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Cement Stabilization of Soft Soil Subgrade

By

Harish Paneru

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CERTIFICATE

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The undersigned certify that they have read and recommended to the institute of Engineering for acceptance, a thesis entitled "**Cement Stabilization of Soft Soil Subgrade**" submitted by Harish Paneru (074/MSGtE/007) in partial fulfillment of the requirements for the degree of Master of Science in Geotechnical Engineering.

Supervisor: ________________________

Dr. Mohan Prasad Acharya

Supervisor : ________________________

Assoc. Prof. Dr. Indra Prasad Acharya

Pulchowk Campus, Lalitpur, Nepal.

External:___________________________

Dr. Biswa Ranjan Shahi

Program Coordinator: _________________

Assoc. Prof. Dr. Indra Prasad Acharya

M.Sc. in Geotechnical Engineering Program

Department of Civil Engineering,

Pulchowk campus, Lalitpur, Nepal

September, 2020

ABSTRACT

The Kathmandu valley consist of vast network of road of length more than 2000 km. These road in many places transverse the soft soil deposits of Kathmandu valley. The rutting problem has excessively affected the serviceability conditions of these roads and require frequent maintenance to keep them serviceable. This study reviewed the stabilization of soft soil subgrade by cement. The sample of soil was collected from the depth around existing subgrade. Series of laboratory test showed that the soil was incompetent for subgrade layer and could suffer from subgrade rutting. Then, soil was stabilized with cement and series of laboratory test run on stabilized soil sample showed an improvement in the desirable properties of soil. CBR and UCS showed significant improvement with cement content and with increasing curing time. Optimum cement content was also determined for soil sample under study. Analysis and design of road using CSS and capping layer was done in Kenlayer to determine final design cross section of road using failure criteria given by AI method. The output of analysis showed that the thickness of pavement using CSS was significantly reduced as compared to pavement using capping layer. The study also found that the cost of road using CSS was cheaper for higher traffic intensity. The use of cement stabilization can be a cheaper option to deal with soft soil subgrade problems even though it was expensive for lower traffic intensity. The study also found that the cement stabilized road subgrade can have favorable impacts on national economy through reduction of use of bitumen surface course.

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LIST OF ABBREVIATION

CSS	Cement Stabilized Subgrade
AI	Asphalt Institute
CBR	California Bearing Ratio
UCS	Unconfined Compressive Strength
LL	Liquid Limit
PL	Plastic Limit
PI	Plasticity Index
OMC	Optimum Moisture Content
MDD	Maximum Dry Density
DOR	Department Of Road
AASHTO	American Association Of State Highway And Transportation
IRC	Indian Road Congress
JICA	Japan International Cooperation Agency
IS	Indian Standard
USACE	US Army Corps Of Engineers
ESAL	Equivalent Single Axle Load
MSA	Million Standard Axle
CMTL	Central Material Testing Lab
OPC	Ordinary Portland Cement
GB	Granular Base
GSB	Granular Sub Base
DBM	Dense Bituminous Macadam
AC	Asphalt Concrete
CL	Low Plasticity Clay
CSH	Calcium Silicate Hydrate
CAH	Calcium Aluminum Hydrate

CHAPTER 1 INTRODUCTION

1.1 Background

The population of Kathmandu valley consisting of Kathmandu, Lalitpur and Bhaktapur metropolitan and Madhyapur Thimi Municipality, is more than 2.5 million. The population seems to be increasing day to day due to internal migration of people (Central Bureau of Statistics, 2011). For this, need for well-planned and integrated transportation system is necessary. The previously planned facilities are insufficient to serve the purpose. The existing facilities are affected by the soft soil of Kathmandu valley. The major soil deposits in valley are lacustrine deposits (kalimati clay) and fluvio deltaic deposit(Dill et al., 2001). Not all but some of the roads built over this deposits are affected by subgrade rutting due to presence of soft soil deposits in these areas.

For better transportation facilities, part of inner ring road has already been expanded. The outer ring road is proposed and planning stage has been finished. Other major roads of Kathmandu valley are Suryabinayak to Maitighar Section of Araniko highway, Tripureshor- Nagdhunga section of Trivuwan highway, Balkhu- Dhanshinkali road section, Satdobato – Tikabhairav road, Satdobato- Phulchowki road, Maharajgunj – Budhanilkantha road etc. There is more than 2000 km of road network in Kathmandu valley of which more than 500 km constitutes strategic road network(JICA, 2012). These major routes transverse the soft soil of Kathmandu valley at various places. Other vital roads are also suffering from the same problems at various places. The major problem associated with soft soil subgrade is that road built over these soil require frequent maintenance and overlay(Wanyan et al., 2010) such that the DOR need huge investment every year to make the roads serviceable.

Currently the roads are built based on past experience and practices. The method of replacement is employed in soft subgrade conditions. The practice in other countries have suggested chemical stabilization are more reliable in soft subgrade condition than the replacement by capping layer(Hopkins et al., 2002; Patel et al., 2015; Rathod, 2017). In addition, the subgrade stabilization with cement is found more durable and provides a more stable working surface for overlying layer(Hopkins et al., 2002). Hence cement could be a better option for stabilization and treatment of subgrades, bases and sub bases.

The cement production in Nepal has been increasing year by year. With the increase in production, the unit cost are deemed to decrease with time. Consequently the cost for cement stabilization of subgrade might be cost effective. However, study for stabilization for soils particularly soft soil subgrade at various location of Kathmandu valley is necessary to determine the applicability, mixing method and cost of application. Cement stabilization is one of the most studied and researched subject in the world, it has rarely been used in Nepal in road stabilization. Thus this study is conducted to compare the results with conventional method of road construction, analyze the comparative cost and life span of the roads with and without subgrade stabilization.

1.2 Statement of Problem

The most important part in the construction of road facility is the preparation of subgrade as it provides the foundation for the overlying road layers. If the soil forming subgrade is soft and very sensitive to moisture variation, the successive loading of overlying layer can cause formation of subgrade rutting (Figure 1.1). The effects of soft soil subgrade can be seen as permanent settlement of pavement along the wheel path of vehicle (Tang et al., 2016). This requires frequent maintenance of road. The remedial measure for tackling the problem associated with soft soil subgrade has been taken at several places.

In the core areas of valley, the soil deposit is characteristically soft soil which in some places is expansive in nature. One of the problem associated with such soil is the selection of method of modification suitable to change a relatively incompetent soil into a material which is competent enough to hold the traffic demands. There are various methods employed all over the world to modify the soil such as, mechanical modification methods, use of chemical modifiers, geosynthetics etc. Selection of any one of the method depends on the level of modification required in terms of strength and workability, time and the cost of construction. Apart from time and cost, the preference of the particular method also depends on the suitability for particular ground conditions. The application of any stabilization method without any prior study can lead to increased cost and time of construction. The soil are stabilized with various chemical with cement and lime being most commonly used stabilizers(Bell, 1995, 1996).

Currently in Kathmandu valley, either a capping layer of stronger material or lime stabilization (DOR, 2016) is used to overcome the problem associated with soft soil. The problem with conventional method of replacement is that it requires acquisition of suitable material away from site which can increase the cost of construction. Furthermore, the soil excavated to be replaced gets wasted and needs to be dumped away. The norms are set to check whether the soil can be used as a competent subgrade layer or should be treated or replaced to a certain depth. At present, cement stabilization is considered as expensive solution to treat soft soil subgrade and replacement method is preferred over cement stabilization technique. The main problem with cement stabilization is quality control and proper mixing and for Nepal, high unit cost is also considered a major factor. In addition lack of norms and standard for cement stabilization are playing factor for lower popularity of cement stabilization.

Figure 1.1 Subgrade Rutting in Flexible Pavement

1.3 Study Objectives

The main objective of the study is to analyze the effectiveness of using, subgrade with cement stabilization in terms of direct cost and life span of the road. The general objective of this study are:

1. Finding optimum stabilizer content
2. Comparing subgrade properties with and without modifier
3. Modelling of road cross section with different layers for vertical and tensile strain to check the rutting and fatigue criteria as per code.

4. Determine the cost for treatment and compare the cost of the road with the conventional methods applied and check the viability of stabilizer in present scenario following standard norms and practices

1.4 Scope

The scope this study includes-

1. Identification of location of subgrade improvement.
2. Analysis of technique of subgrade stabilization
3. Optimization of quantity of cement content from laboratory tests.
4. Comparative study of the methods of road design and construction with and without subgrade stabilization and design of road with and without stabilized subgrade.
5. Review the quality control procedure and construction requirements
6. Detail analysis of cost of road construction for both methods.

1.5 Methodology

The research study can be divided into 4 stages. In first stage, the literature associated with the research were collected and studied. In addition to this, the material were also collected for the study. The first stage was followed by laboratory tests. The laboratory test were conducted as per the DOR norms and IS standards. Only test which were significant for road construction were conducted. In the third stage, the results obtained from laboratory tests were analyzed and discussed. The fourth stage of the research includes acquisition of Kenpave software and parameter required to model road cross section in software using elastic model (Section 2.4.1). In addition, the rates and cost of each work involved in the construction of road section for a lane of kilometer stretch were determined and compared with convention method of replacement. The whole process is documented in this final report together with the important conclusions and recommendations.

1.6 Content of Thesis

The thesis is divided into nine chapters.

Chapter 1: It presents a general background of study, main and specific objective of the study, scope and limitations of the study and thesis layout.

Chapter 2: It presents a review of literature associated with stabilization of soil as well as for the modelling and cost analysis.

Chapter 3: It gives overview of material used in research and also presents outline of study methodology.

Chapter 4: It presents the results from laboratory tests conducted on untreated soil and stabilized soil. It also includes discussion of results obtained from tests.

Chapter 5: It deals with design of road section for soil under study as subgrade through modelling by Kenpave. The results are presented in tabular and graphical format with comparison against the road using capping layer.

Chapter 6: It present cost estimation for two types of pavement used for study. The results are shown in graphical and tabular format and discussed with comparison of cost.

Chapter 7: It deals with impacts of road with stabilized subgrade on national economy.

Chapter 8: It gives conclusions obtained from the study.

Chapter 9: This part deals with limitations of this study and gives recommendation for future works

CHAPTER 2 LITERATURE REVIEW

Soft soil is defined as clay or silty clay soil which is generally young and come to an equilibrium under its own weight but has not undergone significant secondary or delayed consolidation since its formation. It is characterized to carry the overburden weight of the soil and any additional load will result in relatively large deformation. The presence of soft soil as a subgrade material creates problems such as longitudinal depressions along the wheel path, subsidence etc.

Subgrade is the natural soil prepared carefully to either carry the traffic load directly or load transferred by the overlying layer. Typically, a road consists of subgrade as lowermost layer followed by base and surface. Other layer may be provided depending on the load carried by road or other requirements. So the subgrade can be defined as a foundation layer which transfer the load to the natural soil. Presence of soft soil in subgrade or beneath it can lead to serious problems which can adversely affect the long term serviceability of road. One of the serious problem posed by soft soil subgrade is rutting. Rutting is the defined as the longitudinal depression appeared on the pavement wheel-paths repeated loadings and the consequential material failure are the main causes of rutting. Basically, rutting are classified into two types:

1. Mix rutting: Mix rutting occurs when the subgrade does not rut yet the pavement surface exhibits wheel path depressions as a result of compaction/mix design problems.
2. Subgrade rutting: Subgrade rutting occurs when the subgrade exhibits wheel path depressions due to loading. In this case, the pavement settles into the subgrade ruts causing surface depressions in the wheel path (Lotfi et al., 1988).

A subgrade should be stable, should not undergo volumetric changes due moisture variation, have permanency of strength and should be easily compacted with least possible energy. Though a soft soil do not fulfill almost all of these requirements but it can be treated to modify its property. This kind of modification can be done by various methods of soil stabilization.

In its broad context "Soil Stabilization" is a process for developing full load support values of weak soils. Soil stabilization has been long recognized as the "art" of improving the behavior of roadbed materials through careful selection of moisture control and compaction.

The use of improvement of soil behavior, with expected results, is the best way to describe soil treatment methods. Often it is more economical to provide such treatments to in situ and borrow materials, rather than replacing them or somehow avoiding them.

2.1 Mechanical Stabilization, or Compaction

Mechanical stabilization, or compaction, is the densification of soil by application of mechanical energy. Densification occurs as air is expelled from soil voids without much change in water content. This method is particularly effective for cohesion less soils where compaction energy can cause particle rearrangements and particle interlocking. But the technique may not be effective if this soil is subjected to significant moisture fluctuation. The efficiency of compaction may also diminish with an increase of the fine content, fraction smaller than about 75 microns, of the soil. This is because cohesion and inter particle bonding interferes with particle rearrangement during compaction.

Blending of two or more materials can be considered. This procedure involves the mixing of materials that have different properties, with individually unacceptable properties to produce a material with the required properties, (typically particle size distribution and/or plasticity) to form a material having improved characteristics, given the limitations of the source materials.

Altering the physiochemical properties of fine-grained soil by means of chemical stabilizer/modifiers is a more effective form of durable stabilization than densification in these fine grained soils. Chemical stabilization of non-cohesive, coarse grained soils, soils with particles greater than 50 percent by weight coarser than 75 microns is also beneficial if a substantial stabilization reaction can be achieved in these soils. In this case the strength improvement can be much higher, greater than tenfold, when compared to the strength of the untreated material (USACE, 1986).

In this research the area of interest is soft plastic soil and the detail discussions will be on chemical stabilizers and cost evaluation.

2.2 Chemical Stabilization

Chemical stabilization is defined as any treatment or method whereby a chemical is used to either change the soil properties and thereby increase the bearing capacity of the soil layer or increase the strength and stiffness through cementation (Seco et al., 2011).

There is an increasing effort around the world towards introducing innovative and unconditional road construction approaches that aim at reducing costs of construction by enabling use of marginal materials found within the road route.

Chemical stabilizer can be categorized as Conventional and unconventional stabilizers. Conventional stabilizers are stabilizers such as cement, fly ash, and bituminous products have been intensely researched, and their fundamental stabilization mechanisms have been identified. Unconventional soil stabilization is additives consist of a variety of chemical agents that are diverse in their composition and in the way they interact with the soil.

2.3 Role of Chemical Stabilization

In general Chemical stabilization is used for a wide range of purposes, some of them are to;

- Dry out soil where the moisture content is too high for successful compaction for compaction at OMC.
- Make the soil less permeable where it is necessary.
- Reduce the plasticity of soils used in road construction and thereby to reduce the effect of moisture variations.
- Improve the compatibility of clays by changing the clay to a more granular and workable material.
- Reduce the swelling and shrinkage of clays.
- Improve the bearing capacity and strength of pavement layers and temporary bypasses, especially during rainy periods to limit construction delays due to rain.
- Delay certain chemical reactions such as the weathering of sulfides and other minerals that is detrimental to road soils.

- Neutralize the sulfuric acid and to reduce the solubility of the highly soluble sulfate salts in gold and certain other mine waste rock crushed stone base materials etc.

The more commonly used chemical stabilizers are lime, cement, bitumen, slag (GGBS) and fly ash. All of these chemical stabilizers are marketed as a milled powder and are available in either bulk form or in paper bags. A wide range of dust palliatives and other proprietary products have appeared in the stabilization market, including calcium chloride, natural and synthetic polymers, sulfonated oils and enzymes and various other proprietary products of which little is known about their compositions. Many of these are not classified as true stabilizers but may have some soil modifying properties.

2.3.1 Type of Chemical Stabilization

Lime

Lime is one of the common chemical stabilizers. The use of lime as a building material dates back some 5,000 years when lime and clay were mixed and compacted to form bricks used in the construction of the pyramids of Shensi in Tibet. About 2, 000 years ago the Romans used lime to improve the quality of their roads. The Romans made mixtures of lime and volcanic ash called "Pozzolana" in which the principles of today's cement can be seen. The word "cement" is derived from the Latin word "Caementum" and was used by the Romans to describe aggregate particles in a mortar (Petry & Das, 2001). John Smeaton built the Eddystone lighthouse in 1756 using a mixture of blue lime and Pozzolanic clay. He was however not aware that he had discovered the basic principle of cement manufacture and this enabled Joseph Aspdin to patent the process, which he called "Portland cement" in 1824.In the United States, tests have been carried out with lime stabilization since 1930 but success was achieved only ten years thereafter. The development of the triaxial compression test in 1945 allowed stabilization methods to be compared directly with one another.

There are generally two types of lime used for stabilization of soils, namely, hydrated and anhydrate. Unhydrated (unslaked) lime is produced by heating lime stone or dolomite (calcium magnesium carbonate) to form calcium oxide (CaO) with varying percentages of magnesium oxide (MgO). This can be slaked by treatment with steam or water, and calcium hydroxide ($Ca(OH)_2$) or calcium and magnesium hydroxide ($Ca(OH)_2$ + $Mg(OH)_2$) is formed. The hydration of calcium oxide is normally much faster than that of magnesium oxide and has a strong chemical affinity to absorb water.

Hydrated lime, sometimes called slaked lime, is quicklime to which water has been added until all the oxides of calcium and magnesium have been converted to hydroxides, the water has slacked quicklime's thirst. Hydrated lime made from pure calcium oxide and 24 percent chemically combined water. Hydrated lime is white and powdery.

Hydrated lime is most commonly used for the lime stabilization of soils. When hydrated lime is mixed with clay particles, it permanently forms strong cementitious bonds (Bell, 1996). Due to its plasticity nature it is used for road construction and hence avoids pothole formations.

Two basic through complex reaction apparently take place when lime is mixed with a soil, namely:

a) A fairly rapid and sometimes almost instantaneous amelioration that may involve the exchange of Ions: and
b) A pozzolanic reaction taking place over a period of time ranging from a few minutes to several months or longer. In both cases there is a chemical reaction between the lime and the soil.

Ion Exchange

This relatively rapid reaction involves both cations and anions and is accompanied by flocculation and the formation of agglomerations caused by clay particles adhering to one another, This increases the plastic limit and thus the plasticity Index (PI) is reduced, whereas the liquid limit may remain unchanged, increase or decrease. But the material becomes more workable and the strength usually is increased. Lime is often added to acidic, sulphate-contaminated crushed stone to prevent salt damage. This can be regarded as a type of ion exchange although clay minerals are not involved.

Pozzolanic reaction

If sufficient lime is added to a soil the PH is increased to about 12.4 which is the PH of saturated lime water at 25 $^{\circ}$C. At this high PH, reactions take place between lime and clay minerals and other pozzolans, such as amorphous silica to produce cementations hydrated calcium silicate and aluminate gels similar to those presented in hydrated Portland cement. Crystallization and hardening of these gels are largely responsible for the strength developed.

Initial Consumption of lime

The amount of lime required to satisfy the soil-lime reaction varies considerably with different soils and a test for the initial consumption of lime (ICL) has been developed. This is a quick test to determine the amount of lime required by the soil-lime mixture to maintain the lime-saturated PH for one hour after the lime has been added (usually a PH of 12.4 at 25°C). IF ICL of the soil fines is greater than 3.5 per cent, the lime demand is considered to be high. It has been found that most weathered basic igneous rocks have a high demand for lime although certain other materials derived from sedimentary rocks, for example, may also have a high lime demand. Sufficient lime should be added to satisfy the ICL and additional lime is necessary for the formation of cementing compounds (Pozzolanic Reaction). The amount of lime required for the development of a significant pozzolanic reaction is best determined by strength tests.

It should be noted that a high ICL is significant not only in lime stabilization but also in cement stabilization, since soils with a high ICL will consume part of the calcium in the cement stabilization, since soils with a high ICL will consume part of the calcium in the cement and thus the strength of the cement treated with material may be reduced. Sometimes this can explain why unexpectedly high cement contents are necessary to satisfy strength criteria. If soil with a high ICL is treated with cement it may be necessary to increase the cement content or the ICL of the formation of cementing reactions, is also very high.

Cement

Composition and property

Cement clinker is manufactured by heating together a mixture of raw materials, which provide sources of calcium, silica, alumina and iron. The clinker formed is then ground to a fine powder together with gypsum for set control, which is the basis of all the cements produced. The range of cements consists of clinker ground together or blended with various percentages of cement extenders (e.g. slag, limestone, fly ash etc.).

Hydration of the tricalcium aluminate results in the early set and hydration of the tricalcium silicate is the reason for the strength development of cement-water pastes. The long-term strength is provided by hydration of the tricalcium and dicalcium silicates, which initially form calcium silicate hydrate gels. With time, these gels crystallize and form a strong Interlocking matrix, cementing the soil and aggregate particles together. The hardening of dicalcium silicate takes place slowly (only after about 28 days) and this material does not initially contribute much towards the early strength of the hydrated cement. The tri- and dicalcium silicates contribute about 95 per cent of the overall strength. Gypsum is ground together with the clinker to retard the rapid setting of the cement by coating the tricalcium aluminate early during the hydration process. Small quantities of free calcium oxide are present in clinker and additional slaked lime (about 20 per cent $Ca(OH)_2$) is released as part of the calcium silicate hydration reactions. The properties of any cement are influenced by the amount and nature of the constituents and extenders present. The method of manufacture and source materials utilized have a large influence on the properties of cement, particularly the cooling method that is used in the manufacture of the clinker. The degree of grinding has a significant impact on the rate of setting of the cement, with finer cements setting much quicker than coarser cements. Research has shown that the hydration properties of two cement samples with identical compositions are not necessarily the same. For this reason the chemical composition of cement can only be regarded as an indication of its probable behavior. In addition to specific chemical properties, cement must also possess certain definite physical properties, e.g. soundness, setting times and time-strength requirements.

Chemical reaction of cement with water:

Cement reacts with water to release hydrates of the constituent particles. This reaction is known as the hydration of cement. The hydration of cement is a complex process and modifies the soil through following mechanism(Halsted et al., 2008):

1. Cation Exchange: The plasticity of a soil/aggregate is determined by the amount of expansive clay (e.g. montmorillonite) present. This clay mineral forms a bonded crystal structure through the stacking of silica and alumina layers. Because of the negative charge on this crystal structure, cations and water molecules (H_2O) are attracted to its negatively charged surfaces in an attempt to neutralize the charge deficiency. This results in a separation of the charged surfaces, forming a diffuse "double layer." The thicker this double layer, the more plastic the soil/aggregate. If the cation responsible for the neutralization is monovalent, such as sodium, the soil/aggregate becomes plastic. In order to reduce the plasticity, the monovalent cations present in the montmorillonite surface must be exchanged so that the thickness of the double layer is reduced. Fortunately, the monovalent cations within the double layer can be easily exchanged for other cations. Portland cement, a good calcium-based soil modifier, can provide sufficient calcium ions to replace the monovalent cations on the surfaces. This ion exchange process occurs within hours, shrinking the layer of water between clay particles, and reducing the plasticity of the soil/aggregate (Bell, 1995; Croft, 1967).
2. Particle restructuring: The restructuring of modified soil/aggregate particles, known as flocculation and agglomeration, changes the texture of the material from that of a plastic, fine-grained material to one more resembling a friable, granular soil/aggregate. Made possible through cation exchange, flocculation is the process of clay particles altering their arrangement from a flat, parallel structure to a more random edge-to-face orientation. Agglomeration refers to the weak bonding at the edge-surface interfaces of the clay particles, which as a result form larger aggregates from finely divided clay particles and further improve the texture of the soil/aggregate. The reduced size of the double layer due to cation exchange, as well as the increased internal friction of clay particles due to flocculation and

agglomeration, result in a reduction in plasticity, an increase in shear strength, and an improvement in texture. As with cation exchange, the particle restructuring process happens rapidly. The most significant changes occur within several hours after mixing.

3. Cementitious hydration: Cementitious hydration is a process that is unique to cement, and produces cement hydration products referred to in cement chemistry as calcium-silicate-hydrate (CSH) and calcium-aluminum-hydrate (CAH) (Parsons & Milburn, 2003). CSH and CAH act as the “glue” that provides structure in a cement-modified soil/aggregate by stabilizing flocculated clay particles through the formation of clay-cement bonds. This bonding between the hydrating cement and the clay particles improves the gradation of the modified clay by forming larger aggregates from fine-grained particles. This process happens between one day and one month after mixing.
4. Pozzolanic Reaction: In addition to CSH and CAH, hydrated Portland cement also forms calcium hydroxide, or $Ca(OH)_2$, which enters into a pozzolanic reaction. This secondary soil modification process takes the calcium ions supplied by the incorporation of Portland cement and combines them with the silica and alumina dissolved from the clay structure to form additional CSH and CAH. The pozzolanic reactions take place slowly, over months and years, and can further strengthen a modified soil/aggregate as well as reduce its plasticity and improve its gradation. The strength gain in case of cement is faster which allows for immediate strength gain and reduces the construction time. The strength gain during may be below ultimate strength (Little & Nair, 2009). However, the cement stabilized soil will continue to gain strength over the course of several days (Pedarla et al., 2011).

Factors that influence the rate of hydration:

Hydration of cement commences as soon as the cement makes contact with the water. The rate of hydration and thereby the rate of strength development slows as it becomes more difficult for the unreacted cement to come into contact with water. Reference has already been made to the fineness of the cement particles. Cement particles that are more finely ground have an increased specific surface area, i.e. the total surface area of the particles.

The hydration rate is increased because of the greater opportunity for contact between cement and water. Temperature plays an important role in all chemical reactions. As the temperature falls, the cement reaction is slowed down, and when the temperature is below 5°C, no reaction takes place. The opposite is also true: as the temperature rises the reaction speeds up and this can have serious implications when roads are stabilized in hot dry areas.

Setting time:

The time taken for the cement paste to attain its shape is known as the setting time. Two stages are recognized, namely, initial set and final set. There is no well-defined physical meaning to these terms, which arbitrarily describe the gradual setting taking place. However, after the initial set the cement-water paste is regarded as unworkable. Generally, but not necessarily in every case, the setting time increases as the main cement type changes.

Fly ash

Fly ash is a by-product of modern power stations. Fine material (fly ash) is collected by electrostatic or mechanical precipitation in the flues. Fly ash is not a stabilizer on its own, but is a pozzolan that reacts with lime on site as a stabilizer.

Soils can be stabilized by the addition of cement or lime. Such stabilization processes improve the various engineering properties of the stabilized soil and generate an improved construction material. Increase in soil strength, durability stiffness, and reduction in soil plasticity and swelling/shrinkage potential are the benefit of soil stabilization (Das, 2015; Naeini et al., 2012; Prusinski & Bhattacharja, 1999; Sherwood, 1993).

A lot of factors have been identified in the literature as having an effect on the stiffness (or resilient modulus) of cementitiously stabilized soils. These factors include the curing time, the deviatoric stress, the moisture content, the porosity-cement ratio, the curing temperature, the percentage and type of stabilizer, the soil properties, the density, and the delay time in compaction (Achampong et al., 1997; Consoli et al., 2011; Puppala et al., 1996; Solanki et al., 2009; Taheri & Tatsuoka, 2012).

In general, the resilient modulus of the treated /stabilized subgrade soils increases with an increase in stabilizer content under an identical moisture content, while the permanent deformation of the treated/stabilized subgrade soils decreases with an increase in stabilizer content (Achampong et al., 1997; Ling et al., 2008; Mohammad & Saadeh, 2008; Puppala et al., 1996; Solanki et al., 2010).

2.4 Road Pavements

1. Flexible pavement: In this type of pavement, the wearing surface is prepared from bituminous material such that it remains in contact with the underlying layer even if there is irregularity. It generally consist of four layer (Figure 2.2) namely,

- Subgrade- The subgrade is usually the natural material located along the horizontal alignment of the pavement and serves as the foundation of the pavement structure. It also may consist of a layer of selected borrow materials, well compacted to prescribed specifications. It may be necessary to treat the subgrade material to achieve certain strength properties required for the type of pavement being constructed. The subgrade is the fundamental layer which primarily dictates the design of pavement structure.
- Sub base layer: It is the layer lying just over the subgrade. The sub base component consists of material of a superior quality to that which is generally used for subgrade construction. When the quality of the subgrade material meets the requirements of the subbase material, the subbase component may be omitted.
- Base Layer: The base course lies immediately above the subbase. It is placed immediately above the subgrade if a subbase course is not used. This course usually consists of granular materials such as crushed stone, crushed or uncrushed slag, crushed or uncrushed gravel, and sand. The specifications for base course materials usually include more strict requirements than those for subbase materials, particularly with respect to their plasticity, gradation, and strength. Materials that do not have the required properties can be used as base materials if they are properly stabilized with Portland cement, asphalt, or lime.

- Surface Course: The surface course is the topmost layer in flexible pavement structure. The surface course in flexible pavements usually consists of a mixture of mineral aggregates and asphalt. It should be capable of withstanding high tire pressures, resisting abrasive forces due to traffic, providing a skid resistant driving surface, and preventing the penetration of surface water into the underlying layers (*AASHTO Guide for Design of Pavement Structures, 1993*, 1993; California Department of Transportation, 2012; Garber & Hoel, 2009).

2. Rigid Pavement: The wearing surface of a rigid pavement usually is constructed of Portland cement concrete such that it acts like a beam over any irregularities in the underlying supporting material. The pavement structure of rigid pavement generally consist of Subgrade and surface layer with optional base course (Figure 2.1).

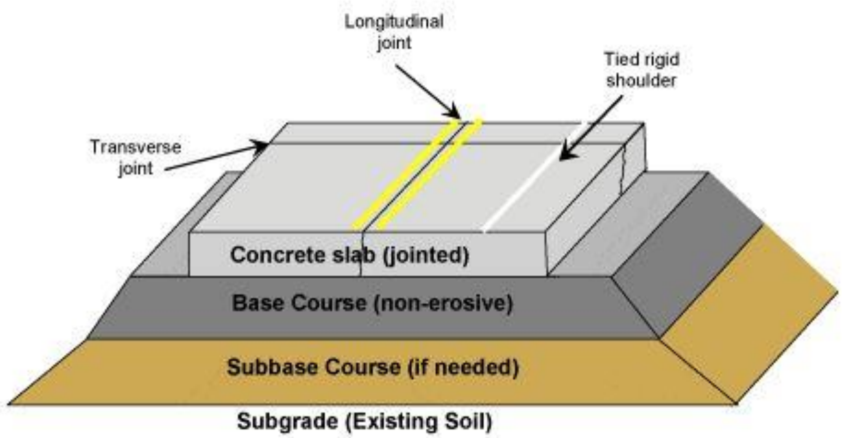

Figure 2.1 Typical Cross section of Rigid Pavement

This study deals with the subgrade and modification of subgrade soil with cement. Apart from this, this study also includes cost analysis of road when natural material (not stabilized) is used and when modified material is used as subgrade.

The subgrade is the top 500 mm of the embankment immediately below the bottom of the pavement, and is made up of in-situ material, selected soil, or stabilized soil that forms the foundation of a pavement. It should be well compacted to limit the scope of rutting in pavement due to additional densification during the service life of pavement (*IRC-37-1998*

Guidelines for the Design of Flexible Pavement, n.d.; IRC, 2012). Road built on modified subgrade can be economic by reducing the thickness of pavement, avoiding capping layer in case of soft soils and reducing the frequent maintenance and increasing the life cycle of road. Properly designed sub- layers can also significantly improve the pavement performance significantly (Little, 1996). The pavement are modelled in Kenpave for different traffic intensity and the output strains are evaluated for failure criteria given by Asphalt Institute Method.

Failure Criteria:

i. Fatigue Criteria: The two points shown in Figure 2.2 are critical location for tensile strain for bituminous layer. The relationship between fatigue life and critical tensile strain (larger out of these 2 value) is given by Department of Road flexible pavement guidelines as below:

$$N_f = 2.21 \times 10^{-4} \times \frac{1}{\varepsilon_t^{3.89}} \times \frac{1}{E^{0.854}} \tag{2.1}$$

Where,

N_f = Number of cumulative standard axles to produce 20 percentage cracked surface area

ε_t = Tensile strain at the bottom of Bituminous layer

E = Elastic modulus of bituminous surfacing

ii. Rutting Criteria: The rutting criteria for average rut depth of 20 mm is as below:

$$N_r = 4.1656 \times 10^{-8} \times \frac{1}{\varepsilon_c^{4.5337}} \tag{2.2}$$

Where, N_r = number of cumulative standard axles to produce rutting of 20 mm

ε_c = Compressive strain at the top of subgrade

The modelling in Kenpave is done using Burmister multielastic layer theory and requires elastic modulus of layer and Poisson’s ratio which are taken as per IRC 37-2012 and DOR Flexible Pavement Guidelines. The Failure criteria are taken as per Asphalt Institute Method which is summarized below:

$$N_f = 0.414 \times \frac{1}{\varepsilon_t^{3.291}} \times \frac{1}{E^{0.854}} \tag{2.3}$$

$$N_r = 1.365 \times 10^{-9} \times \frac{1}{\varepsilon_c^{4.4777}} \tag{2.4}$$

Equation (2.3) and (2.4) are the one used in failure criteria evaluation of road section used in modelling for 5, 10, 20, 30, 50, 100 and 150 msa. The terms in the equation share the same meaning as in the equation (2.1) and (2.2).

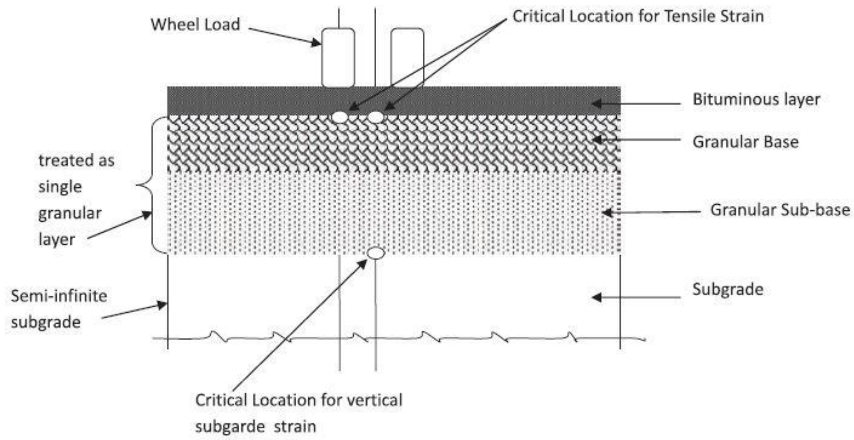

Figure 2.2 Critical Location of Strain in Flexible Pavement

2.4.1 Kenlayer Computer Program:

KENLAYER is a part of computer program KENPAVE, developed by Dr. Yang H. Huang at University of Kentucky which is used for the solution of an elastic multi-layered system under a circular loaded area. Its calculation principle is based on the Burmister's multi-layered elastic theory similar to other programs based on the analytical method. Stress, strain and deformations due to individual wheel assembles (such as dual or dual tandem) are superimposed for their combined effects. KENLAYER is superior to such programs because of its capability of analyzing pavement structure either by linear-elastic, nonlinear-elastic and visco-elastic models or combined of all the above taken together.

2.4.2 Flexible pavement design

Methods for the design of flexible pavement are classified as:

1. Empirical and Semi-Empirical procedures
2. Analytical Design or Structural Design methods
   1. Empirical and Semi-Empirical Method: The Empirical and Semi-Empirical Methods are based on past experience and may include laboratory or field tests of the subgrade and pavement materials. One of the most common methods of this category is the "California Bearing Ratio (CBR) Method". In this method

the total thickness of the pavement is related to the CBR value of the subgrade for particular design traffic. But Empirical and Semi-Empirical design methods for pavement are satisfactory so long as the materials and conditions of loading for which they were developed do not change.

2. Mechanistic (Analytical) Design Methods: Analytical design methods for flexible pavements are based on the mechanics of materials that relates input, such as thickness of layers, material properties and wheel load, to an output or pavement response. In pavement design, the responses are the stresses, strains, and defections within a pavement structure and the physical causes are the loads and material properties of the pavement structure. The composition of various layers of the pavement structure is adjusted till critical factors (stresses and strains) are within permissible limits.

Burmister's analytical responses (stresses, strains and deflections) (D M Burmister, 1943; D M Burmister, 1945) are used to analysis the flexible pavements for elastic multi-layered systems (Huang, 1993; E J Yoder & Witczak, 1975; Eldon Joseph Yoder & Witczak, 1991). Analysis are based on certain assumptions which include static loading, continuity conditions at the interfaces between layers, homogeneous, isotropic, and linear elastic materials. With these assumptions, only two material properties are necessary for analyses that are:

i. Modulus of Elasticity (E) and,
ii. Poisson's ratio (μ).

Structural Models

The structural models have various analysis approaches to determine the pavement responses (stresses, strains and deflections) at various locations in a pavement due to the application of wheel load. The most common structural models are linear layered elastic, non-linear elastic and visco-elastic models.

1. **Linear Layered Elastic Model:** A linear layered elastic model can compute stresses, strains, and deflections at any point in a pavement structure resulting from the application of a surface load. Layered elastic models assume that each pavement

structural layer is homogeneous, isotropic, and linearly elastic. In other words, the material properties are same at every point in a given layer and the layer will rebound to its original form once the load is removed. The linear layered elastic approach is a simple mathematical model, that relates stress, strain and deformation with wheel loading and material properties like modulus of elasticity and Poisson's ratio.

2. **Nonlinear Elastic Model**: The nonlinear elastic model is used for granular material. In granular material the modulus of elasticity varies with the state of stresses. Resilient modulus is considered as the modulus of elasticity based on the recoverable strain under repeated loads.
3. **Viscoelastic Model**: This model is used to analysis bituminous layers. The main material properties that are used for analysis include resilient modulus and creep compliance.

2.4.3 Cost of Road Pavement

Road infrastructures are considered as a vital resources for economic development of a nation. It requires large investment and requires significant resources(Tsamboulas, 2014). Cost is one of most important factor which dictates the development of infrastructure. The cost of road infrastructure includes:

1. Initial capital cost,
2. Future resurfacing costs,
3. Maintenance cost,
4. Traffic delay cost during future resurfacings,
5. Salvage return at the end of analysis period, and
6. User costs of vehicle operation (i.e., time, accident, and discomfort).

1. Initial capital cost: It involves the cost for initial planning, design and construction of road.
2. Future resurfacing cost: Resurfacing cost includes future overlays or upgrading made necessary when the riding quality, or riding comfort index (RCI), of a pavement reaches a certain minimum level of acceptability.

3. Maintenance costs: A comprehensive economic analysis should include the estimation of all costs that are essential to maintain pavement investment at a desirable level of service or at a specified rate of deteriorating service. The level of maintenance, i.e., the type and extent of maintenance operations, affects the rate of loss of the RCI.
4. Traffic delay cost during future resurfacings: Overlay construction generally disrupts traffic flow and causes vehicle speed fluctuations, stops and starts, and time losses. The extra user cost thus incurred is often a significant proportion of the total overlay cost and may warrant its inclusion in the economic analysis.
5. Salvage return at the end of analysis period: Salvage return of a strategy is the value of a pavement at the end of its analysis period.
6. User cost: Each alternative pavement design is associated with a number of indirect (soft) costs that accrue to the road user and must be included in a rational economic analysis. Similar to pavement costs, user costs are related to the performance history of the pavement. A pavement design that provides an overall high level of roughness over a longer time period will result in a higher user cost than a design that provides a relatively smooth surface for most of the time. These cost include vehicle operating cost, user travel time cost, accident cost and discomfort cost(Kher et al., 1976).These cost are combined and are called life cycle cost (Rodrigue & Notteboom, 2013). An economic analysis is a major part of the pavement type selection process. Life-cycle costing is the conventional economic analysis tool used in pavement design(Little, 1996). In this study, the cost of using conventional material for capping layer, stabilized soil as capping layer in both types of pavement is analyzed and compared. In addition, qualitative analysis based on prior researches is done to evaluate overall lifecycle cost when conventional method and stabilized soil are used.

2.5 Transportation Economy

The infrastructure cost can directly and indirectly affect the economy of a country. The cost depends on the method of construction, material used, frequency of maintenance and operating cost during service life. For any project, the overall cost can play a huge role and can severely impact the national economy adversely.

Bitumen is an imported material for Nepal. If we could reduce use of bitumen in surfacing that would cause a lot of saving for project as well as country with the use of native material or material produced with in the country like cement. The practices in other countries have suggested that use of stabilization of subgrade soil can reduce the thickness of overlying layers and also impacted favorably the service life of road with less frequent maintenance(Rathod, 2017). Stabilization of native soil rather than replacement with material brought from elsewhere can reduce the time of construction and could be less expensive. Furthermore, cement is readily available and cost of cement do not vary with places with in the country but might require transporting cost.

2.5.1 Cost of bitumen vs cost of cement

In Kathmandu valley, the cost of bitumen of grade 80/100 and grade 60/70 are around 78 and 81 NRs. Per kg while for OPC cement of 53 grade, it is around 17 NRs. Per kg. If we can reduce a kg of bitumen of grade 80/100 and 60/70 in surface course then it will give the cost for around 4.5 and 4.75 kg respectively of cement for use as stabilizer or for use as binder in cement treated sub base or base. If we use 33 grade and 43 grade OPC cement then the price per kg of cement decreases to 12.5 NRs. and 15 NRs. respectively. Furthermore, bitumen requires heating to bring it to mixing consistency and reduction in the use of bitumen can reduce the fuel charges as well. If we extend this concept to large network of roads built on problematic soils, the reduction in bituminous surface can reduce the cost borne by project due to use of more cement for strengthening of underlying layer such as base, sub base and subgrade.

Table 2-1 Price of bitumen in market

Bitumen	Price per kg (NRs.)
VG10	78.1
VG20	81.1
VG30	81.1

2.5.2 Benefit in National economy

The use of cement treated road layers can reduce the overall cost of road with reduced expenditure on maintenance to keep road serviceable. The roads built on cement stabilized road gain strength at quicker rate and provide a good working platform for construction of road thereby reducing time of construction. In addition, the country could indirectly benefit a lot from savings from reduced imports of bitumen and employment opportunities developed by production of cement. The reduced imports can also reduce the balance of payment deficit which the country has in billions of rupees (Ministry of Finance, 2020) through reduced outflow of currency to international market.

CHAPTER 3 MATERIAL AND METHODOLOGY

3.1 Study area:

The study area is located in Lalitpur district of Kathmandu valley. The tentative location of study area is shown in Figure 3.1.

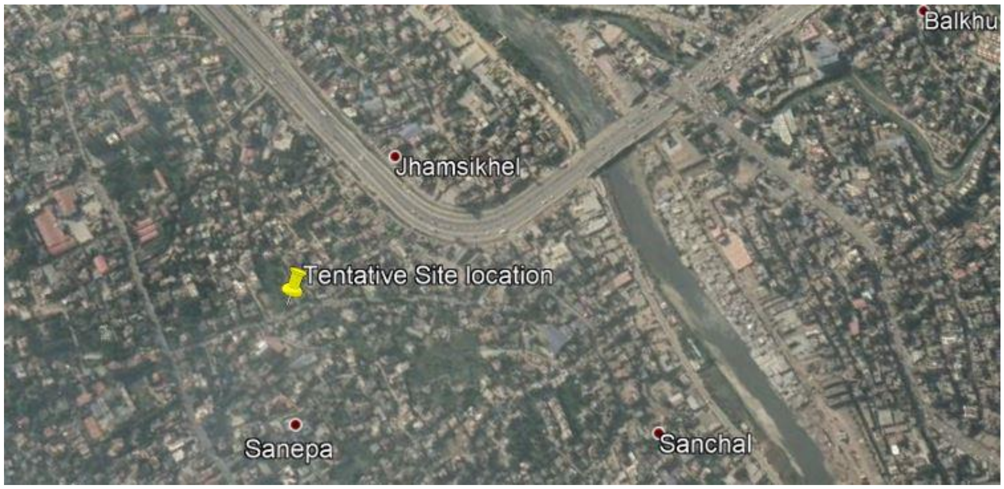

Figure 3.1 Site Location

3.1.1 General Geological Setting

In ancient period, Kathmandu Valley was known to be lake. The lake water was drained out, leading to the formation of lacustrine and fluvial deposits containing living plants, animals and organisms. Decaying of plants, animals and organisms in turn lead to the formation of organic soils found at different locations and varying depths within the valley. These decaying matters are deposited with weathered silt, sand and gravels from the rocks within the watershed boundary. Hence, in most parts the soil are of lacustrine and fluvial in nature and composed of clayey, silty and gravely sediments. Various soil deposits are shown in Figure 3.2. The fluvio lacustrine deposits in Kathmandu valley is known for its high swell potential, low shear strength and highly compressibility nature. Due to its insufficient bearing capacity, low shear strength and excessive settlements; civil structures such as pavements, walkways, roads, foundations, channel lining etc. possess a high risk of failure. The study area consist of soft soil deposits. The existing road facilities transverse the soft soil deposits at various places and there seems to be a problem of permanent settlement of pavement at many places.

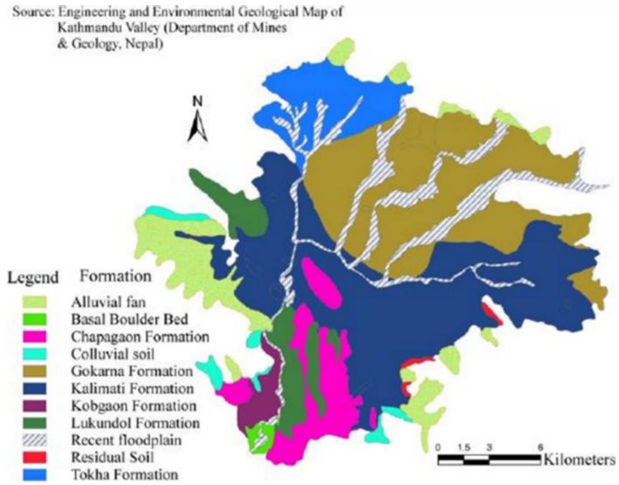

Figure 3.2 Geological setting of Kathmandu valley

3.1.2 General Soil Classification

The soil sample collected from the site was black in color (Figure 3.3) indicating the soil is clayey or silty soil. The soil was easily moldable when in natural condition but turned into hard lumps into drying.

Figure 3.3 Sample soil collected from site

3.2 Methodology

The whole study consist of sample collection, sample testing for characterization, modification of soil with stabilizer and testing and finally analyzing and cost determination for road constructed on stabilized soil followed by comparison with road constructed with capping layer. The whole study can be summarized in following flowchart in Figure 3.4.

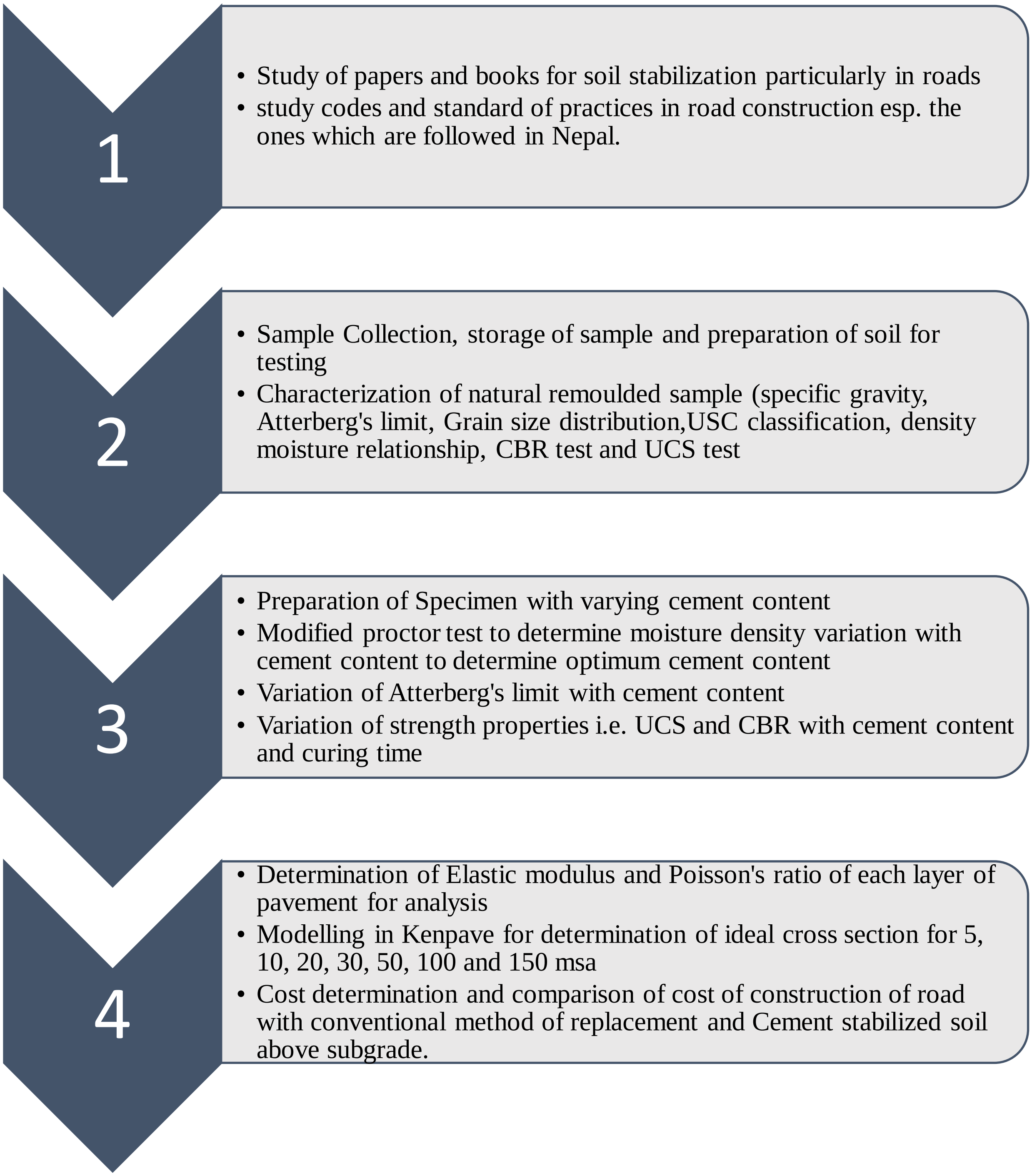

Figure 3.4 Flowchart of Study

3.2.1 Sample Location

The sample was collected from ongoing construction site at Sanepa. The sample was collected from the depth which was around the level of existing subgrade of road which was exposed due to excavation.

3.2.2 Sample Collection

The sample was collected in disturbed form and all samples were stored and preserved at the CMTL.

3.2.3 Tests and Setup

The testing for natural remoulded sample was done in first phase followed by testing on treated soil with varying stabilizer content.

3.2.3.1 Test on Natural Sample

First of all, sample was dried and soil sample was tested for specific gravity, Atterberg's Limit, OMC, MDD, UCS and CBR value with swelling. Index properties of the soil sample and samples with cement were determined in CMTL, Pulchowk Campus, Pulchowk, Lalitpur following test standards mentioned in Table 3-1.

- Atterberg's Limit: Atterberg's limit tests included the determination of liquid limit, plastic limit and shrinkage limit. Liquid limit of the soil samples was determined using conventional Casagrande's method, where it was defined as the water content corresponding to 25 numbers of blows. Plastic limit was determined by rolling the soil sample into a thread of 3 mm diameter. The plastic limit is defined as the water content at which cracks started to appear at that particular condition. Liquid limit and plastic limit tests were performed for oven-dried samples. The samples for the determination of liquid limit and plastic limit were prepared under natural condition.
- Specific Gravity: The specific gravity of solid particles was determined in a laboratory by using pycnometer.
- Particles size Analysis: Particles size analysis was done for samples from combination of sieve analysis and sedimentation analysis. The wet soil retained in 75 µ sieve was analyzed using sieve and soil finer than 75 µ was analyzed using

hydrometer by sedimentation analysis. From the combination, particles size distribution curve is prepared.

- Compaction Test: The modified proctor test was done to determine the moisture density relationship. It was done as per IS standard and with an assumption the road modelled in the analysis part has to cater heavy traffic during service life.
- UCS test: The test was conducted to determine the compressive strength of untreated soil sample. The sample was prepared and tested to determine stress strain relation when subjected to vertical compressive load with zero confining loads.
- CBR test: This test was done to determine the stability of material as a subgrade material. The soil sample was tested after 4 days of soaking for simulating worst condition for subgrade soil.

All these tests followed IS standards as mentioned by DOR norms and standard.

Table 3-1 Test Standards used in study

S.N.	Test	Standard
1	Specific Gravity	IS 2720 part 3
2	Atterberg's Limit	IS 2720 part5
3	Grain Size Distribution	IS 2720 part 4
4	Density Moisture content relationship	IS 2720 part 8
5	CBR test	IS 2720 part 16
6	UCS test	IS 2720 part 10

3.2.3.2 Properties of stabilizer

The Hongshi OPC cement of grade 53 was used as stabilizer. The properties of cement as provided by CMTL are summarized in Table 3-2.

Table 3-2 Properties of stabilizer

S.N	Property	Value
1	Normal consistency (%)	33
2	Initial setting time (mins.)	95
3	Final setting time (mins.)	270
4	7 days Avg. Compressive strength	37.8 MPa
5	28 days Avg. Compressive strength	54.2 MPa
6	Fineness Test	Less than 3.6% passing 90 micron sieve

3.2.4 Stabilization of Soil

Mix proportion for cement content was taken as 4%, 6% and 8% cement content (Table 3-3). The reason for taking 4% as lower limit was to ensure proper mixing and upper limit as 8% was to avoid shrinkage cracks (Bell, 1995).

3.2.4.1 Test setup for stabilized soil

After determination of properties of soil sample, the sample was mixed with varying proportion of cement 2%, 4%, 6% and 8% for Atterberg's limit determination and 4%, 6% and 8% for Moisture density relation, UCS and CBR value. The test standard used for testing were similar to that of test conducted on untreated soil. The moisture density relation was determined for each proportion mentioned in Table 3-3 and optimum stabilizer content was determined by variation of MDD with cement content such that particular proportion results in maximum MDD. For UCS and CBR test sample the sample were compacted with heavy compaction using moisture content equal to OMC. The UCS and CBR test required curing before testing. So, the storage and curing methods are described in section 3.2.4.2.

Table 3-3 Experimental Setup

S.N	Mix Proportion
1	Soil+ 4% cement
2	Soil+ 6% cement
3	Soil + 8% cement

3.2.4.2 Curing and storing

The curing for UCS was taken as 3, 7, 14 and 28 days. Sample were cured in moist condition with wet jute bags in membrane to prevent rapid loss of moisture. For CBR test, the sample were covered with wet jute bags to create damp conditions for 7 days. The soaking of sample before testing was done with 4.75 kg surcharge load with assembly to measure swelling of sample for each 24 hours period.

3.2.5 Analysis and Design of Pavement

The test pavement cross section are modelled in Kenlayer for different intensity of traffic. The output of the model were strains at critical location of pavement structure. The strain values are used to determine the number of standard axle the pavement can carry for given cross section and loading and material conditions in terms of failure criteria assumed in the study. The final section is adopted based on strains at location shown in Figure 2.2 which results critical traffic intensity from equation 2.3 and 2.4 greater than the traffic intensity assumed before modelling.

3.2.6 Cost Analysis

After trial with different cross section, final cross section for particular traffic intensity were determined. The cost analysis was then done with prevailing rates as directed by DOR norms and standards and Kathmandu District rates using the final section for both pavements. The comparison of cost is done for two pavement configuration assumed in the study.

3.2.7 DOR norms and specification for subgrade soil

Minimum CBR: 5% At 95% MDD

Swell: Less than 1%

Plasticity Index: Less than 40 %

Organic Content: Less than 3%

Depth: 500 mm below formation level

For capping layer, the CBR of material shall be at least greater than 15%.

CHAPTER 4 LABORATORY TEST RESULTS AND DISCUSSION

4.1 Natural Soil

Tests were done on samples prepared from soil sample obtained from site.

4.1.1 Test results

The test was performed to characterize the soil and classify the soil. The test on untreated samples was done to determine whether the soil has sufficient strength and other workability criteria to be used as a subgrade layer. The results from the test are summarized in the Table 4-1.

Table 4-1 Test results on soil without cement

SN	Property	Value
1	Specific gravity	2.6
2	Liquid Limit	48.15
3	Plastic Limit	25.55
4	Plasticity Index	22.60
5	Classification of Soil	CL
6	OMC (%)	29.41
7	MDD (kg/m^3)	1421.5
8	Swell (%)	0.72
9	CBR @ 95% MDD (soaked) (%)	0.9912
10	Unconfined Compressive strength, KPa (remoulded)	136

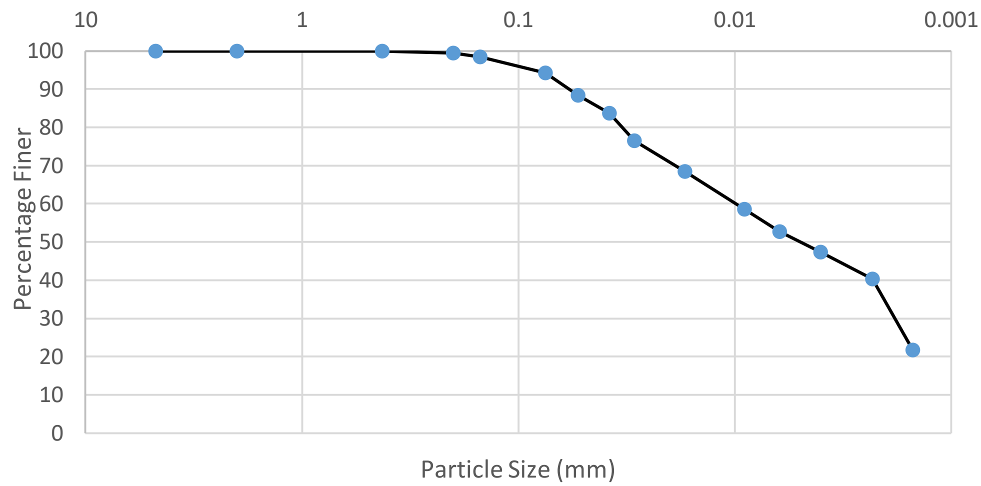

Figure 4.1 Particle Size Distribution Curve

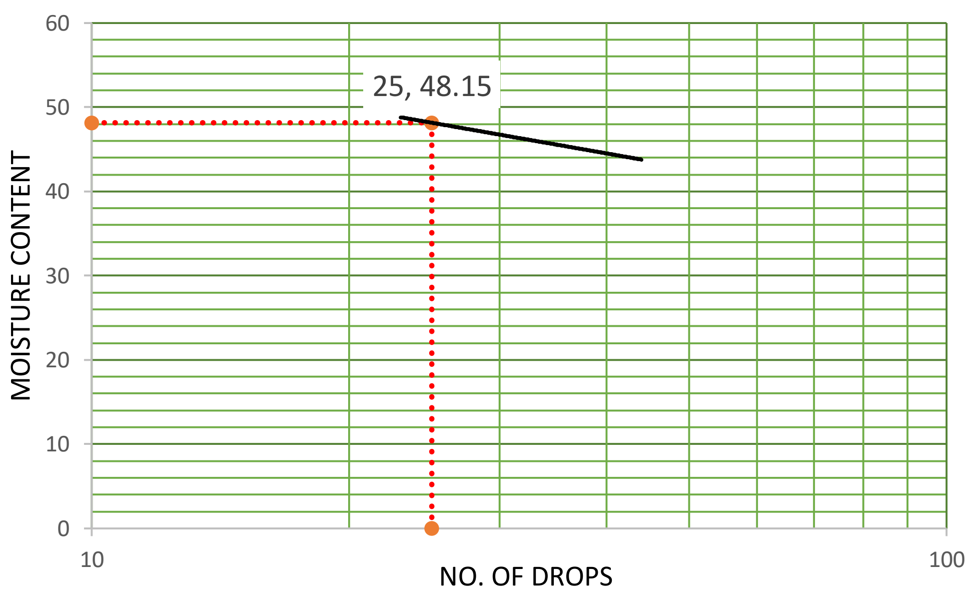

Figure 4.2 Flow curve for soil

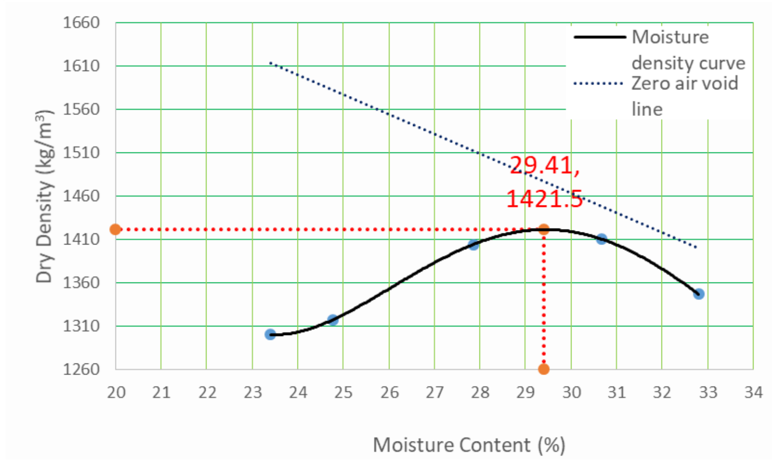

Figure 4.3 Moisture Density relation for untreated soil

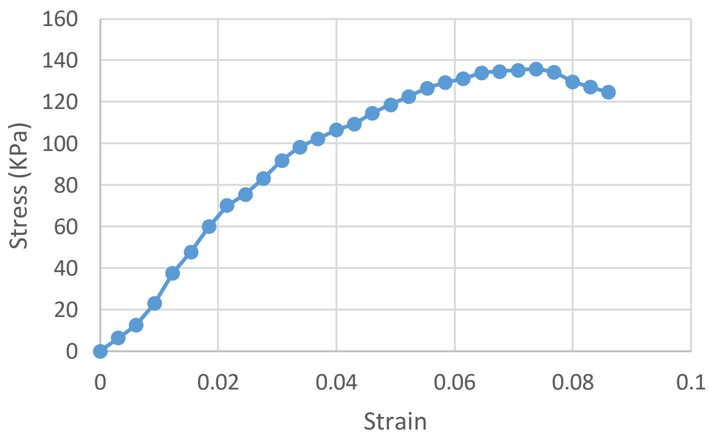

Figure 4.4 UCS of Natural Soil

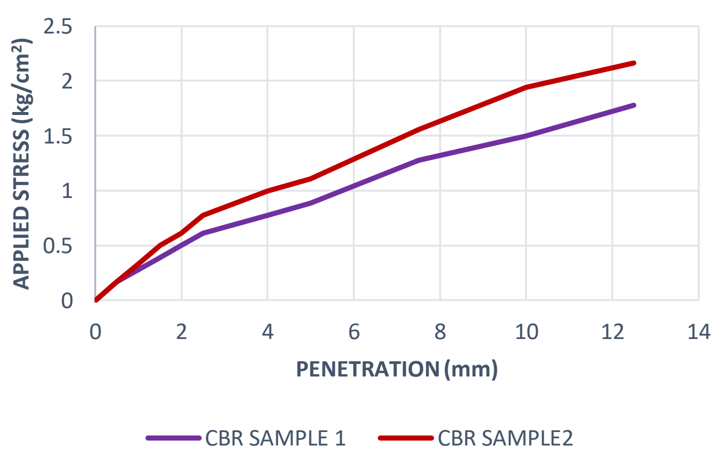

Figure 4.5 CBR Curve plot for Soil

4.1.2 Discussion

The soil consist of 39.2% clay fraction from grain size distribution curve as determined from Figure 4.1. The LL (Figure 4.2), PL and PI for soil were determined and from LL and PI of soil, the soil was classified as CL using USC system (Figure 4.12). Also, the PL limit was well within the criteria marked for PL of subgrade soil. The OMC and MDD of the untreated soil was determined from Figure 4.3. The UCS of soil (Figure 4.4) was determined to be 136 KPa. In case of pavements, the load is so instantaneous that undrained strength parameter can be used as indicative parameter for bearing capacity. The UCS gives the strength of soil under axial compression only. It shows the capacity of soil to transfer the load to weak sub soil in this case. The CBR of soil was found to be 0.99% (Figure 4.5). CBR value gives the resistance against penetration in comparison to standard material. It gives the stability of the tested material. The CBR test results showed that soil is not suitable for subgrade layer as per the criteria given in section 3.2.7. It was determined that the untreated soil is poor considering low CBR value from laboratory test and hence it should be either replaced with capping layer or stabilized to increase its strength properties to be used as subgrade layer. Otherwise, if used as a subgrade layer in untreated form, the pavement might suffer from permanent deformation in subgrade.

4.2 Stabilized Soil

After performing series of test, the untreated soil failed to meet the criteria for CBR value to be used as a subgrade material. So, the soil was modified with cement as a stabilizer and series of laboratory tests were performed to determine optimum cement content and determine the variation of Atterberg's limits, MDD, UCS, CBR and swell percentage with variation of cement dosage.

4.2.1 Test Results

The sample with cement content were first tested for variation of MDD with cement content (Table 4-2 and Figure 4.6). From this variation the optimum cement content was determined. It was taken as content for which maximum MDD is obtained. The test was run for 4%, 6% and 8% cement content. While for LL and PL the test was also done for 2% cement content (Table 4-3).

Table 4-2 Variation of MDD with Cement Content

Cement Content (%)	MDD (kg/ m^3)	Remarks
0	1421.5	
4	1548.34	
6	1572.57	Optimum Cement Content
8	1540.0	

Table 4-3 Variation of LL and PL and PI with Cement Content

Cement Content (%)	Liquid limit (%)	Plastic Limit (%)	Plasticity Index (%)
0	48.15	25.55	22.6
2	55.85	32.29	23.56
4	52.62	32.69	19.93
6	56.12	38.40	17.76
8	49.72	37.23	12.49

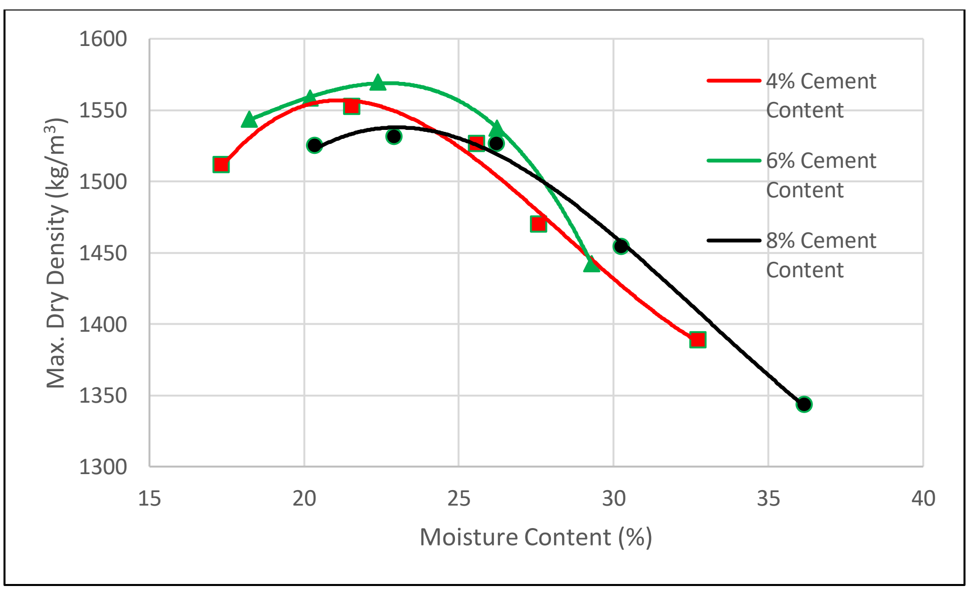

Figure 4.6 Moisture Density Relation for different cement content

After determination of OMC and MDD of soil with each cement content, the samples for CBR and UCS were made and tested after certain days of curing. The results of CBR test are given in Table 4-4. The UCS for different cement content and varying curing periods are summarized in Table 4-5 and the graph plots for stress and strain for 3, 7, 14 and 28 days of curing are shown in Figure 4.7, Figure 4.8, Figure 4.9 and Figure 4.10 respectively.

Table 4-4 Value of CBR with swelling for different cement content

Cement Content	CBR value	Swelling (%)	Increment of CBR by % of the initial value
4%	13.47	0.38	1250
6%	15.32	0.12	1450
8%	17.97	0.04	1713

Table 4-5 Variation of UCS with variation of cement content and Days of Curing

Cement Content (%)	3 days UCS (KPa)	7 days UCS (KPa)	14 days UCS (KPa)	28 days UCS (KPa)
4	388	522	764	868
6	544	776	946	1254
8	634	940	1160	1407

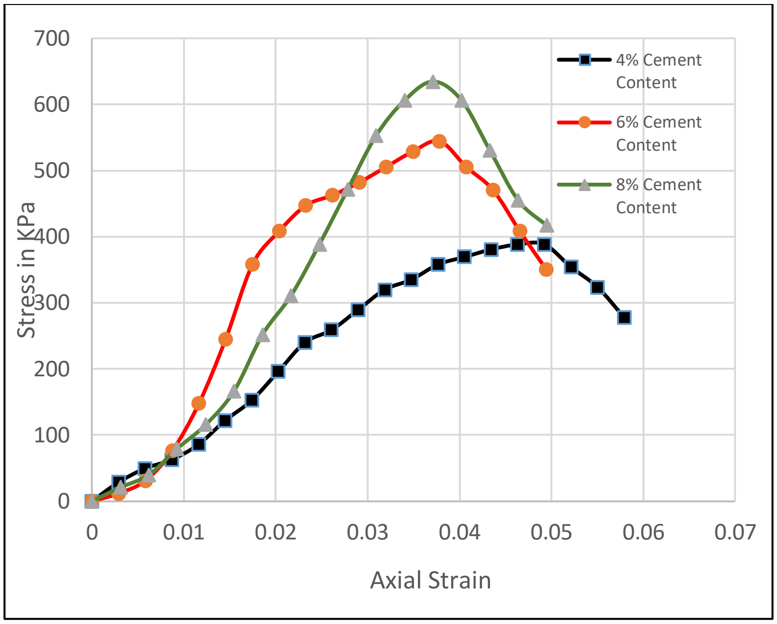

Figure 4.7 UCS after 3 days

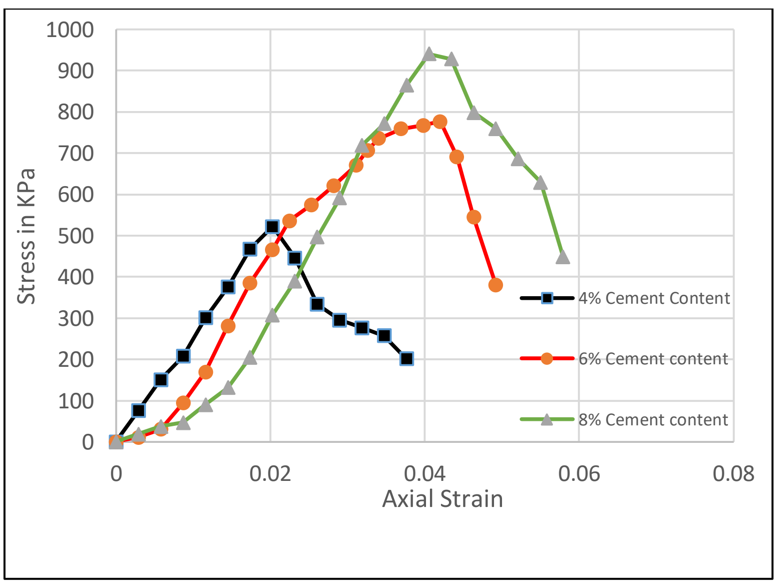

Figure 4.8 UCS after 7 days

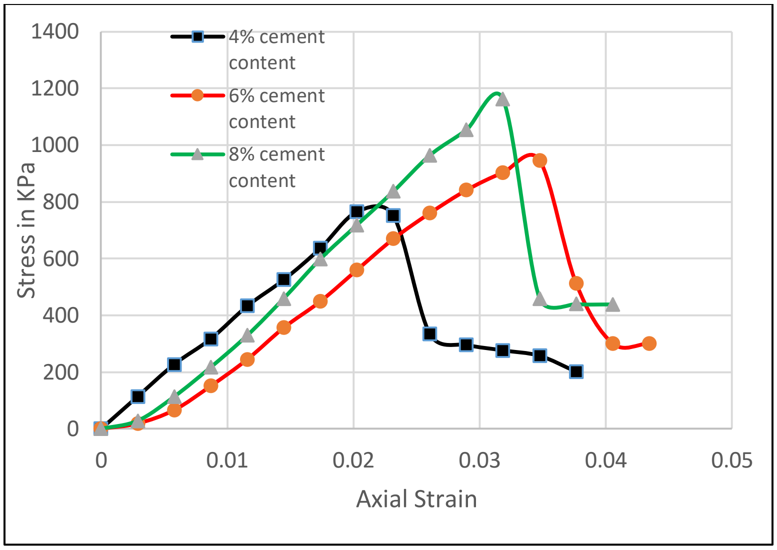

Figure 4.9 UCS after 14 days

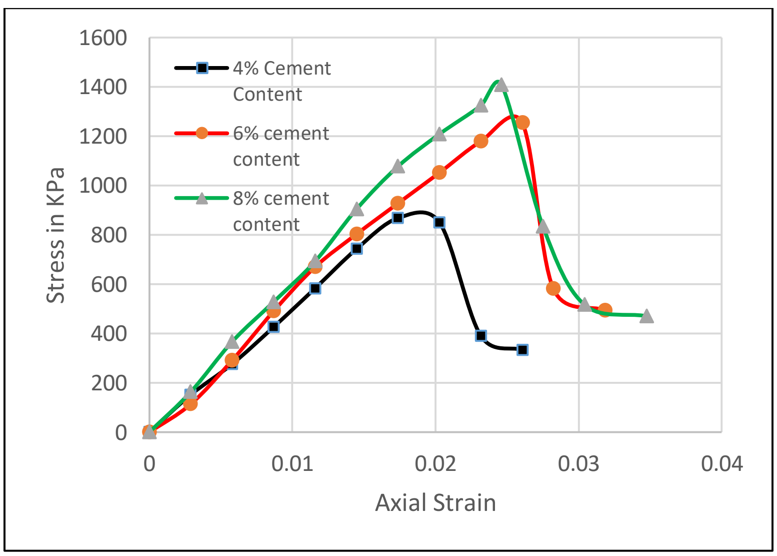

Figure 4.10 UCS after 28 days

4.2.2 Discussion

4.2.2.1 Effect of cement content on LL, PL and PI

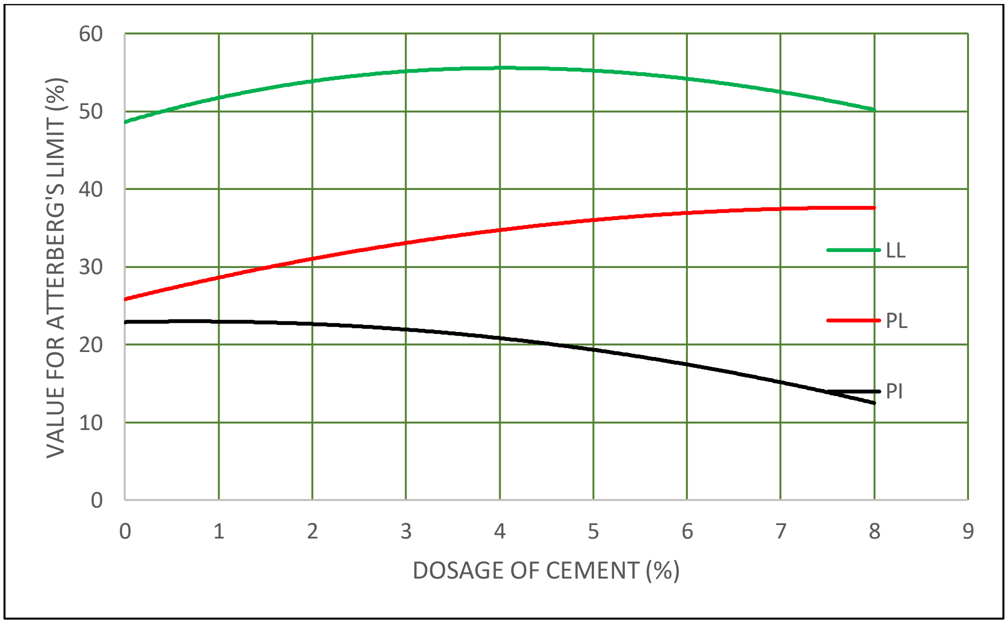

Figure 4.11 Variation of LL, PL and PI

The variation as shown in Figure 4.11, showed that the liquid limit increased initially with the increase in the dosages of cement but showed a decreasing trend after 4% dosage and again increased for 6% cement content then again decreased for 8 % cement content. The stabilized soil showed maximum LL for 6 % cement content. The plastic limit increased with the cement content up to 6% marks but shows a reduction in value for 8% content. The stabilized showed maximum PL for 6 % cement content. Although PI increased slightly for 2% cement content, it showed continuous reduction with further addition of cement. The LL, PL and PI are measure of a soil's cohesive properties and is indicative of the amount and nature of clay in the soil/aggregate. Higher PI soil are difficult to work with than lower PI value because of their instability and stickiness. Furthermore, high PI soils also have potential for detrimental volume changes during wetting and drying, which can lead subsequently to pavement roughness. The reduction in PI is due to cation exchange in which monovalent ions are replaced by divalent ions like Ca^{2+} ions and the net charge on the surface of soil forming mineral neutralized thereby decreasing the thickness of double diffused layer.

4.2.2.2 Position of Soil in Casagrande's plasticity chart

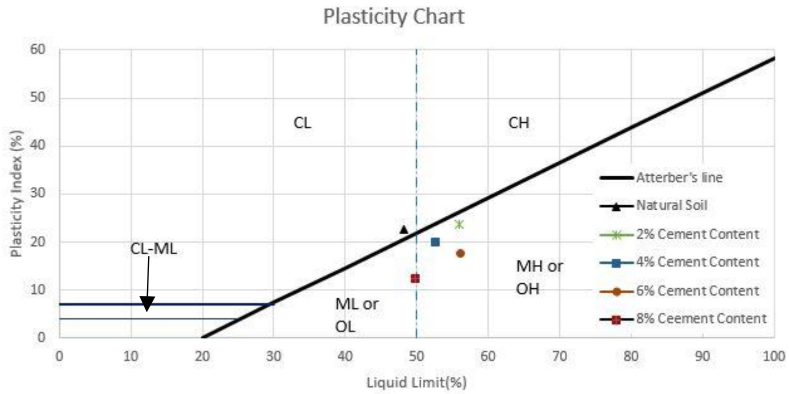

Figure 4.12 Soil on Plasticity Chart with and without Cement

The soil with and without cement content is represented in plasticity chart in Figure 4.12. The soil is placed below A- line but slight increase in plasticity from low plastic region to high plastic region is due to addition of cement and the initial LL is also in boundary region of low and high plasticity. The cement when added to plastic soil shows slight increase in LL for low content of cement and shows a decreasing trend after certain increase in cement content(Bell, 1995).

4.2.2.3 Variation of MDD with Cement content

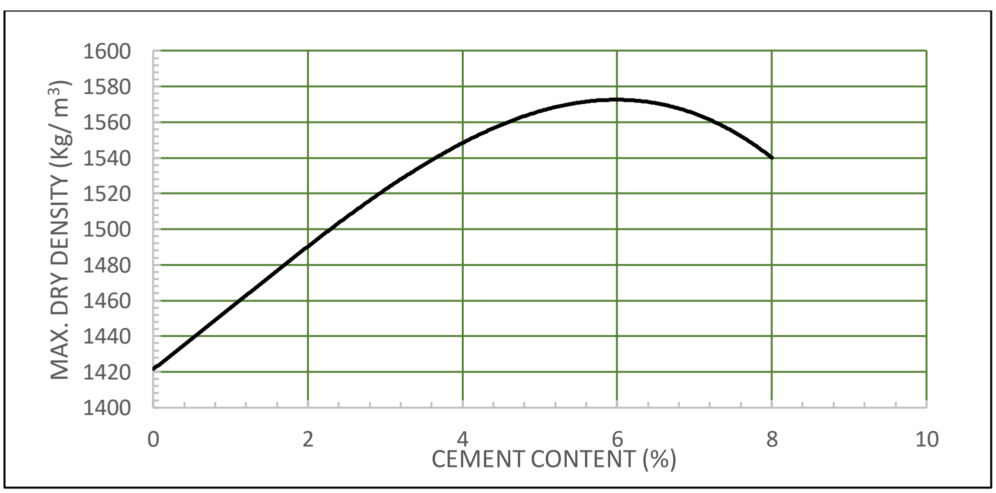

Figure 4.13 Variation of MDD with cement content

The determination of the relationship between water content and density of soils is used in determining the compaction of the material. The purpose of compaction is to arrange the particles in such a way as to achieve the highest possible density for the sample with minimum voids. By achieving high densities, not only is the shear strength and elastic modulus are improved but also the ingress of water is reduced or eliminated. The maximum MDD was found at 6% cement content with OMC of 22% from Figure 4.13.

4.2.2.4 Variation of UCS and CBR

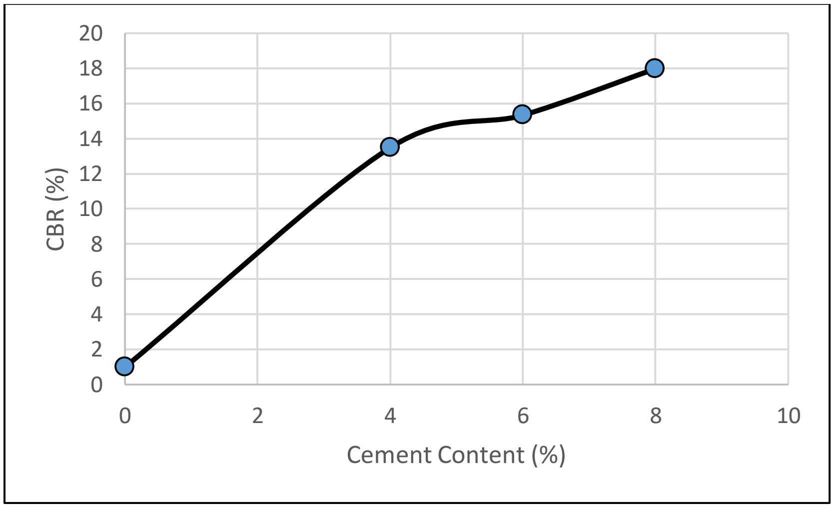

Figure 4.14 Variation of CBR with Cement Content

The CBR showed sharp increase in value with addition of cement (Figure 4.14). The swelling is also reduced with addition of cement. The increase in CBR can be attributed to the formation of cementing material CSH and CAH in the soil sample and bonding formation between particles in edge to face configuration through process known as agglomeration. These also process contribute to the increase in shear strength of soil. In addition, cement stabilization made the soil less affected by ingress of water after soaking of sample. Therefore, stability of soil has been increased after the stabilization and the soil after stabilization has fulfilled the requirement in order to be used in subgrade layer.

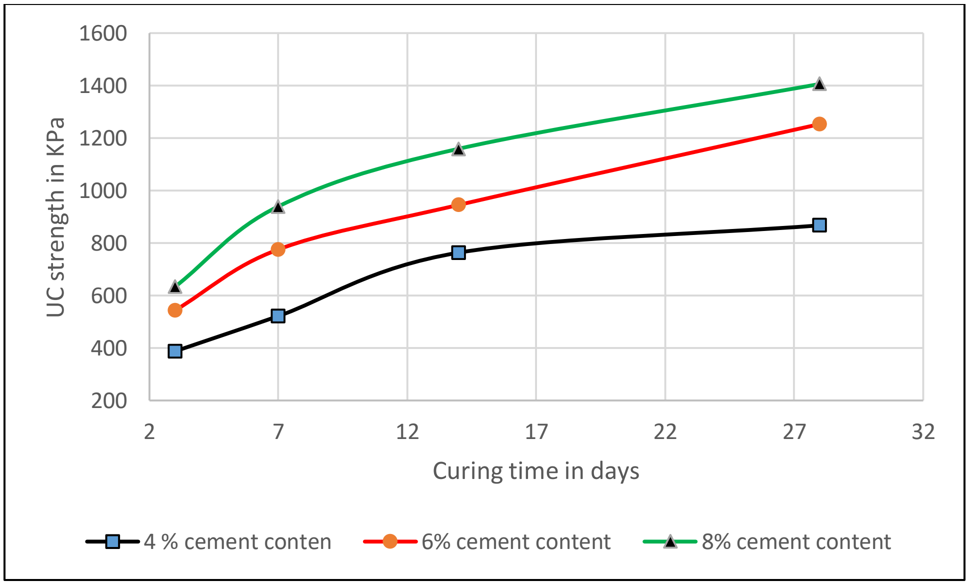

Figure 4.15 Variation of UCS with curing period

The UCS showed increase in value with both increase in cement content as well as curing period (Figure 4.15). In case OPC cement, the rate of gain of strength was greater at initial days but later was reduced. The gain of strength is rapid for cement in initial day due to cementitious hydration and cation exchange. In addition particle restructuring of mineral from parallel to edge to face configuration and formation of weak bonding between edge and face along with cementitious gel binding particles together is the reason for increase in UCS of sample. With the increase of curing time, the gain of strength is more dictated by pozzolanic reaction due to the calcium hydroxide produced as byproduct of hydration of cement so the rate of gain of strength is lower than initial days(Bell, 1995; Halsted et al., 2008). With increase in curing period, the samples showed the peak at lower strain rate and the peak was sharp indicating brittle failure in comparison to soil without cement which showed no such sharp peaks. The soil after stabilization showed significant improvement in both strength and stability.

4.3 Validation of Laboratory Results

The verification of results obtained from laboratory test of stabilized soil are done with available literature. The changes in Atterberg's limit are found to be similar which has been determined for similar soil by Bell (Bell, 1995) and Dahal et. al. (Dahal et al., 2018). The comparison are given in Figure 4.16, Figure 4.17 and Figure 4.18. The black line represents the variation found in this study and red lines show the relation found by Bell (1995). The study on Kathmandu clay by Dahal et. al. is also shown in the Figure 4.19.

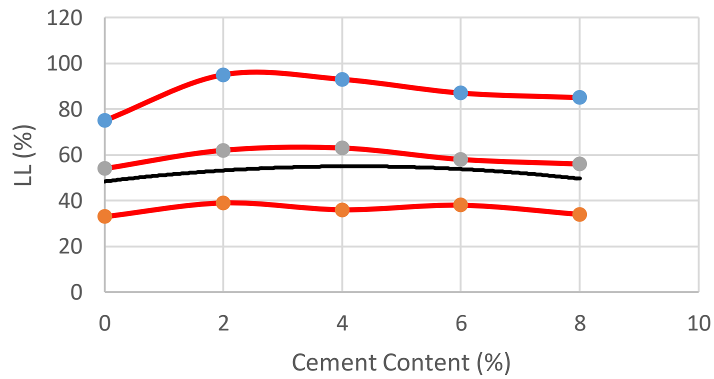

Figure 4.16 Variation of LL with cement content after Bell (1995)

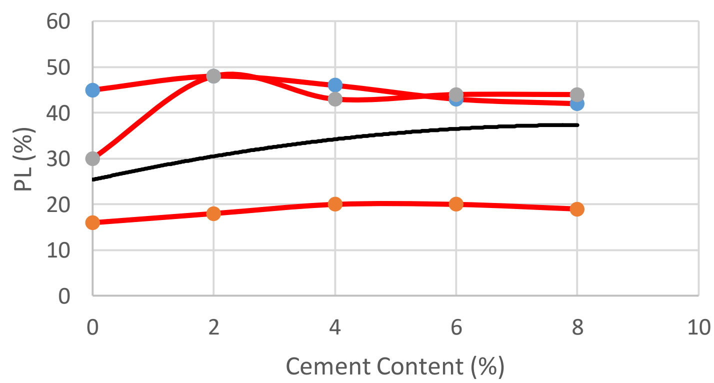

Figure 4.17 Variation of PL with cement content after Bell (1995)

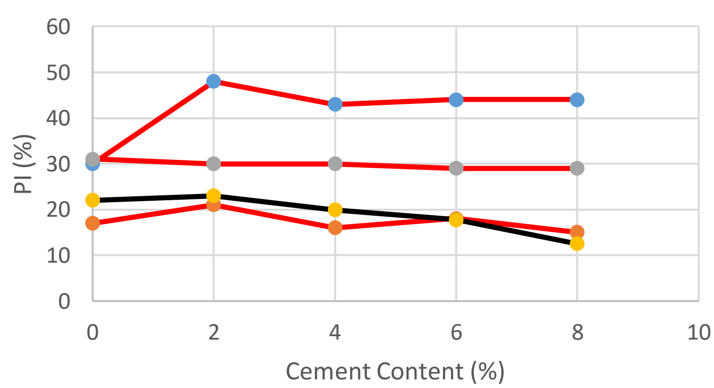

Figure 4.18 Variation of PI with cement content after Bell (1995)

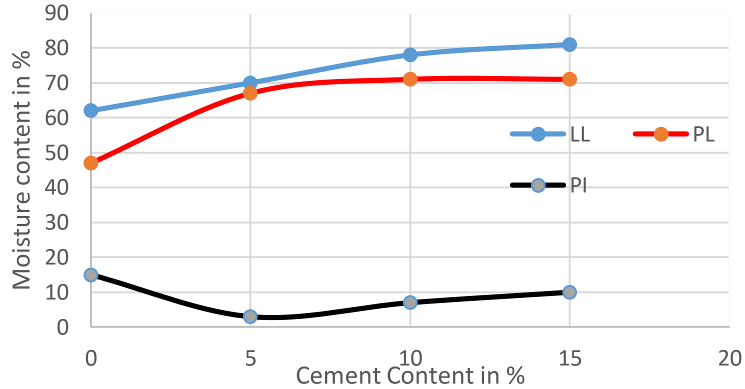

Figure 4.19 Variation of LL, PL and PI with cement content after Dahal et. al. (2018)

The variation of MDD is similar with study conducted by Ashraf et. al. for soft soils(Ashraf et. al. , 2018) is summarized and compared with the results obtained in this study in Table 4-6.

Table 4-6 Comparison of MDD variation with cement content with study by Ashraf et. al.

Cement Content (%)	MDD (KN/m^3)		
	Ashraf et. al.		This study
	Sample 1	Sample 2	
0	16.85	16.4	14.21
4	16.14	16.64	15.48
6	15.86	16.7	15.72
8	16.49	16.33	15.40
10	16	16.56	-

The UCS Results are also in agreement with results obtained by Bell (1995) and Ashraf et. al. (2018). The increase in CBR is also similar to the research mentioned above for similar soil. The studies shows that both UCS and CBR increase with increase in cement content and number of curing days. The swelling is also reduced due to addition of cement (Halsted et al., 2008)

CHAPTER 5 ANALYTICAL DESIGN OF PAVEMENT CROSS SECTION

5.1 Introduction

The pavement design are done with two methods namely:

i) Empirical or semi empirical method

ii) Analytical (mechanistic) method

IRC 37- 2012 and DOR pavement guidelines are semi mechanistic approach for pavement design. They use material properties to derive the strains at critical locations. These strains should be less than permissible strains given by failure criteria for given traffic intensities. The DOR guidelines only gives pavement design catalogue for CBR greater or equal to 2%. For CBR less than 2% as in the case of soil under study, DOR guideline suggest to model pavement using capping layer at the top of weak subgrade and check the design with respect to failure criteria to finalize the design. This study tries to give the design procedure for design of pavement with cement stabilized soil and with capping layer using failure criteria.

5.2 Design on cement stabilized subgrade and conventional subgrade

The structural design and modelling of road is done in freeware software named ‘Kenpave’. For design of road structure in soft soil as the case in this study, this study uses the DOR guidelines and IRC 37-2012 extensively for the values of design parameters (Table 5-1) as well as for failure criteria involving flexible pavement. The failure criteria considers following two failure conditions:

a) Rutting
b) Fatigue

Also this study involves mechanistic empirical model for determining the strain and deformation at various layers in pavement structure using Kenpave. The tensile strain at the bottom of surface course is used for fatigue criteria for failure and compressive strain at the point in top of subgrade layer is used to model rutting failure by determining the minimum number of standard axle to initiate the failure in flexible pavement.

Table 5-1 Parameters used in Pavement modelling

SN	Parameter	Value	Remarks
1	Weight of Standard Axle	80 KN	Single axle load
2	Contact Pressure	800 KPa	IRC 37-2012
3	Equivalent Standard Axle Load (ESAL)	30 and 50 msa	
4	Contact Radius	8.92 cm	IRC 37-2012
5	Elastic Modulus and Poisson's ratio of Surface	1455 MPa and 0.35	Taken for 30 degrees Celsius for 80/100 grade bitumen
6	Elastic modulus and Poisson's ratio of base and sub base course for P1 pavement	$E = 0.2 \times h^{0.45} \times M_R{}^*$ and $\mu = 0.35$	Taken as per clause 7.2 and 7.3 of IRC 37- 2012
7	Elastic modulus and Poisson's ratio of base and sub base course for P2 Pavement	E=400 MPa and μ=0.35	Taken as per ANNEX VIII of IRC 37- 2012
8	Elastic modulus and Poisson's ratio of Capping layer	E= 150 MPa and Poisson's ratio = 0.4	As Per IRC 37-2012
9	Elastic modulus and Poisson's ratio of CSS	E= 400 MPa and Poisson's Ratio = 0.25	As per ANNEX XII of IRC 37-2012
10	Elastic modulus and Poisson's ratio of Subgrade	$M_R = 10 \times CBR$	As per clause 5.3 of IRC 37-2012

*It is taken equal to modulus for capping layer 'E'

Two types of road cross section are considered in this study (Table 5-2).The cross section are assumed and modelled for different traffic intensities i.e. 5, 10, 20, 30, 50, 100 and 150 msa. For each cross section of pavement, the model was analyzed in Kenlayer using values of parameters as per IRC 37- 2012 and DOR Flexible Pavement Guidelines (Table 5-1). As an output, the value of strains at the bottom of surface layer (tensile strain) and at the top of subgrade (compressive strain) are obtained. The strains are used in failure criteria adopted by Asphalt Institute method for fatigue and rutting failure. Process was repeated for each traffic intensity and final cross section was adopted which gave strains value output that satisfy both criteria.

Table 5-2 Pavement Cross section used in study

SN	Pavement designation	Surface Course	Base layer	Sub base layer	Subgrade
1	P1	AC + DBM	GB	GSB	Natural soil with capping layer
2	P2	AC + DBM	GB	GSB	CSS

5.3 Assumptions for analysis

Following assumptions were used for analysis:

i) Burmister multi-layer elastic model is used.

ii) The variation of material properties in vertical direction is assumed and modulus is assumed constant throughout the layer.

iii) Granular base and Granular sub base are modelled as single layer and similarly DBM and AC are modelled as single layer while interface layer (capping layer or CSS layer) and natural subgrade layer is taken as separate layers. So, Pavement is modelled as 4 layer including subgrade layer.

iv) In both type of pavement used in analysis, capping layer or cement stabilized layer is used as interface layer which is placed at the top of weak subgrade.

v) The modulus of capping layer is used to determine the composite modulus of granular layer placed above it.

vi) The contact area is assumed to be circular which is also one of the limitation of this analysis.

$$Contact\ Radius, r = \sqrt{\frac{Load\ on\ Single\ Axle}{3.14 \times Tyre\ pressure}} \tag{5.1}$$

5.4 Analysis

The analysis was done in Kenlayer for strain at critical location for mode of failure assumed in this study using parameters in Table 5-1 and assumptions in section 5.3.

5.4.1 Analysis outputs

The modelling was done and the output are present in the form of table. For P1 pavement, Table 5-3 shows final cross section for different traffic intensity and Table 5-5 gives the final cross section for P2 pavement. The Table 5-4 and Table 5-6 summarizes the tensile and compressive strain for final cross section obtained from Kenlayer and they show the corresponding critical traffic intensity for fatigue and rutting criteria using equation 2.3 and 2.4 respectively. Figure 5.1 and Figure 5.2 shows variation of total thickness of pavement for P1 and P2 pavement respectively with the traffic intensity.

Table 5-3 Final Pavement Cross section for P1 pavement

Traffic (msa)	Capping layer (cm)	Sub base (cm)	Base (cm)	Surface (cm)	
				DBM	AC
5	30	30	25	4	4
10	30	30	30	4	4
20	30	35	30	6	5
30	30	35	35	7	5
50	30	35	35	9	5
100	30	40	35	12	5
150	30	40	35	13	7

Table 5-4 Strain value and no. of ESAL for Fatigue and Rutting criteria for P1 pavement

S.N	Traffic (msa)	ε_t	ε_c	N_f (msa)	N_r (msa)
1	5	0.0003158	0.0003223	273.118	5.890
2	10	0.0003092	0.0002855	292.777	10.136
3	20	0.0002519	0.0002341	574.742	24.652
4	30	0.0002356	0.0002074	716.286	42.399
5	50	0.0002043	0.0001975	1145.043	52.780
6	100	0.0001608	0.000166	2517.839	114.909
7	150	0.0001326	0.0001564	4749.245	150.037

Sample Calculation:

For 5 msa traffic:

ε_t= 0.0003158 and ε_c= 0.0003223, putting these values in equation 2.3 and 2.4 respectively.

$$N_f = 0.414 \times \frac{1}{0.0003158^{3.291}} \times \frac{1}{1455^{0.854}}$$

$$N_f = 273117821.2\ ESAL$$

$$N_r = 1.365 \times 10^{-9} \times \frac{1}{0.0003223^{4.4777}}$$

$$N_r = 5887731.3\ ESAL$$

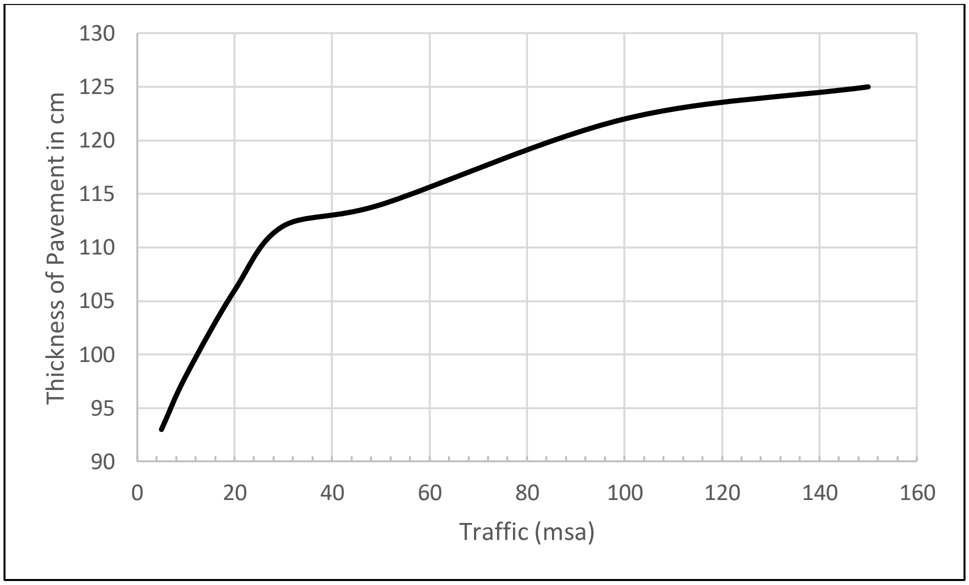

Figure 5.1 Variation of total thickness of P1 pavement with traffic intensity

Table 5-5 Final pavement cross section for P2 pavement

Traffic (msa)	CSS (cm)	Sub base (cm)	Base (cm)	Surface (cm)	
				DBM	AC
5	30	25	20	4	4
10	30	25	25	4	4
20	30	30	25	5	4
30	30	30	30	5	4
50	30	35	30	6	4
100	30	40	30	8	5
150	30	40	35	10	5

Table 5-6 Strain value and no. of ESAL for Fatigue and Rutting criteria for P2 pavement

S.N	Traffic (msa)	ε_t	ε_c	N_f (msa)	N_r (msa)
1	5	0.0002759	0.0003052	425.992	7.518
2	10	0.0002875	0.0002737	371.995	12.244
3	20	0.0002748	0.0002328	431.629	25.275
4	30	0.000276	0.0002174	425.484	34.338
5	50	0.0002606	0.0001929	513.976	58.654
6	100	0.0002123	0.000165	1009.073	118.060
7	150	0.0001845	0.0001472	1601.479	196.830

Sample Calculation:

For 5 msa traffic:

ε_t= 0.000275 and ε_c= 0.0003052, putting these values in equation 2.3 and 2.4 respectively.

$$N_f = 0.414 \times \frac{1}{0.000275^{3.291}} \times \frac{1}{1455^{0.854}}$$

$$N_f = 425992054.2\ ESAL$$

$$N_r = 1.365 \times 10^{-9} \times \frac{1}{0.0003052^{4.4777}}$$

$$N_r = 7518107.03\ ESAL$$

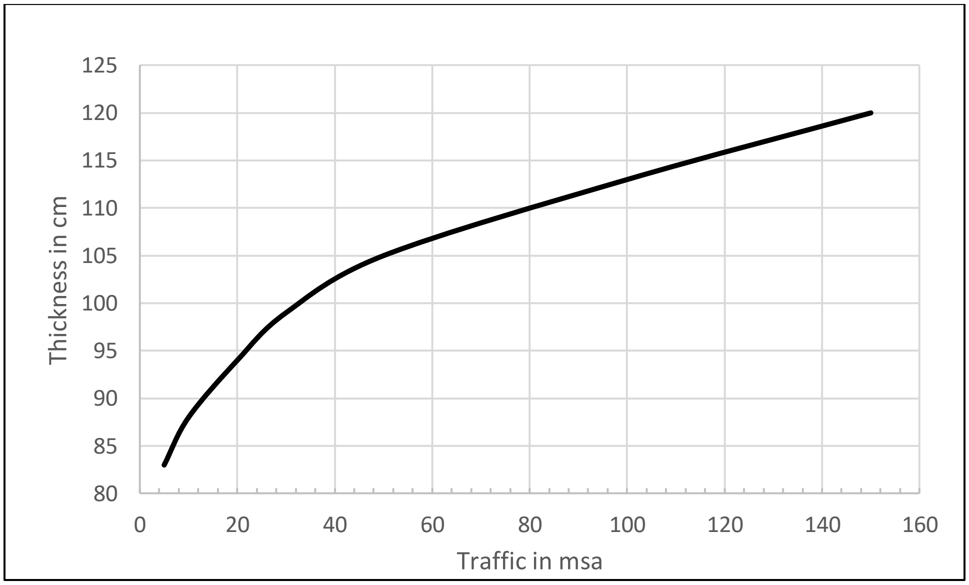

Figure 5.2 Variation of total thickness of P2 pavement with traffic intensity

Table 5-7 Total pavement thickness comparison

Traffic (msa)	**Thickness of P1 Pavement (cm)**	**Thickness of P2 pavement (cm)**	**Reduction in Thickness (cm)**	**% Reduction**
5	93	83	10	10.75
10	98	88	10	10.20
20	106	94	12	11.32
30	112	99	13	11.61
50	114	105	9	7.89
100	122	113	9	7.38
150	125	120	5	4.00

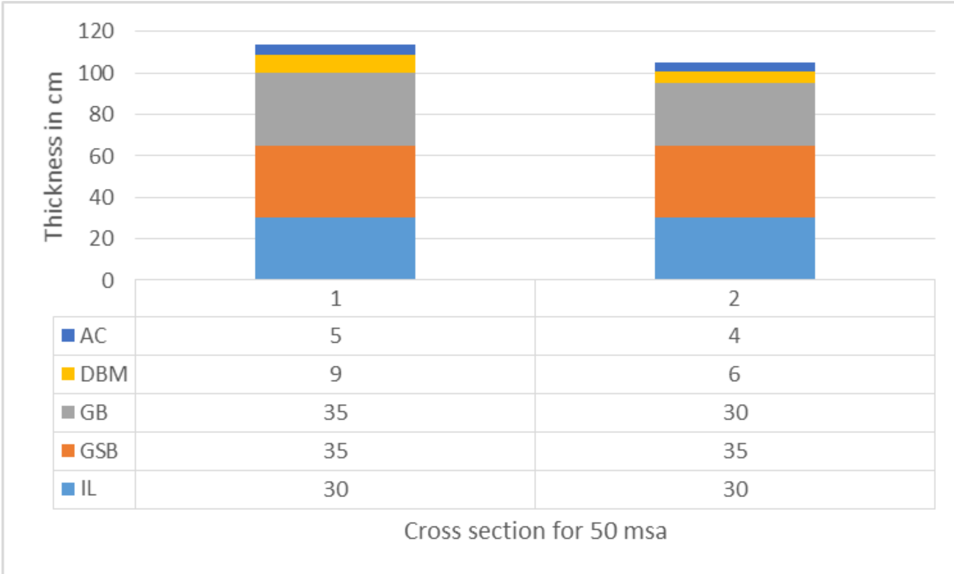

Figure 5.3 Sample Cross section for 50 msa Traffic intensity

5.5 Discussion

Kenlayer can be used to model the pavement for different thickness of layer with different properties. The rutting criteria was found to be the dictating failure criteria as pavement were found to be safe in fatigue criteria by significant margin. The total thickness of road pavement P2 was found smaller than P1 pavement for same traffic intensity (Table 5-3 and Table 5-5). It was found that use of a cement stabilized soil in the interface of subgrade and sub base can reduce the thickness of pavement. Maximum reduction in total thickness was obtained for 30 msa traffic category but the lower reduction percent for higher traffic category is attributed to the reduction in surface layer rather than in relatively weak base and sub base layer. The fatigue criteria was significantly fulfilled by P1 pavement in comparison to P2 pavement. The reason for this result is due to use of thicker surface layer for P1 pavement. But if we look at the pavement with same thickness of bituminous layer, the number of standard axle required for triggering fatigue failure was more for P2 pavement than P1 pavement. This is due to the reason that use of stiff layer below the surface can decrease the deformation of surface layer due to loading thereby reducing the effects of fatigue in surface course. The sample cross section of P1 and P2 pavement is shown in Figure 5.3 and other cross section including this are presented in Annex.

5.6 Validation of Methodology Used for Analysis and Design

The road constructed on soft soil subgrade are more susceptible to rutting failure. The methodology used in modelling used rutting criteria as crucial one as once the road is constructed over the poor subgrade, the severity of settlement problem might require complete rehabilitation of road. The Table 5-8 shows the comparison of both AI and DOR guideline for failure criteria for subgrade soil with CBR 2%. The cross section used is prescribed by DOR pavement guidelines for road using capping layer for 2% CBR (Table 5-9). The cross section is safe for both failure criteria prescribed by both method except for 100 msa where critical traffic intensity is exceeded by actual designed traffic intensity. It can be made safe for fatigue criteria used by DOR guidelines by increasing thickness of surface course. The analysis shows that for soft subgrade with lower CBR value, AI method gives more reliable value for critical compressible strain at the top of the subgrade. So, AI method is used over DOR method for pavement evaluation for failure criteria. This is also validated by researches conducted in past (Gedafa, 2006).

Table 5-8 Kenlayer strain analysis for 2% subgrade CBR using cross section given by DOR for road using Capping layer

Traffic (msa)	Tensile Strain	Compressive strain	AI method (msa)		DOR Method (msa)	
			Nf	Nr	Nf	Nr
5	0.0003132	0.0003718	280.65	3.16	18.82	147.53
10	0.0002224	0.000309	865.95	7.11	71.28	341.31
20	0.0002161	0.0002859	951.85	10.07	79.71	485.44
30	0.0002132	0.0002723	995.12	12.53	84.01	605.48
50	0.0002099	0.0002565	1047.54	16.37	89.26	793.96
100	0.0002068	0.0002418	1100.12	21.33	94.58	1037.53
150	0.0001526	0.0002225	2991.11	30.95	308.52	1512.82

Table 5-9 Design cross section for road in 2% CBR subgrade given by DOR

Traffic intensity (msa)	Surface works (mm)		Base (mm)	Sub base (mm)	Capping layer (mm)
	AC	DBM			
5	50	50	150	240	300
10	50	100	200	200	300
20	50	100	200	230	300
30	50	100	200	250	300
50	50	100	250	225	300
100	50	100	250	250	300
150	50	150	250	225	300

CHAPTER 6 COST ESTIMATE AND COMPARISON

6.1 Introduction

Presently, road construction practices in Nepal tackles soft soil and other incompetent soil deposit as subgrade by either replacement or providing capping layer wherever suitable. Some practices involve use of lime as stabilizer or using a relatively rigid layer in base layer etc.

Replacement method is an easy solution, but it creates waste as Insitu material will be dumped away. In addition, it requires foreign material to be transported to site thereby increasing the cost of burrowing and its transportation. While for lime stabilization, cement stabilized soil shows superior results in most mechanical property improvement. The use of rigid layer under surface or base can be an expensive solution for minor city roads.

For cost determination, cost will be determined using present rates for a lane of 1 km stretch having same overlying layer. Another approach will include cost savings for reduced pavement thickness due to more stable subgrade. Apart from the benefit or loss from direct cost comparison, indirect benefits of using cement as stabilizer for subgrade are:

1) Use of Insitu material thereby reducing the waste
2) Adaptable to any type of soil
3) Reduce time of construction as time for hauling material and preparation of foreign material is avoided.
4) Less susceptible to damage from water
5) Strong and durable

6.2 Cost Estimate

The cost of construction has been determined for both pavements considered in the study using the norm and standards set by DOR and rates set by Kathmandu districts and DOR (Annex B). The cost are determine for a 1 km road length with a lane width of 3.5 m for cross section given in Table 5-3 and Table 5-5. For the rates, the rates from current running projects are also taken for layers of pavement cross section. This study only consist of cost of construction and does not contains operation and maintenance cost.

6.2.1 Results of cost analysis

6.2.1.1 Cost of construction

From the rate analysis, following rates are determined for each work involved for construction of road cross section from subgrade preparation (Table 6-1).

Table 6-1 Rate of item of works in construction of road

S.N.	Item	Rate per m^3 (NRs.)	Remarks
1	Subgrade soil disposal	90	
2	Capping Layer	907	
3	Cement Stabilized Soil	2,563	
4	Sub base course	2,315	
5	Base Course	2,968	
6	Dense Bituminous Macadam	17,010	Using batch mixer
7	Asphalt Concrete	20,380	Using batch mixer

Using the rates for construction of each layer, the construction cost of whole cross section of road was determine for a road of length 1 km and width 3.5 m. The cost of construction of P1 and P2 pavement are summarized in Table 6-2 and Table 6-3 respectively.

Table 6-2 Cost of construction of P1 pavement

Traffic (msa)	Cost of Disposal of insitu soil (NRs)	Capping layer Cost (NRs)	Sub base Cost (NRs)	Base Cost (NRs)	Surface Cost (NRs)		Total Cost (NRs.)
					DBM	AC	
5	94,500	952,350	2,430,750	2,597,000	2,381,400	2,853,200	11,309,200
10	94,500	952,350	2,430,750	3,116,400	2,381,400	2,853,200	11,828,600
20	94,500	952,350	2,835,875	3,116,400	3,572,100	3,566,500	14,137,725
30	94,500	952,350	2,835,875	3,635,800	4,167,450	3,566,500	15,252,475
50	94,500	952,350	2,835,875	3,635,800	5,358,150	3,566,500	16,443,175
100	94,500	952,350	3,241,000	3,635,800	7,144,200	3,566,500	18,634,350
150	94,500	952,350	3,241,000	3,635,800	7,739,550	4,993,100	20,656,300

Table 6-3 Cost of construction of P2 pavement

Traffic (msa)	CSS Cost (NRs)	Sub base Cost (NRs)	Base Cost (NRs)	Surface Cost (NRs)		Total Cost (NRs.)
				DBM	AC	
5	2,691,150	2,025,625	2,077,600	2,381,400	2,853,200	12,028,975
10	2,691,150	2,025,625	2,597,000	2,381,400	2,853,200	12,548,375
20	2,691,150	2,430,750	2,597,000	2,976,750	2,853,200	13,548,850
30	2,691,150	2,430,750	3,116,400	2,976,750	2,853,200	14,068,250
50	2,691,150	2,835,875	3,116,400	3,572,100	2,853,200	15,068,725
100	2,691,150	3,241,000	3,116,400	4,762,800	3,566,500	17,377,850
150	2,691,150	3,241,000	3,635,800	5,953,500	3,566,500	19,087,950

Table 6-4 Reduction in cost of construction due to P2 pavement compared to P1 pavement

Traffic (msa)	Cost of P1 Pavement (NRs.)	Cost of P2 Pavement (NRs.)	Cost Difference (NRs.)	% Reduction
5	11,309,200	12,028,975	-719,775	-6.36
10	11,828,600	12,548,375	-719,775	-6.09
20	14,137,725	13,548,850	588,875	4.17
30	15,252,475	14,068,250	1,184,225	7.76
50	16,443,175	15,068,725	1,374,450	8.36
100	18,634,350	17,377,850	1,256,500	6.74
150	20,656,300	19,087,950	1,568,350	7.59

The cost of construction for P1 pavement was cheaper for lower traffic intensity than P2 pavement as shown in Table 6-4. For higher traffic intensity, the P2 pavement was cheaper significantly. The cost comparison also showed that the significant saving in higher traffic intensity was due to reduction of surface course despite cement stabilized soil being expensive than the capping layer. The capping layer has been found a lot cheaper to construct but in actual practice the price is bit higher than what has been determined from rate analysis using standard rates.

6.2.1.2 Cost sensitivity with cement price fluctuation

The cost and savings are very much affected by the price of cement. With the increasing trend of production of cement in Nepal, there is much possibility of reduction of cost. Even if the cost increase, the study has also been done for cost sensitivity of savings against price fluctuation of cement. For sensitivity analysis, the unit cost of cement has been varied with 10% rise or fall and 20% fall. The effect of the variation of unit price of stabilizer on savings made from P2 pavement compared to P1 pavement are summarized in Table 6-5 and shown in Figure 6.1

Table 6-5 Sensitivity of reduction of cost of construction with cost of cement

Traffic (msa)	Total Cost of P2 pavement with cement price at (Million NRs.)			P1 pavement Cost at present price (Million NRs.)	Saving from P2 pavement (Million NRs.)			
	10% rise	10% fall	20% fall		Present Price	10% rise	10% fall	20% fall
5	12.21	11.84	11.65	11.30	-0.72	-0.91	-0.53	-0.34
10	12.74	12.36	12.17	11.82	-0.72	-0.91	-0.53	-0.34
20	13.74	13.36	13.17	14.13	0.59	0.40	0.78	0.96
30	14.26	13.88	13.69	15.25	1.18	0.99	1.37	1.56
50	15.25	14.88	14.69	16.44	1.37	1.19	1.56	1.75
100	17.56	17.18	17.00	18.63	1.26	1.07	1.44	1.63
150	19.27	18.90	18.71	20.65	1.57	1.38	1.76	1.94

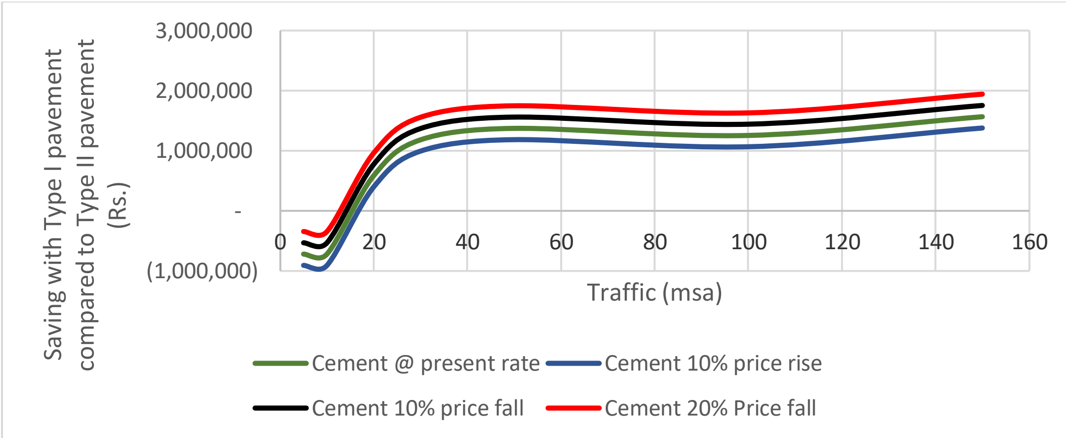

Figure 6.1 Sensitivity curve for cement cost variation on savings

6.2.1.3 Saving from bitumen and cost sensitivity against bitumen price

From the analysis, it was found that, there was reduction of surface course (Table 6-6) amounting as much as 175 cubic meters (for 150 msa) of surface course in 1 km stretch of road with 1 lane width which is a significant amount considering bitumen is an imported material. The cost sensitivity (Table 6-7 and Figure 6.2) was also done for saving made from bitumen course against fluctuation in price of bitumen. For this the bitumen prices are increased and decreased by 10% to determine the trend of saving from reduction of surface course due to use of CSS.

Table 6-6 Reduction in amount of surface course from P2 pavement

Traffic (msa)	Surface course thickness (cm)				Volume of Surface Course (cu. m)				Reduction in Surface course (cu. m)		% Reduction	
	P1 Pavement		P2 Pavement		P1 Pavement		P2 Pavement					
	DBM	AC	DBM	AC	DBM	AC	DBM	AC	DBM	AC	DBM	AC
5	4	4	4	4	140	140	140	140	0	0	0	0
10	4	4	4	4	140	140	140	140	0	0	0	0
20	6	5	5	4	210	175	175	140	35	35	16.67	20
30	7	5	5	4	245	175	175	140	70	35	28.57	20
50	9	5	6	4	315	175	210	140	105	35	33.33	20
100	12	5	8	5	420	175	280	175	140	0	33.33	0
150	13	7	10	5	455	245	350	175	105	70	23.08	28.57

Table 6-7 Cost savings from reduction of bitumen amount from P2 pavement and sensitivity against bitumen price

Traffic (msa)	Reduction of volume in Surface course (cu. m)		Saving Bitumen in Ton		Saving In NRs.		Total Saving in NRs.	Saving in NRs. With bitumen price	
	DBM	AC	DBM	AC	DBM	AC		10% rise	10% fall
5	0.00	0	0.00	0.00	0	0	0	0	0
10	0.00	0	0.00	0.00	0	0	0	0	0
20	35.00	35	3.43	4.74	268,023	370,382	638,405	702245.8	574564.7
30	70.00	35	6.86	4.74	536,046	370,382	906,428	997071.3	815785.6
50	105.00	35	10.30	4.74	804,070	370,382	1,174,452	1291897	1057006
100	140.00	0	13.73	0.00	1,072,093	0	1,072,093	1179302	964883.4
150	105.00	70	10.30	9.48	804,070	740,764	1,544,834	1699317	1390350

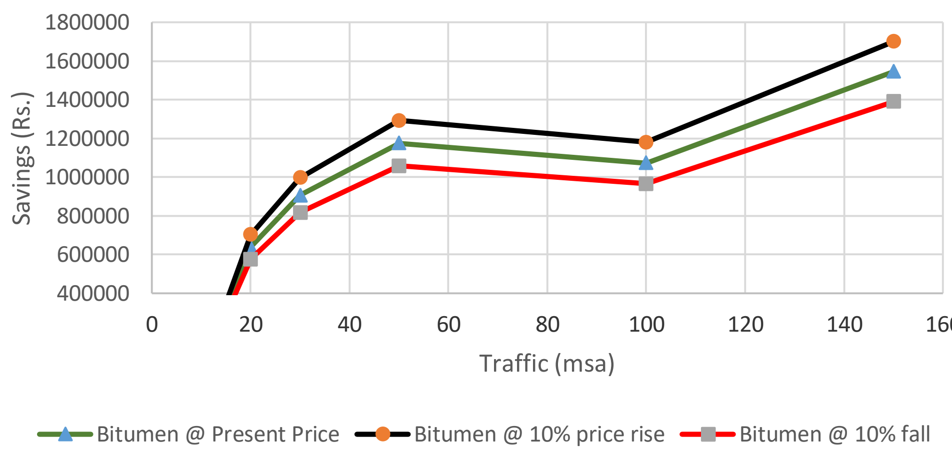

Figure 6.2 Sensitivity of bitumen prices on saving made from surface course

6.3 Discussion

The P1 pavement was found to be cheaper for lower traffic intensity while P2 pavement was found to be cheaper for higher traffic intensity. This saving is influenced by saving made from reduction of surface course. From sensitivity analysis (Figure 6.1) even with 20% fall in price of cement, it was determined that P1 type pavement was cheaper for lower range of traffic. But the construction of flexible pavement is done in stage for varying traffic needs, using a relative strong layer for construction of road for lower traffic might open the future options of expansion with increase in traffic demand. In addition, use of CSS can also eliminate the need for providing AC and DBM layer for lower traffic demand. A simple surface treatment with increased base and sub base thickness should be enough to cater lower traffic demand. For future, AC and DBM layer can be provided to meet increased demand.

The P2 pavement also saved significant amount of bituminous surfacing course for same range of traffic in comparison to P1 pavement (Table 6-6). The construction with CSS layer in between sub base and subgrade layer might save a lot of money from reduction of use of bitumen. Reduction in bitumen is determined from typical amount of bitumen used to produce the certain amount of surface course as per DOR norms. The sensitivity analysis (Figure 6.2) showed a decrease in saving for 100 msa and again increased saving for 150 msa. The reason for this abnormal curve slope at 100 msa is due to use of thicker surface course for 100 msa which can be reduced by using thicker base and sub base layer and thinner surface course. This can increase the saving for 100 msa traffic intensity thereby making constantly increasing saving curve. Maximum saving from surface course was found for 150 msa which amounted to about NRs. 1.5 million at current price of bitumen. This can lead to large savings in road construction in Nepal.

6.4 Cost Saving With Different Bitumen Grade

Above cost analysis is done based on rate of VG 10 grade bitumen or bitumen 80/100. If we use different viscosity grade of bitumen such as VG 20 or VG 30 with rates mentioned in Table 2-1, the cost of DBM and AC layer increases to NRs. 17337 and NRs. 20825 per cubic meter and for 1 km stretch of road with 3.5 m width, reduction of 1 centimeter in thickness of each DBM and AC layer can lead to saving of NRs. 606,795 and NRs. 728875 respectively which was previously NRs. 595,350 and NRs. 713,300 respectively for same amount of reduction in thickness for DBM and AC layer construction.

6.5 Cost Saving with Continuous Batching Plant

The construction cost of DBM and AC are determined to be NRs. 20615 and NRs. 24090 respectively for continuous hot mix plant. The saving with reduction in unit centimeter in thickness of DBM and AC layer for road of stretch 1km and width 3.5 m turns out to be NRs. 721,525 and NRs. 843,150 respectively in comparison to previous saving of NRs. 595,350 and NRs. 713,300 respectively for the same using bitumen of grade 80/100.

6.6 Drying of Subgrade Material for Practical Implication

The poor subgrade have natural moisture in the wet side of OMC curve and require drying to reduce the moisture content to the value on the dry side of OMC for ease in compaction and mixing with stabilizer. For that, soil layer to the depth of stabilization should be scarified regularly for proper air drying. Once the moisture content fall to the dry side of OMC, it should be mixed with the stabilizer and compacted as soon as possible. The problem with air drying is that it may require time for drying which might increase the project duration. One benefit with repeated application of scarifier is that the crushed soil becomes finer and helps with more effective stabilization. The cost of drying from approximate estimation turns out to be around NRs. 400,000. It consist of scarifying the subgrade soil 4 times with ripper and rotavator and checking for size of crushed soil particles. These cost are only approximate costs and may vary from actual cost incurred in the field. If done with this technique then the cost of CSS layer may decrease as the scarifying of soil has already been done. This cost analysis might be the major limitation of this study as this may vary with practices and subgrade conditions. After deducting this cost from the saving, the resulting savings are summarized in Table 6-8 for present rates.

Table 6-8 New Cost Saving With Addition of Drying Cost in Lump Sum

Traffic (msa)	Previous difference in construction cost (NRs.)	New difference after addition of drying cost (NRs.)
5	-719,775	-1,119,775
10	-719,775	-1,119,775
20	588,875	188,875
30	1,184,225	784,225
50	1,374,450	974,450
100	1,256,500	856,500
150	1,568,350	1,168,350

CHAPTER 7 TRANSPORTATION ECONOMICS FOR NEPAL

7.1 Introduction

The objective of this thesis also included the possible reduction in surface layer due to use of cement stabilized subgrade over road with capping layer. The reduction in bituminous surfacing can add a huge saving to the construction cost.

7.1.1 Construction material

The use of cement stabilization significantly reduced the surfacing material over the P1 type pavement (Table 6-6). This can be advantageous for running road construction project. The cost of surfacing is 17520 NRs. per cubic meter for DBM and 20380 NRs. for AC layer (Table 6-1). Reducing small thickness of these layer significantly reduces the cost of construction if calculated for large network of roads. In addition to this, the reduction of these layers means reduction in the use of bitumen which is an imported material. Thus reducing the money spent outside the country to buy these material. The cement is produced with in the country and use of it can directly and indirectly impact the economy of country favorably.

7.1.2 Fuel

The fuel required for heating the bitumen to bring it mixing consistency is also reduced. This can add to the savings made through application of cement stabilization.

7.1.3 Labor and Equipment

The mixing of cement stabilizer to native soil could require some sophisticated equipment. The quality control for cement stabilization is also strict which requires more skilled labor and testing instrumentation in field. This could increase the cost of P2 pavement but the saving made as described on sections 7.1.1 and 7.1.2 can make up for the cost added for quality control and extra equipment requirement.

7.2 Cost Saving with Cement Stabilization

The study found that the cost saving in P2 pavement was mainly due to reduction in surfacing material (Table 6-7). The cement stabilized layer was expensive to construct as compared to construction cost of same thickness of capping layer. But the structural load carrying capacity was significantly increased due to CSS thereby reducing overlying layer. The CSS layer also provides support for longer life span (Hopkins et al., 2002).

7.3 Contribution to National Economy

The P2 pavement can have possible benefits over conventional pavement P1 for Nepal. The reduction in use of bitumen is the major benefit for national economy. The saving from reduction in the use of bitumen in one lane road of a kilometer stretch amounted as much as NRs. 1.5 million (Table 6-7) for 150 msa traffic. Moreover the use of material produced with in the country can increase the job opportunities and appreciate the industrial development with in the country. The reduction in import of bitumen can reduce the balance of payment deficit through reduced outflow of cash from country to foreign market. This can appreciate the value of national currency in the international market. The country can also benefit internally from savings made from reduced demand for maintenance to make the road serviceable.

CHAPTER 8 CONCLUSION

1. The addition of cement to natural soil modified Atterberg's limits and the plasticity index was reduced for all proportion of cement. LL shows increasing trend for low cement content followed by gradual fall after 4% cement content. On the other hand, PL shows gradual increasing trend for all. The soil has become more workable with increase in cement content.

2. The stability and strength of natural soil increased significantly. Addition of 6% cement content shows the 1450% increment to the initial value of soaked CBR for untreated soil. The UCS also showed the significant increment in initial value. It showed increment in both condition of increasing cement content and curing period. Hence the soil has become more stable with the addition of cement.

3. The increment of strength of natural soil with cement makes the soil competent enough to be used as supporting layer above natural soil subgrade. It represents improvement in the load carrying capacity of subgrade soil.

4. The thickness of each layer and total thickness of pavement can be determined using Kenpave model and Pavement design guidelines. The result showed that the overall thickness of P2 pavement is small compared to P1 pavement. This shows that stabilization of subgrade can save significant amount of material.

5. The cost was determined for both type of pavement for assumed traffic loadings. Though expensive for lower traffic range, P2 pavement is found to be cheaper for higher traffic intensity. This could lead to significant saving in construction of road in soft soil subgrade. Although the cost of cement stabilization is high for per cubic meter rate but the overall reduction of pavement thickness is the reason for cost reduction in whole pavement compared to pavement using capping layer. Even for the lower traffic provision of CSS can help in future expansion of road in case of increase in traffic demand without major rehabilitation. The cost of construction is found to be largely dependent on cost of surface course. So, if the use of cement stabilization reduces the surface course thickness then the pavement using CSS layer can be made cheaper even though the unit cost of construction of CSS is higher.

6. In model of pavement for both type of pavement, it can be seen that P2 pavement requires lesser thickness of surface layer i.e. BDM and AC. Therefore, the road cross section using CSS showed significant saving from reduction of use of bitumen in the surface course for almost all traffic loading considered for study. Hence, use of cement stabilization in pavement reduced the use of bitumen in pavement for adopted traffic intensity. This can be taken as an indirect benefit of the proposed pavement with CSS layers as cement is produced with in the country while bitumen is an imported material. Country can directly benefit from the reduction in import of bituminous material and might reduce balance of payment deficit for Nepal.
7. From pavement using same thickness of surfacing, the critical traffic intensity to trigger fatigue failure was higher for P2 pavement. From this, it can be concluded that use of CSS or stiff layer beneath the surface course can reduce the chance of fatigue failure in addition to rutting failure.

CHAPTER 9 RECOMMENDATION AND LIMITATIONS

This research reviews the stabilization for particular type of soil used in this study. So, this cannot be generalized for all type of soil. Furthermore, it is recommended that use of stabilization technique should be selected based on extensive laboratory and field test conducted on soil under consideration.

This study provides a methodology to design and analyze the cross section of road based upon subgrade condition. The Kenlayer has been used for modelling with failure criterion given by AI method. The use of particular failure criterion is taken based on failure condition which might be dominant for soil subgrade condition in this case. The use of failure criterion should be selected as per the design parameters and condition provided by subgrade. The cost are determined using the current rate prescribed by District and DOR which might change with time. Furthermore, the cost determined here does not include exact cost of drying of soil to sufficient moisture level so that it can be mixed properly, but only approximate cost in lump sum for drying and preparation of soil for mixing has been provided. Therefore, for practical use of this study, another study about possible drying method of very moist soft soil as in the case of Kathmandu valley is required so that, the natural soil can be dried to a point where mixing with cement can be done without much impact on final strength and stability parameters of stabilized soil. The variation of the drying cost can bring changes to the saving made from road using CSS layer. Other limitation with recommendation are summarized in points below:

1. Whole study is based on laboratory results on soil, so it might be difficult to exactly replicate the results on the field. It can be done with extensive quality control.

2. There are various methods to determine the optimum cement content. The one used by this study might not be appropriate for other type of soil. Hence, study should be conducted for other methods of determination of optimum content.

3. The modulus of resilience used in the study are based on UCS values after 7 days of curing. It is recommended that the value should be determined with proper testing rather than using the values from code.

4. The cost of capping layer has been found much lower than in actual practice. So, study about the costing of capping layer used in road practices in Nepal can be done to know actual cost differences.

5. Only subjective inference has been drawn from available research about effects of CSS on life span of road. A detailed study is suggested for determining influence of using cement stabilization of subgrade on life span of road.

6. The analysis used elastic theory for modelling with the assumption that the loading in road is for small duration and for small duration, the stress strain relation can be assumed as elastic. The study can be done considering nonlinear or viscoelastic theory. Furthermore, the damage analysis can be done to evaluate life span variation more accurately due to use of CSS layer in comparison to capping layer.

7. The study is recommended for use of rigid pavement for lower traffic intensity to determine if it is more reliable and cheaper than the flexible pavement.

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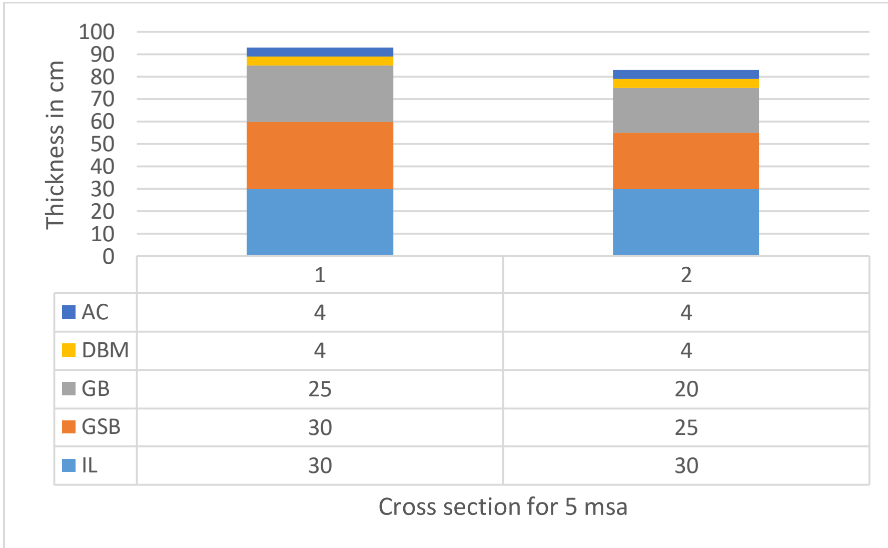
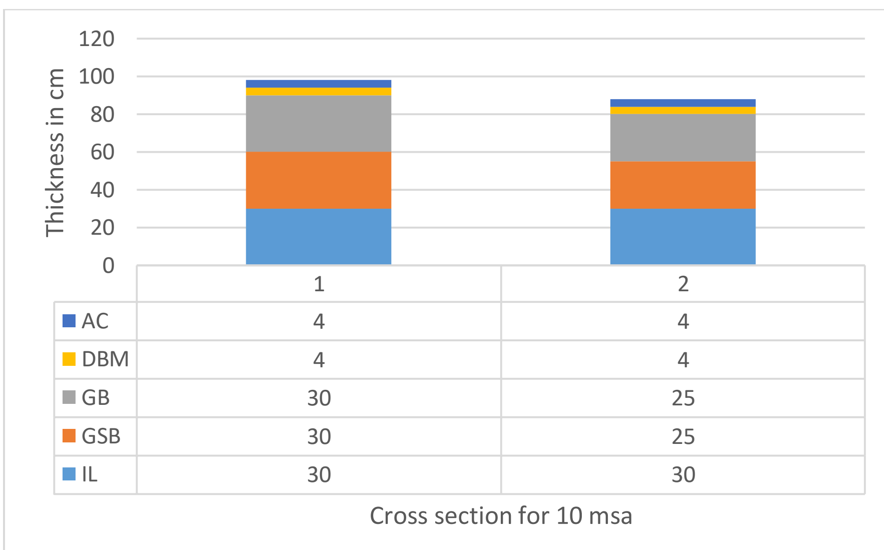
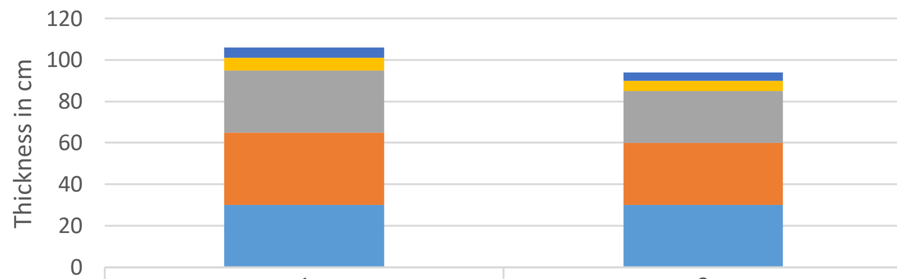
ANNEX

ANNEX A: FINAL CROSS SECTION OBTAINED FROM KENLAYER ANALYSIS

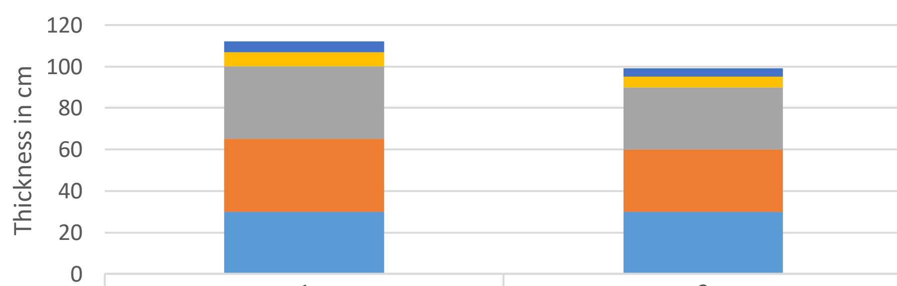






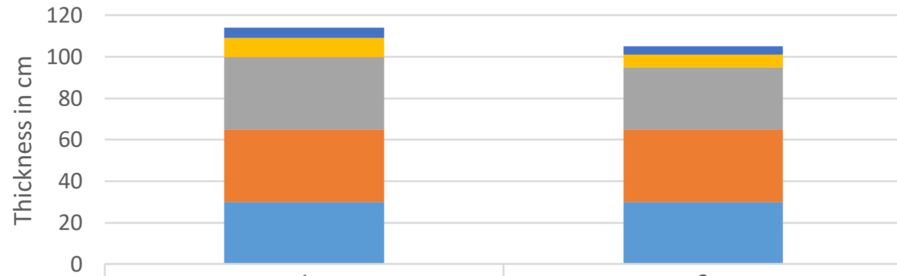
	1	2
AC	5	4
DBM	6	5
GB	30	25
GSB	35	30
IL	30	30

Cross section for 20 msa



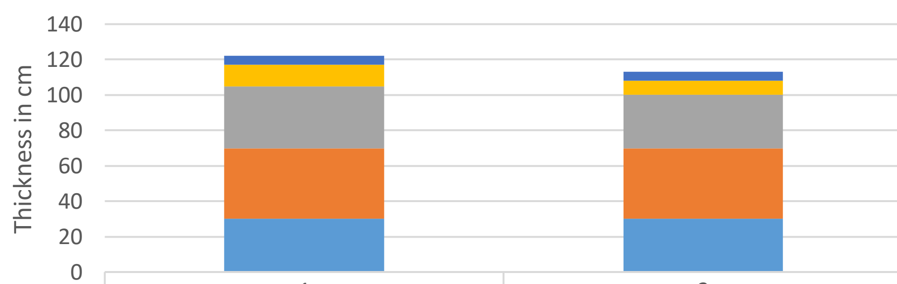
	1	2
AC	5	4
DBM	7	5
GB	35	30
GSB	35	30
IL	30	30

Cross section for 30 msa



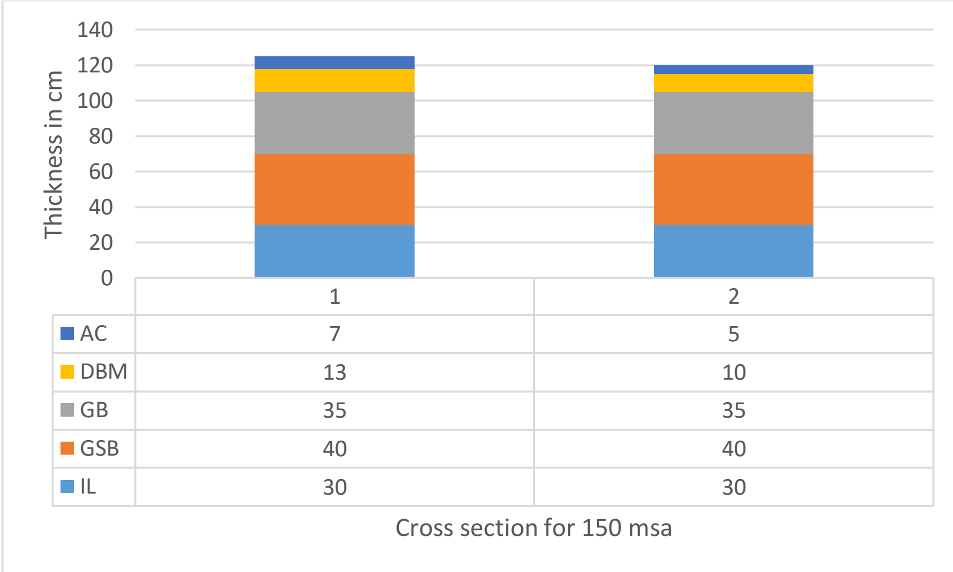
	1	2
AC	5	4
DBM	9	6
GB	35	30
GSB	35	35
IL	30	30

Cross section for 50 msa



	1	2
AC	5	5
DBM	12	8
GB	35	30
GSB	40	40
IL	30	30

Cross section for 100 msa


Thickness in cm
140
120
100
80
60
40
20
0
1
2
AC 7 5
DBM 13 10
GB 35 35
GSB 40 40
IL 30 30
Cross section for 150 msa

ANNEX B: RATE

The rate for each material or equipment are used from district rate provided by Kathmandu district. Some of the major item and their rates are summarized in the table below.

S.N	Item	Rate (NRs.)	Remarks
1	Skilled manpower	1030	Per day
2	Unskilled manpower	750	Per day
3	OPC grade 53	825	Per bag (50 kg)
4	Capping material	550.8	Per cu. m.
5	Stone dust	41.04	Per cu. ft.
6	Aggregates	Rate as per Kathmandu district rate 2076/77	For Kathmandu Metropolitan
7	Water	0.26	Per liter
8	Bitumen (80/100)	78.1	Per kg
9	Loader	2957	Per hr.
10	Grader	3618	Per hr.
11	Tractor with rotavator	1133	Per hr.
12	Ripper attachment	93	Per hr.
13	Tandem Road roller	1704	Per hr.
14	Pneumatic roller	3319	Per hr.
15	Vibratory roller	2413	Per hr.
16	Batch mixer HMP	26888	Per hr.
17	Paver finisher	5231	Per hr.
18	Generator	2281	Per hr.

Standard and specification used for construction of each layer.

SN	Item	Specification	Remarks
1	Capping Layer	SS- 1004	
2	CSS	SS- 1006	
3	Sub base	SS- 1201 ‘A’	
4	Base	SS- 1203	
5	DBM	SS- 1308	Grading II 19 mm (nominal size)
6	AC	SS- 1309	Grading II 13 mm (nominal size)