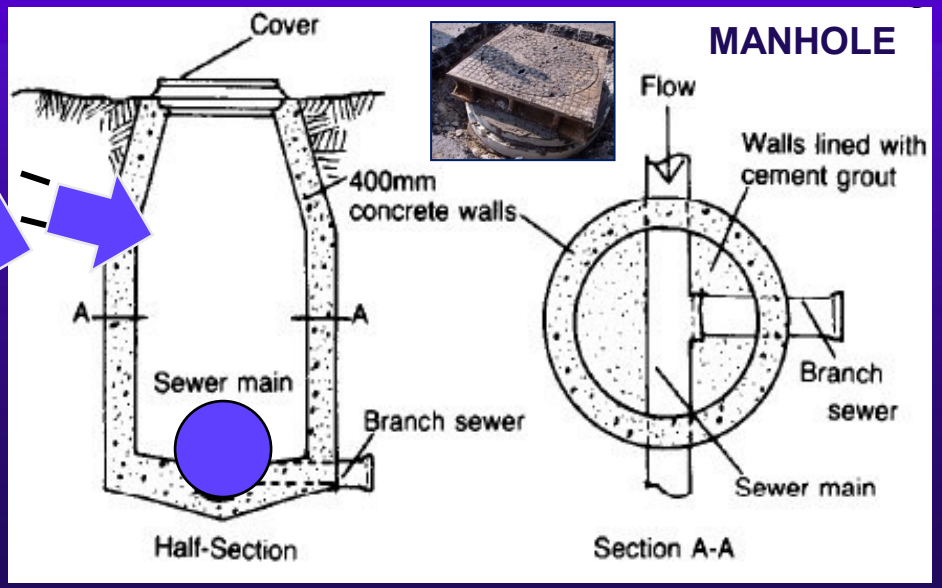
URBAN ROAD DRAINAGE 2

- A *gutter* is a depression running parallel to a road designed to collect rainwater flowing along the street and divert it into a *storm-drain*
- A gutter alleviates water buildup on a street, allowing pedestrians to pass without walking through puddles and reducing the risk of hydroplaning/aquaplaning by road vehicles
- When a *curbstone* is present, a gutter may be formed by the convergence of the road surface and the vertical face of the sidewalk; otherwise, a dedicated gutter surface made of concrete may be present

GUTTER, INHOLE & MANHOLE







GULLY, SOAKAWAY & SEWER

- A *gully* is a drainage pit covered by an open metal grating located on the road edge; it's purpose is to drain rainwater from the road surface into the sewerage system through the *drain pipe*
- A *soakaway* is a drainage pit covered by a me-tal cover or sometimes by soil; its purpose is to allow rainwater from buildings to permeate into the surrounding subsoil
- A *sewer* is a large underground drain con-necting the road drains and carrying surface water to the *wastewater treatment plant*

MANHOLE COVER, GULLY & UNDERGROUND SEWER

STORMWATER DAMAGING URBAN ROAD (Mátrakeresztes/Hungary; 2005)