REPUBLIC OF CAMERO0N
****
Peace – Work – Fatherland

Ecole Nationale Supérieure des Travaux Publics

****
DEPARTEMENT DE GENIE CIVIL
DEPARTEMENT OF CIVIL ENGINEERING

REPUBLIC OF CAMERO0N
****
Peace – Work – Fatherland

UNIVERSITÀ DEGLI STUDI DI PADOVA

****
DEPARTMENT OF CIVIL, ARCHITECTURAL AND ENVIRONMENTAL ENGINEERING

TREATMENT OF CAPILLARY RISE ON THE UNDERLYING LAYER OF A ROADWAY: CASE OF THE BANGANGTÉ – FOUMBOT – BAMENDJING – GALIM ROADWAY

A thesis submitted in partial fulfilment of the requirements for the degree of Master in Engineering (MENG) in Civil Engineering.

Curriculum: **Geotechnical Engineering**

Presented by

TSAGUE TEMOTSOP Rita Mabelle

Matricule number: **15TP20950**

Supervised by:

Prof. Eng. Simonetta COLA

Academic year: 2019-2020

DEDICATION

To my beloved parents TSAGUE Paul and KINFACK VOUFO Christiane

Unconditionally grateful for your love and support

AKNOWLEGEMENT

I would like first of all to thank the Almighty GOD for his benevolence and beneficence that enabled me to complete my studies and consequently this thesis. This thesis is a humble attempt to sketch down the contributions of all those persons who have directly or indirectly contributed by their precious time, help and guidance to the completion of this thesis. I therefore extend my sincere thanks and gratitude to :

- My supervisor Prof. **Simonetta COLA** for their continuous guidance, advices and constructive criticisms they provide me with, during this thesis work;
- Prof. **George NKENG ELAMBO**, Director of the National Advanced School of Public Works Yaounde, for his great contribution and devotion to the promotion and the success of the new academic status;
- Prof **Carmelo MAIORANA** for the participation in initiating the Engineering curricula in the National Advanced School of Public Works Yaounde;
- Prof. **MBESSA Michel**, the head of department of Civil Engineering for his availability, corrections and valuable advices during this thesis work;
- Eng **MBO Franky Serein , Head of Control Mission** for his continuous guidance, advices and constructive criticisms he provided me with, during this thesis work;
- **All the teaching staff** of the National Advanced School of Public Works Yaounde and University of Padova for their good quality teaching and the motivation they developed in us to continue our studies;
- **All my classmates** who were a source of motivation and tenacity;
- **My beloved family** for the education, moral and financial support during all these years;
- **All those people,** who are not mentioned here who from near or far have given me their support.

LIST OF ABBREVIATIONS AND SYMBOLS

List of abbreviations

GW	Well-Graded Gravel
GP	Poorly Graded Gravel
SW	Well Graded Sand
SP	Poorly Graded Sand
MH	Heavy Silt
ML	Lean Silt
CL	Lean Clay
CH	Heavy Clay
SWCC	Soil Water Characteristic Curve
AC	Asphalt Concrete
PCC	Pavement And Rigid Pavement
HDPE	High Density Polyethylene
L.A	Los Angeles
AASHTO	American Association Of State Highway And Transportation Officials
DRIP	Drainage Requirement In Pavement
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
NHI	National Highway Institute
Mn/DOT	Minnesota Department Of Transportation
AOS	Apparent Opening Size
ASTM	American Society For Testing And Materials
CPE	Corrugated Polyethylene
PVC	Polyvinyl Chloride
SDR	Standard Dimension Ratio
FE	Finite Element
2D	2 Dimensions
PK	Point Kilometrique
IRAD	Institut De Recherche Agricole Pour Le Développement
PNDP	Programme National De Développement Participatif
CBR	Californian Bearing Ratio
HMA	Hot Mix Asphalt

List of symbols

S_r	degree of saturation
w	Water content
M_w	Mass of water
M_s	Mass of solid
V_v	Volume of voids
V	Total volume
e	Void ratio
ψ_m	Matric suction
ψ_o	Osmotic suction
ψ_t	Soil suction
u	pressure
z	elevation
h_c	Height of capillary rise
q_i	Infiltration
C	Infiltration ratio
U	Degree of drainage
k	permeability
k_x	Horizontal permeability
k_y	vertical permeability
L_R	Resultant length
S_R	Resultant slope
N	porosity
Ne	effective porosity
γ_{dry}	Dry unit weight
γ_{sat}	Saturated unit weight
Gsb	specific gravity
q_d	Discharge rate
H	thickness
t_d	Time to drain
Q	Flow capacity
W	Width
φ	Friction angle

E	Young's modulus
ν	Poisson's ratio
ψ	dilatancy angle
PK	Point kilometrique
P_{200}	#200 Sieve
D_x	15% finer
D_{50}	50% Finer
D_{85}	85% Finer
D_{10}	10% Finer

ABSTRACT

The main objective of this study was to propose a techno-economic solution to remedy the (negative) impacts of capillary rise and to redirect it outside the pavement structure, preventing it from affecting its strength, life span and material behaviour. To carryout this research, we visited the site of the road project entitled *" Routes de désenclavement du bassin agricole de l'Ouest "* . The site visit enabled us to have a view of the problem and to collect the necessary data (geometric, geotechnical, etc.) for the design of the drainage system. Two softwares were used: DRIP (Drainage requirement In Pavement Systems) for the design of the drainage system elements and PLAXIS 2D for the stability analysis of the system. Two drainage systems were designed and analysed: Case 1 with a laterite, pozzolana and boulders as drainage layer and Case 2 with pozzolana and crushed stone (25/63) as drainage layer. The results of the analysis revealed that the drainage system containing boulders has a better drainage capacity than that with crushed stone with resultant drainage rates of 5.68 m/day and 3.74 m/day respectively. A cost analysis (based on the costs generally applied in the locality in road works) showed that case 1 with boulders was more cost effective than case 2 with crushed stone with a cost representing 47.2% of that of case 2. This is mainly due to the cost of the input materials, as boulders requires fewer resources than 25/63 crushed stone due to its hierarchical positioning in the production line.

Keywords: Capillary rise, subsurface drainage, subsurface water, drainage system

RESUME

L'objectif principal de cette étude était de proposer une solution technico-économique pour remedier aux impacts (négatifs) des rémontées d'eaux par capillarités et rediriger ces dernieres hors emprise des couches de la structure chaussée, afin qu'il n'affecte pas sa résistance, sa durée de vie et le comportemnet des materiaux. Pour mener à bien cette recherche, nous avons visité le site du projet routier intitulé " *Routes de désenclavement du bassin agricole de l'Ouest* " . La visite de site nous a permis d'avoir une vue d'ensemble du problème et de collecter les données nécessaires (géométriques, géotechniques, etc.) pour la conception du système de drainage. Deux logiciels ont été utilisés : DRIP (Drainage requirement In Pavement Systems) pour la conception des éléments du système de drainage et PLAXIS 2D pour l'analyse de stabilité du système. Deux systèmes de drainage ont été conçus et analysés : : le cas 1 avec une couche de drainage en latérite, pouzzolane et moellon et le cas 2 avec un système de drainage en pouzzolane et pierres concassées 25/63. Les résultats de l'analyse ont révélé que les le système avec les moellons présentent une meilleure capacité de drainage que celle avec les pierres concassées avec respectivement des vitesses de drainage de 5,68 m/jour et 3,74 m/jour. Une analyse des coûts (à la base des coûts généralement appliqueés dans la localité dans les travaux routiers) a demontré que le cas 1 avec des moellons était plus rentable que le cas 2 avec des pierres concassées avec un coût representant 47.2% de celle du cas 2. Ceci est principalement dû au coût des matériaux d'entrée, les moellons nécessitant moins de ressources que les pierres concassées 25/63 en raison de leur positionnement hiérachique dans la ligne de production.

Mots clés : remontée capillaire, drainage souterrain, eau souterraine, système de drainage.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENT

GENERAL INTRODUCTION

The road construction project entitled *"Routes de desenclavement du basin agricole de l'Ouest"* presents several natural phenomena that must be solved for the project to be completated and projected objectives reached. One of these is upwelling by capillarity along several parts of its length. Water in and beneath a road pavement has a major impact on the road's performance and its survivability. Hence, it is of great importance to identify the sources of moisture into the pavement, one of which is capillary rise and find a way to move it out of the pavement body. The detrimental effects of water on the structural support of the pavement system include *stripping* (debonding of aggregates and binder at the bottom of HMA layer), *bleeding* (formation of asphalt binder film on the pavement) and *rutting* (surface depression along wheel path). The phenomenon of upwelling by capillarity can be solved through the design of an adequate subsurface drainage system to convey water out of the pavement layers toward gutters. This research aims at setting out requirements and a technical-economic solution to guide excess water out of the pavement layers in order to prevent water beneath the pavement to weaken the pavement structure and allow subterranean water to enter the structure affecting its strength, service life and traffic conditions. To do this, we have to design a drainage system, analyse its stability and perform a comparative analysis to select the adequate solution to solve the above mentioned problem.

This study is divided into three (03) chapters where chapter 1 introduces us to the knowledge of soils, how they are formed, their properties and types, as well as sources and fates of water in roads. Different subsurface dranage system used in literature to guide water out of the pavement are presented in this chapter. Chapter 2 presents the method used in the design of the drainage system including a presentation of the softwares, DRIP (Drainage Requirement in Pavements) and PLAXIS, used in the design and stability analysis of the drainage system respectively. Finally, the case study site, results of design and analysis as well as a technico-economic analysis will be presented in chapter 3.

CHAPTER 1: LITERATURE REVIEW

Introduction

Soil is one of the most important parts of the natural environment. The word soil has different meanings for different professions. To the agriculturalist, the soil is the top thin layer of the earth within which organic forces are predominant and which is responsible for the support of plant life. To geologist, the soil is the material in the top thin zone within which roots occur. From the point of view of an engineer, soil includes all earth materials, organic and inorganic, occurring in the zone overlying the rock crust (Murthy,2002). The behaviour of a structure depends on the properties of the soil material on which the structure exists. It is of great importance to understand the soil constituents, its formation, properties, classification and functions. With these known, we will have a better understanding of soil behaviour and how it is affected by its environment as well as engineering structures such as road pavement and how to treat the effects of natural phenomenon affecting these structures.

1.1. Soil constituents

Most soils consist of four components and three phases (Figure 1.1). The four components include inorganic solids, organic solids, water, and air. Inorganic components are primary and secondary minerals derived from the parent material. Organic components are derived from plants and animals. The liquid component consists of a dilute aqueous solution of inorganic and organic compounds. The gaseous component includes soil air comprising a mixture of some major gases (e.g., nitrogen, oxygen) and trace gases (e.g., carbon dioxide, methane, nitrous oxide) (Dragila,2005).

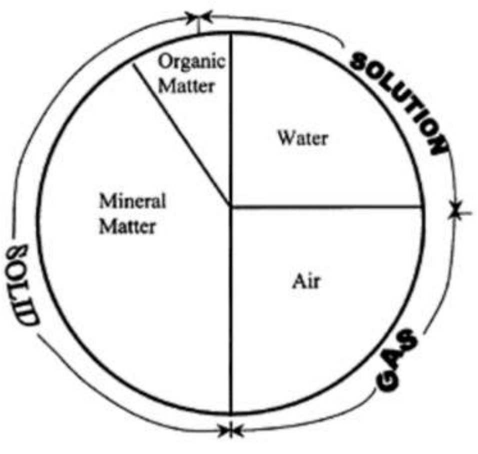


Figure 1.1. Soil constituents (Dragila, 2005)

The components of a soil can be represented by a phase diagram as shown in Figure 1.2(a). The following relationships are defined with reference to Figure 1.2(a). (Craig, 2004): Water content, degree of saturation, void ratio and porosity.

The water content (w), or moisture content (m), is the ratio of the mass of water to the mass of solids in the soil, i.e.

$$w = \frac{M_w}{M_s} \quad (1\text{-}1)$$

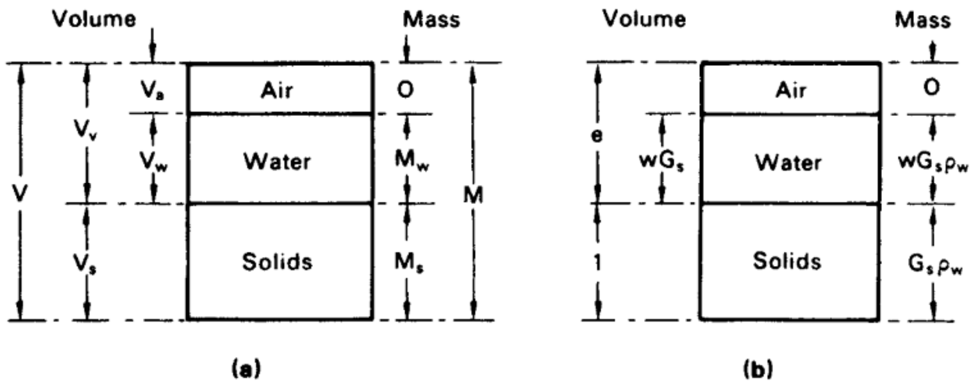


Figure 1.2. Phase diagram (Dawson, 2005)

The degree of saturation (S_r) is the ratio of the volume of water to the total volume of void space, i.e.

$$S_r = \frac{V_w}{V_s} \quad (1\text{-}2)$$

The degree of saturation can range between the limits of zero for a completely dry soil and 1 (or 100%) for a fully saturated soil.

The void ratio (e) is the ratio of the volume of voids to the volume of solids, i.e.

$$e = \frac{V_v}{V_s} \quad (1\text{-}3)$$

The porosity (n) is the ratio of the volume of voids to the total volume of the soil, i.e.

$$n = \frac{V_v}{V} \quad (1\text{-}4)$$

1.2. Soil formation

Soil is a most outer soft most layer of the earth, formed by different process. The factors which transformed rocks into soil differ in from place to place. The soil formation or the pedogenesis is a continuous process. It is the process that involves environment and its component, time and geological history.

1.2.1. Soil formation factors

The soil scientist, Hans Jenny in 1941 suggested that type of soil found on any site is dependent upon the interaction of five factors. Jenny's state factor equation for soil genesis:

$$S = f(C, O, R, P, T, \dots) \qquad (1\text{-}5)$$

C = Climate, O = Organisms, R = Relief (topography) , P = Parent Material, T = Time

...= Other unspecified factors

1.2.1.1. Climate

Temperature plays a vital role in soil formation. Temperature and moisture affect the rate of weathering, organic decomposition and biological activity. High rate of heat and humidity accelerates the microbial action, where as cold and dry climates slow down the process. The seasonal change of heat flux, precipitation and water movement influence the depth and pattern of removal and accumulation of soluble and colloidal constituent of soil. Extreme climatic condition such as ice, wind and precipitation can cause physical weathering, soil erosion and as well as deposition accumulation of parent materials. Stable and humid condition causes deep soil deposition (Tripathy, Raha, 2019).

1.2.1.2. Organism

Soil formation is influenced by organisms and micro-organisms, burrowing insects, animals and humans. As soil forms, plants begin to grow in it. The plants mature, die and a new one takes their place. Their leaves and roots are added to the soil. Animals eat plants and their wastes and eventually their deceased bodies are added to the soil (Tripathy, Raha, 2019).

1.2.1.3. Topography

Topography is meant by the lay of land which includes shape, length and grade of slope. It may be the relative steepness of slope or the flatness of plain. It is overall orientation of the land with the respect to sun rays and the aspect of the land determines the type of vegetation and indicates the type of rainfall it receives. These factors change the way soil is formed. It also directly impacts the water drainage (Tripathy, Raha, 2019).

1.2.1.4. Parent Material

Soil minerals are the basis of soil. They are produced from parent rocks through the process of weathering and other process of natural disintegration. Water, wind, temperature change, gravitation force, chemical reaction, intervention of living organism and differences in pressure, all work as a united force to break down the parent material. The type of parent rock and the condition, under which it broke down, deeply influences the property of the soil (Tripathy, Raha, 2019).

1.2.1.5. Time

Soils develop very slowly. Young soils retain many of the characteristics of the parent material. Over time they acquire other features resulting from the addition of the organic matter and the activity of the organism. The most important feature of the soil is that they pass through a number of stages as they develop, resulting in a deep profile with many well differentiated horizons. The chronosequence used in soil studies assumes sites that have developed over different periods of time with relatively small differences in soil forming factors. The soil profile continuously changes with time (Tripathy, Raha, 2019).

1.2.2. Soil formation processes

Soil development includes processes which are essential in the genesis of different type of soil owing to varied diversity in alignment with the aforesaid factors. The main soil forming processes include: Weathering, decomposition, and translocation.

1.2.2.1. Weathering

Weathering is the in situ breakdown of intact rock and rock masses due to physical and chemical processes under the influence of atmospheric and hydrospheric factor (Hack, 2006) which implies the decay and change in state from an original condition to a new one (Price, 2009). Weathering can be of three types namely physical weathering, chemical weathering and biological weathering.

a. Physical or mechanical weathering

Physical or mechanical weathering is the disintegration of a rock material into smaller pieces without any change in the original property of the rock. It usually results from temperature and pressure changes. The main mechanism for this type of weathering are wedging, exfoliation and abration. Exfoliation occurs when rock layers break apart due to the removal of confining pressure such as when slopes are excavated (Huisman et al,2011) or eroded (Gamon, 1983). Abrasion is the physical grinding of rock fragments either by action of water or air.

b. Chemical weathering

This process involves the formation of new materials (clays and salts) when minerals react with water. This process is more favoured in warm, damp, climate. The most common processes of chemical weathering are dissolution, hydrolysis and oxidation. Dissolution mainly occurs when certain minerals are dissolved by acidic solutions. Hydrolysis occurs when pure water ionizes and reacts with silicate minerals and it is assumed that the original mineral is transformed to a totally new mineral. Oxidation or rusting involves the combination of certain metals with oxygen allowing electron transfer leading to the formation of crumbly and weak rocks (Colman & Dethier, 1986).

c. Biological weathering

Biological weathering encompasses weathering caused by plants, animals and microbes. Some organisms release acidic and chelating compounds as well as inorganic nutrients that enhances chemical weathering. Microorganisms can oxidise organic or mineral compounds that they use as a source of enrgy for their growth and reproduction (Lerman & Meybeck, 1988). The ability of large plant species like trees to thrive in rocky slopes that their roots and the associated microorganisms can potentially induce mineral weathering (Boyle & Voigt, 1973).

1.2.2.2. Decomposition

Decomposition is the breakdown, by physical and biological mechanisms, of organic substances found in the soil. Plant remains, deposited on or in the soil, are known as plant litter. Concomitant with the breakdown of litter is the synthesis of meta-stable substances known as humus. During decomposition inorganic substances including plant nutrients are both released (mineralized) from and incorporated (immobilized) into the decaying material. Animal remains are qualitatively quite different from plant remains. Although animal remains may be locally significant, they represent a very small proportion of the organic matter input to a soil (McClaugherty, 2001).

1.2.2.3. Translocation

Apart from the physical disintegration and chemical alteration processes, there is a third process that has an extremely important action on the formation of soil and that is the translocation of substances, which on the one hand mixes and adds the edaphic materials and on the other separates and concentrates them. All these actions are carried out either by soil organisms, especially those that excavate galleries, such as worms and ants, or by a simple mechanical effect, very often due to the action of water transporting materials, sometimes in suspension and sometimes in dissolution. This dragging by the action of water has very important effects on the soil and can eliminate the substances transported from the profile or accumulate them at a certain depth.

1.3. Properties of soils

Civil engineering structures like building, bridge, highway, tunnel, dam, tower, etc. are founded below or on the surface of the earth. For their stability, suitable foundation soil is required. To check the suitability of soil to be used as foundation or as construction materials, its properties are required to be assessed. The main properties discussed are the physical, chemical and geotechnical properties of soil.

1.3.1. Physical properties

Soil is comprised of minerals, soil organic matter, water, and air (Figure 1.1). The composition and proportion of these components greatly influence soil physical properties, including texture, structure, and porosity, the fraction of pore space in a soil. In turn, these properties affect air and water movement in the soil, and thus the soil's ability to function.

1.3.1.1. Soil Texture

Soil texture can have a profound effect on many other properties and is considered among the most important physical properties. Texture is the proportion of three mineral particles, sand, silt and clay, in a soil. These particles are distinguished by size, and make up the fine mineral fraction (Table 1.1). Particles over 2 mm in diameter (the 'coarse mineral fraction') are not considered in texture, though in certain cases they may affect water retention and other properties. The relative amount of various particle sizes in a soil defines its texture, i.e., whether it is a clay, loam, sandy loam or other textural category (Figure 1.3). Texture is the result of 'weathering,' the physical and chemical breakdown of rocks and minerals. Because of differences in composition and structure, materials will weather at different rates, affecting a soil's texture. Since weathering is a relatively slow process, texture remains fairly constant and is not altered by management practices (McCauley et al,2005).

Table 1.1. Diameter of soil particles (McCauley et al,2005).

Soil particle	Diameter(mm)
Gravel	>2.0
Sand	0.05-2.0

Silt	0.002-0.05
Clay	<0.002

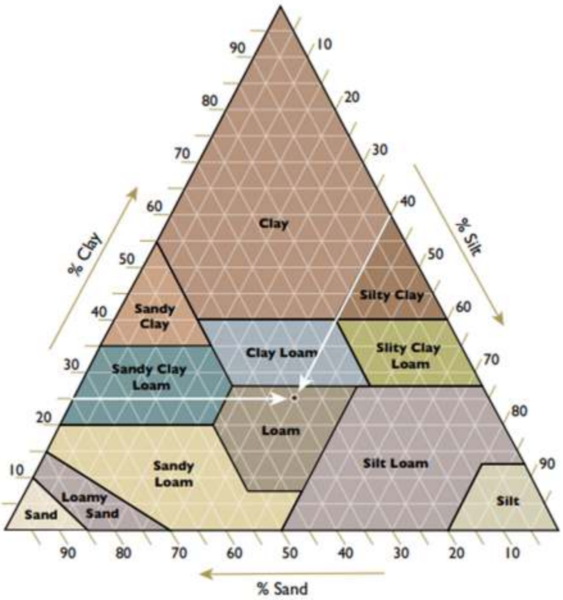


Figure 1.3. Textural triangle showing a soil's textural class according to percentage of sand, silt and clay content (McCauley et al,2005)

1.3.1.2. Soil Structure

Soil structure is the arrangement and binding together of soil particles into larger clusters, called aggregates or 'peds.' Aggregation is important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility and carbon sequestration in the soil (Nichols et al., 2004). 'Granular' structure consists of loosely packed spheroidal peds that are glued together mostly by organic substances. As soil swells (wets or freezes) and then shrinks (dries or thaws), cracks form around soil masses, creating peds. Peds are held together and in place through the adhesion of organic substances, iron oxides, clays or carbonates. Cracks and channels between peds are important for water, air, and solute transport and deep-water drainage. Finer soils usually have a stronger, more defined structure than coarser soils due to shrink/swell processes predominating in clay-rich soils and more cohesive strength between particles.

1.3.1.3. Soil Porosity

Many important soil processes take place in soil pores (the air or water-filled spaces between particles). Soil texture and structure influence porosity by determining the size, number and interconnection of pores. Coarse textured soils have many large (macro) pores because of the loose arrangement of larger particles with one another. Fine-textured soils are more tightly arranged and have smaller (micro) pores (Figure 1.4). Macropores in fine-textured soils exist between aggregates. Because fine-textured soils have both macro- and micropores, they generally have a greater total porosity, or sum of all pores, than coarse-textured soils. Unlike texture, porosity and structure are not constant and can be altered by water and chemical processes.

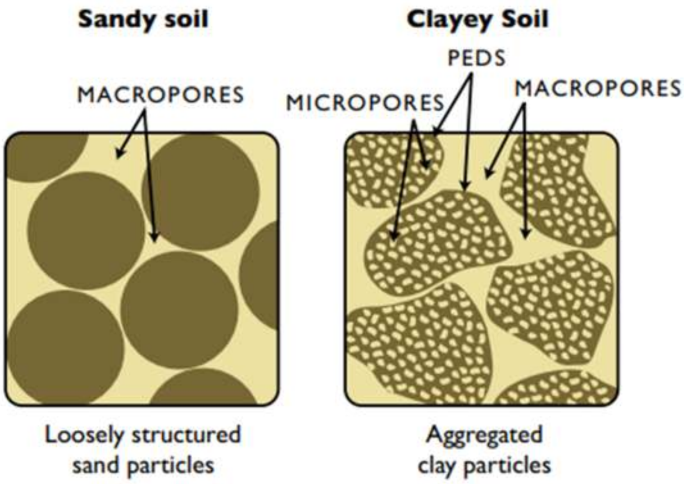


Figure 1.4. Generalised porosity in sandy and clayey soils (McCauley et al,2005)

1.3.2. Chemical properties

The chemical properties of soils discussed here are: exchange capacity and soil PH

1.3.2.1. Exchange capacity

Most chemical interactions in the soil occur on colloid surfaces because of their charged surfaces. Due to their chemical make-up and large surface area, colloids have charged surfaces that are able to sorb, or attract, 'ions' (charged particles) within the soil solution. Depending on the ion's charge, size and concentration in the soil, it can be sorbed and held to the colloid surface or exchanged with other ions and released to the soil solution. The soil's ability to sorb and exchange ions is its 'exchange capacity'. Although both positive and negative charges are present on colloid surfaces, soils of this region are dominated by negative charges and have an overall (net) negative charge. Therefore, more cations (positive ions) are attracted to exchange sites than anions (negative ions), and soils tend to have greater cation exchange capacities (CEC) than anion exchange capacities (AEC). Fine-textured soils usually have a greater exchange capacity than coarse soils because of a higher proportion of colloids (McCauley et al,2005).

1.3.2.2. Soil PH

Soil pH refers to a soil's acidity or alkalinity and is the measure of hydrogen ions (H+) in the soil A high amount of H+ corresponds to a low pH value and vice versa. The pH scale ranges from approximately 0 to 14 with 7 being neutral, below 7 acidic, and above 7 alkaline (basic). Soil pH can affect CEC and AEC by altering the surface charge of colloids. A higher concentration of H+ (lower pH) will neutralize the negative charge on colloid thereby decreasing CEC and increasing AEC. (McCauley et al,2005).

1.3.2.3. Salt affected soils

The presence and concentration of salts in soil can have adverse effects on soil function and management. Salt affected soils are most common in arid and semi-arid regions where evaporation exceeds precipitation and dissolved salts are left behind to accumulate, or in areas where vegetation or irrigation changes have caused salts to leach and accumulate in low-lying places (saline seeps). The three main types of salt-affected soils are saline, sodic and saline-sodic (Q&A #1). Saline soils contain a high amount of soluble salts, primarily calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}), whereas sodic soils are dominated by sodium (Na^{+}). Saline-sodic soils have both high salt and Na^{+} content. Salts in soil can affect structure, porosity and plant/water relations that can ultimately lead to decreased productivity (McCauley et al,2005).

1.3.3. Geotechnical properties

Different geotechnical properties of soils have different influence on the civil engineering structures. They depend upon each other and include: specific gravity, density index, consistency limit, particle size, consolidation and permeability.

1.3.3.1. Specific gravity

Specific gravity is the ratio of the mass of soil solids to the mass of an equal volume of water. It is an important index property of soils that is closely linked with mineralogy or chemical composition and also reflects the history of weathering. It gives an idea about suitability of the soil as a construction material; higher value of specific gravity gives more strength for roads and foundations. Based on the study, Roy and Dass found that increase in specific gravity can increase the shear strength parameters (cohesion and angle of shearing resistance). Roy observed that increase in specific gravity also increases the Calfornia bearing ratio i.e. strength of the subgrade materials used in road construction. Typical values of specific gravity are given in Table 1.2.

Table 1.2. Typical values of specific gravaity (Bowles,2012)

Type of soil	Specific gravity
Sand	2.65-2.67
Silty sand	2.67-2.70
Inorganic clay	2.70-2.8
Soil with mica or iron	2.75-3.00
Organic soil	1.00-2.6

1.3.3.2. Density index

The degree of compaction of fine-grained soils is measured in relation to maximum dry density for a certain compactive effort, like 90% of light compaction density or proctor density. But in case of coarse-grained soils, a different sort of index is used for compaction. Depending upon the shape, size, and gradation of soil grains, coarse grained soils can remain in two extreme states of compaction, namely in the loosest and densest states. Any intermediate state of compaction can be compared to these two extreme states using an index called relative density or density index (Roy, 2007).

1.3.3.3. Consistency limits

The consistency of a fine-grained soil is largely influenced by the water content of the soil. A gradual decrease in water content of a fine-grained soil slurry causes the soil to pass from the liquid state to a plastic state, from the plastic state to a semi-solid state, and finally to the solid state. The water contents at these changes of state are different for different soils. The water contents that correspond to these changes of state are called the Atterberg limits. The water contents corresponding to transition from one state to the next are known as the liquid limit, the plastic limit and the shrinkage limit. The range of the plastic state is given by the difference between liquid limit and plastic limit and is defined as the plasticity index (Roy, 2007).

a. The liquid limit

The liquid limit of a soil is the water content, expressed as percentage of the weight of the oven dried soil, at the boundary between the liquid and plastic states of consistency of the soil. The soil has negligibly small shear strength.

b. The plastic limit

The plastic limit of a soil is the water content, expressed as a percentage of the weight of oven dried soil, at the boundary between the plastic and semi-solid states of consistency of the soil.

c. The shrinkage limit

The shrinkage limit is the maximum water content expressed as a percentage of oven-dried weight at which any further reduction in water content will not cause a decrease in volume of the soil mass, the soil mass being prepared initially from remolded soil. The finer the particles of the soil, the greater are the amount of shrinkage.

d. The plasticity indexes

The plasticity index is used in soil classification and in various correlations with other soil properties as a basic soil characteristic. Based on the plasticity index, the soils were classified by Atterberg, shows the correlations between the plasticity index, soil type, degree of plasticity and degree of cohesiveness (Table 1.3). Skempton observed that the plasticity index of a soil increases linearly with the percentage of the clay-sized fraction. Laskar and Pal found that plasticity depends on grain size of soil. With the increase of sand content plasticity index of soil decreases, which might be due to decrease of inter molecular attraction force.

Table 1.3. Types of soils based on plasticity index (Roy,2007)

Plasticity index (%)	Soil type	Degree of plasticity	Degree of cohesiveness
0	Sand	Non-plastic	Non-cohesive
<7	Silt	Low plastic	Partly cohesive
7-17	Silty clay	Medium plastic	Cohesive
>17	Clay	High plastic	Cohesive

1.3.3.4. Particle size

The percentage of different sizes of soil particles coarser than 75 μ is determined by sieve analysis whereas less than 75 μ are determined by hydrometer analysis. Based on the particle size analysis, particle size distribution curves are plotted. The particle size distribution curve (gradation curve) represents the distribution of particles of different sizes in the soil mass. It gives an idea regarding the gradation of the soil i.e., it is possible to identify whether a soil is well graded or poorly graded. Bowles found that particle-size is one of the suitability criteria of soils for roads, airfield, levee, dam, and other embankment construction. Information obtained from particle-size analysis can be used to predict soil water movement, although permeability tests are more generally used (Roy, 2007).

1.3.3.5. Permeability

The amount, distribution, and movement of water in soil have an important role on the properties and behavior of soil. The engineer should know the principles of fluid flow, as groundwater conditions are frequently encountered on construction projects. Water pressure is always measured relative to atmospheric pressure, and water table is the level at which the pressure is atmospheric. Soil mass is divided into two zones with respect to the water table: (i) below the water table (a saturated zone with 100% degree of saturation) and (ii) just above the water table (called the capillary zone with degree of saturation ≤ 100%) (Roy, 2007).

1.3.3.6. Shear strength

The shear resistance of soil is the result of friction and the interlocking of particles and possibly cementation or bonding at the particle contacts. The shear strength parameters of soils are defined as cohesion and the friction angle. The shear strength of soil depends on the effective stress, drainage conditions, density of the particles, rate of strain, and direction of the strain. Thus, the shearing strength is affected by the consistency of the materials, mineralogy, grain size distribution, shape of the particles, initial void ratio and features such as layers, joints, fissures and cementation. The shear strength parameters of a granular soil are directly correlated to the maximum particle size, the coefficient of uniformity, the density, the applied normal stress, and the gravel and fines content of the sample. It can be said that the shear strength parameters are a result of the frictional forces of the particles, as they slide and interlock during shearing (Roy, 2007).

Raj,2012 and Prakash,2002 explained that the capability of a soil to support a loading from a structure, or to support its overburden, or to sustain a slope in equilibrium is governed by its shear strength. The shear strength of a soil is of prime importance for foundation design, earth and rock fill dam design, highway and airfield design, stability of slopes and cuts, and lateral earth pressure problems. It is highly complex because of various factors involved in it such as the heterogeneous nature of the soil, the water table location, the drainage facility, the type and nature of construction, the stress history, time, chemical action, or environmental conditions.

1.4. Types of soils

The actions of frost, temperature, gravity, wind, rain and weathering are continually forming rock particles that eventually become soils. There are three types of soil when considering modes of formation; Transported soils, residual soils, and organic soils (Smith, 2014).

1.4.1. Transported soil (gravels, sands, silts and clays)

Most soils have been transported by water. As a stream or river loses its velocity it tends to deposit some of the particles that it is carrying, dropping the larger, heavier particles first. Hence, on the higher reaches of a river, gravel and sand are found whilst on the lower or older parts, silts and clays predominate, especially where the river enters the sea or a lake and loses its velocity. Ice has been another important transportation agent, and large deposits of boulder clay and moraine are often encountered. In arid parts of the world, wind is continually forming sand deposits in the form of ridges. The sand particles in these ridges have been more or less rolled along and are invariably rounded and fairly uniform in size. Light brown, wind-blown deposits of silt-size particles, known as loess, are often encountered in thin layers, the particles having sometimes travelled considerable distances.

1.4.2. Residual soil (topsoil, laterites)

These soils are formed in situ by chemical weathering and may be found on level rock surfaces where the action of the elements has produced a soil with little tendency to move. Residual soils can also occur whenever the rate of break up of the rock exceeds the rate of removal. If the parent rock is igneous or metamorphic the resulting soil sizes range from silt to gravel. Laterites are formed by chemical weathering under warm, humid tropical conditions when the rainwater leaches out of the soluble rock material leaving behind the insoluble hydroxides of iron and aluminium, giving them their characteristic red-brown colour.

1.4.3. Organic soil

These soils contain large amounts of decomposed animal and vegetable matter. They are usually dark in colour and give off a distinctive odour. Deposits of organic silts and clays have usually been created from river or lake sediments. Peat is a special form of organic soil and is a dark brown spongy material which almost entirely consists of lightly to fully decomposed vegetable matter.

1.5. Classification of soils

There are a number of systems and methods used to classify soils. The most common of these systems are the American Association of State Highway and Transportation Officials (AASHTO) soil classification system, the Unified Soil Classification System (USCS), and the United States Department of Agriculture (USDA) soil classification system. The common feature of these systems is the use of particle size distribution to differentiate the various groupings of each particular system (WisDOT, 2017).

1.5.1. The AASHTO soil classification system

The AASHTO system was developed specifically for highway construction and is still widely used for that purpose. With practice and experience, a reasonably accurate field classification can be determined. However, it is necessary to run sieve analyses and plasticity determinations to precisely classify a soil with this method. Table 1.4 presents the basic AASHTO soil classification system (WisDOT, 2017).

Table 1.4. AASHTO soil classification system (WisDOT, 2017).

General Classification	Granular Materials 35 percent or less of total sample passing No. 200 (75 µm)								Silt-Clay Materials More than 35 percent of total sample passing No. 200 (75 µm)						
Group Classification	A-1		A-3 [1]		A-2				A-4		A-5	A-6		A-7	
	A-1-a	A-1-b	A-3	A-3a	A-2-4	A-2-5	A-2-6	A-2-7	A-4a	A-4b		A-6a	A-6b	A-7-5	A-7-6
Sieve analysis, percent passing:						*				**	*			*	
No. 10 (2 mm)	50 max														
No. 40 (425 µm)	30 max	50 max	51 min	[2]					[3]	[4]					
No. 200 (75 µm)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	35 max	36 min	50 min	36 min	36 min		36 min	
Characteristics of fraction passing No. 40															
Liquid limit	—	—	Non-	—	40 max	41 min	40 max	41 min	40 max		41 min	40 max		41 min	
Plasticity index	6 max	6 max	Plastic	6 max	10 max	10 max	11 min	11 min	10 max		10 max	11 – 15	16 min	≤LL-30	>LL-30
Group Index	0						4 max		8 max		12 max	10 max	16 max	20 max	
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Sand	Silty or clayey gravel and sand				Silty soils			Clayey soils			
General rating as subgrade	Excellent to good								Good to fair						

Notes

With the test data available, the classification of a soil is found by proceeding from left to right on the chart. The first classification that the test data fits is the correct classification.

* A-2-5 is not allowed under 703.16.B. A-5 and A-7-5 is not allowed under 703.16.A. See "Natural Soil and Natural Granular Soils" (203.02.H) in this manual

** A-4b is not allowed in the top 3 feet (1.0 m) of the embankment under 203.03.A.

[1] The placing of A-3 before A-2 is necessary in the "left to right" process, and does not indicate superiority of A-3 over A-2.

[2] A-3a must contain a minimum 50 percent combined coarse and find sand sizes (passing No. 10 but retained on No. 200, between 2 mm and 75 µm).

[3] A-4a must contain less than 50 percent silt size material (between 75 µm and 5 µm).

[4] A-4b must contain 50 percent or more silt size material (between 75 µm and 5 µm).

1.5.2. Unified Soil Classification System

The Unified (USCS) system was developed later, and as the name suggests, it was intended to be a more all-encompassing system for geotechnical engineering. It is the most detailed system but it requires laboratory analysis for application. While the system does have limitations for uses as a field classification method, it is widely used for many geotechnical applications. Table 1.5 presents the basic Unified soil classification system (WisDOT, 2017).

Table 1.5. USCS soil classification system (WisDOT, 2017).

Major Divisions			Group Symbol	Typical Names
Course-Grained Soils More than 50% retained on the 0.075 mm (No. 200) sieve	**Gravels** 50% or more of course fraction retained on the 4.75 mm (No. 4) sieve	Clean Gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands 50% or more of course fraction passes the 4.75 (No. 4) sieve	Clean Sands	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		Sands with Fines	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine-Grained Soils More than 50% passes the 0.075 mm (No. 200) sieve	**Silts and Clays** Liquid Limit 50% or less		ML	Inorganic silts, very fine sands, rock four, silty or clayey fine sands
			CL	Inorganic clays of low to medium plasticity, gravelly/sandy/silty/lean clays
			OL	Organic silts and organic silty clays of low plasticity
	Silts and Clays Liquid Limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts
			CH	Inorganic clays or high plasticity, fat clays
			OH	Organic clays of medium to high plasticity
Highly Organic Soils			PT	Peat, muck, and other highly organic soils

Prefix: G = Gravel, S = Sand, M = Silt, C = Clay, O = Organic
Suffix: W = Well Graded, P = Poorly Graded, M = Silty, L = Clay, LL < 50%, H = Clay, LL > 50%

1.5.3. USDA Classification System

The USDA system was developed for agricultural purposes. It has some engineering application in that it provides a relatively easy method for general field classification of soils. However, “loamy”, while descriptive, is not an engineering term and should be avoided when discussing the engineering properties of a soil. Figure 1.5 presents the basic USDA soil classification system (WisDOT, 2017).

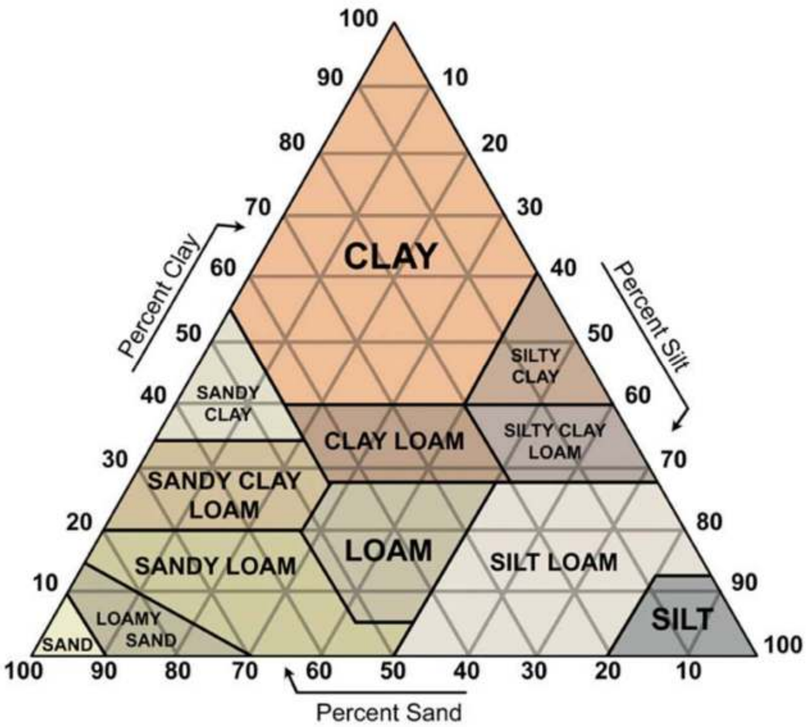


Figure 1.5. USDA soil classification system (WisDOT,2017)

1.6. Subsurface water

Subsurface water is the term used to define all water found beneath the earth's surface (Smith, 2014). The main source of subsurface water is rainfall, which percolates downwards to fill up the voids and interstices. The change in moisture content of soil affects its bearing capacity of engineering structures. Road pavement as part of engineering structures is greatly affected by water. The sources and effects of water has to be known so as to provide an adequate subsurface drainage system to control the flow of water through it for the road pavement to properly achieve its function.

1.6.1. Sources of subsurface water in road pavement

The Queensland state Department of Transport and Main Roads identified the main mechanisms by which moisture can enter a road subgrade and/or pavement shown diagrammatically in figure 1.6. The prevailing mechanism include:

- Longitudinal seepage from higher ground, particularly in cuttings and in sag vertical curves;
- Rise and fall of water table level under a road;
- Rainfall infiltration through the road surfacing;
- Capillary moisture from the verges;

- Capillary water from a water table;
- Vapour movements from a water table;
- Lateral movement of moisture from pavement materials comprising the road shoulder;
- Water flowing or standing in table drains, in catch drains, in median areas, within raised traffic islands or adjacent to the road;
- Leakage of water supply and drainage lines;
- Passage of water through construction joints in pavements, and back and front of kerb and channel, between old and new pavements and behind bridge abutments.

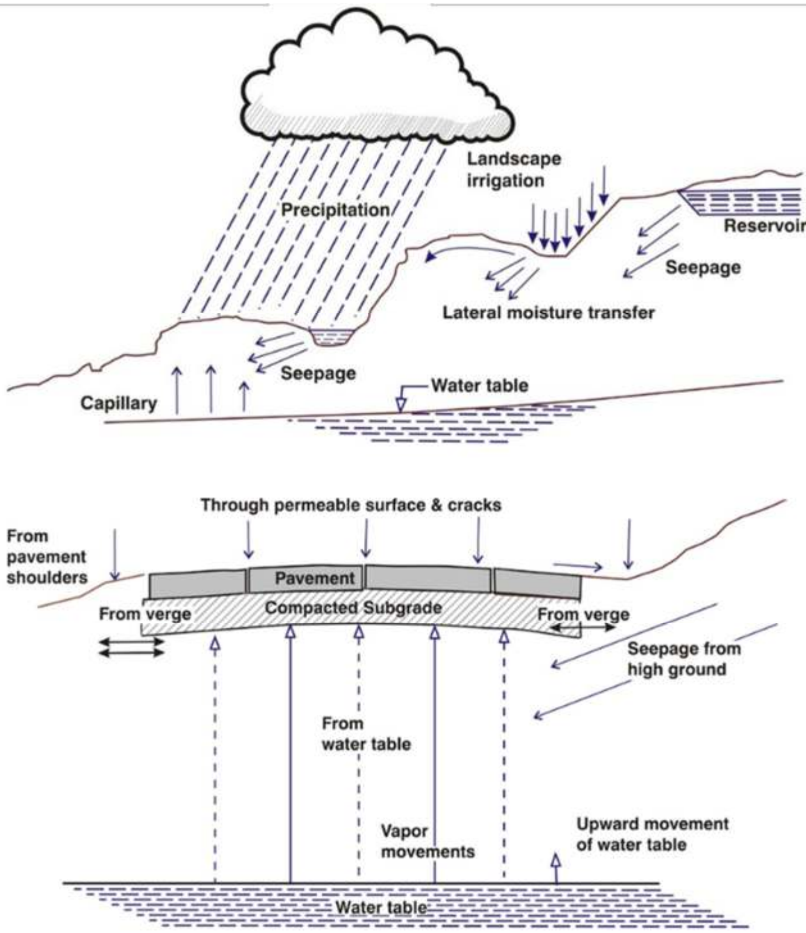


Figure 1.6. Sources of moisture (Queensland state department of transport,2019)

1.6.2. Effects of subsurface water on pavement

Accumulation of moisture introduced into the pavement subgrade from any of the sources can adversely affect pavement performance, leading to accelerated pavement deterioration. Pavement problems associated with infiltrated water may fall into three categories (ERES, 1998; ERES, 1999):

- Softening of the pavement layers and subgrade by becoming saturated and remaining so for prolonged periods;

- Degradation of the quality of pavement and subgrade material due to interaction with moisture;
- Loss of bonding between pavement layers due to saturation with moisture.

The detrimental effects of water on the structural support of the pavement system are as follow:

- Stripping (Debonding of aggregates and binder at the bottom of HMA layer);
- Bleeding (Formation of asphalt binder film on the pavement);
- Rutting (Surface depression along wheel path);
- Corrugation and Shoving (Plastic movement typified by ripples or an abrupt wave across the pavement surface);
- Cracking, Water Bleeding and Pumping;
- Raveling (Progressive disintegration of HMA layer);
- Localized failures (Progressive loss of adhesion between binder and aggregates or progressive loss of cohesion in aggregates and in binder).

Figures 1.7, 1.8 and 1.9 illustrates AC pavement stripping, rutting and fatigue cracking respectively

Figure 1.7. AC Stripping (Tran-Set, 2018)

Figure 1.8. Pavement Rutting (http://www.sptc.org/briefs/2016/5/17/evaluating-ruttingstripping-potentials-of-asphalt-mixes-using-hamburg-wheel-tracking-device)

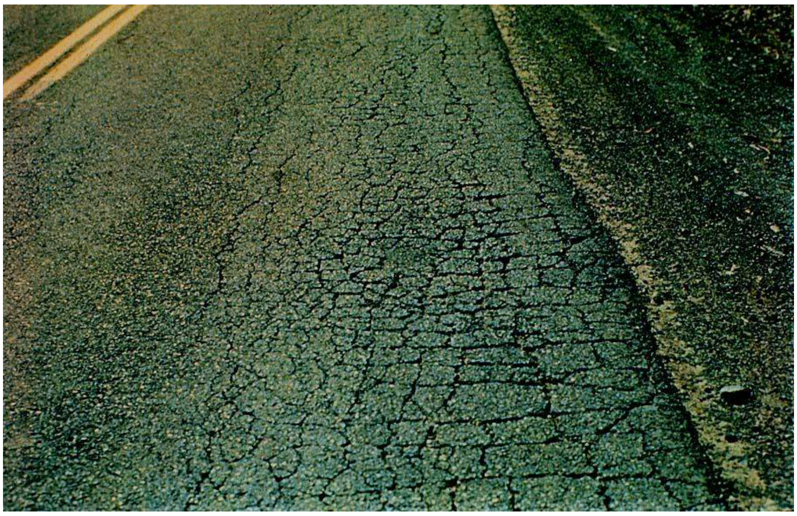


Figure 1.9. Fatigue cracking (https://pavementinteractive.org/reference-desk/pavement-management/pavement-distresses/fatigue-cracking/)

Appendix 1 describes the moisture related distresses in flexible (AC) pavement and rigid pavement (PCC) pavement according to the Federal Highway Administration.

1.6.3. Subsurface drainage

Subsurface drainage is the process through which artificial underground water drains, which may be piped or pipeless, are used for the purpose of removing excess water. The primary goal of this type of drainage is to improve properties of the subsoil and base materials for improved performance of supported structures, such as highway or airfield pavements. Proper design, construction, and maintenance of the drainage systems should take the following into consideration: Sources of moisture in pavement, and their effects on road pavement; Distresses that are caused or accelerated by excessive moisture in pavement systems; Types and components of drainage systems; Requirements for a drainage system; Identifying the benefits and risks of providing subsurface pavement drainage.

1.6.4. Subsurface drainage systems

Many types of subsurface drainage have been developed over the years to remove moisture from the pavement system. These subsurface drainage systems can be classified into several groups. One criterion for classifying various subsurface drainage systems is the source of moisture that the system is designed to control (NHI 05-037, 2006). Some systems are groundwater control system**,** infiltration control system and capillary break system.

1.6.4.1. Groundwater control system

This refers to a subsurface drainage system designed to remove and control the flow of groundwater. In order to avoid excessive pressure on subgrade and pavement it is essential that water table should be fairly below level of subgrade. It has been found that water table should be kept at least 1.2 m below the subgrade. In place where the formation level is to be kept at or below the ground level, it necessary to lower the water table. It is possible to lower the water table in relatively permeable soil by construction of longitudinal drainage trenches with drain pipe and filter sand (Figure 1.10).

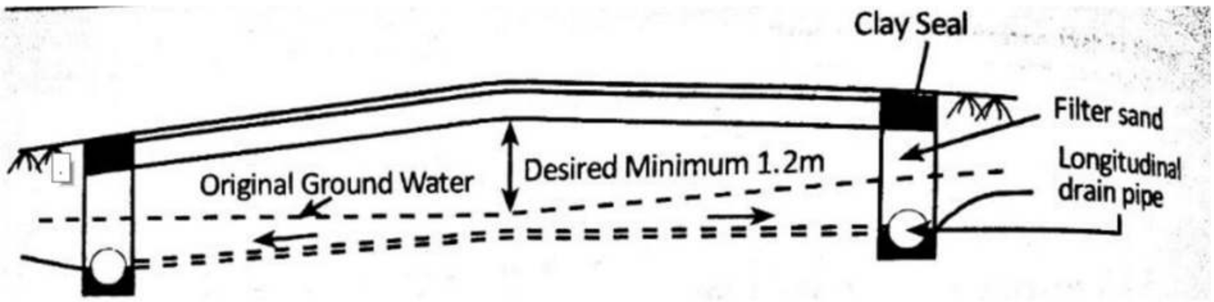


Figure 1.10. Groundwater control system

1.6.4.2. Infiltration control system

They are designed to remove water that seeps into the pavement structural section. Seepage may occur from the higher ground in hilly topography or in road cuttings where a layer of permeable soil overlies an impermeable stratum which affects the strength characteristics of the subgrade. The best solution to this type of problem would be to intercept the seepage water on the uphill side of the road. If the seepage level reaches a depth less than 60-90 cm from the road subgrade, it should be intercepted to keep seepage line at a safe depth below the road subgrade (NHI05-037, 2006).. Figure 1.11 shows a typical infiltration control system.

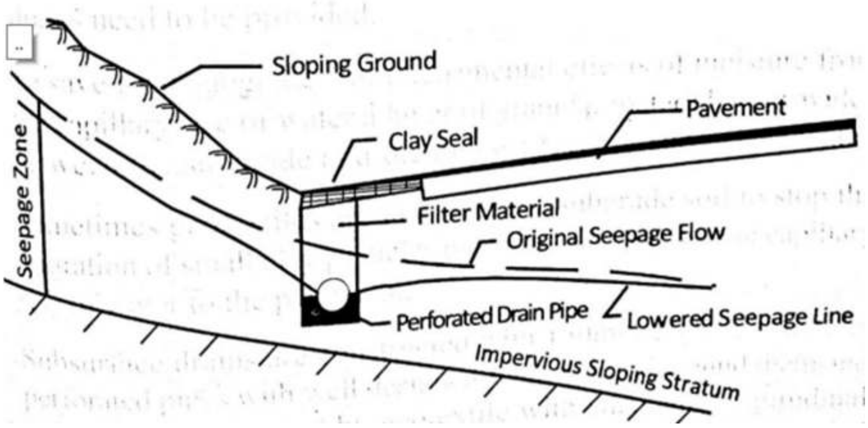


Figure 1.11. Infiltration control system

1.6.4.3. Capillary brake system

Capillary brake systems are designed to intercept and remove rising capillary water and vapor movement. In water logged sections, there will be possibility of rising of water to the subgrade level due to the phenomenon of capillary action which affects the strength of the subgrade. Thus, capillary cut off measures needs to be provided to free the subgrade from the excessive moisture. If the subgrade soil is of permeable type, the lowering of water table is economical but in case of retentive type of soil, drainage becomes very difficult and costly. In these cases, capillary cut offs become more economical. There are two types of capillary cut off, granular capillary cut off and impermeable capillary cut off. (NHI05-037, 2006).

a. Granular capillary cut off:

Provision of granular material of suitable thickness between the subgrade and the highest level of subsurface water table during the construction of embankment. The granular capillary cut off layer's thickness should be sufficiently higher than the anticipated capillary rise within the granular layer so that the capillary water cannot rise above the cut off the layer. Suitable sand blanket and gravel blanket can be used for cut off. This is illustrated in figure 1.12 (NHI05-037, 2006).

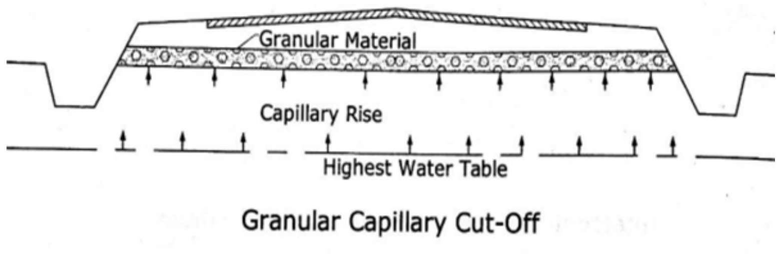


Figure 1.12. Granular capillary cut-off for capillary control

b. Impermeable capillary cut off:

Provision of impermeable membrane such as prefabricated bituminized surfacing is used instead of granular blanket. Bitumen stabilized soil, heavy duty tar felt or heavy-duty polythene envelope can also be used. Figure 1.13 presents an impermeable capillary cut off system

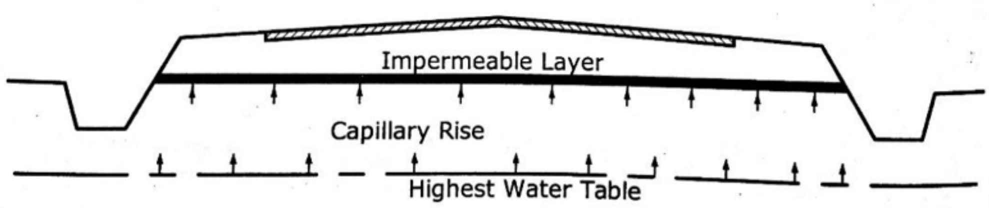


Figure 1.13. Impermeable capillary cut-off for capillary control

1.6.5. Types of subsurface drainage

Probably the most common way to classify a subsurface drainage system is in terms of its location and geometry. Using this classification, subsurface drainage systems are typically divided into five distinct types (NHI05-037, 2006):

- Longitudinal edgedrains or lateral drains.
- Transverse and horizontal drains.
- Permeable bases.
- Drainage blankets
- Deep drains or underdrains.

Each type may be designed to control several sources of moisture and may perform several different functions. In addition, the different types of subsurface drainage system may be used in combination to address the specific needs of the pavement being designed.

1.6.6. Application of subsurface drainage systems

In Figure 1.14, a horizontal blanket drain used in connection with shallow longitudinal collector drains to control both infiltration and the flow of groundwater from an artesian source. Figure 1.15 shows a horizontal blanket drain used to remove water that has seeped into the pavement by infiltration alone. An outlet has been provided by «daylighting» the drainage blanket. Drainage blankets can be used effectively to control the flow of groundwater from cut slopes and beneath side hill fills, as illustrated in Figures 1.16. When the drainage blanket is used in connection with a longitudinal drain, this will help improve the surface stability (relieve sloughing) of cut slopes by preventing the development of a surface of seepage.

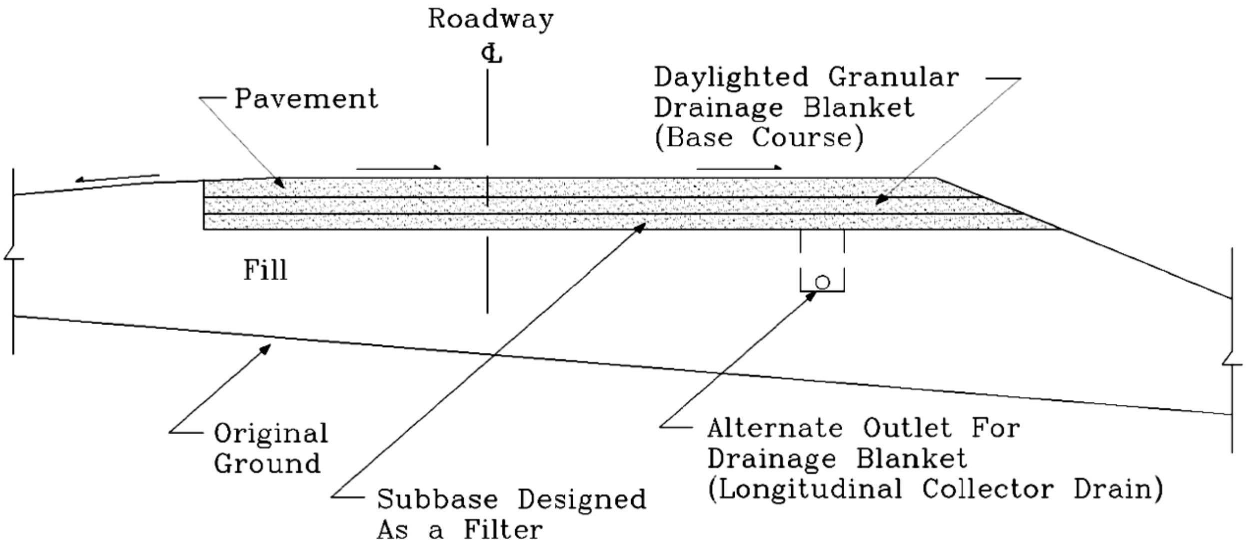


Figure 1.14. Applications of horizontal drainage blankets (redrawn from Moulton, 1980).

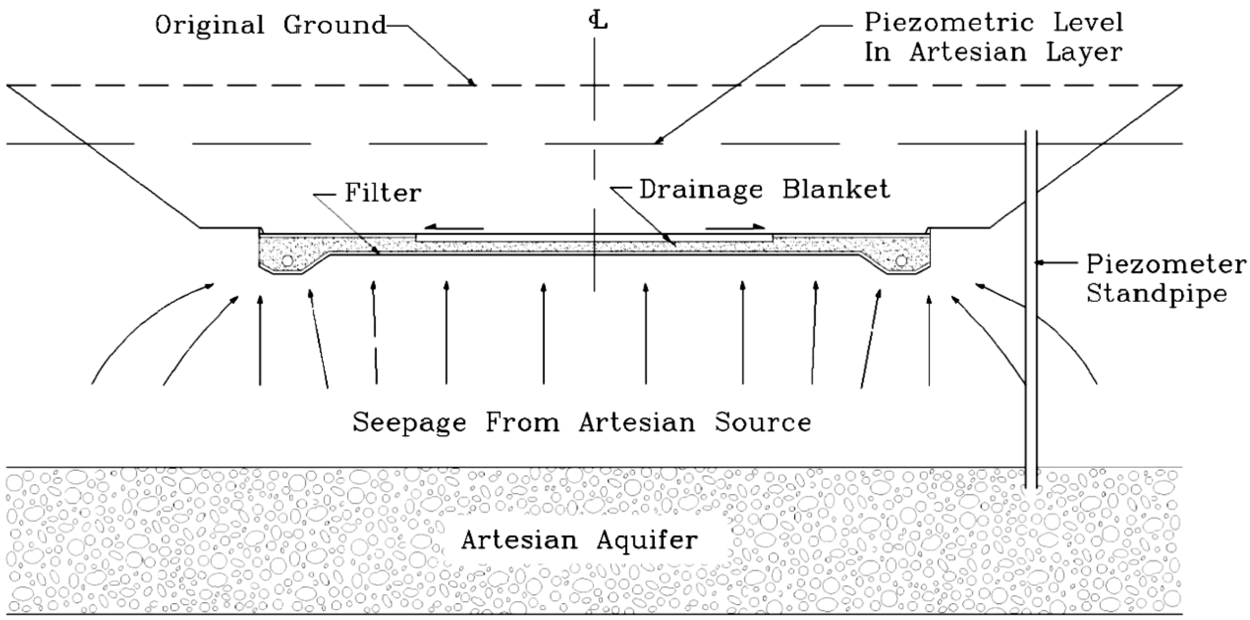


Figure 1.15. Applications of horizontal drainage blankets (redrawn from: Moulton, 1980).

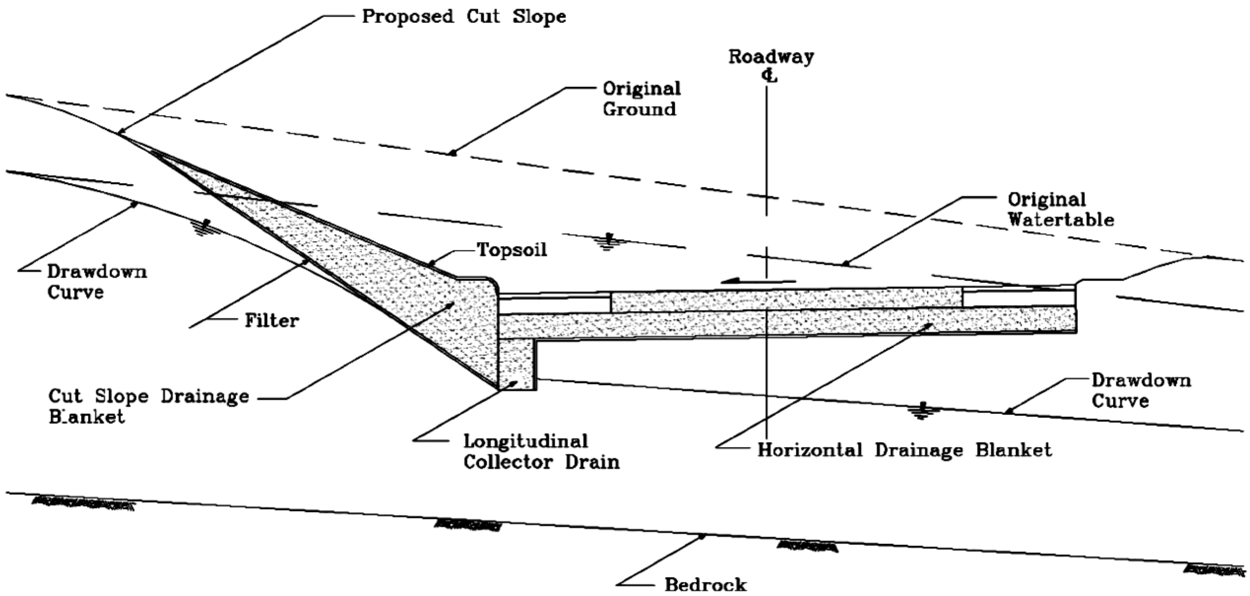


Figure 1.16. Drainage blanket (wedge) on cut slope drained by longitudinal collector drain (redrawn from Moulton, 1980)

Examples of types of longitudinal drains commonly used in control of seepage and groundwater are shown in Figures 1.16, 1.17 and 1.18.

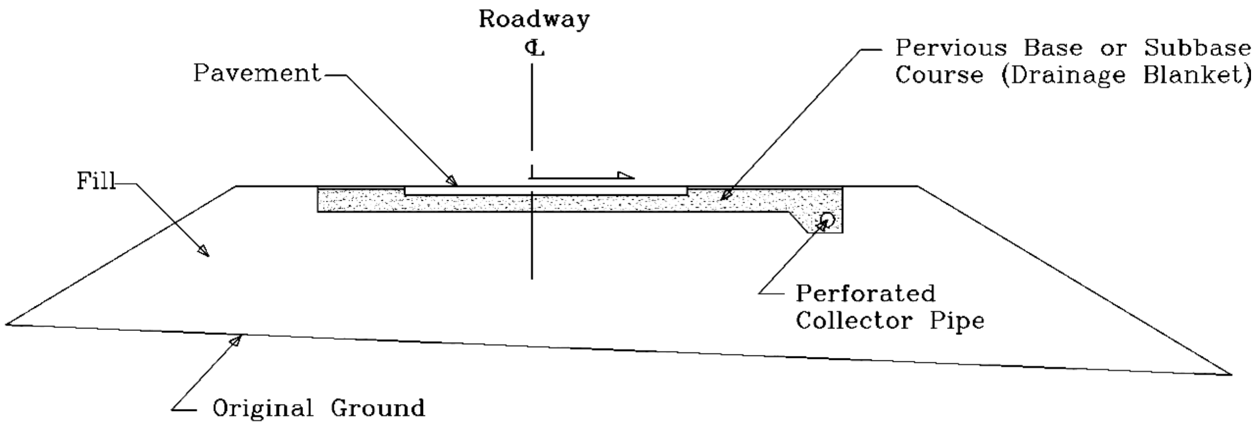


Figure 1.17. Longitudinal collector drain used to remove water seeping into pavement structural section (redrawn from: Moulton, 1980)

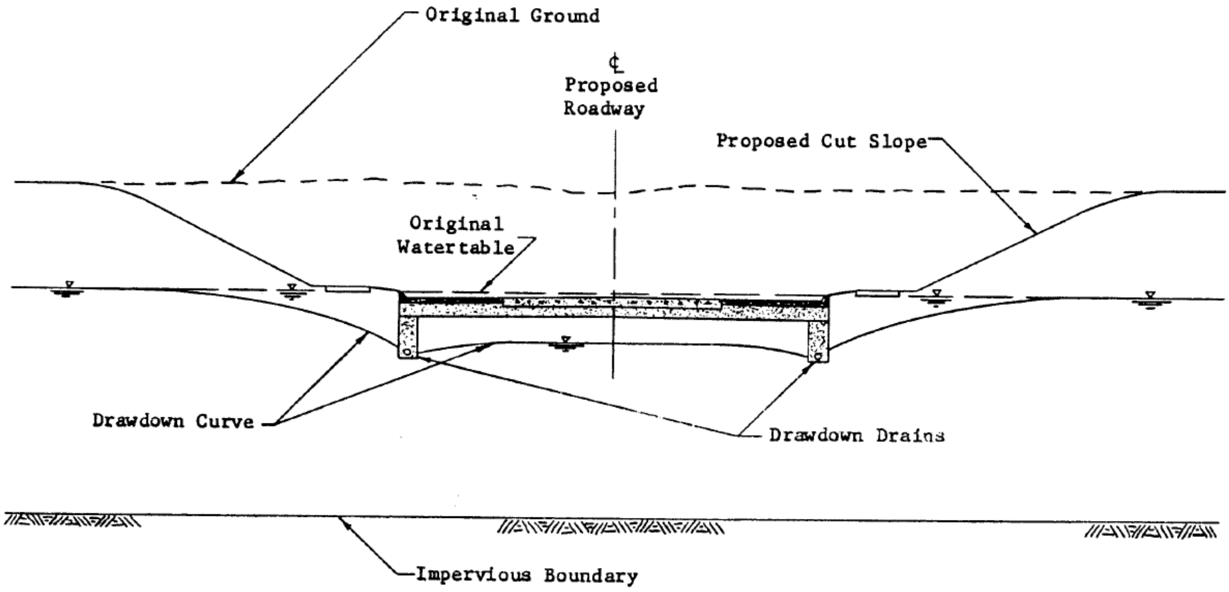


Figure 1.18. Symmetrical longitudinal drains used to lower the groundwater table and to collect water infiltrating the pavement (Moulton, 1980).

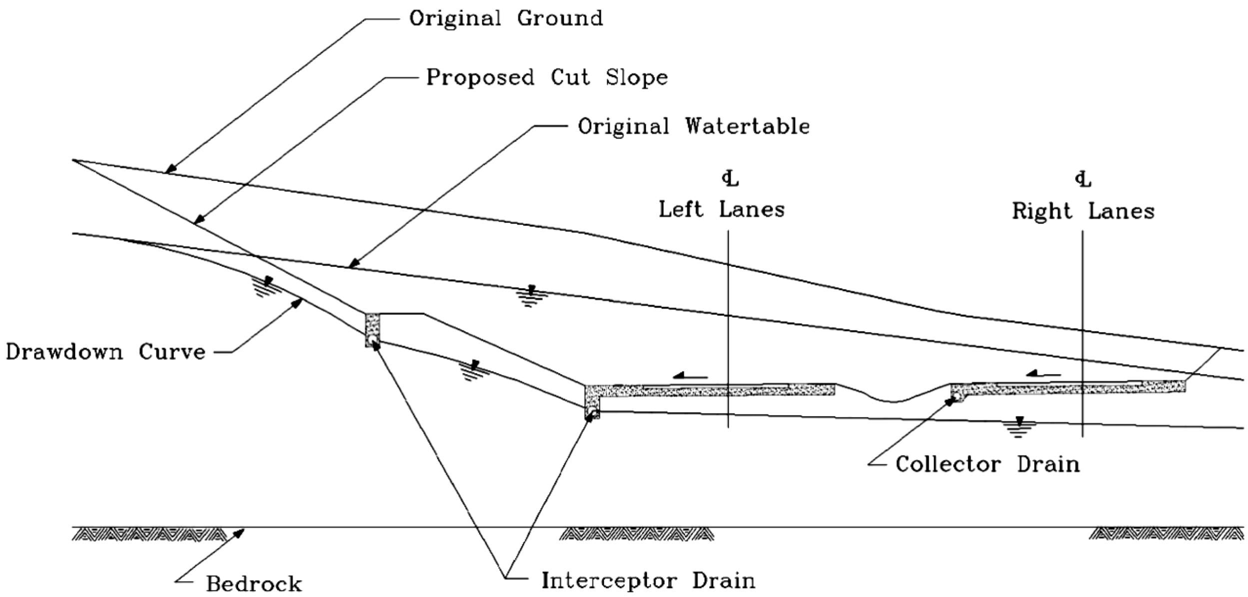


Figure 1.19. Multiple, multipurpose longitudinal drain installation (redrawn from : Moulton,1980).

Conclusion

Most engineering structures are found on soil and their life span depend on the properties of the foundation soil on which it is found. Soils are formed by physical, chemical and biological processes resulting in different soil types with distinct physical, chemical and engineering properties. These soil types are further classified according to their particle size into systems used in application for engineering projects. Knowledge of soil formation, its constituents, properties and types are of great importance to civil engineers for the design of long-life structures. Water being a treat to most structures, its sources are identified to better deviate them from structures. The effects of water on structures are described to have a measure of the consequence of the treat to the structure. This is followed by an outline of the different subsurface systems, types and how they are applied in projetcs. The next chapter will guide us on how to design an adequate drainage and stabilisation system for treatement capillary rise in road pavement.

CHAPTER 2: METHODOLOGY

The design of an effective drainage system requires a specific layout of the method used. The previous chapter gave a view of the different drainage system used all over the world to resolve moisture issues in pavement. The system designed consist of a permeable base and edgedrain. For the design of the drainage system, adequate data will be used to define all the parameter necessary for an effective system. The softwares DRIP (Drainage Requirements In Pavement) will be used to design the drainage components and the finite element analysis software Plaxis 2D for stability analysis.

2.1. Site recognition

The aim here is to have an overview of the two main parameters governing the site, notably physical and socio-economic parameters. This requires documentary researches. The physical parameters of the site are; the location, the climate, the topography, the geology, the hydrology, the fauna and the flora. While, the socioeconomic parameters are given by the demography and economic activities of the region.

2.2. Site visit

After a documentary research in order to determine the characteristics (Physical and socio-economic) of the site object of our study, a site visit will enable us to have a view of the capillary rise phenomenon going on at the location of our case study.

2.3. Data collection

The collection of geotechnical and geometric characteristics a road section from 12+400 to 12+650 will permit us to perform a two-dimensional modelling and analysis using analytical and numerical methods later described in this chapter. Traffic and climatological information are also important for the design. These informations will guide us in the evaluation of the need and type of drainage system required.

2.3.1. Geotechnical data

The geotechnical data of the problem were gotten from the laboratory of the company in charge of the construction works of the project entitled "Route de desenclavement du basin agricole de l’Ouest Lot 2 Bangangté Foumbot-Bamendjing-Galim". These data present the physical and geotechnic characteristics of the material of the excavated area.

2.3.2. Geometric data

The geometrics data are provided by the company. The principal geometric data include: the longitudinal profile of the excavated area as well as the cross-sections of the typical profiles, pavement width, shoulders, pavement thickness, depths of cuts.

2.3.3. Traffic data

Traffic data is one of the key information for pavement and drainage design, for it determines the pavement material properties, thickness and design procedures.

2.3.4. Climate date

Climate data give an insight of the fundamental source of subsurface water. These data are used in the evaluation of the drainage time, moisture content potention of the base and subgrade of the structure. The main climatological data include the frequency, intensity and duration of precipitation.

2.4. Design of subsurface drainage layer

The drainage layer will consist of an aggregate permeable base and an edge drain. The DRIP microcomputer program developed by FHWA will be used to rapidly evaluate the effectiveness of the drainage system and calculate the design requirements for the permeable base design, and edgedrain design, including filtration requirements. The finite analysis software PLAXIS 2D will be used to model and perform stability analysis of the cut section after application of the drainage system.

2.4.1. Design procedure for permeable base and edgedrain

A major objective in pavement drainage design is to keep the base, subbase, subgrade, and other susceptible paving materials from becoming saturated or even being exposed to constant high moisture levels over time. Design of pavement drainage consists of determining:

a) Quantifying the net inflow of water that must be removed by the drainage system;

b) Design of permeable base;

c) Design of Edgedrain.

2.4.1.1. Quantification of water inflow

Water enters the pavement through several sources as discussed in Chapter 1. The amount of water infiltrating one-meter square of pavement can be determined by two methods (FHWA,1992): the infiltration ratio method and the crack infiltration method. The infiltration ratio method will be used in designing the drainage system.

In this method, a design rainfall and an infiltration ratio are selected. Based on these parameters, the pavement infiltration (q_i) is determined using equation 2-1

$$q_i = 0.24C.R \tag{2-1}$$

where

q_i = Pavement infiltration, m²/day/sq. m of pavement

C = Infiltration ratio

R = Rainfall rate, mm/hr

The infiltration ratio, C, is the portion of rainfall entering the pavement through joints and cracks. For design guidance, a range of infiltration coefficient values of 0.33 to 0.50, and 0.50 to 0.67 have been suggested for asphalt concrete pavements and Portland cement concrete pavements, respectively (FHWA, 1992). For simplicity, it is suggested that designers adopt an infiltration coefficient of 0.50. In the design of drainage systems, it is important that engineers select a design storm whose frequency and duration will provide an adequate design. The 2-year frequency, 1-hour duration storm is usually suggested (FHWA, 1992).

2.4.1.2. Design of the permeable base

The primary function of the permeable base is to dissipate water infiltrating the pavement by moving it laterally towards the edge of the pavement within an acceptable timeframe. The drainage path and the hydraulic gradient are determined by the pavement geometry. The recommended approach for the hydraulic design of permeable base layer is the time-to-drain approach.

The time-to-drain approach is the time required for a percentage of the free water (e.g., 50%) to drain, following a moisture event where the pavement section becomes saturated. The time to drain approach is an approach recommended by the FHWA, AASHTO, and NCHRP 1-37A for pavement design. The time-to-drain approach assumes the flow of water into the pavement section until it becomes saturated (the drainage layer plus the material above the drainage layer). Excess precipitation will not enter the pavement section after it is saturated; this water will simply run off the pavement surface. After the rainfall event, the drainage layer will drain to the edgedrain system.

The main parameter of interest in the time-to-drain procedure is the time required to drain the permeable base to a pre-established moisture level. The design standard based on this parameter rates the permeable base quality of drainage from "Excellent" to "Poor." Table 2.1 presents guidance for selecting permeable base quality of drainage based on this method.

Table 2.1. Permeable base quality of drainage rating based on time taken to drain 50 percent of the drainable water (MnDOT,2009)

Quality of drainage	Time to drain
Excellent	2 hours
Good	1 day
Fair	7 days
Poor	1 month
Very poor	Does not drain

The inputs to the time-to-drain design procedure include basic pavement design and material properties such as roadway geometry (cross-slope, longitudinal slope, lane width), thickness of the permeable base, porosity and effective porosity of permeable base aggregate, and permeability of the permeable base material. Using these inputs, the time-to-drain parameter is calculated for a given degree of drainage (U). The final design is then chosen on the basis of this information.

The following is a step-by-step procedure for completing the time-to-drain design.

(a) Assume a desired degree of drainage (U). For typical highway situations, U = 0.5;

(b) Select a value for the permeable base thickness (H);

(c) Determine the coefficient of permeability (k) of the proposed base material through laboratory testing;

(d) Calculate the resultant length (L_R) and resultant slope (S_R) from known roadway longitudinal grade (S), cross-slope (S_x), and permeable base width (W);

$$L_R = W\left[1 + \left(\frac{S}{S_x}\right)^2\right]^{1/2} \quad (2\text{-}2)$$

$$S_R = (S^2 + Sx^2)^{\frac{1}{2}} \qquad (2\text{-}3)$$

(e) Calculate the porosity (N) and the effective porosity (N_e) of the base material from known values of bulk specific gravity (G_{sb}), unit weight (γ_d), and water loss coefficient (WL);

$$N = \left(1 - \frac{\gamma_d}{9.81 \times G_{sb}}\right) \qquad (2\text{-}4)$$

$$N_e = N \times WL \qquad (2\text{-}5)$$

Typical ranges of bulk specific gravity and unit weight for permeable base material are 2.65 to 2.70 and 15.5 to 19.0 kN/m3, respectively. The water loss coefficient for a permeable base is a function of the type and amount of fines present in the base and can be determined from table 2.2.

Table 2.2. Water loss values as a percentage of total water (ERES,2004)

		Type and amount of fine								
		Filler			**Silt**			**Clay**		
		2.5%	5%	10%	2.5%	5%	10%	2.5%	5%	10%
Material type	Gravel	70	60	40	60	40	20	40	30	10
	Sand	57	50	35	50	35	15	25	18	8

Notes:
Fines are defined as material passing the No. 200 sieve
For gravel with 0% fines, water loss is equal to 80%
For sand with 0% fines, water loss is equal to 65%

(f) Use either equation 2-6 or DRIP to determine the time required to remove 50% of the drainable water from the saturated permeable base (U = 0.5). Compare this value to the target time-to-drain. If the design is unsatisfactory, continue iterations by changing the inputs until the desired solution is obtained.

$$t_{50} = \frac{N_e {L_R}^2}{2k(S_R L_R + H)} \qquad (2\text{-}6)$$

Equation 2-6 represents a single point calculation of the time-to-drain parameter at a degree of drainage of 0.5. DRIP can be used to compute the time required to drain to any desired degree of drainage or saturation (S). When DRIP is used to compute the time to drain, time-history plots from an initial fully saturated state to a completely drained state can be obtained. Figure 2.1 is a sample plot of time to drain against the percent drained.

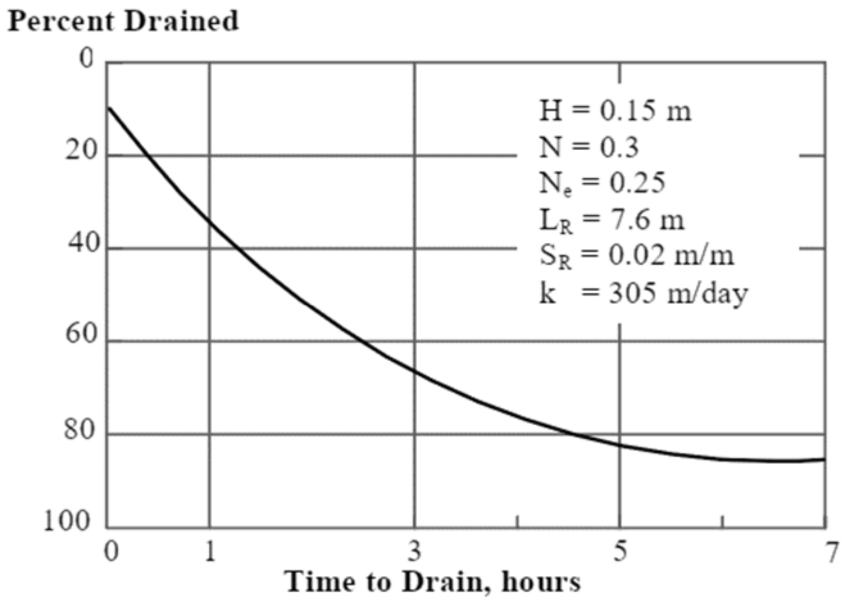


Figure 2.1. Percent drained versus time (ERES, 2004)

2.4.1.3. Edgedrain design

This involves the hydraulic design of the edgedrain, filter requirements, pipe edgedrain types, geotextile placement and the design of the outlet pipe.

a. Hydraulic design of edgedrain

The hydraulic design of edgedrains is basically a four-step process. Each step is explained below.

i. Determine pavement discharge rate, q_d.

For pavements with permeable bases the time to drain discharge rate calculation is appropriate to ensure consistency with the recommended permeable base design methodology (time to drain). The equation to estimate the design discharge is as follows:

$$q_d = 24WHN_eU\frac{1}{t_D} \quad (2\text{-}7)$$

where :

q_d = Design pavement discharge rate, ft^3/day/m.

W = Width of permeable base, m.

H = Base thickness, m.

N_e = Effective porosity.

U = Percent drained in decimal (50 percent is used most often).

t_d = Time to drain, hr.

ii. Determine edgedrain flow capacity, Q

For pipe edgedrains, the flow capacity of circular pipes can be determined from Manning's equation

$$Q = \frac{0.2693 \times 10^{-3}}{n} D^{8/3} S^{1/2} \qquad (2\text{-}8)$$

Where

Q = Pipe capacity, m^3/day

N = Manning's roughness coefficient

= 0.012 for smooth pipes and 0.024 for corrugated pipes (4)

D = Pipe diameter, mm

S = Longitudinal slope, m/m

iii. Determine outlet spacing, L

Once the pavement discharge rate (q_d) and the edgedrain flow capacity (Q) have been determined, the outlet spacing (L) can be determined from the following equation:

$$L \leq \frac{Q}{q_d} \qquad (2\text{-}9)$$

iv. Trench design

Trench design involved several aspects including: trench backfill, trench width and depth, trench compaction and geotectile placement.

(1) Trench backfill

The edgedrain is installed as the permeable base is being placed. The trench material surrounding the edgedrain pipe is the same as the permeable base material. It is feasible to install the edgedrain in a separate operation. This would allow the trench backfill to be compacted before the permeable base is placed. For this case, the backfill material should be stable and as permeable as the permeable base material.

(2) Trench width and depth

The edgedrain trench must be wide enough to transmit the water discharging from the pavement structure without interrupting the flow. In general, if a permeable backfill material is used, the width needed for the installation of the pipe drain is more than adequate to meet the hydraulic requirement. The following equation can be used to ensure that the trench width is adequate to meet the hydraulic requirement:

$$W_T = \frac{q_d}{k} \times 1000 \qquad (2\text{-}10)$$

Where :

W_T = Required minimum trench width, mm

q_d = Pavement discharge rate, m3/day/m

K = Permeability of the backfill material, m/day

(3) Trench compaction

Adequate compaction of the trench backfill is essential to prevent premature deterioration of the shoulder. Trench backfill should be placed in three layers with compaction being applied after each lift.

b. Filter Requirements for Edgedrains

The filter material must be fine enough to prevent the adjacent soil from piping or migrating into the edgedrains but coarse enough to allow the passage of water with no significant resistance. To meet the filter criteria, it may be necessary to use several different aggregates, one placed adjacent to the other.

Geotextiles may be used as an envelope for trench drains, a wrapping for pipe drains, or as a filter for permeable bases. A geotextile can be selected to satisfy the filter criteria and replace the aggregate filter. Due to the relative ease of installation (as compared to the difficulty of placing a filter aggregate and a coarse aggregate in separate layers without contamination), the use of geotextiles may be more cost-effective. Unlike the filter criteria used in the gradation analysis of aggregates, a variety of filter criteria have been developed by a number of organizations and researchers. Based on a review of these criteria, the FHWA Geotextile Engineering Manual (FHWA, 1995) suggested the use of more stringent criteria when the hydraulic loadings are severe or the performance of the drainage system is critical to the protection of roadways and pertinent structures. The retention or pumping resistance criteria, the permeability criteria, and the clogging criteria for selecting the required AOS (apparent opening size) of geotextiles have been specified in ASTM (ASTM, 1989). The filter criteria for pipes are also required when perforated or slotted pipes are used for the collection and removal of water. The material in contact with the pipes must be coarse enough that no appreciable amount can enter into the pipes. The current filter criteria used in selecting pipes are based on the U.S. Army Corps of Engineers criteria (1955).

c. Pipe edgedrains types

Conventional pipe edgedrain are recommended because of their high flow capacity and their ability to be aintatined. Pipes must have enough strength to resist the loads placed on them. There are different plastic materials used in the manufacture of plastic pipes; corrugated polyethylene (CPE) or smooth, rigid, polyvinyl chloride (PVC) pipes.

i. Corrugated polyethylene (CPE) pipe

For corrugated polyethylene, AASHTO Specification M 252, corrugated polyethylene drainage pipe is used.

ii. Polyvinyl Chloride (PVC) pipes

Table 2.3 outlines the specification number and specification title for different PVC piped. These specifications provide a large range of pipe stiffness.

Table 2.3. Specification of different PVC pipes (ERES,2004)

Specification number	Specification title	Pipe classification
AASHTO M 278	Class PS46 Polyvinyl Chloride (PVC) Pipe	PS 46
ASTM D 3034	Type PSM Poly (Vinyl) Chloride (PVC) Pipe and Fittings Based on Controlled Inside Diameter	SDR 35
		SDR 26
		SDR 23.5
AASHTO M 304	Polyvinyl Chloride (PVC) profile wwall drain pipe and fittings based on controlled inside diameter	Corrugated
ASTM F 949	Polyvinyl Chloride (PVC) corrugated sewer pipe with a smooth interior and fittings	Corrugated
ASTM F 789	Type PS-46 and Type PS-115 Polyvinyl Chloride (PVC) plastic gravity flow sewer pipe and fittings	PS46
		PS 115
ASTM D 2665	Polyvinyl Chloride (PVC) plastic drain and vent pipe and fittins	Schedule 40

iii. Smooth wall pipe with corrugations

This pipe should conform to AASHTO M 304 Polyvinyl Chloride profile wall drain pipe and fittings based on controlled inside diameter, ASTM F 949 Polyvinyl Chloride corrugated sewer pipe with a smooth interior and fittings or AASHTO Specification M 252, corrugated polyethylene drainage pipe – type SP for CPE pipe.

d. Geotextile placement for pipe edgedrain

Geotextile placement will vary depending on whether the edgedrain is installed before or after the construction of the permeable base. The edgedrain trench should be lined with a geotextile to prevent fines from the surrounding subgrade from entering the pavement section. The primary purpose of the geotextile is filtration; that is, keeping the fines in the subgrade from contaminating the trench backfill material. The geotextile should have a permeability several times greater than the subgrade soils. Since the permeable base should contain no fines, discharge of fines from the permeable base should not be a problem. The top of the trench adjacent to the permeable base is left open to allow a direct path for the water into the edgedrain pipe.

e. Design of Outlet Drain

Installation of an outlet pipe is critical to drainage system. Outlets are short pipes that carry the water from the edgedrains to the side ditches. It is recommended that a high stiffness polyethelene or PVC non-perforated pipe be used for the outlet pipe to ensure proper grade and significant stiffness to withstand installation and traffic loads without damage or significant deformation. Design of the outlet drain mainly consists of checking the capacity of the outlet pipe to ensure the capacity of this pipe is at least as great as the edgedrain. The slope is dictated by the roadway geometry, but if possible, it should not be less than 3 percent. The capacity of outlet pipes is checked by using Manning's formula.

2.4.2. DRIP SOFTWARE

DRIP is a Windows based microcomputer program, created by the Federal Highway Administration and Applied Research Associates, to perform hydraulic design computations for the subsurface drainage analysis of pavements. Features of DRIP include Roadway Geometry Calculations, Sieve Analysis Calculations, Inflow Calculations, Permeable Base Design, Separator Layer Design, and Edgedrain Design. The programs allow to determine whether or not several design factors are satisfactory or not.

2.4.2.1. DRIP Software interface

Figure 2.2 show the software interface display. The first window that appears is that of the road geometry where all the inputs of the road and inserted for further calcultions.

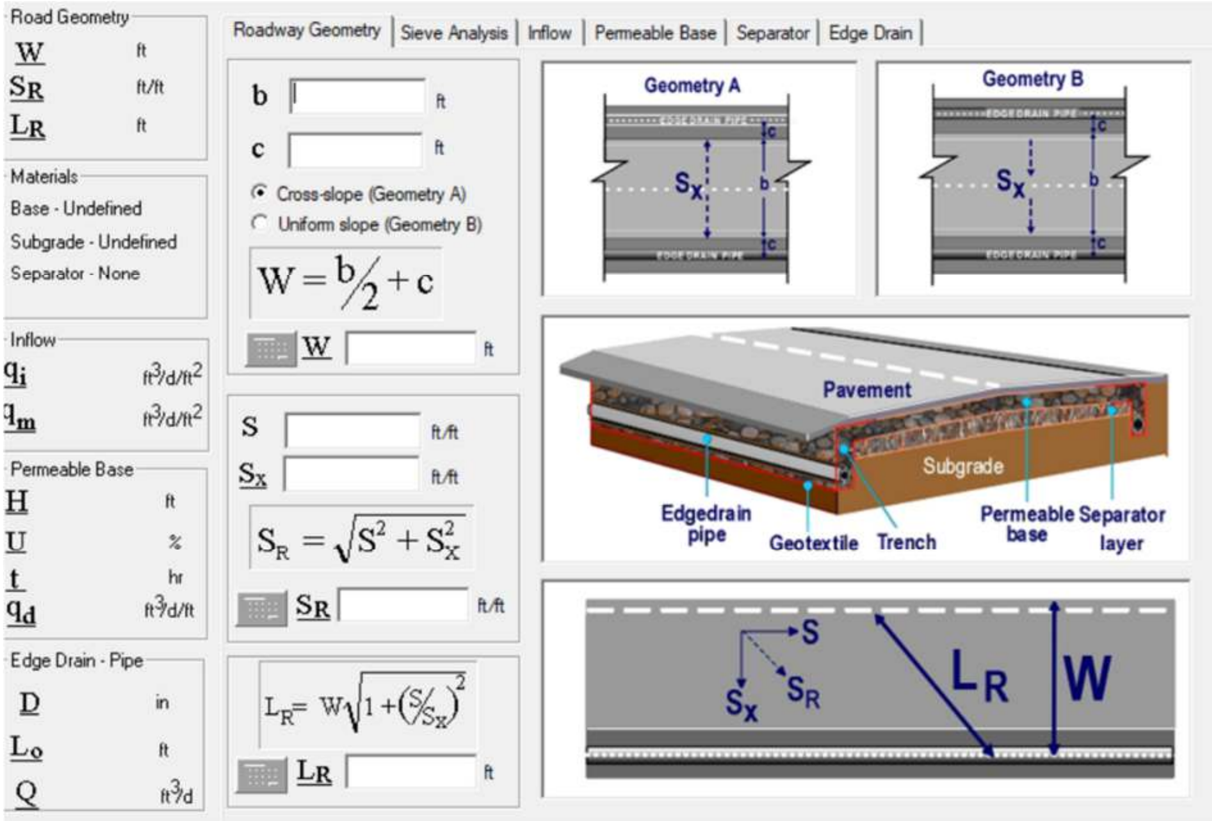


Figure 2.2. Drip 2.0 interface (DRIP,2004)

2.4.2.2. Design concept

Design concepts have been developed and put into practice for subsurface drainage systems for highway pavements. Most of the design procedures used in DRIP are identical to the procedure advocated by Demonstration Project 87 (FHWA, 1994) and the NHI Course No. 131026 (FHWA, 1999) on pavement subsurface drainage design. The major steps in the procedures are:

a. Quantifying water inflow;
b. Designing the permeable base;
c. Designing the separation layer if it exists;
d. Quantifying flow to edgedrains;
e. Computing outlet spacing;
f. Checking outlet flow.

2.4.2.3. Roadway geometry calculation

Using this program feature, the user can compute the length and slope of the true drainage path based on the longitudinal and transverse grade of the roadway, as well as the width of the underlying base material. The user can perform these calculations for the two common roadway cross-sections commonly encountered – crowned and superelevated (uniform slope) section.

2.4.2.4. Sieve analysis calculations

The effective grain sizes (D_x), total and effective porosities, coefficient of uniformity and gradation, and coefficient of permeability can be computed for any user-entered gradation using the program feature. Plots of the gradations on semi-log and FHWA power 45 templates can also be obtained.

2.4.2.5. Inflow calculations

The major sources of inflow into the pavement structure are surface infiltration, water flow from high ground, groundwater seepage, and meltwater from ice lenses (Cedergren, 1994; FHWA, 1990; AASHTO, 1986). The amount of moisture infiltrating the pavement structure from rainfall and meltwater can be computed using this program option. The surface infiltration calculations can be performed using two different approaches; the Infiltration Ratio approach and the Crack Infiltration approach. Meltwater computations can be performed for a variety of soil types and pavement cross-section depths.

2.4.2.6. Permeable base design

The program offers two permeable base design options; depth-of-flow and time-todrain. These methods allow the user to design an open-graded base that can handle the inflow entering the pavement structure. The quantification of drainage material parameters plays an important role in determining drainage capacity. Porosity and effective porosity define an aggregate material's ability to store and give up water. Effective porosity, the coefficient of permeability, and percentage of saturation are required in the calculation of the time to drain.

2.4.2.7. Separator layer design

Using the corresponding program option, two types of separator layers can be designed; geotextile and aggregate separator layers. In some cases, a separator layer is not necessary.

Based on the gradations of the proposed permeable base and the subgrade under consideration, the program also verifies whether a separation layer is required at all.

2.4.2.8. Edgedrain design

Two types of edgedrains can be designed using Edgedrain design option of the software; geocomposite of fin drains and pipe edgedrains. The program calculates the edgedrain capacity and the outlet spacing required.

2.4.3. PLAXIS 2D

Plaxis 2D is a powerful and user-friendly finite-element (FE) package intended for 2D analysis of deformation and stability in geotechnical engineering and rock mechanics. Plaxis is used worldwide by top engineering companies and institutions in the civil and geotechnical engineering industry. The user interface consists of four sub-programs: input, calculation, output and curves. The software will be used to model the soil behaviour and infiltration and will determine the correct fonctionning and stability of the drainage system.

2.4.3.1. The input program

To carry out a finite element analysis using Plaxis, a finite element model has to be created and material and boundary condition introduced. This is done in the input program of Plaxis. The accuracy of the analysis depends on correct geometry modeling, introduction of the appropriate material properties, meshing, initial conditions at the initial phase of the analysis. Figure 2.3 present the input program interface of Plaxis.

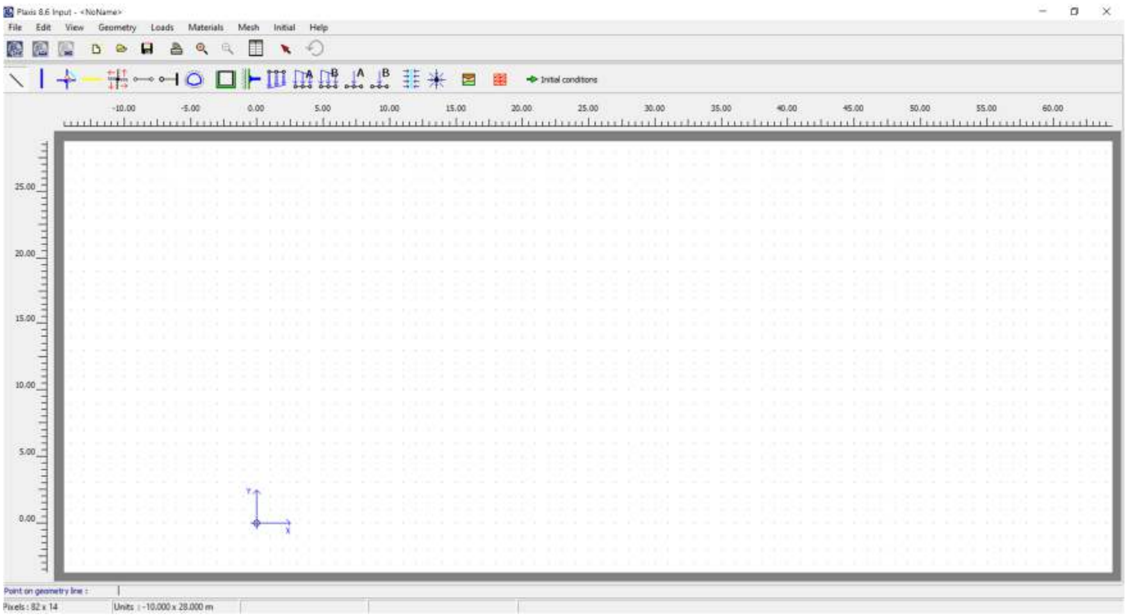


Figure 2.3. *Plaxis input program interface (Plaxis 2008)*

a. Geometry modeling

The generation of a finite element model begins with the creation of a geometry model which is a representation of the problem of interest. A geometry model consists of points, lines and clusters. After the geometry components of the model have been created, material parameters have to be assigned to each component

b. Material properties

Material properties and model data for soil clusters are entered in the material data set. A data set for soil and interface generally represents a certain soil layer and can be assigned to the corresponding cluster in the geometry model. Plaxis supports various models to simulate soil and other continua. The main model used are the Mohr-coulomb model and the jointed rock model.

i. The Mohr-Coulomb model

This model is used as a first approximation of soil behavior in general. The model involves five parameters: Young's modulus (E) and Poisson's ratio (ν) for soil elasticity, Friction angle (φ) and Cohesion (c) for soil plasticity, and dilatancy angle (ψ).

ii. Jointed rock model

This is an anisotropic elastic-plastic model where plastic shearing can only occur in a limited number of shearing directions. This model is used to simulate the behavious of stratified or jointed rock.

c. Hydraulic behaviour

An important feature of soil is the presence of pore water. Pore pressures significantly influence the soil response. To enable incorporation of the water skeleton interaction in soil response, two types of the behaviours offered by Plaxis will be used: the drained and undrained behaviour.

i. Drained behavior

Using this setting, no excess pore pressures are generated. This is the case for dry soils and for full drainage due to high permeability and/or a low rate of loading.

ii. Undrained behavior

This setting is used for a full development of excess pore pressures. Flow of pore water can sometimes be neglected due to a low permeability and/or a high rate of loading.

d. Meshing

Mesh generation is the practice of creating a mesh, a subdivision of a continuous geometric space into discrete geometric and topological cells. This is a fundamental aspect of finite element analysis. This is done after the model has been fully defined and material properties assigned to all clusters.

e. Initial conditions

Once the geometry model has been created and meshing done, the initial stress state and the initial configuration must be specified. The initial conditions consist of two modes: one mode for the generation of initial water pressures and one mode for the specification of the initial geometry configuration and the generation of initial effective stress field.

With the generation of the initial stresses, the generation of the initial situation of the finite element model is complete. Calculation can now be perfomed.

2.4.3.2. Calculation program

Plaxis allows for different types of finite element calculation. Calculation program considers only deformation analysis and distinguished between a plastic calculation, a consolidation analysis, Phi-c reduction (safety analysis) and a dynamic calculation. Plastic analysis will be used which allow for the effect of large displacement beig taken into account.

In engineering practice, a project is divided into phases. Similarly, a calculation process in Plaxis is also divided into calculation phases. In plastic calculation, several loading inputs are used of which staged construction, total multiplier and incremental multiplier. The staged construction input will be used which provides loading in the sense of changing the load combination, stress state, weight, strength or stiffness of elements, activated by changing the load and geometry configuration or pore pressure distribution.

After calculation phases have been defined and before the calculation process is started, some points may be selected by the user for the generation of load-displacement curves and stress paths. At the end of this, calcultations can be executed.

Figure 2.4 presents the calculation program interface

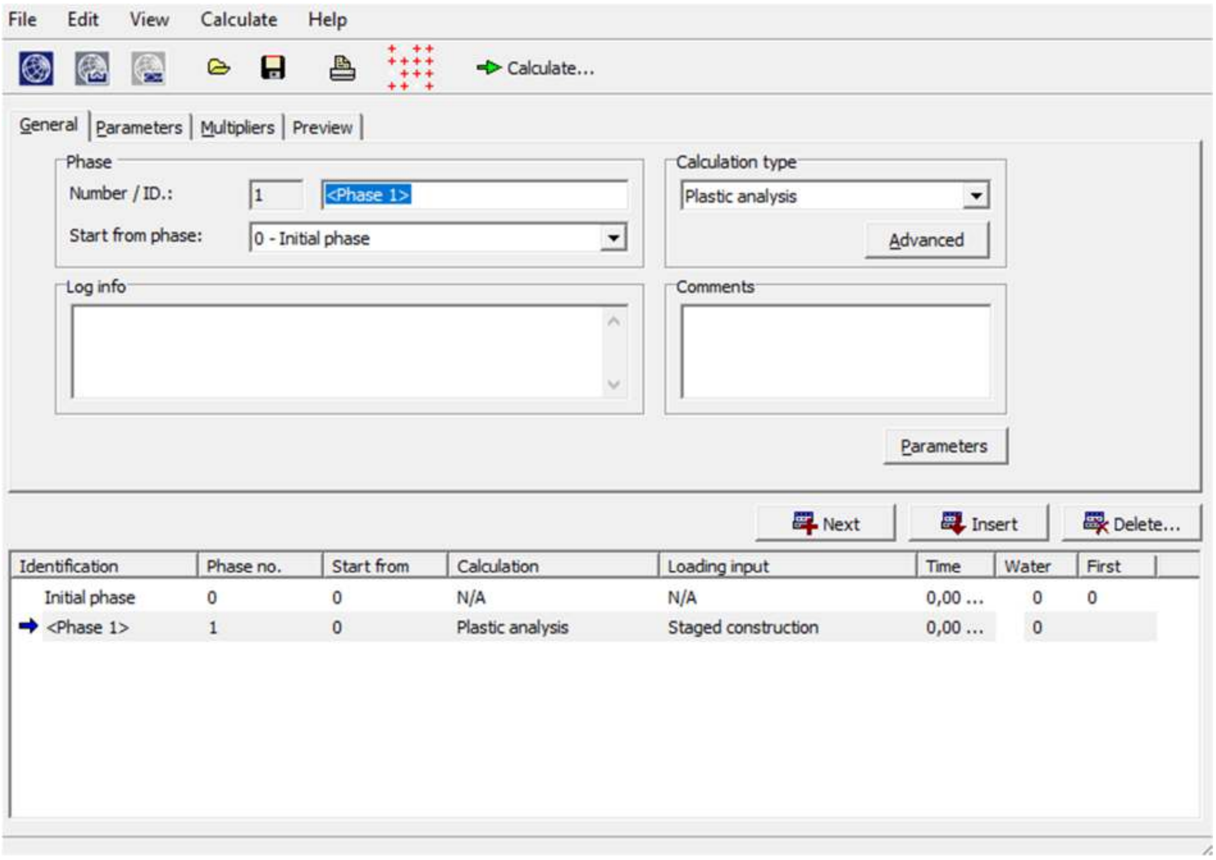


Figure 2.4. Plaxis calculation program interface (Plaxis 2008)

2.4.3.3. The output program

The main output quantities of a finite element calculation are the displacement at the nodes and the stresses at the stress points. An extensive range of facilities exist within Plaxis to display the results of a finite element analysis. The output program enables the visualization of deformations (deformed mesh, total, horizontal and vertical displacements, strains), stresses (effective stresses, total stresses, active and excess pore pressures, ground water head, flow field, degree of saturation) … The output program also permits to view the general project informations including material data and calculation informations

2.4.3.4. The curves program

The curves program can be used to draw load- or time-displacement cures, stress-strain diagrams and stress or strain path of pre-seleccted points in the geometry. These curves visualize the development of certain quantities during the various calculation phases.

2.4.4. Criteria for the comparism of the drainage system

Multi-criteria decision-making methods are the most often used for the selection of construction projects. These methods are applied in various kinds of industries and fields of science due to the possibility of examining the problem of multi-aspect selection taking quantitative and qualitative factors. Construction project variant solutions and the specifying criteria by which they will be estimated ensure their mutual comparison at the primary selection stage. Two criteria will be used for choosing the appropriate drainage system: Technical criteria and economic criteria.

2.4.4.1. Technical criteria

Technically, the systems will be compared based on drainage capacity and production time of the inputs of the different drainage systems designed.

2.4.4.2. Economic criteria

Among all factors the main evaluation factor is cost or price consideration. Increase of building materials prices, failures in estimation of production costs, labor cost are items which determines the faisability of a project during project planning. A comparative analysis of the cost of implementing the different systems designed will help using the choice of the most cost-effective solution. This will be based basically on the material cost, production cost, labor and engine cost.

In most cases, aggregates with big size are less costly and smaller aggregate due to their manufacturing procedure. Manufacturing process of the normal aggregates include the following steps: Supply, extraction, crushing, grinding and screening (Neves,2015).

a. supply

Three major sources of aggregates can be identified:

i. Unconsolidated (loose) rock consisting of sand and alluvial materials (dry river beds). This is "rolled" sand because the grains are rounded.

ii. Solid rock basically of limestone and hard rock or crushed volcanic rock. This is "crushed" sand because the grains are pointed.

iii. Recycled materials often of industrial origin, from demolition, recycled concrete, railway ballast, etc.

b. Extraction:

Extraction is a key phase during production from solid rock, particularly because strategic choices, such as the selection of a slab for color or hardness, can make a real difference.

c. Crushing, grinding, screening:

Once extracted, the materials are transported to the processing site for scalping. This process involves removing unwanted materials, such as blocks, clay, etc. The scalped product is crushed once to transform the block into broken stone. The process is repeated as many times as necessary to obtain the desired fragment size. The resulting material is then screened to obtain aggregates of the desired grade. The larger pieces that are rejected are returned to the crusher and subsequently re-screened, with the process continuing until the desired size is obtained.

Some categories of aggregates, such as sand and gravel, undergo complementary processing including washing, cycloning and scrubbing, primarily to make them cleaner. Figure 2.5 presents the aggregate production chain

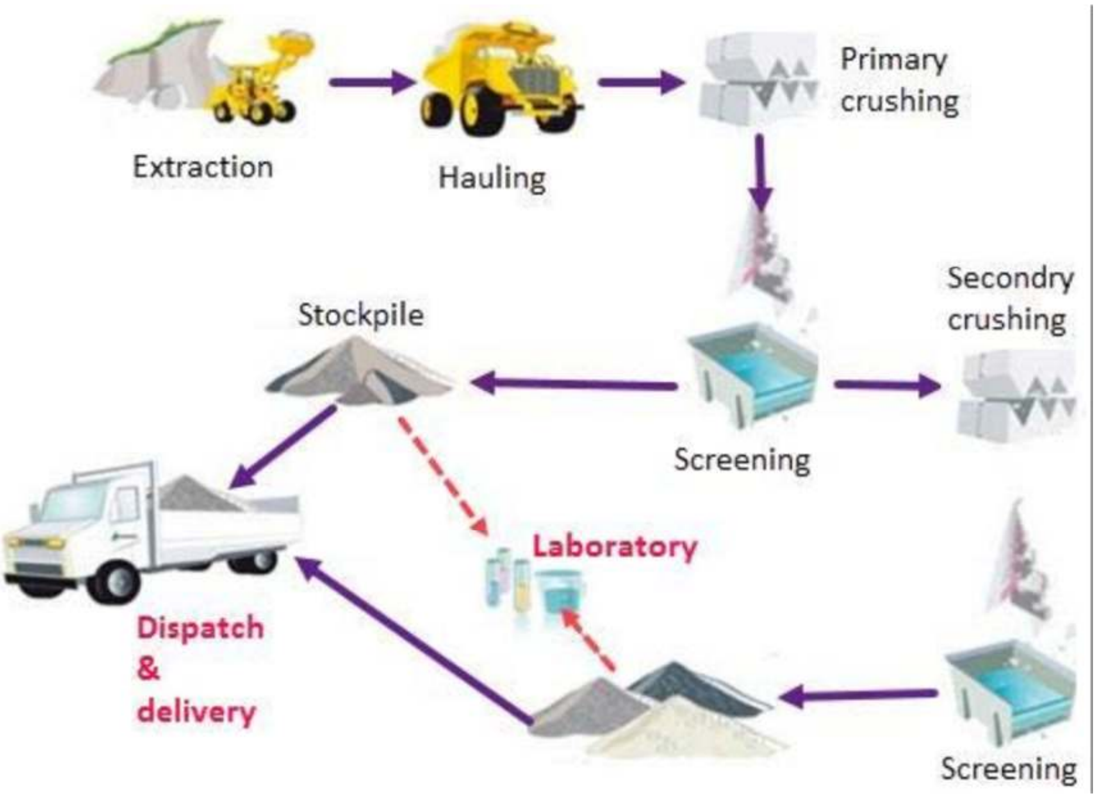


Figure 2.5. Aggregate manufacturing process (Neves,2015)

Conclusion

The aim of this chapter was the presentation of the methodology that will be used in the design of an effective drainage system consisting basically of a permeable base and an edgedrain. The software used to design the components of the drainage system is DRIP (Drainage Requirement in Pavement). The time-to-drain approach is used to design the permeable base and edgedrain based on the drainage time of the layer. The finite element analysis software, Plaxis 2D, will be used to check the drainage system functioning and effectiveness in responding to the drainage problem due to capillary rise in the pavement system as well as the stability of the road pavement on loading. A technico economic analysis will be used in choosing the adequate drainage system. The results obtained from the analysis will be discussed in the next chapter.

CHAPTER 3: RESULTS AND INTERPRETATION

Introduction

This chapter presents the results obtained from the detailed methodology outlined in chapter 2. This section presents the area in which the case study is observed followed by a presentation of the site and project. The case study to be analysed and its corresponding inputs shall be presented and analysed. To solve the problem studied here, two solutions will be designed using the software DRIP and analysed using the finite element analysis software Plaxis 2D. The results obtained from the analysis will be interpreted along the process A comparative analysis (technical and economic) of the solutions will help us decide on the most technical and economic solution suitable for the case study.

3.1. General presentation of the site

The presentation of the site hosting the case study of this research work will be based on two main aspects, namely the physical characteristics (geographical location, climate, topography, geology...) and the social and economic characteristics (population, agriculture).

3.1.1. Physical characteristics

This section concerns the geographical position of the road construction project as well as the physical features characterizing the area.

3.1.1.1. Geographical location of the project

The project entitled "*Routes de desenclavement du basin agricole de l'Ouest* " is a social project designed to facilitate the evacuation of agricultural production. Situated in the western region of Cameroon precisely in the eastern zone, lot 2 of this road project links over 107 km the towns of Bangangté-Foumbot-Bamendjing-Galim, subdivided into 2 sections as shown in the Figure 3.1. Section 1 extends over a length of 60 km from PK 0 to PK 60 and links the city of Bangangté, capital of Ndé division, and Foumbot city in the Noun division. Bangangté is connected to the capital city of the west region (Bafoussam) by the national road N°4 over about 50km, while the national road N°6 connects Foumbot to Bafoussam over 26.1km. As for section 2, it links over 47 km (from PK 0 to PK 47) the town of Foumbot to the towns of Bamendjing and Galim both located in the Bamboutos division. In terms of geographical coordinates, the project extends in longitude from 10° 24' 00" to 10° 31' 38" East, and in latitude from 5° 41' 59" to 5° 08' 46" North.

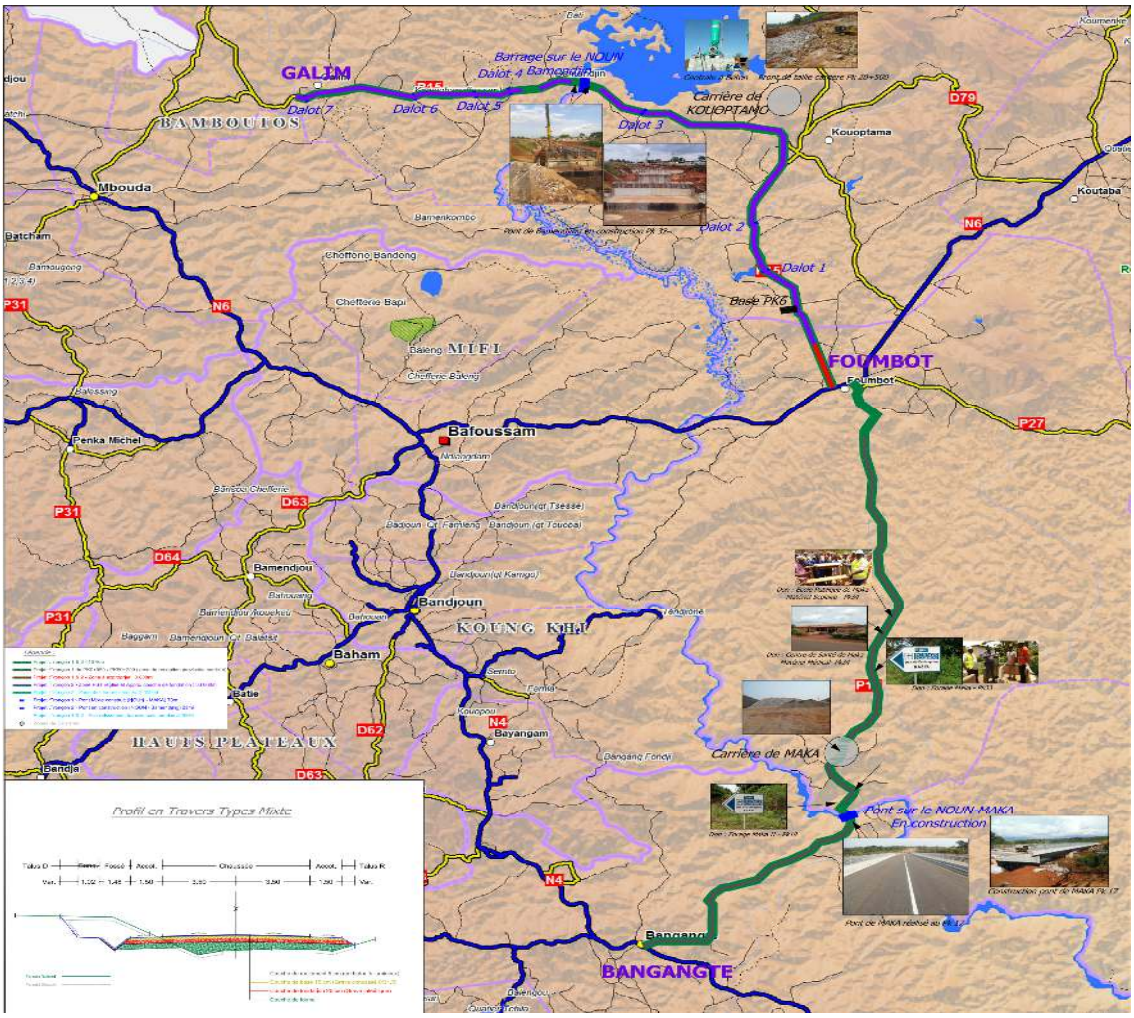


Figure 3.1. Localization of the study area (Project documents)

3.1.1.2. Climate

The climate of the west region is in general equatorial of the Cameroon sub variety and has two main seasons: a dry season from October/November to March/April characterised by a strong evapotranspiration and a rainy season covering the rest of the year. Among the towns in the study area, the commune of Foumbot has the highest rainfall value, which varies between 2,500 and 5,000 mm of rain per year (IRAD, 2013). Temperatures oscillate around 21°C with maxima of 32°C and minima of 14°C. As for humidity, the study area has a high average relative humidity of 80% with peaks in August and September. The region is also subject to strong winds that change direction and strength according to the seasons, sometimes causing damage to fragile plantations such as coffee trees.

3.1.1.3. Topography

On the whole, the Western region of Cameroon presents a mountainous relief with altitudes ranging from 500 to more than 2500 m which extend along the Cameroonian fault. The highest peak in the region, standing at 2740 m, is part of the chain of the Bamboutos Mountains which are dormant volcanoes on the western side of the town of Mbouda, 22.4 km from Galim. The territory of the Foumbot municipality is made up in places of isolated mounds and residual hills of very low height, the western hillside of Mount Mbapit (2352m of altitude) is installed in this territory. In general, the hilly areas are excellent places for large livestock while the valleys and abundant plains are used for seasonal crops. The present relief forms are the result of a long and complex volcanic action that occurred in the area.

3.1.1.4. Geology

Most of the soils in the study area are the result of volcanic activity. In the plains of the commune of Foumbot, there are very porous and fertile black amorphous alluvial soils resulting from volcanic projections (pozzolana). These soils have an important agronomic value due to their high nitrogen, phosphorus and potassium content (PNDP, 2014). Due to their overexploitation and the difficulty of managing rain and wind erosion, this soil is becoming increasingly poor. There are also several other types of soil in the region, namely hydromorphic alluvial soils mainly in the lowlands, reddish lateritic soils remarkably present on the slopes of some peaks in the commune of Bangangté and sandy-clay soils in the marshy areas (PNDP, 2015). Pozzolana deposits are found at several locations along the project. Figure 3.2 shows a deposit of pozzolana along section 1 of the project

Figure 3.2. Pozzolana deposit at section 1 of the project. (Project image)

3.1.1.5. Hydrology and hydrography

The territory of West Cameroon, due to its mountainous relief and the depth of the valleys, is watered by a dense hydrographic network made up of tortuous rivers with regular and seasonal regimes. These rivers, all part of the Atlantic basin, experience a high-water period during the rainy season and a low water period during the dry season. Among these rivers, the most important in the study area is the Noun River which is fed by smaller rivers such as the Kon, Ngam and Ndé and flowing from the central region around Bafoussam to the Bamendjing reservoir. This artificial lake is created by a dam on the river Noun, which contributes to the regulation of the Sanaga at Edéa in the Littoral region. Most of the lakes in the region are crater lakes formed as a result of the collapse of volcanoes. One example is Lake Baleng, northeast of Bafoussam, and the twin lakes of Foumbot.

3.1.2. Social and economic characteristics

3.1.2.1. Population

According to the last census of the population of Cameroon in 2005, the western region had about 1,720,047 inhabitants, making with respect to its surface area, one of the most densely populated regions with 124 inhabitants/km². As far as the Foumbot commune is concerned, its population is estimated at about 76,486 inhabitants with 38,891 women and 37,595 men. With a growth rate of 2.6%, this would give a population of 90,406 in 2012 PNDP, 2014). This population is essentially made up of Bamilékés, Bamouns, Banso'o and Mbororos who have migrated from the north in search of pasture for their cattle and have settled there permanently.

3.1.2.2. Agriculture

Agriculture occupies an important place in the economic activity of the West Cameroon region in general and the commune of Foumbot in particular. This is due to the richness of the soil in nutrients and fertilizers. Thus, we encounter annual cultures dominated by maize, okra, watermelon, tomatoes; semi-perennial cultures such as plantains and perennial cultures such as coffee trees which are quite widespread in the commune.

3.2. Physical description of the site

A site visit enabled us to have an insigth of the problem studied. The project is divided into two (02) sections: Section 1 extends over 60km from PK0 to PK60 (Bangangté - Foumbot); Section 2 extends over 47km from PK0 to PK47 (Foumbot -Bamendjing - Galim). The zone studied here is found in section 2 from PK12+400m - PK12+650m. This zone is an excavation area of 16m deep. The phenomenon of upwelling by capillarity is observed along a section of the bottom of the excavation. Preliminary surveys done on this area during the project study phase revealed the presence of soil with the required characteristics for use as backfilling material at a shallow excavation depth. Unfortunately, during the excavation and earthworks, a fractured rock was found few meters below this backfilling material. On reaching the red line of the project, upwelling of water by capillarity was observed at spaced zones through 60m along the road profile. The problem of upwelling by capillarity was also observed in several areas along the project. A solution for the treatment of the upwelling by capillarity has to be proposed regarding the technical, social and economic aspects of the region. Figure 3.3 presents the excavated zone where upwelling by capillarity phenomenon was observed.

Figure 3.3. Excavated zone showing upwelling by capillarity (Project image)

3.3. Project information

This includes the geometric parameters of the road section and its profile, traffic parameters and the geotechnical pararmeter of the soil and road.

3.3.1. Geometric parameters

The road is a two-lane road of 7m large. The typical road profile for the road construction project and the cut section profile of our case study (PK12+400m - PK12+650m) are shown in Figure 3.4, and figure 3.5 respectively.

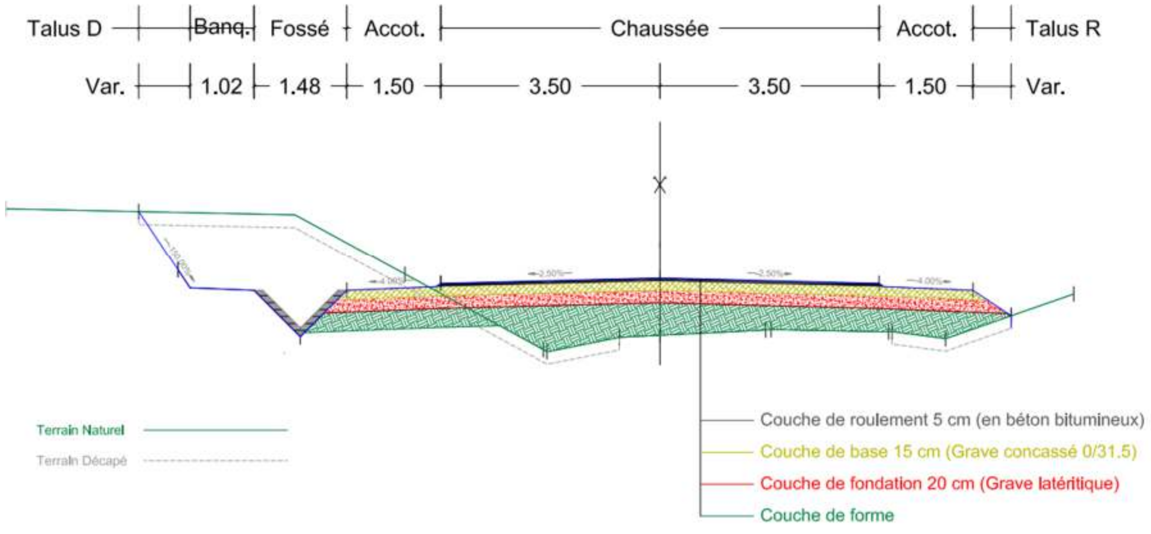


Figure 3.4. Typical road profile for the road construction project (Project documents)

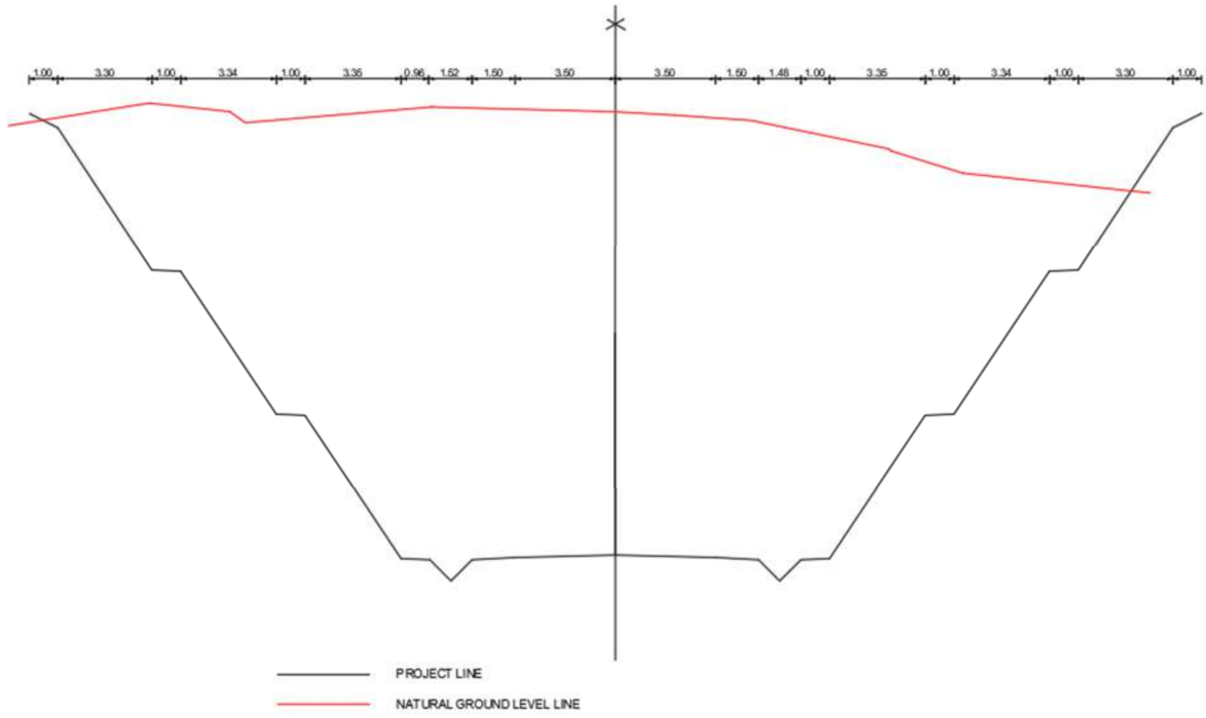


Figure 3.5. Cut section profile (Redrawn from Project documents)

3.3.2. Traffic parameters

The road is a T2 class road which traffic parameters used for the design of the road layers. These parameters are illustrated in Table 3.1

Table 3.1. Traffic parameters (Project documents)

DESIGNATION	Value
Service life	15 years
Growth rate	5%
Average traffic per year	95 /day
Cumulative traffic for heavy loads	702170
Average aggressiveness coefficient	1.1
Cumulative traffic	772390
Traffic class	T2

3.3.3. Geotechnical parameters

The road profile subject of this study ranging from PK12+400 to PK12+650 corresponds to a 16m deep excavation zone presenting capillary upwelling at the bottom. Geotechnical data presenting the properties of the differents stratas, the drainage layers' properties and road material properties are presented below.

3.3.3.1. Cut section properties

Figure 3.6 shows the soil stratigraphy present at the road section studied. The section consists of four different materials with properties outlined in table 3.2

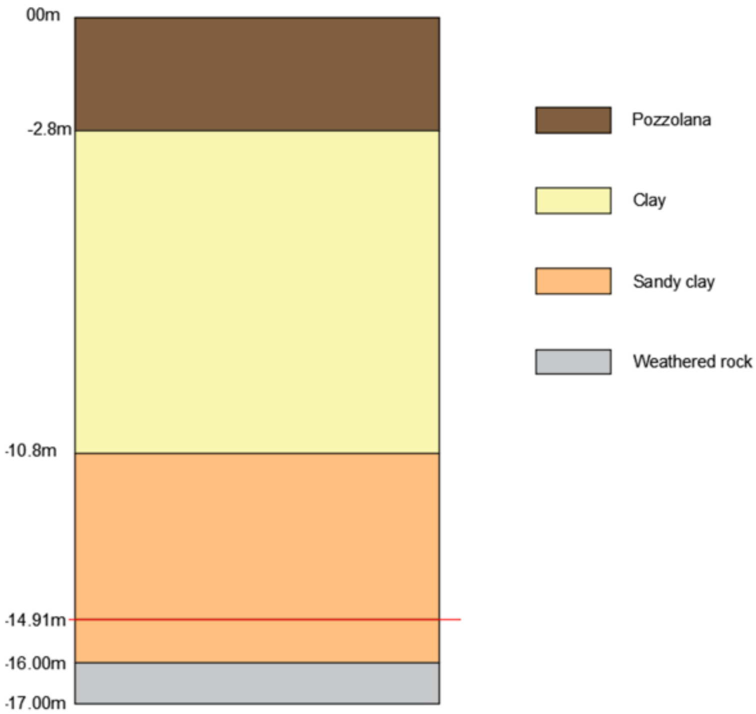


Figure 3.6. Soil stratigraphy (Project documents)

Table 3.2. In place soil parameters (Project documents)

Parameters	**Pozzolana**	**Clay**	**Sandy clay**	**Fractured rock**
Model	Mohr-Coulomb	Mohr-Coulomb	Mohr-Coulomb	Jointed rock model
γ_d[g/cm3]	1.301g/cm3	1.681g/cm3	1.600g/cm3	1.94 g/cm3
γ_{sat}[g/cm3]	1.410g/cm3	1.960g/cm3	1.800g/cm3	
E [MPa]	100MPa	25MPa	45MPa	45MPa
υ []	0.3	0.3	0.3	
k_x [m/day]	10m/day	10^{-3}m/day	10^{-3}m/day	10m/day
k_y [m/day]	10m/day	10^{-3}m/day	10^{-1}m/day	100m/day
c [KPa]	1KPa	10KPa	10KPa	0KPa
Ψ [°]	38°	30°	22°	42°
CBR []	/	/	/	

3.3.3.2. Road material properties

Table 3.3 presents the properties of the road material to be used obtained after design by the design company in charge of the project.

Table 3.3. Road material properties (Project documents)

Road layers	**Nature of material**	**CBR**	**E (MPa)**	**υ**
Surface course	Asphalt concrete	/	3245	0.35
Base course	Crushed stones (0/31.5)	≥ 80	600	0.35
Subbase course	GLAR/Pozzolana	≥ 30	200	0.35

3.3.3.3. Drainage material properties

The drainage material used is made up of pozzolana, boulders and crushed stone (25/63) are shown in table 3.4.

Table 3.4. Drainage material parameters (Project document)

Parameter	**Pozzolana**	**Boulders**	**Crushed stones 25/63**
Model	Mohr-Coulomb	Mohr-Coulomb	Jointed rock model
E[MPa]	10	600	600
v	0.3	0.35	0.35
c′[kpa]	0.5	0	0
Φ’ [°]	38	42	42

Ψ' [°]	0	0	0
K_x [m /day]	10	1000	100
K_y [m /day]	10	1000	100
γ_{sat}[kN/m3]	14.10	22	22
γ_{dry}[kN/m3]	13.01	20	20

3.4. Design, numerical modeling and analysis

The aim of this study was to design a subsurface drainage system for our case study which resolves the upwelling by capillary issue observed. Firstly, the components of the drainage system were designed inorder to have suitable parameters for the system components. Design of these components were done using the software DRIP. Numerical modeling and analysis were perfomed using the finite element analysis software Plaxis 2D. Since the CBR (Californian Bearing Ratio) of the in-situ subgrade material was found to be low (less than 10 as compared to the value of 30 or greater) with respect to the project requirements, the substitution of the subgrade material is necessary.

3.4.1. Design of subsurface drainage system

The subsurface system designed is composed of a permeable base and an edgedrain. Two drainage system were designed; case 1 with drainage layer of laterite, pozzolana and boulders, and case 2 with a drainage layer of pozzolana and crushed stones (25/63). The design steps involved road geometry calculation, sieve analysis, inflow analysis, permeable base design, separator layer design and edgedrain design. Input parameters for the design were obtained from the project information collect.

3.4.2. Numertical modeling and analysis in Plaxis 8.6

Inorder to study the stability of the drainage system on the cut section object of this research work, the road section and inputs were numerically modeled and analysed using the finite element analysis software Plaxis. This analysis permitted us to verify the stability of our proposed solutions.

3.4.2.1. Numerical modeling

Finite element analysis in Plaxis involved the creation of a model, specification of material properties, loadings and boundary conditions in the input program of the software. The generation of an appropriate finite element mesh and the generation of properties and boundary conditions were automatically perfomed by the plaxis mesh generator. The final part of the input comprised the generation of the water pressures and initial effective stresses to set the initial state. Figure 3.7 presents the project model. Boundary conditions, initial phreatic level and active pore pressures before excavation are illustrated in Figure 3.8. Material model and loading conditions are presented in table 3.6.

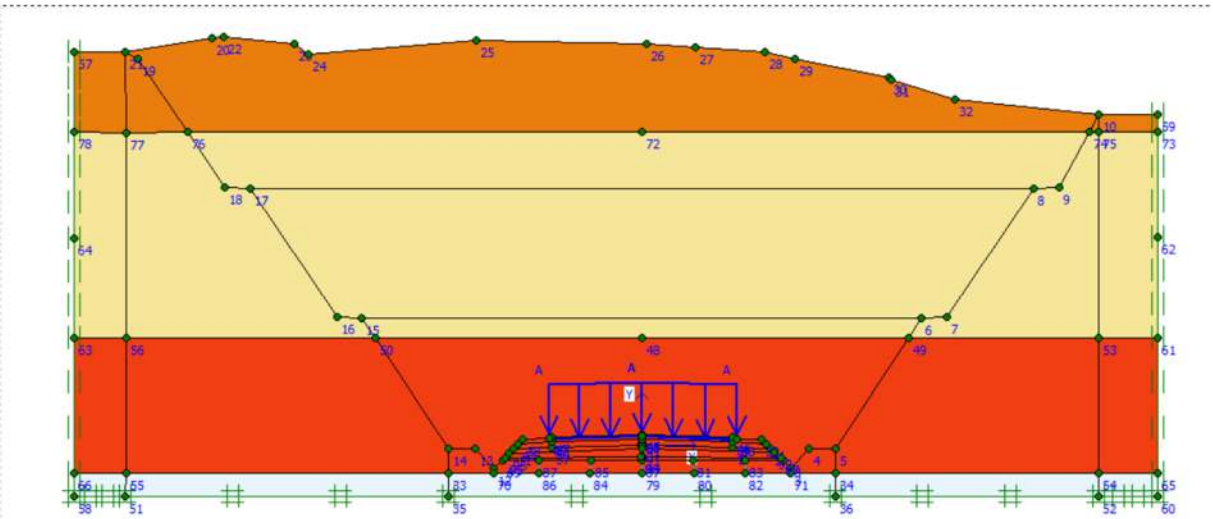


Figure 3.7. Soil model in plaxis (Plaxis 2008)

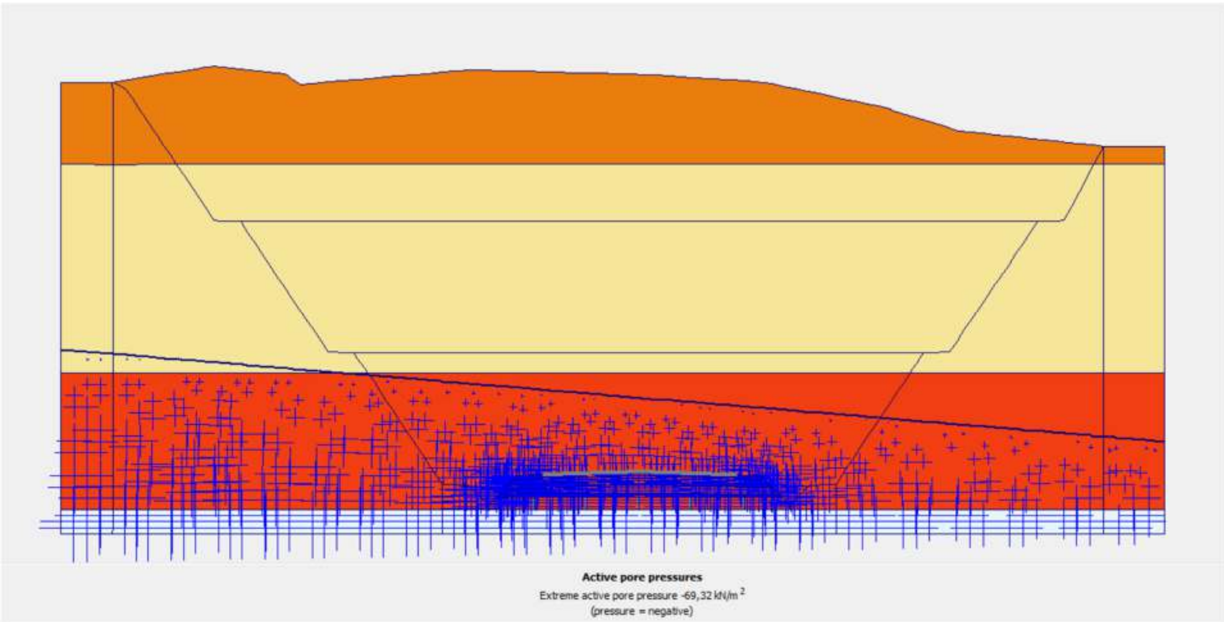


Figure 3.8. Active pore water pressure before excavation (Plaxis 2008)

Table 3.5. Layer of material for the road section and drainage system

	Layers	Thickness	Material model
Pavement layers	Asphalt concrete	5cm	Linear Elastic
	Base layer (Crushed stones 0/31,5)	15cm	Jointed rock model
	Subbase (laterite)	20cm	Mohr-Coulomb
Drainage layers	**Drainage layer of laterite, pozzolana and boulders**		
	Laterite	20cm	Mohr-Coulomb
	Pozzolana	10cm	Mohr-Coulomb
	Rocks (0/400)	70cm	Jointed rock model
	Drainage layer of pozzolana and gravel		
	Pozzolana	15cm	Mohr-Coulomb
	Crushed stones (25/63)	85cm	Jointed rock model

3.4.2.2. Numerical analysis and calculation

Generally, projects are divided into project phases. Our numerical analysis comprises of eight (08) phases of which: Gravity loading, 1st, 2nd, 3rd, 4th excavations, substitution, road layers and loading phases. Figure 3.9 and 3.10 illustrate the calculation phases in the plaxis window and the model at the end of the loading phase.

a. Gravity loading phase

Calculation of initial stresses in plaxis can be done by two procedures; the K_0-Procedure or the gravity loading procedure. The K_0-Procedure is used for horizontal soil layers and phreatic level whereas gravity loading is used when the soil surface, the layering or the phreatic level is non horizontal with the soil weight multiplier set at 1.

b. 1st excavation

This phase involved the excavation of the pozzolana and part of the clay upto the first berm.

c. 2nd excavation

Here, most of the clay is excavated upto the second berm.

d. 3rd excavation

The sandy clay is removed upto the upper earthwork level.

e. 4th excavation

Arrived at this level, further excavation is done up to the fractured rock.

f. Substitution

The drainage layers were placed as substitute of the excavated sandy clay upto the upper earthwork level of the road profil.

g. Road layers

Road layer material were added.

h. Loading

The service load for the road was activated and calculation launched.

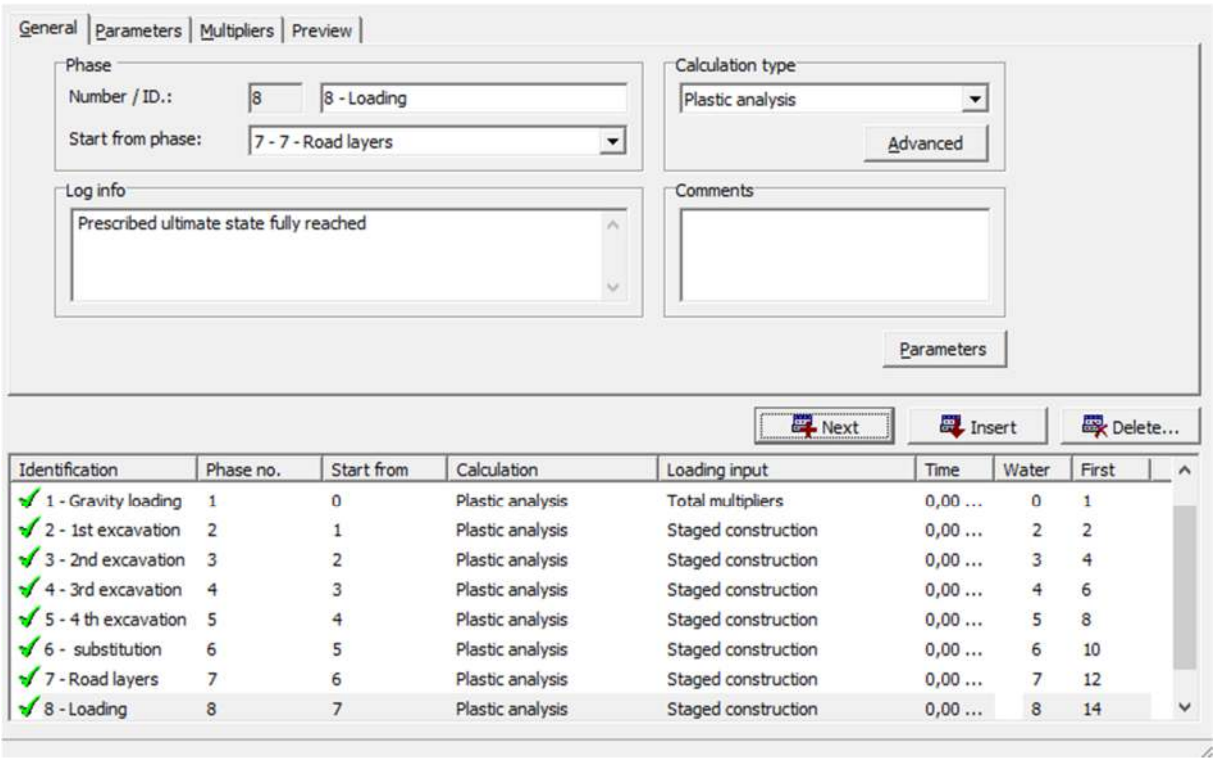


Figure 3.9. Analysis phases (Plaxis 2008)

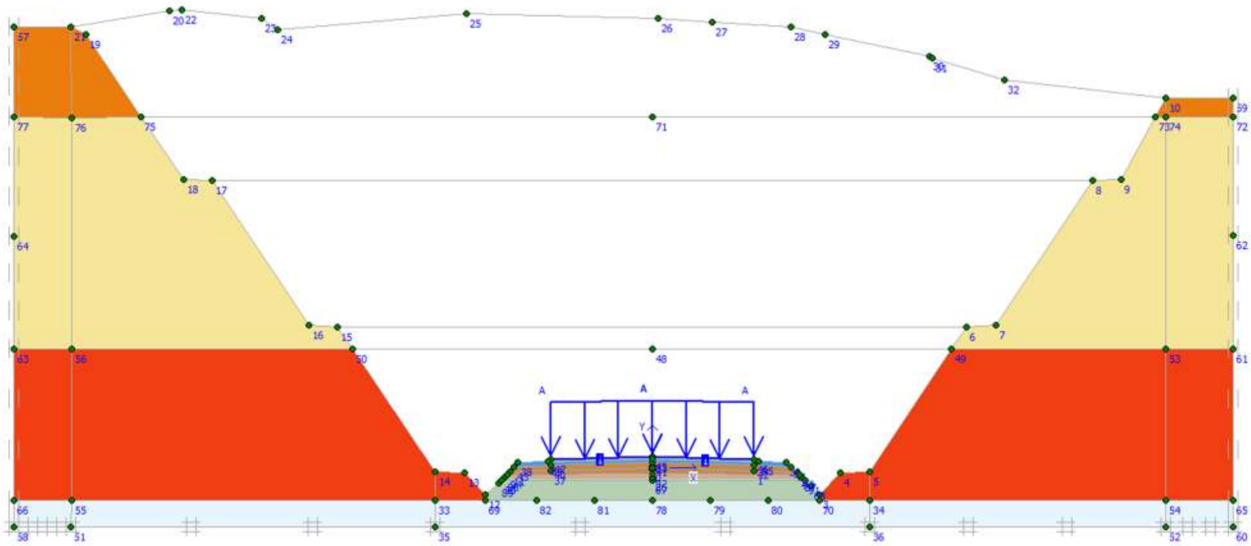


Figure 3.10. Model after loading (Plaxis 2008)

3.5. Results description

Design and anaysis enabled us to have results of the drainage layers' section values and different parameters including excess pore water pressure, total displacement, mean effective stresses and flow velocity along the road section for the two solutions proposed. and case 2 respectively.

3.5.1. Design results and interpretation

Table 3.5 Shows the results obtained from the design of the two proposed solution cases.

Table 3.6. Result of design of drainage system

DESIGNATION	Drainage layer of laterite, pozzolana and boulders	Drainage layer of pozzolana and crushed stones (23/65)
(1) Roadway geometry		
Width of surface (b)	7m	7m
Distance from edge of surface to edge of base (c)	1.5m	1.5m
Width of drainage path (W)	5m	5m
Longitudinal slope (S)	0.03m/m	0.03m/m
Transverse slope (S_x)	0.025m/m	0.025m/m

Resultant slope of drainage path (S_R)	0.0391 m/m	0.0391 m/m
Resultant length of drainage path (L_R))	7.81 m	7.81 m
(2) Sieve analysis		
(a) **Sieve Analysis Permeable Base**		
P_{200}	0	0.17 %
% passing for sieve 0.075	0	2.3
% passing for sieve 25	0	48.1
% passing for sieve 37.5	0	88.3
% passing for sieve 50	0	98.8
% passing for sieve 63	0	0
% passing for sieve 75	0	0
(b) **Sieve Analysis Subgrade**		
P_{200}	0	0.17 %
% passing for sieve 0.075	0	0
% passing for sieve 63	0	0
% passing for sieve 75	0	0
(3) Inflow design		
Asphalt Cement Concrete Infiltration coefficient (C)	0.5	0.5
Two year, One Hour, Rainfall rate (R)	0.5708 mm/hr	0.5708 mm/hr
Rate of infiltration through surface (qi)	7.9283e-008 $m^3/s/m^2$	7.9283e-008 $m^3/s/m^2$
(4) Permeable base design (Time-to-drain method)		
Effective porostity (N_e))	0.515	0.415
Permeability of base (K_{base})	1000.00 m/d	100.00 m/d
Resultant slope of drainage path (S_R))	0.0391 m/m	0.0391 m/m
Resultant length of drainage path (L_R))	7.81 m	7.81 m
Percent saturation (S)	52.048 %	61.359 %
Thickness of the base (H)	0.5 m	0.85 m
Percent drainage (U)	50. %	50. %

Time to drain U% of water from base (t)	0.47hr	2.65 hr
(5) Separator layer design		
Base D_{15}	78.4987mm	28.1886 mm
Base D_{50}	87.0052mm	38.0465 mm
Subgrade D_{50}	87.0052mm mm	87.0052mm mm
Subgrade D_{85}	95.9968 mm	95.9968 mm
$D_{15}^{Base} \leq 5D_{85}^{Subgrade}$	**Pass**	**Pass**
$D_{50}^{Base} \leq 25D_{50}^{Subgrade}$	**Pass**	**Pass**
(6) Edge drain design		
(a) **Pipe**		
Roughness coefficient of pipe (n)	0.024	0.024
Pipe diameter (D)	100mm	100mm
(b) **Discharge Rate Approach - Time to Drain**		
Width of drainage path (W)	5. m	5. m
Thickness of the base ($\mathbf{H_{base}}$)	0.5 m	0.85 m
Effective porostity ($\mathbf{N_e}$)	0.515	0.415
Percent drainage (U)	50. %	50. %
Time to drain U% of water from base (t)	0.47 hr	2.65 hr
(c) **Edge Drain Results**		
Pipe capacity (Q)	4.84e-003 m^3/day	4.84e-003 m^3/day
Outlet spacing ($\mathbf{L_0}$)	12.7 m	52.4 m

Design results for case 1 with drainage layer of laterite, pozzolana and boulders, gave a minimum thickness of 50cm for 50% time to drain of 0.47hours (excellent with reference to table 2.1), and a corrugated pipe diameter of 100mm with outlet spacing 12.7m.

For case 2 with drainage layer of pozzolana and crushed stones (23/65) the minimum required permeable base thickness was 85cm for a 50% time to drain of 2.65 hours (good with reference to table 3.1), and a corrugated pipe diameter of 100mm with outlet spacing 52.4m. The final thickness required for stability will be determined from the stability analysis in Plaxis**.**

Edgedrain result gave a pipe capacity of 4.84e-003 m^3/day for both cases. The minimum trench width used shall be a 300mm trench (Drainage, 2002). The trench shall be wrapped with a geotextile material and crushed stone (gravel 25/63) as backfill material surrounding the edgedrain.

3.5.2. Analysis results and interpretation

Results obtained from analysis of the two drainage systems are described as follows.

3.5.2.1. Case 1 : Drainage layer of laterite, pozzolana and Boulder

Figures 3.11 to 3.16 illustrates the results obtained for that drainage system.

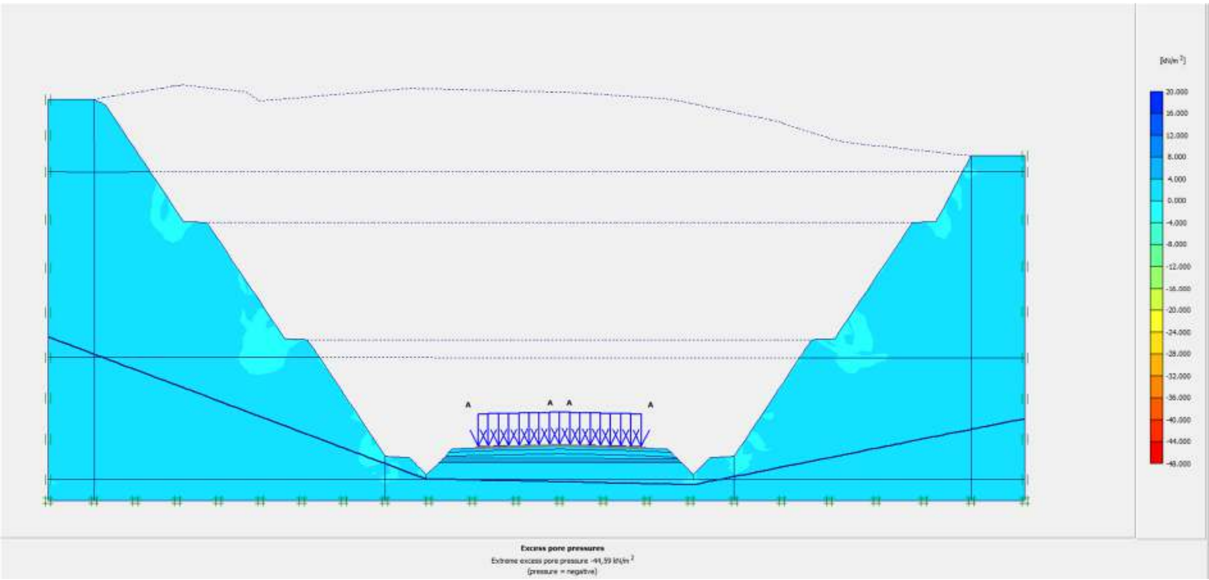


Figure 3.11. Excess pore water pressure (Plaxis 2008)

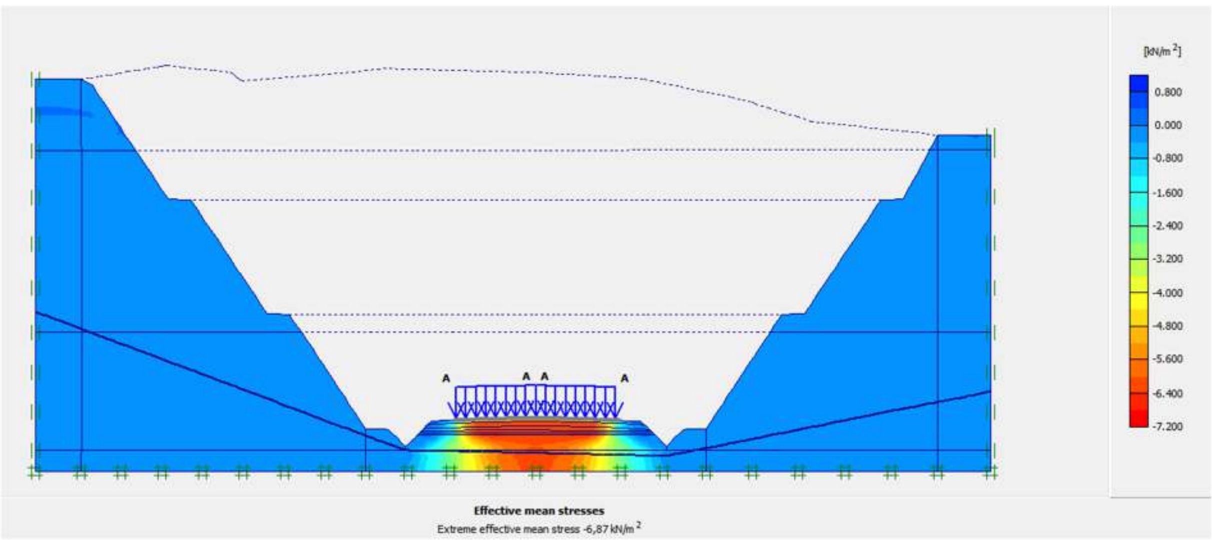


Figure 3.12 . Mean effective stresses (Plaxis 2008)

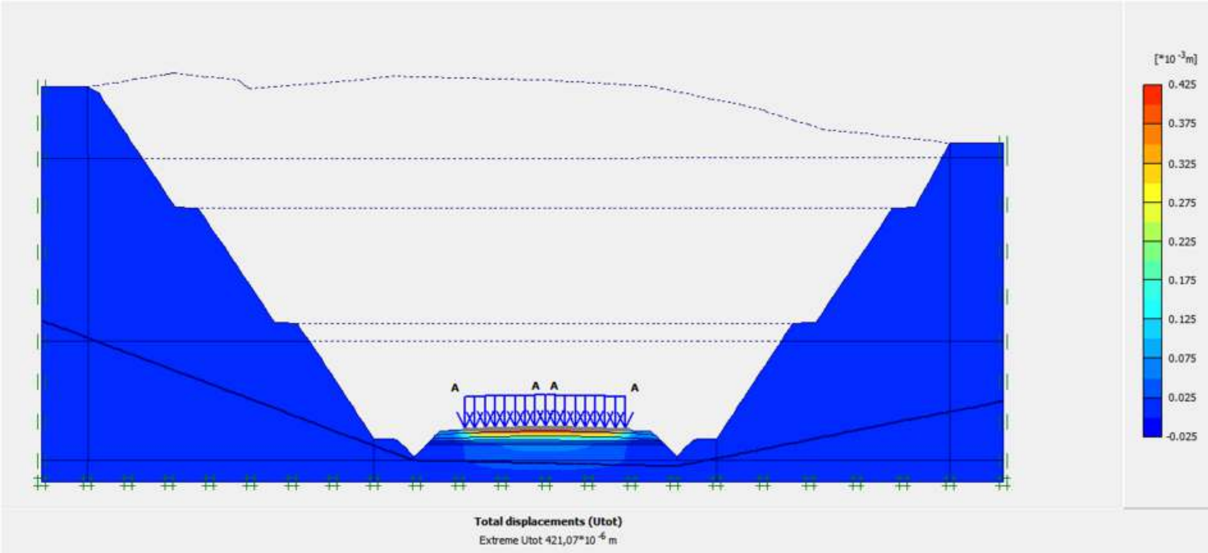


Figure 3.13. Total displacement (Plaxis 2008)

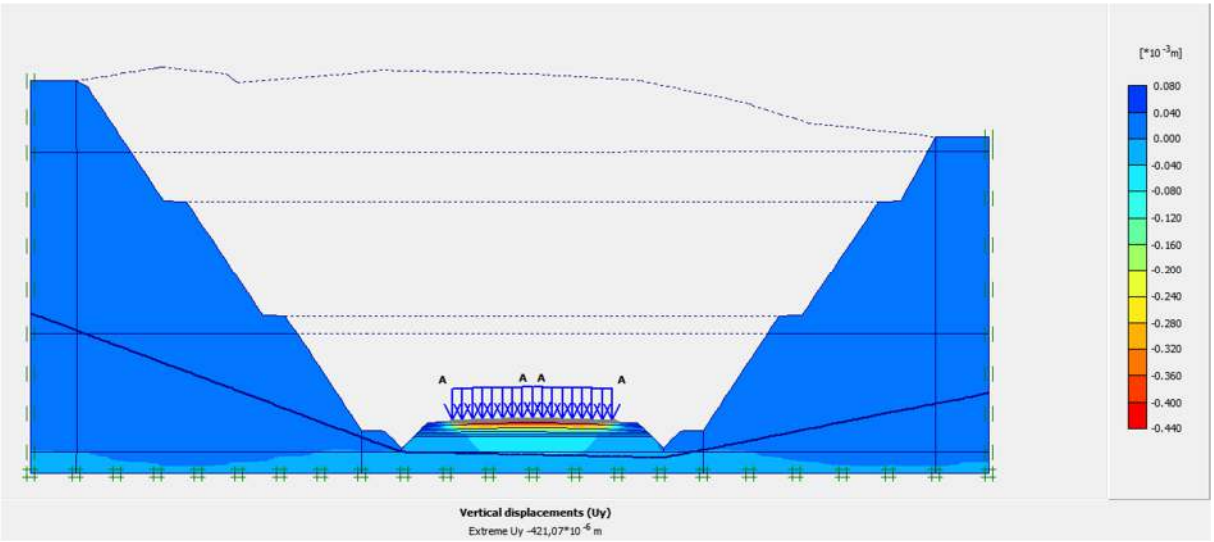


Figure 3.14. Vertical displacement (Plaxis 2008)

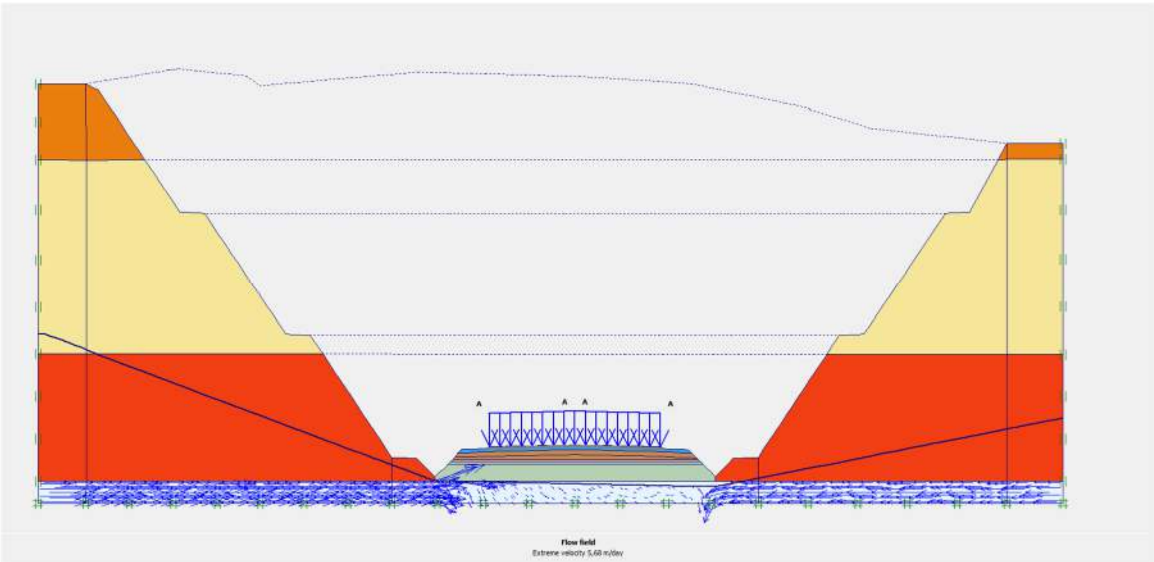


Figure 3.15 Extreme velocity (Plaxis 2008)

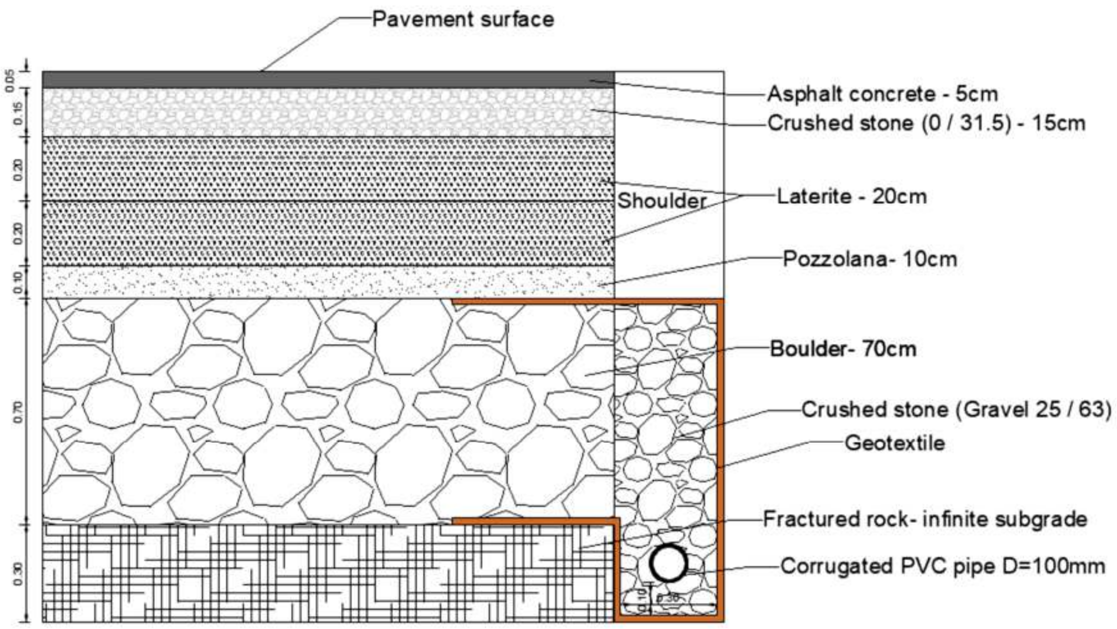


Figure 3.16 Case 1 Road and pavement drainage layer

3.5.2.2. Case 2 : Drainage layer of pozzolana and crushed stone 25/63

Figures 3.17 to 3.22 illustrates the results obtained from analysis of case 2 drainage system.

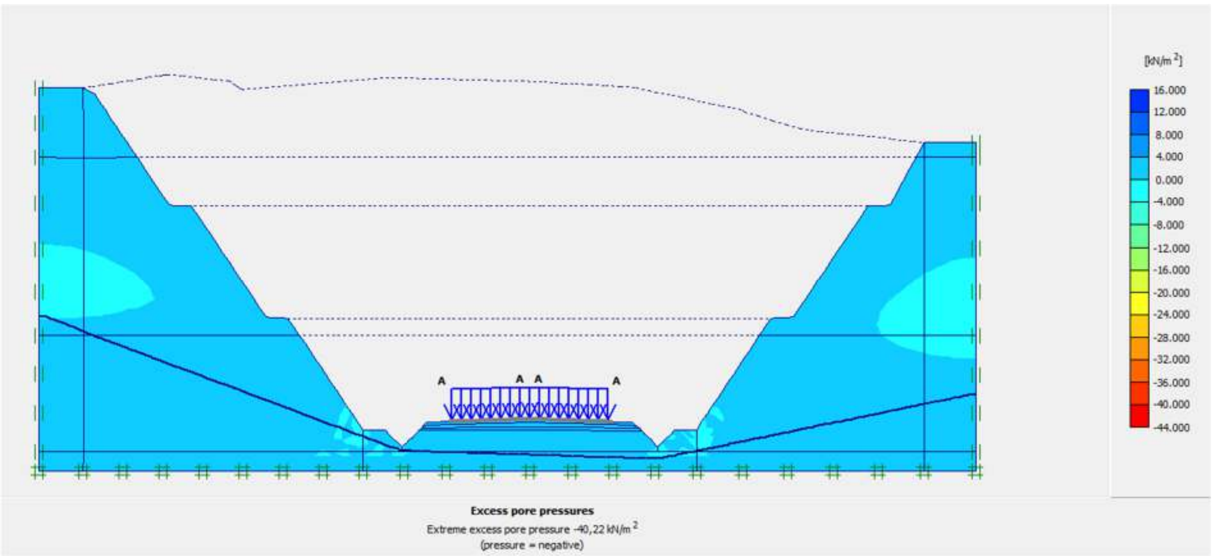


Figure 3.17. Excess pore water pressure (Plaxis 2008)

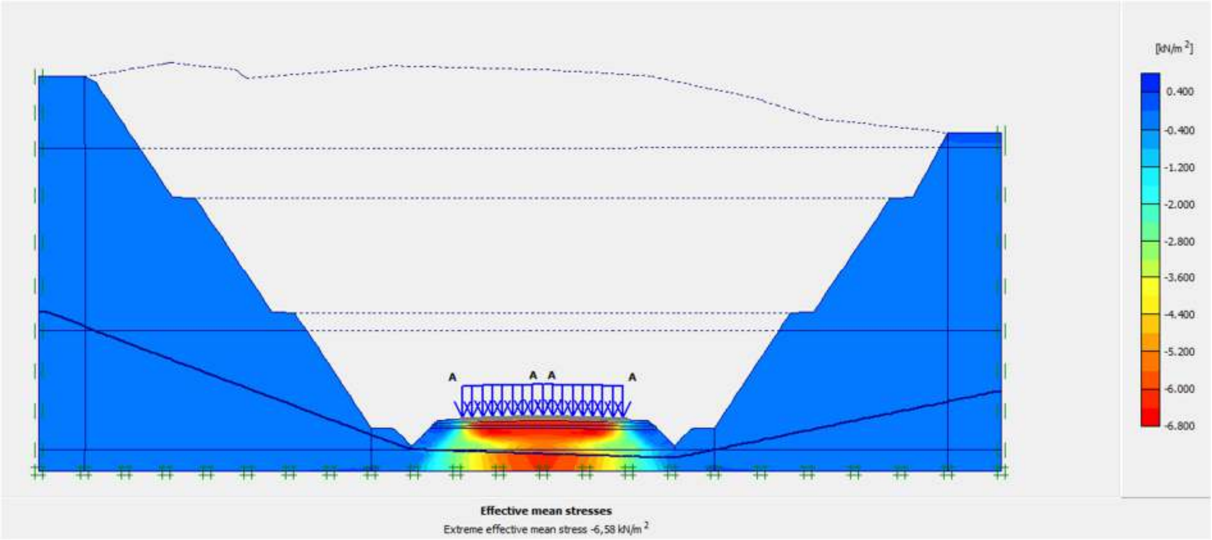


Figure 3.18 . Mean effective stresses (Plaxis 2008)

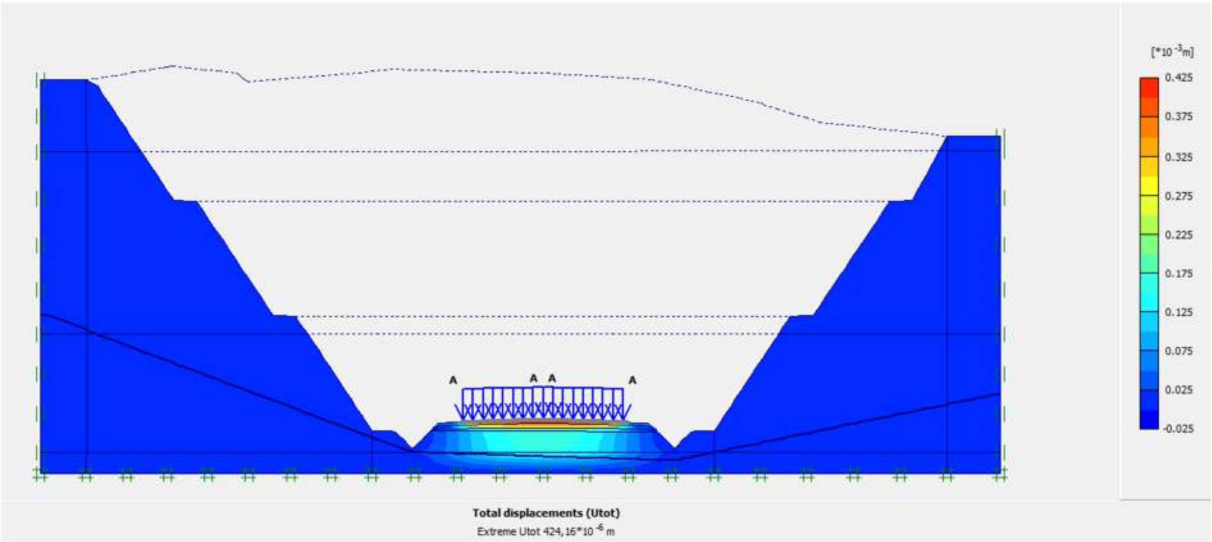


Figure 3.19. Total displacement (Plaxis 2008)

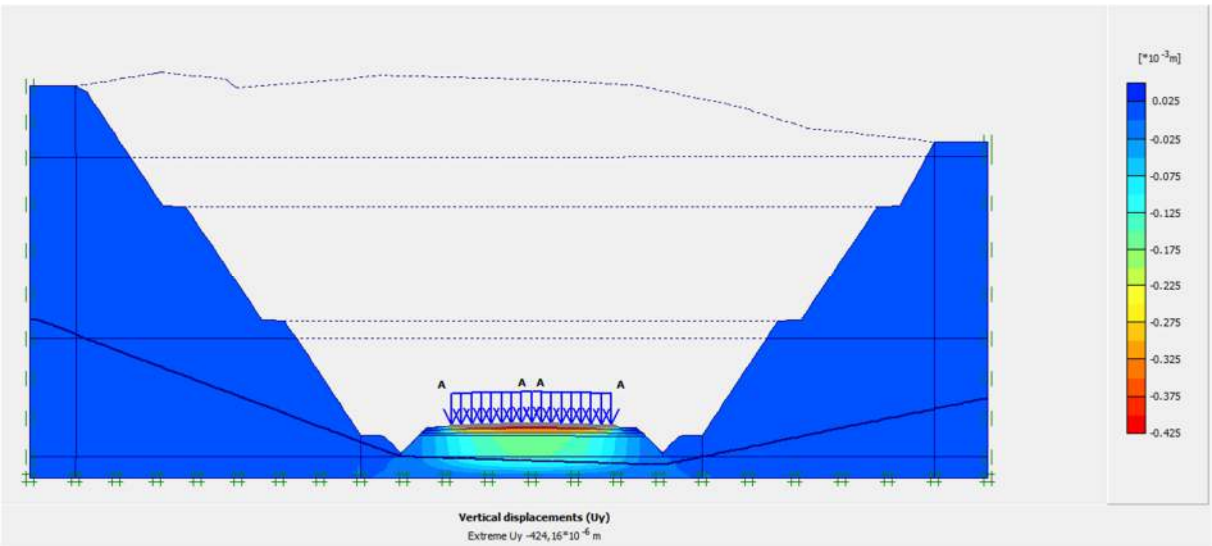


Figure 3.20. Vertical displacement (Plaxis 2008)

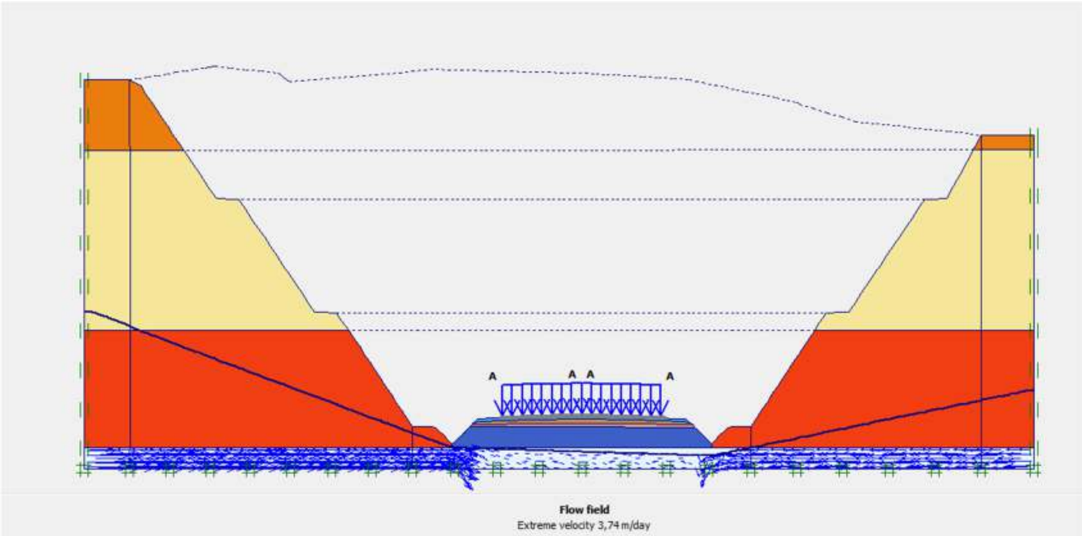


Figure 3.21. Extreme velocity (Plaxis 2008)

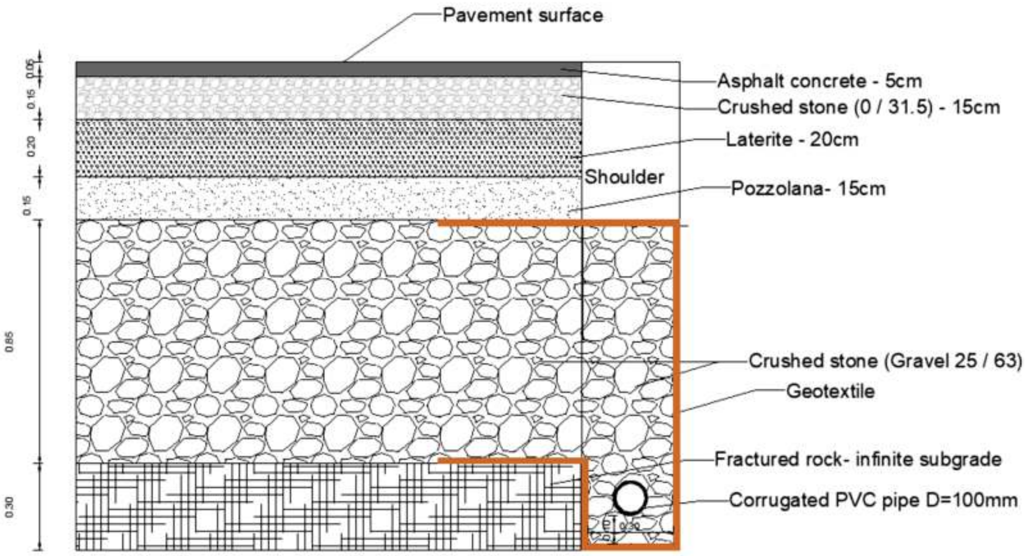


Figure 3.22. Case 2 Road and drainage layers

From analysis, the permeable base height required for stability of the structure is 70cm.

3.5.2.3. Summary of results

Results obtained from the analysis of the two drainage systems are summarized in Table 3.7

Table 3.7. Summary of output results for the drainage layers

Parameter	Case 1 : Drainage layer of laterite, pozzolana and boulders	Case 2 : Drainage layer of pozzolana and crushed stones (25/63)
Excess pore water pressure [KN/m²]	-44.59	-40.22
Effective mean stresses [KN/m²]	-6.87	-6.58
Total displacement [m]	421.07E-6	424.14E-6
Vertical displacement [m]	-421.07E-6	-424.14E-6
Extreme velocity [m/day]	5.68	3.74

From table 3.7, it can be observed that the total stability of the structure is reached for both cases with each having negligeable total and vertical displacement values. The two cases present approximately identical excess pore pressure values and effective stress values. Case 1 happens to presents a higher resultant effective velocity of flow field with 5.68m/day indicating a higher drainage capacity than case 2 with 3.74m/day flow velocity.

3.6. Comparative analysis

In engineering as well as in other fields, generally, several solutions are found for a problem. The next step is to choose which solution best fits the project projections technically and economically. A technical and economic analysis of the solutions found will help us choose the most convenient solution.

3.6.1. Technical analysis

Technical analysis will be based on; drainage capacity and production time of the two proposed solutions.

3.6.1.1. Drainage capacity

The main aim of a drainage system is to drain water. Drainage material requires to have a high drainage capacity. The open gradation of boulders gives the material a high permeability providing a high drainage capacity. The spacing between particles of crushed stone is reduced as compared to that of boulders, increasing the path of water flow hence reducing the drainage capacity of the material.

3.6.1.2. Production time

During project planning, the main aim is to end the project within the least possible time frame. Production time of construction material is hence and important point taken into consideration. The hierarchical positioning of boulders in the production line of aggregate, being the first product during processing makes it the less timely available material for construction. Crushed stones 25/63 is found steps below boulders and requires more processing, increasing the production time increasing the project time frame.

3.6.2. Economic analysis

Cost analysis aims at selecting the most economic solution in terms of cost amongst all. A cost analysis will be done comparing the two solutions proposed for the drainage system.

Table 3.8 presents a summary of the unit prices for each material used

Table 3.8. Unit prices for material (Project document)

Material	Unit price (FCFA)
Excavation of loose soil + embankment by laterite or pozzolana	21 000
Boulders	42 000
Crushed stones (25/63) (m^3) + excavation of loose soil	93 000
Geotextile (m^2)	2 600
Corrugated edgedrain (D=100mm)	10 650

A cost analysis for 1m length of road section will be done. Table 3.9 and 3.10 respectively presents the cost analysis of the two-case studied: case 1 with drainage layer made of laterite, pozzolana and boulders and case 2 with drainage layer made of pozzolana and crushed stones (25/63)

Table 3.9. Cost analysis for the drainage layer of laterite, pozzolana and boulders

DESIGNATION	Height	Quantity	Unit price (m3)	Total price / m
Laterite	20cm	0.2x7=1.4m²	21 000 FCFA	29 400 FCFA
Pozzolana	10cm	0.1x7=0.7m²	21 000 FCFA	14 700 FCFA
Boulders	70cm	0.7x7=4.9m²	42 000 FCFA	205 800 FCFA
Corrugated edgedrain (D=100mm)		1m	10 650 FCFA	10 650 FCFA
Backfill material for trench + excavation of bad soil	100cm	(0.7+0.3)x0.3 = 0.3m²	93 000 FCFA	27 900 FCFA
Geotextile		3m²	2 600FCFA	7 800FCFA
TOTAL PRICE				**296 250 FCFA**

Table 3.10. Cost analysis for the drainage layer of pozzolana and crushed stones (25/63)

DESIGNATION	Height	Quantity	Unit price	Total price
Pozzolana	15cm	0.15x7=1.05m²	21 000 FCFA	22 050 FCFA
Crushed stones (25/63) + excavation of bad soil	85cm	0.85x7=5.95m²	42 000 FCFA	553 350 FCFA
Corrugated edgedrain (D=100mm)		1m	10 650 FCFA	10 650 FCFA
Backfill material for trench+excavation of bad soil	100cm	(0.85+0.3)x0.3 = 0.345	93 000 FCFA	32 085 FCFA
Geotextile		3.15m²	2 600FCFA	8 190FCFA
TOTAL PRICE				**626 325 FCFA**

Figure 3.23 presents a comparism graph of the cost of the two proposed solutions.

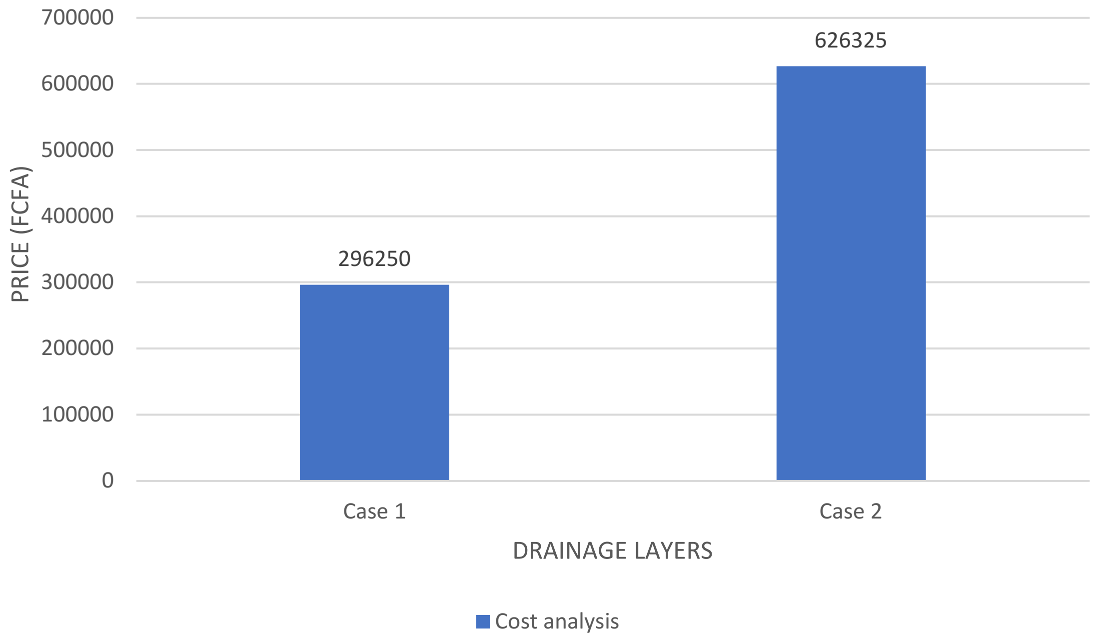


Figure 3.23. Graphical comparism of cost of the two drainage layers

From the above economic analysis, it can be observed that the cost of implementing case 1 represents 47.2% of that of implementing case 2 as drainage solution. Hence, case 1 is the most economic solution.

3.6.3. Choice of optimal solution

The above technical and economic analysis will permit us to choose the optimal solution amongst the two proposed solutions. Table 3.11 summarizes this analysis.

Comparism will be done using the codification that follows: 1 = low, 2 = Medium and 3 = satisfactory

Table 3.11. Comparative analysis

	Drainage solutions	
Criterion	**Case 1 : Drainage layer of laterite, pozzolana and boulders**	**Case 2 : Drainage layer of pozzolana and crushed stones 25/63**
Drainage capacity	3	1
Production time	2	1
Cost	3	1

From the above analysis, there is a clear evidence of case 1 (drainage layer of laterite, pozzolana and crushed stones) being the optimal solution technically and economically relative to strength, drainage capacity, production time and cost as compared to case 2 (drainage layer of pozzolana and crushed stones). Figure 3.24 presents the solution to be adopted.

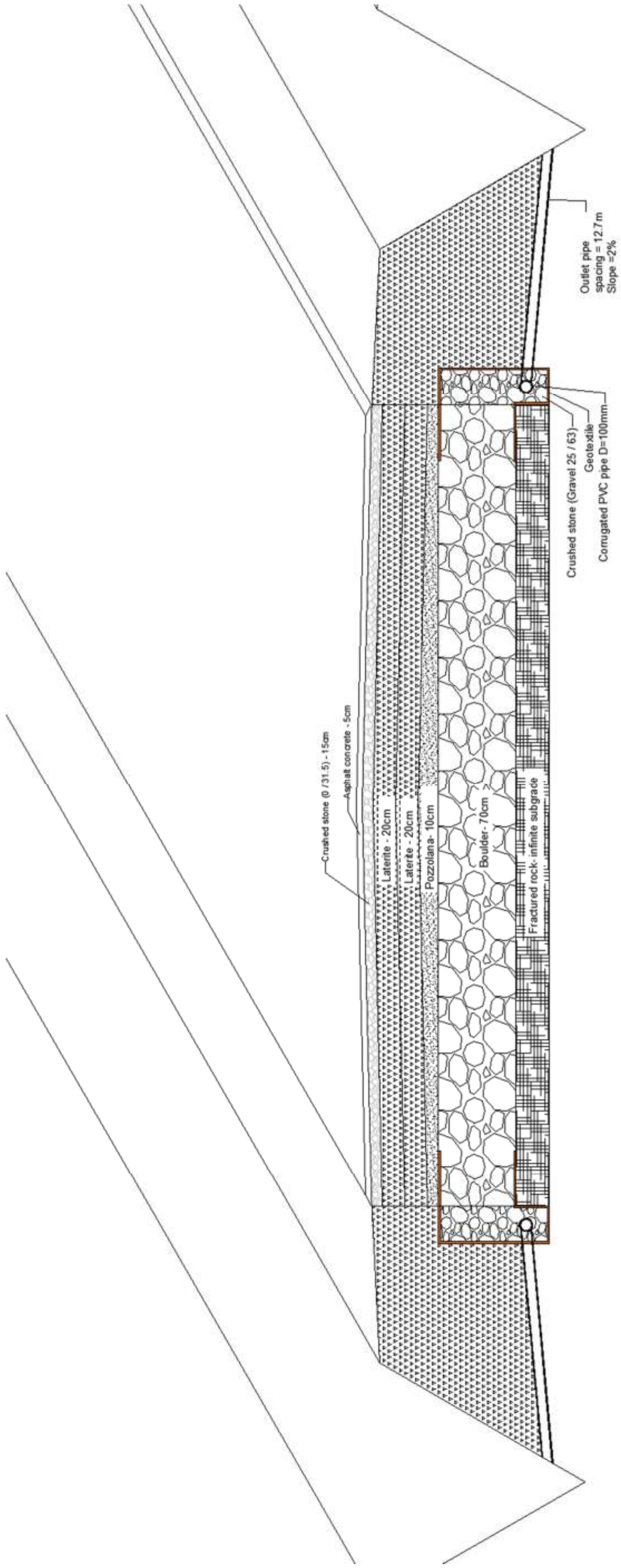


Figure 3.24. Technico – economic solution (drainage layer of laterite, pozzolona and boulders)

Conclusion

A general presentation of the site and case study permitted us to have an insight and an understanding of the region in general and zone of our case study from the physical caracteristics through the geology, hydrology and a summary of the site visit. Caracteristics of the road section and geotechnical material used for building was presented. These were used for ithe design of the drainage system. Two solutions to the upwelling by capillary was proposed: case 1 with a drainage system of laterite, pozzolana and boulders and case 2 with a drainage system of pozzolana and crushed stones (25/63). The driange design was done using the software DRIP. The results obtained from DRIP enabled us to have a preview of the drainage material and heights to be used for the stability analysis in the finite element analysis software Plaxis V8.65. From analysis, case 1 presents a resultant flow velocity of 5.68m/day while case to presents a flow velocity of 3.74m/day showing a higher drainage capacity for case 1 than case 2. An economic analysis permitted us to identify case 1 being the cost effective solution as compared to case 2 with a cost representing 47.2% of that of case 2. This is mainly due to the production cost of crushed stones 25/63 which is relatively high as compared to boulders. From the numerical and comparative analysis, the most optimal drainage solution was found to be case 1 with a drainage layer of laterite, pozzolana and boulders winning on all aspects.

GENERAL CONCLUSION

The main objective of this study was to design a solution for the treatement of upwelling by capillarity at the bottom of a 16m deep excavation along a road construction project. The solution for the treatment had to fit the project line and context technically and economically. To achieve this goal, a documentary research was carried out to have an understanding of soils, their formation, types and properties. Following the upwelling by capillary phenomenon studied, a review of the sources and effect of water in pavement was done as well as the methods used in litterature to prevent or reduce its harmful effect on the pavement structure and foundation. Next was a detailed presentation of the methodology used to design the drainage system composed of a permeable base and an edge drain. This enabled us to perform the design of two possible drainage systems: case 1 with drainage layer of laterite, pozzolana and boulders and case 2 with a drainage system of pozzolana and crushed stones 25/63. The design was done using the software DRIP and stability analysis using the finite element analysis program Plaxis 2D. A comparative analysis of the solution showed case 1 to be the best solution with a better drainage capacity and cost with flow velocity of 5.68m/day as compared to case 2 with 3.74m/day and a cost representing 47.2% of that of case 2.

This study limits itself in the design of the drainage system but does not gives requirements on construction and maintainance procedures. Implementation of a drainage system involves several steps, one of which is its design. The following perspective are proposed for the system to function optimally: Adequate construction procedures should be studied to ensure the correct construction of the designed system; studies should be done on adequate maintainance procedure of drainage system to prevent it from being non-functionning during the pavement service life; During the site visit, it was observed that the slope along the cut section was unstable with erosion taking place. Studies should be done on adequate method of slope stabilization with respect to the material and project specifications.

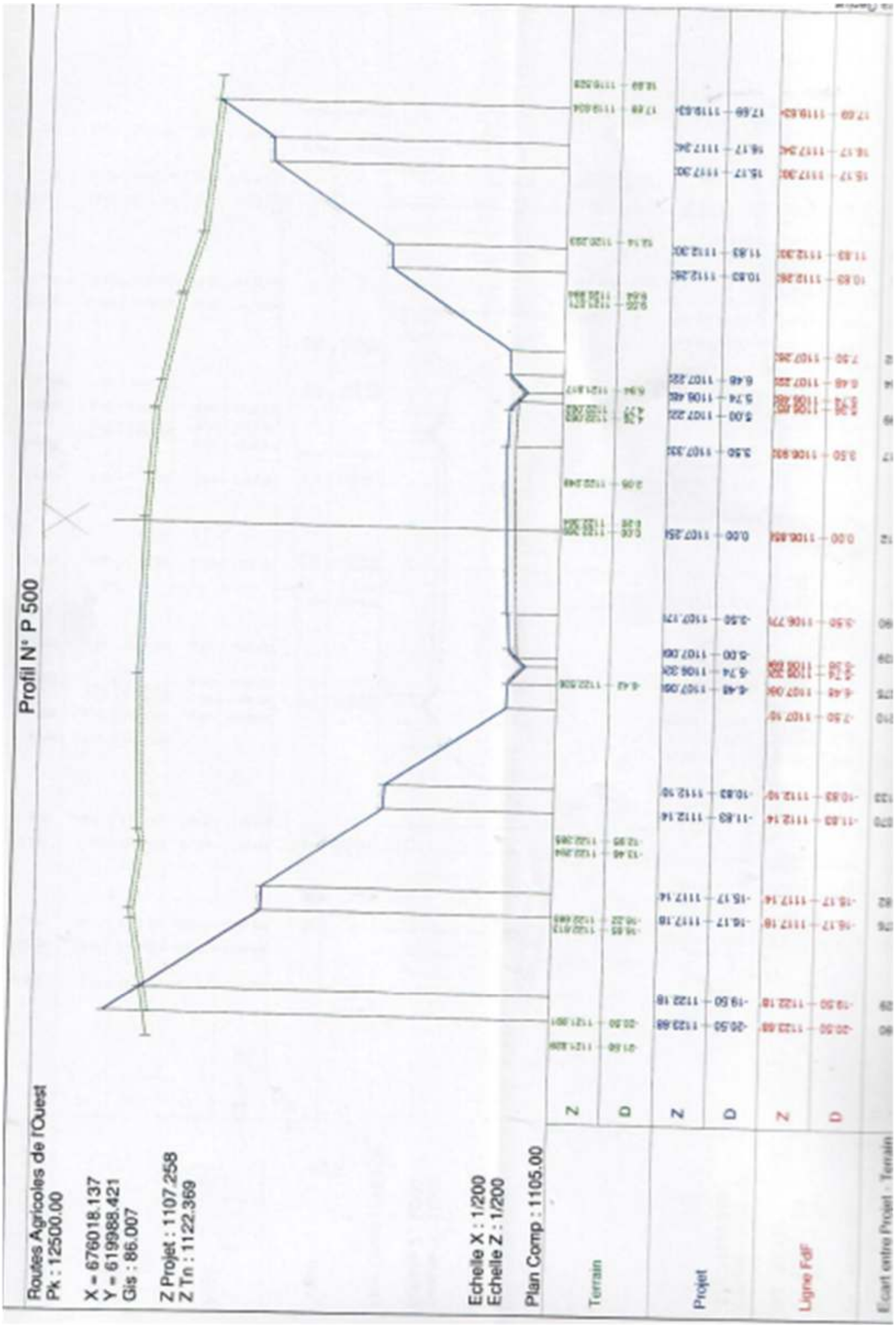
APPENDIXES

Appendix 1 : Moisture-related distresses in flexible (AC) pavements (NHI 13126; adapted after Carpenter et al. 1979)

Type	Distress Manifest-ation	Moisture Problem	Climatic Problem	Material Problem	Load Assoc-iated Distress	Structural Defect Begins in		
						AC	Base	Sub-grade
Surface Deform-ation	Bump or Distortion	Excess Moisture	Frost Heave	Volume Increase	No	No	No	Yes
	Corrugation or Rippling	Slight	Moisture and Temperature	Unstable Mix	Yes	Yes	Yes	No
	Stripping	Yes	Moisture	Loss of Bond	No	Yes	No	No
	Rutting	Excess in Granular Layers or Subgrade	Moisture	Plastic Deformation, Stripping	Yes	Yes	Yes	Yes
	Depression	Excess Moisture	Suction & Materials	Settlement, Fill Material	No	No	No	Yes
	Potholes	Excess Moisture	Moisture, Temperature	< Strength, > Moisture	Yes	Yes	Yes	Yes
Cracking	Longitudinal	No; Accelerates	No	Construction	No	Faulty Construction	No	No
	Alligator (fatigue)	Yes; Accelerates	Spring - Thaw, Strength loss	Thickness	Yes	Yes, Mix	Yes	No
	Transverse	No; Accelerates	Low Temp. Freeze - Thaw Cycles	Thermal Properties	No	Yes, Temp. Susceptible	No	No
	Slippage	Yes	No	Loss of Bond	Yes	Yes, Bond	No	No

n° ECH	PK prélèvement	Niveau de prélèvement (m)	W% naturelle	Poids spécifique γ_s	Analyse granulométrique								Compacité		Limites d'Atterberg		CBR à 95% de l'OPM	Classe de PLATE FORME	Classification H.R.B.
					31,5	25	20	10	5	2	0,5	0,080	γ_d t/m³	ω %	LL	IP			
ECH440	47+300	1,10-1,30	22,4	2,805	95	95	92	69	39	24	20	19	1,839	19,6	66,6	23,3	54	S5	A2-7 [1]
ECH441	47+300	1,10-1,20	19,4	2,737	100	100	100	81	41	16	10	9	1,915	18,8	70,0	28,3	90	S5	A3 [0] (S
ECH442	47+300	1,10-1,30	17,8	2,753	100	99	97	83	44	18	14	14	2,010	15,8	62,8	23,6	89	S5	A2-7 [0]
ECH443	47+300	1,10-1,30	21,0	2,788	100	100	98	82	46	23	18	18	1,951	18,6	64,6	28,2	85	S5	A2-7 [0]
ECH448	47+300	0,30-1,20	24,2	2,728	100	98	97	68	35	21	17	17	1,869	17,6	67,7	29,3	36	S5	A2-7 [0]
ECH449	47+300	0,25-1,20	22,8	2,743	98	96	93	77	45	24	19	18	1,912	18,4	60,7	26,4	42	S5	A2-7 [1]
ECH450	47+300	0,20-1,20	26,0	2,735	93	91	90	77	51	27	20	19	1,790	19,9	66,2	26,3	45	S5	A2-7 [1]
Valeurs moyennes			21,9	2,8	98,0	97,0	95,3	76,5	43,3	22,0	17,0	16,1	1,9	18,4	65,5	26,5	63,0		
Ecartype			2,8	0,0	2,9	3,2	3,6	6,2	5,2	3,7	3,5	3,6	0,1	1,4	3,1	2,3	24,0		
Dispersion			13%	1%	3%	3%	4%	8%	12%	17%	21%	23%	4%	7%	5%	9%	38%		

Appendix 2 : Laterite laboratory analysis results



Appendix 3 : Road project profile

Appendix 4 : Kouoptamo quarry from the section 2 (Foumbot - Bamendjing - Galim) of the project KP 21+250m.

Appendix 5 : Sieve analysis for crushed stone 25/63

Analyse granulométrique par tamisage à sec après lavage [NF P 94-056]

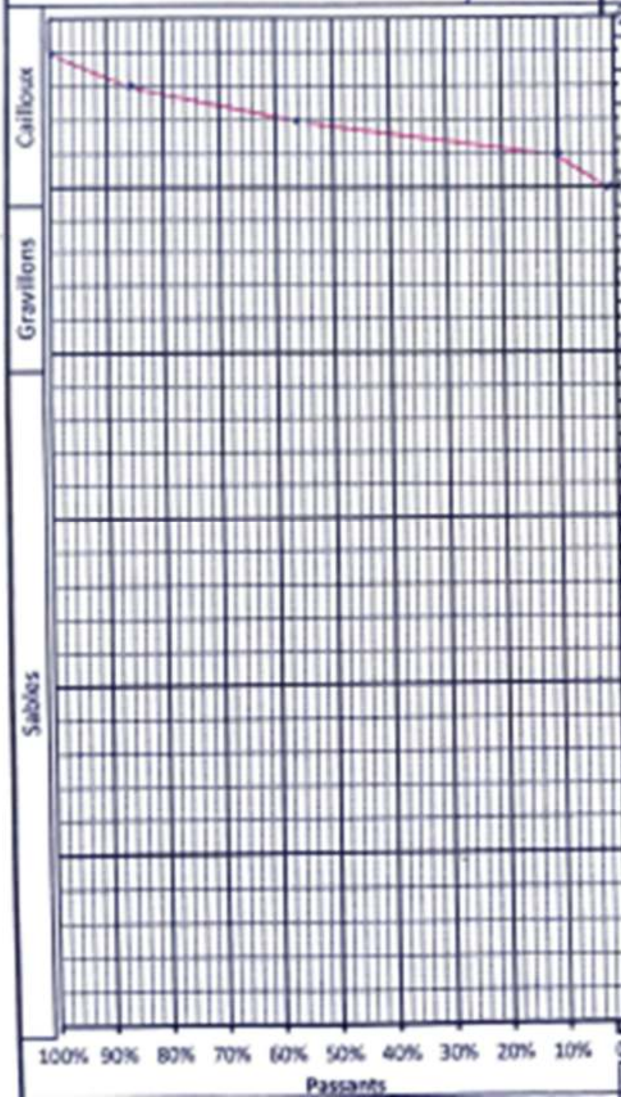
PROVENANCE : Carrière de MOUOPTAMO Prélèvement à la droite

NATURE DU MATERIAU : 25/63

Date de prélèvement :	N° Echantillon :	Etuvage :	Teneur en eau
29/03/2021 à 12H00	47 ESS: 01	/	/

Destination:

Masse seche de la prise d'essai : Ms (g) = 13273.6



Module	Tamis	Refus cumulé (g)	Refus cumulé (%)	Passant (%)	Fuseau Min	Fuseau Max
50	80	00	00	100		
49	63	00	00	100		
48	50	1860.4	14.0	86		
47	40	5778.9	43.5	56.5		
46	31,5	11950.8	90.0	10.0		
45	25	13017.1	98.1	1.9		
44	20					
43	16					
41	12,5					
40	10					
39	8					
38	6,3					
37	5					
36	4					
35	3,15					
34	2,5					
33	2					
32	1,6					
31	1,25					
30	1					
29	0,8					
28	0,63					
27	0,5					
26	0,4					
25	0,315					
24	0,25					
23	0,2					
22	0,16					
21	0,125					
20	0,1					
19	0,08					

D_{10} = D_{30} = D_{60} =

BIBLIOGRAPHY

1) Ackerman, A. F. (2007). Unsaturated Soil Mechanics. In Environmental and Engineering Geoscience (Vol. 13, Issue 1). https://doi.org/10.2113/gseegeosci.13.1.87

2) Arika, C. N., Canelon, D. J., & Nieber, J. L. (2009). Subsurface Drainage Manual for Pavements in Minnesota. http://conservancy.umn.edu/handle/11299/151318

3) Balasubramanian, A. (2017). By Prof . A . Balasubramanian Centre for Advanced Studies in Earth Science , University of Mysore , Mysore. February.

4) Baxter, N., Williamson, J., & Bendigo, A. V. (n.d.). (2001) Part 1 Introduction to Soils

5) Christopher, B. R., Schwartz, C., & Boudreau, R. (2006). NHI Course No. 132040, Geotechnical Aspects of Pavements, Reference Manual / Participant Workbook (Report).FHWA,NHI-05-037,888. https://www.fhwa.dot.gov/engineering/geotech/pubs/05037/05037.pdf

6) Ann McCauley, Clain J., Jeff J. (2005) Soil Properties

7) Dawson, T. M. (2007). Preface. In Parkinson's Disease: Genetics and Pathogenesis. https://doi.org/10.4159/harvard.9780674331372.prf

8) DEPARTAMENT OF TRANSPORT AND MAIN ROADS. (2010). Road Surface and Subsurface Drainage Design. Road Drainage Manual, March, 73. http://www.tmr.qld.gov.au/~/media/02f0ea64-d4aa-43f5-a99c-dbb00642675b/22rdmchapter11mar2010.pdf

9) Des, D., & Et, R. (1997). Guide de drainage routier.

10) Altan Y., Sebnem S. (2012). Water effect on deteriorations of asphalt pavements

11) Dragila, M. I. (2005). Principles of Soil Physics. Vadose Zone Journal, 4(2), 448–448. https://doi.org/10.2136/vzj2004.0012br

12) Zahid H., Sumon R. (2018). Impacts of Moisture on Asphalt Properties.

13) Fredlund, D. G., Rahardjo, H., & Fredlund, M. D. (2012). Unsaturated Soil Mechanics in Engineering Practice. In Unsaturated Soil Mechanics in Engineering Practice. https://doi.org/10.1002/9781118280492

14) Gaitan, T., Seutchueng, T., Kamogne, F. D., & Kamtchoum, S. M. (2020). Extreme

Rainfall and the 14 October 2019 Flooding at the IRAD Multipurpose Station Foumbot (IMSF):West Region of Cameroon. February. https://doi.org/10.14445/23942568/IJAES-V7I2P111

15) Herrmann, H., & Bucksch, H. (2014). Soil Mechanics and Foundation Engineering. In Dictionary Geotechnical Engineering/Wörterbuch GeoTechnik. https://doi.org/10.1007/978-3-642-41714-6_195271

16) Kabir, N., Aliyu, S., Nasara, M. A., & Chinade, A. U. (2019). Characteristics of Different Type of Coarse Aggregate on Properties of High Characteristics of Different Type of Coarse Aggregate on Properties of High Performance Concrete. Sustainable Structure and Materials, 2(October), 88–96.

17) D.G. Fredlund. (2019). Determination of unsaturated soil property functions for engineering practice.

18) J M Reid, G I Crabb, J Temporal and M Clark. (2006). A STUDY OF WATER MOVEMENT IN ROAD PAVEMENTS.

19) R B J Brinkgreve; et al, (2002) Plaxis Manual Version 8.

20) ERES. (2001). Guide for Mechanistic-Empirical Design Appendix Ss : Construction Details Of Subsurface Drainage. Construction, February.

21) ERES (2004). Guide for Mechanistic-Empirical Design Appendix TT : Drainage Requirement In Pavements (DRIP) Microcomputer Program User ' S Guide.

22) V.N.S Murthy (2002) Geotechnical Engineering, Principles and practice of soil mechanics and Foundation Engineering

23) Commune de Foumbot (2014). Plan communal de developpement de Foumbot.

24) ALBTP, CTGA . (2018). Règles techniques pour la construction routière dans les pays africains de la zone intertropicale. 1984.

25) Ian Smith, (2014) Element of soil mechanics.

26) Marie-Odile C., et al (2006) Sétra Drainage routier Guide technique Drainage routier collection les outils.

27) State, I. (2015). Evaluating Roadway Subsurface Drainage Practices – Phase II. April.

28) Tripathy, B., & Raha, S. (2019). Formation Of Soil. August. https://doi.org/10.26643/tjg.v8i8.8140

29) Yang, Y. (2019). Observation and Measurement of Ecohydrological Processes. In Observation and Measurement, Ecohydrology (Issue September). http://link.springer.com/10.1007/978-3-662-48297-1