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Study of the CBR Requirements of Subgrade for Roads Design in the Gaza Strip

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بسم الله الرحمن الرحيم

" يا أيها الناس اتقوا ربكم و اخشوا يوماً لا يجزي والدٌ عن ولده و لا مولودٌ هو جازٍ عن والده شيئاً، إن وعد الله حق فلا تغرنكم الحياة الدنيا و لا يغرنكم بالله الغرور. إن الله عنده علم الساعة و ينزل الغيث و يعلم ما في الأرحام و ما تدري نفس ماذا تكسب غداً و ما تدري نفس بأي أرض تموت، إن الله عليمٌ خبير."

إهداء

بسم الله الرحمن الرحيم

الحمد لله رب العالمين و الصلاة و السلام على أشرف المرسلين سيدنا محمد و على اله و صحبه و سلم.

إنه ليسعدني و يشرفني أن أهدي هذا العمل المتواضع إلى روح والدتي و روح والدي سائلاً المولى عز و جل أن يغفر لهما و أن يسكنهما الفردوس الأعلى. إنه نعم من سئل و خير من أجاب.

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I would like finally to inscribe this work to all the Palestinian people looking forward to having our freedom and independence.

Engineer

KH.IS

31/08/2005

ABBREVIATIONS

PNA	Palestine National Authority
PECDAR	Palestinian Economic Council for Development and Reconstruction
UNDP	United nations Development Program
UNRWA	United Nations for Relief and Work Agency
PWA	Palestinian Water Authority
NGOS	Non-governmental Organizations
PIP	Piece Implementation Projects
AASHTO	American Association of State Highway Transportation Officials
ASTM	American Society for Testing and Materials
BS	British Standard
HDOT	Hawaii Department of Transportation
ODOT	Ohio Department of Transportation
CDOT	Colorado Department of Transportation
ESAL	Equivalent Single Axle Road
CBR	California Bearing Ratio
MDD	Maximum dry density
MR	Resilient Modulus
R-Value	Resistance value
E	Elastic Modulus
SN	Structural Number
TSL	Terminal Serviceability Index
DPSI	Loss of Serviceability
PSI	Present Serviceability Index
HMA	Hot Mixed Asphalt
LL	Liquid Limit
Kg	Kilogram
P1	Plasticity Index
CM	Centimeter
PL	Plastic Limit
IP	bound
B.SC	Bachelor of Science
Psi	Pound per Square
M.SC	Master of Science
KN	Kilo Newton
NIS	New Israeli shekel
$	United State Dollar
ADT	Average Daily Traffic
MN	Mega Newton

ملخص البحث

لقد جاء هذا البحث من خلال التجربة العملية للباحث كمهندس مصمم لأعمال الطرق في دائرة صحة البيئة في وكالة الغوث الدولية في غزة فلقد وجد الباحث أن المواصفات المطبقة في إعداد طبقة الأساس للطرق هي مواصفات غير مناسبة في جزئية معينة، حيث وضعت هذه المواصفات قيمة مرتفعة لنسبة تحمل كاليفورنيا لتربة الأساس كحد أدنى، إذا لم يتحقق، يتم استبدال تربة الأساس أو تحسينها وذلك لكل أنواع الطرق دون الربط بين هذه القيمة و نوع الطريق أو الحمل المتوقع مروره عليه. وفي هذا زيادة في التكلفة والجهد والوقت خاصة إذا علمنا أن معظم الطرق التي يتم تطويرها هي طرق سكنية أو محلية لا تمر عليها أحمال كبيرة في المدة التصميمية المتوقعة.

من هنا فإن هذا البحث جاء ليعالج هذا الضعف في المواصفات فيربط بين الحد الأدنى لنسبة تحمل كاليفورنيا (Minimum CBR Value) والحمل الذي يمكن أن يمر على الطريق متمثلاً بالوزن المحوري القياسي (ESAL) والذي يعكس درجة وأهمية الطريق أيضا.

لذلك كان من أهداف هذا البحث إيجاد الحد الأدنى لنسبة تحمل كاليفورنيا المناسب لتربة الأساس حسب الحمل المتوقع مروره على هذا الطريق لدرجات الطرق المختلفة، كذلك عمل تصنيف لأنواع الطرق وإعطاء مساحة أكبر من التصنيف للطرق السكنية والطرق المحلية والتي تمثل أكبر نسبة من مساحات الدرجات الأخرى للطرق سوءا كانت سريعة أو شريانية.

وفي هذا الإطار فلقد شمل البحث جانباً عملياً متمثلاً في العد المروري واختبارات التربة ورصد الأسعار وجانباً نظرياً عني بتطبيق كل من معادلة التصميم الأساسية لطريقة آشتو المعدلة وكذلك تطبيق معادلة المعامل الإنشائي الكلي وذلك باعتبار متغيرين اثنين فقط هما نسبة تحمل كاليفورنيا (CBR) والحمل القياسي (ESAL)كما شمل الجانب النظري أيضاً إيجاد عمق الاستبدال المناسب لتربة الأساس من خلال إيجاد الإجهاد الرأسي علي طبقة الأساس و كذلك سمك الدمك المناسب. كما تم إيجاد قيم الحد الأدنى لنسبة تحمل كاليفورنيا مع الأحمال المختلفة من تحليل نتائج ألعد واستعراض قيم نسبة تحمل كاليفورنيا وتطبيق معاد لتي التصميم. كما تم اقتراح جدول تصنيف للطرق و كذلك إعداد جداول و مخططات لتصميم طبقات الطريق بالإضافة لبعض التوصيات.

ABSTRACT

This research was proposed based on the practical experience of the researcher as a design engineer in the Special Environment Health Program (SEHP) at UNRWA Gaza, in the field of road design and specifications.

It was found that the specifications recommended for the minimum CBR (California Bearing ratio) value used in the preparation of the sub-grade layer for roads in most national and international institutions in the Gaza Strip, Such as UNRWA, PECDAR, Gaza and other Municipalities and Consultancy offices, are not suitable. These specifications require a relatively high value of CBR (15%) for the natural soil below the sub-grade layer. This also requires that the top layer (in most cases) should be replaced or improved regardless of the road class or the expected ESALs during the design period. This is expected to cause an increase of cost, time, human and material resources. This is particularly true for low category roads as well residential and local roads.

Determination of the minimum CBR value corresponding to each category of roads was one of the main objectives of this thesis in addition to road classification according to the ESALs. Special attention was given to residential and local roads which form the highest percentage of the area of roads. This is expected to lead to more adequate and economical design.

In this frame, the research methodology included in the practical part; traffic counts, soil tests, theoretical analysis and cost analysis. The theoretical part included the applications of the basic design equation of AASHTO Modified Method, the application of total structural number equation and finding the most suitable replaced depth for sub-grade.

Based on the analysis of the traffic count results and the applications of the above mentioned equations, tables of the roads classification and the minimum CBR values corresponding to the load categories were determined. In addition, design tables and charts were prepared under the condition that all parameters are constant except CBR and the total design equivalent single axle load (TDESAL) values.

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1 CHAPTER ONE

INTRODUCTION

1.1. General

It has been clarified that the progress and welfare of any country depend on the development of infrastructure assets for distributing resources and essential services to the public. Infrastructure assets always reflect the economic strength of a country.

Roads are classified as the most important component of infrastructure assets. From history, the Romans built a strong and wide empire by constructing a great network of roads in Europe, North Africa and the Middle East. Recently the United States of America U.S.A has the biggest road network all over the world which reflects the economy strength on one side and the progress and welfare on the other side.

Local materials are used in the road industry in all countries. Construction cost and life cycle cost generally shall be taken into consideration too, for the optimum choice of pavement layers materials.

In Palestine, and specifically in the Gaza Strip, the road sector suffered a lot during the Israel occupation from the year 1967 to the year 1994, the year in which the Palestinian National Authority (PNA) was established. After that, the Gaza Strip had achieved great steps of progress in the sector of roads. For example, Salah Eddine Street had been reconstructed from the northern border of the Gaza Strip to Wadi Gaza in both directions, having six lanes with a total width of 40m. A new coastal road had been constructed from Gaza town to Deir El Balah which is used now a day as an alternative to Salah Eddine Street. Many old paved roads had been renewed and rehabilitated and many other dust roads had been paved with asphalt or interlock block tiles. New other roads had been built across the Gaza Strip. To make sense of this progress in the sector of roads, Table 1.1 indicates the road area paved by the United Nations Relief Work Agency (UNRWA) all over the Gaza Strip since 1994 until 2004, not only in the refugee camps but also in other different municipalities. Table 1.2 indicates also the roads area paved by the PNA since 1994 until 2004 in Gaza Strip.

Table 1.1: Roads area paved by UNRWA from 1994 to 2004[(3)]

Municipality	Paved road area constructed by UNRWA (m2)
Rafah	140000
Khan Younis	35400
Deir El Balah	173400
Nuseirat	37400
Magazi	10600
Bureij	17700
Beach	218300
Jabalia	224000
Total	856800

Table 1.2: Roads area paved by PNA from 1994 to End of 2004[(4)]

Municipality	Paved road area constructed by PNA (m2)
Rafah	478,200 (from 1996-2004)
Khan Younis	754,000
Deir El Balah	306000
Nuseirat	250,000
Magazi	148,000
Bureij	232,000
Gaza	3,000,000
Jabalia	1,200,000
Beit Lahia	350,000
Beit Hanoun	525,000
Total	7,243,200

The projects of road industry which may include new road construction, reconstruction or rehabilitation are funded like many other projects after the return of the PNA by the donors within a general frame called the Peace Implementation projects (PIP), either directly by the PNA through the Palestinian Economic Council for Development and Reconstruction (PECDAR), PWA, Municipalities or indirect by the Non Governmental Organizations (NGOs) such as; UNRWA, United Nations Development Program (UNDP), and others.

Rehabilitation of the existing roads or construction of new roads needs always a complete design study based on a theoretical side and a practical and experimental side also.

1.2. Background

The study of this research will focus on the subgrade layer of flexible pavements in the Gaza Strip.

As it is known, all pavements in the Gaza Strip consist generally of three or four layers: surface layer which may be asphalt, interlock or concrete, base layer which is almost crushed stone aggregate, sub base which is selected material (kurkar) and the compacted subgrade. Compacted subgrade layer is the most important layer that has the main role in determining the total thickness of the pavement. It should be able to support safely and without critical deformation all traffic loads expected to pass over during the design period which range from 20-25 years.

In the Gaza Strip, General Specifications of road construction are prepared by national institutions such as Municipalities and the Palestinian Economic Council for Development and Reconstruction (PECDAR), or international such as UNRWA, UNDP and other consultancy offices. All above mentioned institute's specifications recommend the replacement or improvement of the top layer of subgrsde if the CBR is less than15% as it will be clarified later in chapter 2.

Replacement or Improvement of subgrade soil of CBR value less than 15% is carried out without considering the loads expected to pass over the roads, as specified in the road general or technical specification of national or international institutes in the Gaza Strip. In many projects for local roads of small volume of traffic and small number of ESALs, it becomes a waste of time and money to fulfill such specifications. Therefore in this thesis a classification of roads with respect to their expected ESALs during the design period will be carried out across the Gaza Strip. The sub-grade CBR value will be determined for different locations and different soil types. Economical comparative study should be covered so as to determine the minimum CBR value of the sub-grade to be recommended for each category of roads. Finally, design tables will be prepared in terms of the CBR value and Equivalent Single Axle Loads (ESAL) or road category, based on the American Association of State Highway Transportation Officials (AASHTO) modified method.

1.3. Definition of the problem:

The problem briefly is the inconvenient use of specification with roads of light load traffic and low volume traffic or in other words low category roads. Low category roads are generally the residential and local roads. They constitute the biggest percent area of any developed populated zone as will be indicated later on.

General Specifications for road industry used in Gaza strip or even in the West Bank is a mixed of different specifications from different countries. It's not only for road works but also in all types of work: Concrete works, sewerage works and mechanical Works. Road specifications applied in UNRWA, PECDAR, and Gaza Municipality when describing sub-grade preparation specify the CBR value of the upper 45cm by 15% below which replacement or improvement of the sub-grade soil should be carried out. This means that the replaced depth is considered as a sub base and the subgrade CBR is still below 15 and should be replaced. So the problem of subgrade replacement or improvement without reasonable justification will remain without solution for ever. Any how, replacement or improvement of subgrade is some times accepted and in many times is not accepted. Replacement means extra cost and time for the project. It also causes annoyance to the residents, especially in the populated areas. It causes the breakdown and suspension of existing shallow utilities and services such as water supply, waste water, electricity cables networks and others. In addition, this causes many difficulties of movements for residents.

1.4. Aim of the thesis:

The aim of thesis is to enhance the road industry in the Gaza Strip. This can be achieved by the study of the sub-grade requirement of CBR for road design and construction. This means to save much time and cost and to maintain high quality levels of design and construction. That is to include minimum CBR values for the sub-grade soil for each road category, below which subgrade soil should be replaced or improved.

1.5. Objective of thesis:

1. Classification of roads in the Gaza strip according to the expected ESAL during the design period (20 years) by surveying all vehicle types and axle loads and counting the traffic volume and loads in such roads during the design period.

2. To make economic comparative studies of different options of pavements, with and without replacement and between pavements of different layer materials.

3. Modification of road specifications by defining the minimum CBR values of sub-grade soil below which it should be improved or replaced, for the different road categories.

4. To save extra times and costs needed to replace or improve the pavement sub-grade in case of small values of ESALs.

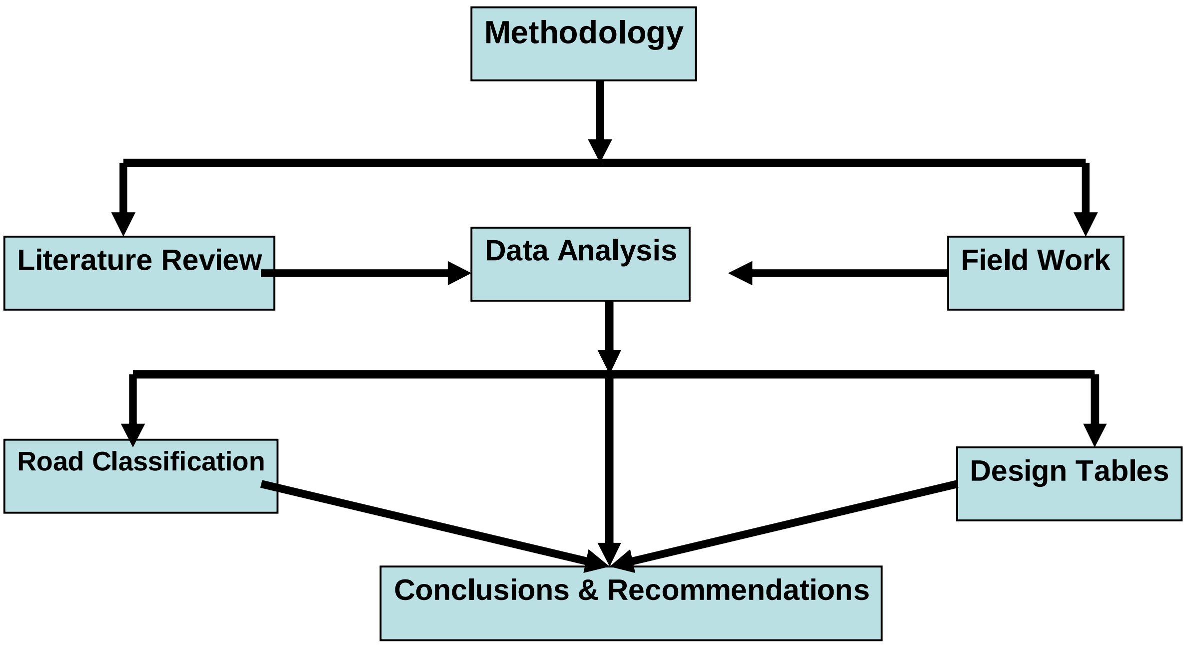
5. Preparation of design tables and charts for pavement layers in terms of the resillent modulus MR or CBR value of sub-grade and the ESAL expected in the design period (20 years).

6. To prepare tables and charts for the cost, structural number and CBR values.

1.6. Methodology of work

Methodology of work used here may be represented by the indicated flow chart

Figure 1.1: Methodology Flow Chart



Summary

The minimum CBR value used by specification in subgrade preparation was behind the choice of this research. It is used for all types of roads and for the same total design ESAL. The research main objective is, to bind between these two variables, minimum CBR value and the total design ESAL to find the liable, economical and faster results.

2 CHAPTER TWO
LITERATURE REVIEW

2.1 Introduction

This chapter will include the required studies concerning the subgrade and the related subjects. The following topics will be focused on:

- Soil classification
- Subgrade soil
- Traffic
- Design of flexible pavement
- Traffic count [13].

2.2 Soil classification:-

2.2.1 General

"Soil classification can be defined by the process of grouping all soil of the like characteristics in separated groups. Accordingly, performance of soil of each group or in the same group can be predicted to a certain limit. Different systems of classifications were proposed to fit the intended purpose, geological, agricultural or structural foundation engineering or structural high way engineering as described herein after". [5]

Soil classification shall be used in this thesis to include or find a relationship between the different types of soil all over the Gaza Strip and the CBR value. In such a way when the classification or the description is known, the corresponding CBR could be defined by a range of two values.

2.2.2 Textural classification

The textural classification was developed in 1890 depending on the grain size distribution of soil excluding the gravel portion.

The textural classification includes three groups; sand, silt and clay. The textural classification is represented in a "triangle textural classification diagram" as shown in fig 2.1[5]. Table 2.3 show the textural classification for subgrade soils of sand and smaller sizes.

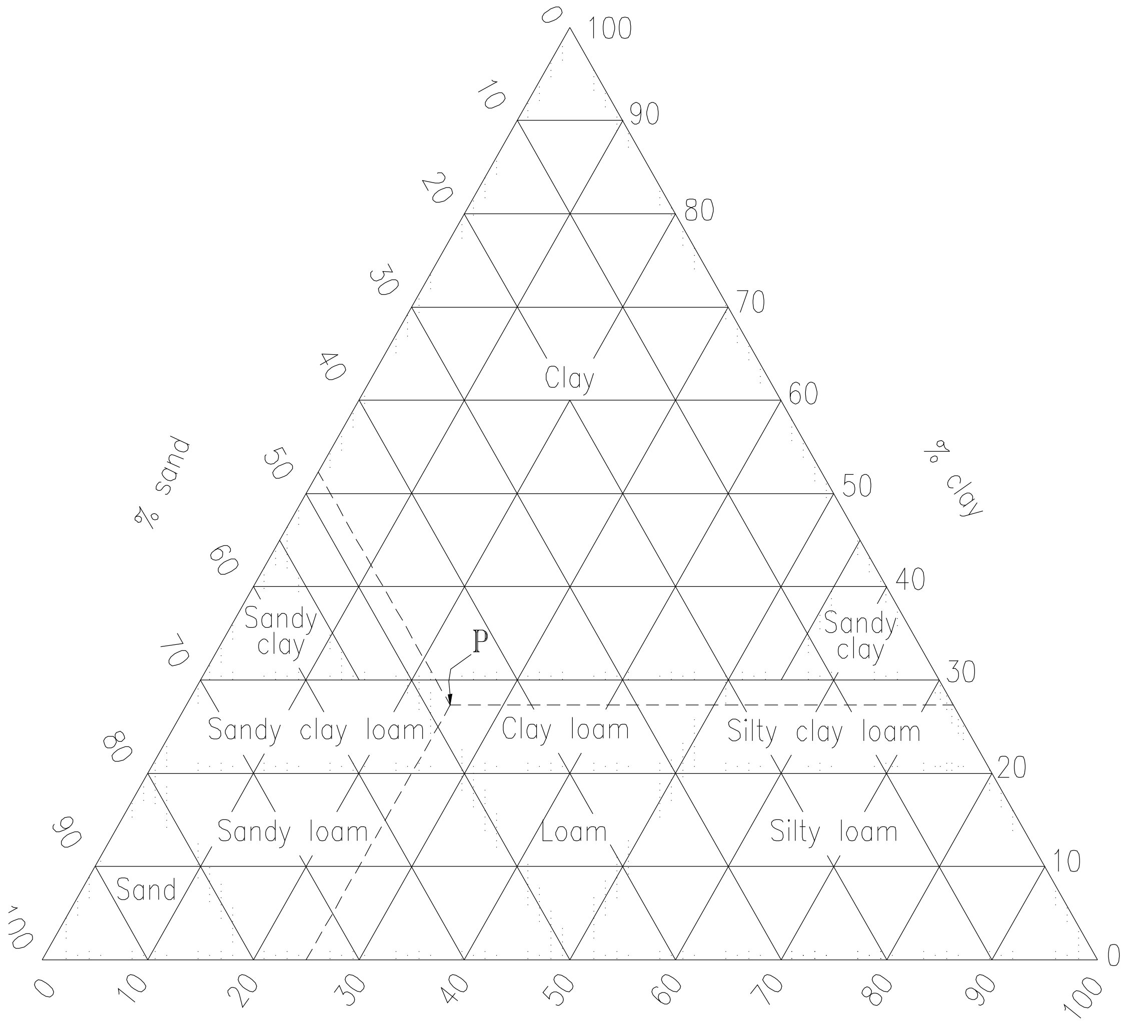


Fig 2.1 Textural Clasification for Subgrade Soils of Sand and Smaller Sizes

Table 2.1: Textural classification for subgrade soils of sand and smaller sizes [(5)]

Grade	Size of particles mm
Course sand	2.0-0.25
Fine sand	0.25-0.05
silt	0.05-0.005
clay	Smaller than 0.005

2.2.3 AASHTO classification

"AASHTO classification was developed from the public roads administration classification in 1828 to classify soil for the purpose of road surface and bases". [(5)]

The herein after table 2.4 represents the AASHTO classification. The group index is an important feature of the AASHTO classification. It is based on the service performance of many soils. It is used to predict the behavior of the soil and to guide in determining the combined thickness of pavement and base over a given soil. [5]

The group index is defined by the empirical formula,

Group index = 0.2a+0.005ac+0.001bd

Where:

a = that portion of percentage passing no. 200 sieve greater than 35% and not exceeding 75% , expressed as a positive whole number (0-40).

b = that portion of percentage passing No.200 sieve greater than 15% and not exceeding 55% , expressed as a positive whole number (1- 40).

c = that portion of the numerical liquid limit greater than 40 and not exceeding 60, expressed as a positive whole number (1- 20) .

d = that portion of the numerical plasticity index greater than 10 and not exceeding 30,

Expressed as a positive whole number (1- 20) [5]

.

Table 2.2: American association of States Highway and Transportation Officials (AASHTO) Classification of Soils and Soil Aggregate Mixtures, with suggested groups [5]

AASHTO Designation M145											
General Classification*	Granular Materials (35% or Less Passing No. 200 Sieve)							Silt-Clay Materials (More Than 35% Passing No. 200 Sieve)			
	A-1		A-3	A-2							A-7
Group Classification*	A-1-a	A-1-b		A-2-4	A2-5	A-2-6	A-2-7	A-4	A-5	A-6	A-7-5 A-7-6
Sieve analysis: % passing											
No. 10 (2.00mm)	50max.										
No. 40 (0.425mm)	30max.	50max.	51min.								
No. 200 (0.075mm)	15max.	25max.	10max.	35max.	35max.	35max.	36min.	36min.	36min.	36min.	36min.
Characteristics of fraction Passing No. 40 (0.425mm)											
Liquid limit				40max.	41min.	40max.	41min.	40max.	41min.	40max.	41min.
Plasticity index	6 max.		NP	10max.	10max.	11min.	11min.	10max.	10max.	11min.	11min.+
Group index+	0		0	0		4max.		8 max.	12max.	16max.	20max.
Usual types of Significant Constituent materials	Stone fragments, gravel and sand		Fine sand	Silty of clayey gravel and sand				Silty soils		Clayey soils	
General rating as Subgrade	Excellent to good							Fair to poor			

Classification procedure: with required test data available, proceed from left to right above chart, and correct group will be found by process limitation. The first group from the left into which the test data will fit is the correct classification.

Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30.

See group index formula for method of calculation.

2.2.4 Unified Soil Classification System:

Unified Soil Classification System was adopted by both the crops and Bureau of Reclamation from the old system adopted in 1942 by the Corps Engineers, U.S Army depending on the experience of Engineers through visual and manual inspections. (5)

The Unified system uses letters instead of numbers to distinguish the different groups. Mechanical analysis and liquid and plastic limit tests are the primary classification tools.

Principal system and soil designations are as follows:

A) for course-grained soil (>50% retained on N.200 sieve).

G: Gravels or Gravelly soils

S: Sands and sandy soils.

W: Well graded, fairly clean material

GW: Well graded gravel.

SW: Well graded sand

GC: gravel with clay.

SC: Sand with clay.

P: poorly graded, fairly clean material.

GP: gravel poorly graded

SP: sand poorly graded.

M: course material containing silts or rock flour.

GM: gravel with silt.

SM: sand with silt.

B: for fine – grained soils (>50% passing No. 200 sieve)

M: the inorganic, silty and very fine soils

C: inorganic clay.

O: organic silts and clays.

L: fine-grained soils of L.L < 50, of low to medium compressibility.

ML: inorganic silty of L.L < 50, of low to medium compressibility.

CL: inorganic clay of L.L < 50, of low to medium compressibility.

OL: organic silts and clay of L.L < 50, of low to medium compressibility.

H: fine-grained soils having liquid limits > 50 of high compressibility.

MH: inorganic silty of high compressibility.

CH: inorganic clay of L.L > 50 of high compressibility.

OH: organic silts and clays of L.L > 50 of high compressibility.[5]

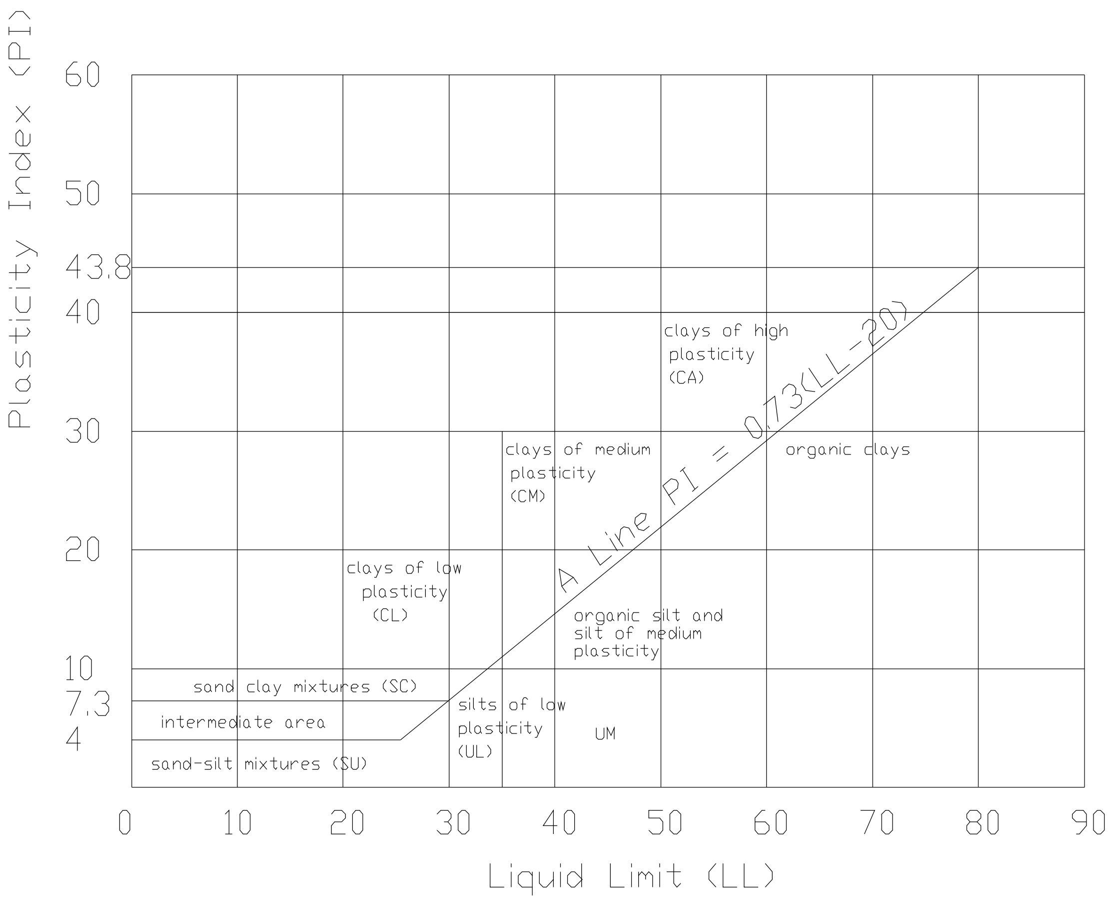


Fig2.2: Plasticity chart "Casaegrand"

(Flowchart group for gravelly and sandy soil (after ASTM, 1991) [15]

2.3 Subgrade

2.3.1 Definitions

"The "Subgrade" is the in situe material upon which the pavement structure is placed. Although there is a tendency to look at pavement performance in terms of pavement structure and mix design alone, the subgrade can often be the overriding factor in pavement performance." (6) In other words the strength of the soil subgrade is the greatest factor in determining total thickness of pavement (7)

"The bottom of the excavation for the pavement, or top of the fill, will be known as the pavement subgrade and will conform to the lines, grades, and cross sections shown on the accepted plans." (8)

2.3.2 Subgrade performance

A subgrade performance generally depends on two interrelated characteristics: (5)

2.3.2.1 Load bearing capacity

It is the ability to support loads, transmitted through pavement layers. Load bearing capacity or strength is considerably affected by compaction, moisture, and density of the soil. The effect of these three factors on the subgrade soil at Gaza Strip will be studied later.

2.3.2.2 Volume changes

Considerable volume change may take place when exposed to excessive moisture or freezing conditions.

2.3.3 Specification of Subgrade preparation

In the Gaza Strip, General Specifications of road construction are prepared by national institutions such as Municipalities and the Palestinian Economic Council for Development and Reconstruction (PECDAR), or international such as UNRWA, UNDP and other consultancy offices such as Universal Group for Engineering & Consulting. For example UNRWA General Specification for road construction regarding to sub-grade preparation before 2001, states: "All sub-grade material within the upper 450mm below the top of sub-grade elevation shall have minimum California Bearing Ratio (CBR) of 15 when tested in accordance with AASHTO T-193. When the upper 450mm below the sub-grade elevation of earth cut is found to be incapable of compaction as specified, such sub-grade material shall be removed and replaced."[9]

Second example is the Universal Group for Engineering & Consulting Technical specification, Volume II, for road constructions which states: "All sub-grade material within the upper 450mm below the top of sub-grade elevation shall have minimum California Bearing Ratio (CBR) of 15 when tested in accordance with AASHTO T-193. When the upper 450mm below the sub-grade elevation of earth cut is found to be incapable of compaction as specified, such sub-grade material shall be removed and replaced."[10] It is evident that this article is identical to that of UNRWA SEHP General Specification related to the subgrade preparation.

Third example is Gaza Municipality specifications for road constructions which states:

"كما و تستخدم كطبقة إحلال للتربة الطبيعية (subgrade) في حال إذا لم تحقق التربة الطبيعية للطريق نسبة تحمل كاليفورنيا (CBR) و قدرها "15%" [1]

Fourth example is the Palestinian Economic Council for Development and Reconstruction (PECDAR) specification for road constructions states in article 13.2: " The finished subgrade immediately prior to placing subsequent sub base or base material thereon shall be compacted to not less than 95 percent maximum density according to BS 1377: Part 4 or latest version there of. The material should have minimum (CBR BS 1377: Part 4 or latest version there of) 15% at 95% Maximum dry density or as specified on the drawings.

Where the material fails to meet the required CBR as determined by laboratory testing at 95% maximum dry density the subgrade shall be improved by replacement as detailed in clause 4.3 of this specification."

Article 4.3 titled by Improvement of subgrade states: "At all locations of roadway cut where, in the opinion of the engineer, unsuitable material is found, or where the subgrade is not homogenous, roadway cuts shall be excavated to minimum depth of

15 cm below subgrade elevation. The cut foundation shall be compacted to a depth of 150mm to 95% of the MDD. Subgrade material shall be placed on the cut foundation and compacted to the required density. After compaction, the subgrade surface shall conform to the grade and typical section shown on the drawings. The contractor will be paid for the actual quantity of subgrade material replacing the unsuitable material, under embankment. The subgrade material shall be as approved by the Enginer but must give a CBR (BS 1377: Part 4) of minimum 15% at 95 percent maximum dry density (BS1377: Part 4) using a 96 hour soaked method. The material and testing requirement shall be as per clause 4.8." (11)

2.3.4 Subgrade compaction

Compaction of the subgrade is necessary for the construction of pavement. Compaction the subgrade soil reduces the compressibility of soil, the permeability and absorption of water and thus increases the shear strength. This is as a result of reduction of the voids of the compacted soil and the increase of density.

"Enough compaction should be carried out to a reasonable depth. Compaction of the subgrade soil during construction should be at least 95% of AASHTO T-99 or ASTM D 698 for cohesive clay soils and at least 95% of AASHTO T-180 or ASTM D 15777 for non cohesive (sandy and gravelly) soils."(12) Generally reasonable depth of compaction is between 6-12 inches (15-30cm) (12). Due to the variation of density of soil with water content, laboratory tests on the subgrade soil with different water content are carried out to determine the optimum water content to meet maximum dry density required for specifications.

2.3.5 Alignment and grading the road bed (subgrade)

The purpose of alignment and grading the road bed or subgrade is to construct a clear and stable foundation of a specified cross section on which the pavement is based. The levels of the grade line are governed by alignment, gradient, soil characteristics and drainage conditions. (12)

2.3.6 Subgrade material main physical properties

1-Stiffness: resistance to deformation under loads.

2-Strength: in other words is the bearing capacity.

2.3.7 Tests used to describe the bearing capacity and stiffness

Bearing capacity and stiffness can be described using one of the following tests:

2.3.7.1 California bearing ratio (CBR) (6)

A test that compares the bearing capacity of a given material with that of a well graded crush stones. CBR is primarily intended for, but not limited to evaluation the strength of non stabilized cohesive materials of maximum particles size less than 0.8 mm (sieve No. 200).

CBR is widely used to describe and measure the bearing capacity of the subgrade as well as the base and subbase layers. This is generally for granular soil.

Subgrade bearing capacity should be able to resist traffic loads without reaching the critical deformation value. CBR values which reflect the bearing capacity of the subgrade should be limited in its minimum value so as to resist loads without deformation that may cause dangerous damage to all the pavement layers.

2.3.7.2 Resistance value (R-value) (6)

It is a test that expresses a material resistance to deformation as a function of the ratio of transmitted lateral pressure to applied vertical pressure. It is a modified triaxial compression test. The testing apparatus used is called a stablometer and is identical to the one used in the Hveem HMA maximum design.

The R-value is basically a measure of stiffness.

2.3.7.3 Resilient Modulus (MR) (6)

It is a test used to estimate elastic modulus (a material stress strain relationship). The resilient modulus test applies a repeated axial cyclic stress of fixed magnitude, load, and duration to a cylindrical test spacemen. While the spacemen is a subject to his dynamic cyclic stress, it is also subjected to a static confining stress provided by a triaxial pressure chamber. It is essentially a cyclic version of triaxial compression test; the cyclic load application is thought to more accurately simulate actual traffic loading. Resilient modulus is basically a measure of stiffness

Table2.3: Typical CBR and Modulus of Elasticity Values for Various Materials [6]

Material	CBR	R-VALUE	Elastic Modulus or MR(psi)
Crushed Stone (GW, GP, GM)	20-100	30-50	20000 - 40000
Sandy Soils (SW, SP, SM, SC)	5-40	7-40	7000 - 30000
Silty Soils ML, MH)	3 - 15	5 - 25	5000 - 20000
Clay Soils (CL, CH)	3 - 10	5 - 20	5000 - 15000
Organic Soils (OH, OL, PT)	1 - 5	<7	<5000

Table 2.4: Selected Subgrade Strength / Stiffness Correlation Equations [6]

Equation	Origin	Limitations
MR = (1500) CBR	Heukelom & Klomp (1962)	Only for fine grained none expansive soils with a soaked CBR of 10or less
MR = 1000+555(R-value)	1993 AASTO Guide	Only for fine grained non expansive soils with R-values of 20 or less
R-value = (1500CBR – 1155)/555	HDOT	Only for fine grained none expansive soils with a soaked CBR of 8or less
$MR = 2555x\ CBR^{0.64}$	AASHTO 2002 Design Guide (not yet released)	A fair conversion over a wide range of values

2.3.8 Undesirables types of subgrades

Undesirable types of subgrade are summarized as follows:

2.3.8.1 Subgrade with large quantities of mica and organic materials

They are elastic and their resilience is high. Mica and organic materials are subject to rebound upon removal of loads and this may cause fatigue failure. Subgrade soil of this type is classified by the HRB as A-5 or A-7 should be avoided if possible [10].

Soil subgrade of high organic content should never be used because stability of the pavement will become unsafe.

2.3.8.2 Subgrade of high volume changes

Subgrade of high volume changes shrink when water is removed. They should be kept wet to compat volume change due to drying out. Such subgrades can be encased with plastic sheets or bituminous membranes or by other proper covers. [12]

2.3.8.3 Swelling soils

Swelling soil is undesirable type of subgrade. It should be compacted at water table content near or slightly higher than the optimum water content. The weight of the pavement should be enough to resist the swelling pressure. [12]

2.3.8.4 Subgrade susceptible to frost heave

Susceptibility of subgrade to frost heave causes volume change, and so cracks of the pavement layers. In this case, it is necessary to lower the ground water using site drains deeper than the water table. The use of proper filter material around the drain is important. [12]

2.3.9 Treatment of the subgrade soil

2.3.9.1 General

If the subgrade material is not adequate for the pavement as a foundation, it should be improved or replaced. There are many factors affecting the treatment of the subgrade soil as followed:

1- Load carried by the pavement layers

2- Available resources of treating materials

3- Weathers conditions

4- The cost, which is the most important factor

2.3.9.2 Methods of treatments of the subgrade soil (12)

1- Compacting the existing subgrade to increase the strength

2- Using side ditches to drain the water with a sand filter to prevent the pumping of silt or clay up into the coarse backfill

3- Improving the grading of subgrade materials by adding the missing sizes with the required percentage

4- Treatment by adding chemical additives such as Portland cement, lime or a mixture of lime and fly ash. Portland cement is used for granular soil, silty soil and lean clay. Portland cement can not be used in organic materials. Hydrant lime is most efficient when used in granular and lean clay.

5- Treatment of subgrades susceptible to frost heave by lowering down the ground water table below the frost susceptible layer, through a ground drainage system or by using a bituminous under seal to prevent or retard the capillary rise.

2.4 Traffic

In the Gaza Strip and before the establishment of the PNA in 1994 the field of road industry as well as all related works such as roads geometrical design or traffic studies was out of consideration. With the opening of the Engineering College in the Islamic University, and after 1994 many studies had matched the development requirements of the Gaza Strip. Traffic count was one of these studies. Partial traffic count study was carried out by a group of B.Sc. graduates of the Civil Engineering Department in the Islamic University in Gaza (13) as part of their graduation project.

2.4.1 Traffic load

Pavements are designed to carry safely the loads from the vehicles weights through wheels. As a result, the knowledge of truck and wheel arrangements, spacing and loads are very essential. In this research, only truckloads will be considered for the purpose of pavement design of roads and highways.

2.4.1.1 Equivalent Single Axle Loads

Traffic is generally of deferent types and loads: passengers' cars, busses, heavy trucks and others. Heavy trucks have the main effect on the pavement design, although passenger's cars are of highest percentage of traffic. So, it was necessary to use a simple loading system by choosing a standard equivalent single axle load equals to 18000 psi (8200kg) for design. Vehicles are either of single units or of multiple units. Single unit vehicle has 2, 3 or 4 axles. Multiple unit vehicles have 3, 4 & 5 axles. The axles are either single, tandem axles with one or dual tires or tridem axles.

2.4.1.2 Load equivalency factors for highway flexible pavements.

Load equivalency factors for single, tandem and tridem axle loads could be found in all highway engineering text bocks. These factors represent the equivalent numbers of application of the 18000 Ib (8100 kg) standard single axle load.

2.4.1.3 Allowable Axles Loads

The maximum allowable load for single unit truck is between (12.6-27.3 ton) according to North America according to the numbers of axles and wheels and according to the specifications of design.(12)

.The maximum allowable load for tractor with a Simi trailer and for full trailer varies "between" (27.3-61 ton) (12).

The maximum single axle load varies "between" (7.1-10.0 ton). [12]

The maximum tandem axle load varies "between" (12.5-18 ton). [12]

Spacing centerline to centerline between dual wheels is about 34 cm and tyre pressures are (60-90 psi) (4.2-6.3 kg). In Europe, higher axle load are generally used. The Maximum single axle load is 13.0 ton and the maximum tandem axle load is 20 ton. [12]

The legal axle load is the maximum allowable axle load, which is generally from 11-13 tonne for single axle load and from 19-20 tonne for tandem axle load. The actual axle load is the actual weighted axle load. Its value may be above the value of legal axle load. [2]

The standard load used in design is the 18000 Ib (8100 kg) single axle load with dual load in each side.

Table 2.5 indicates the total permitted load as prepared from the ministry of transportation.

Table 2.5: Legal axles and total permitted weights [13]

Vehicle Description	Permitted Load (kg)
Vehicles of two axles	19000
Vehicle of one front axle and one double arrear axles	27000
Vehicle of one front axle and two double arrear axles	32000
Vehicle of one front axle and three double arrear axles	34000

2.4.2 Dimensions of vehicles

The overall length of single commercial vehicles, in North America varies between (10.7m-12.2m) and the length of combinations, consisting of a tractor, semi-trailer and/or full trailer varies between (19.2m-21.4m). Max width is 2.6 m and maximum height is between (4.1- 4.4) [12].

In the Gaza Strip, truck surveying was prepared in the study made in 2003 by a group of B.Sc. graduates of the Civil Engineering Department in the Islamic University in Gaza and will be denoted by phase 1[13]. Tables 2.6, 2.7 & 2.8 summarize the permissible total dimensions and loads of trucks prepared in phase 1.

Table 2.6: Vehicles total width in the Gaza Strip (13)

Description of the vehicle	Total width(m)
Commercial vehicles of total weight >3500kg	2.55
buses	2.50

Table 2.7: Vehicles total height in the Gaza Strip (13)

Description of the vehicle	Total height(m)
Total permissible weight up to 1500kg	2.5
Total permissible weight from 1501to 3500kg	3.0
Total permissible weight from 3501 to 8000kg	3.50
Vehicles with cylindrical tanks	4.0

Table 2.8: Vehicles total length in the Gaza Strip (13)

Description of the vehicle	Total length(m)
Trucks with normal box	12
Bus	12
Articulated bus	18
Tractor with semi trailer	12.5
Tractor with full trailer	12.5
Tractor with semi and full trailer	24

2.4.3 Traffic count

It includes surveying of the existing vehicles used in the Gaza Strip specially trucks, finding the equivalent single axle loads for each vehicle and counting the traffic in different roads in Gaza City. The required output was the average daily truck factor as indicated in Table 2.9. Table 2.10 indicates the truck factor summary (ESALs) prepared in phase 1 for each type of vehicle from X1 to X15.

Table 2.9: Average daily truck factor of roads, phase 1 (13)

Urban Areas			
Road	Road class	Average daily truck factor	
		Direction (A)	Direction (B)
Al-Rashid	Interstate	0.554	0.537
Salah Eddin	Interstate	0.502	0.445
Jamal Abdel Naser	Collector	0.317	0.374
Al-Jalaa	Collector	0.209	0.168
El Naser	Collector	0.075	0.078

Locations and names of counted roads in phase 1 will be presented and considered in Chapter3 with the traffic count prepared by the researcher.

Table 2.10: Truck Factor summary for Vehicles, phase 1 (Equivalent ESALs) [13]

No	Vehicle Symbol	Truck Factor
1	X_1	0.1
2	X_2	0. 1
3	X_3	7.766
4	X_4	4.966
5	X_5	5.762
6	X_6	9.136
7	X_7	7.813
8	X_8	9.932
9	X_9	8.612
10	X_{10}	14.826
11	X_{11}	115.466
12	X_{12}	12.666
13	X_{13}	13.462
14	X_{14}	7.766
15	X_{15}	1.592

2.5 Design of Flexible Pavement

2.5.1 General

Pavements are generally subjected to different types of effects. Traffic loads with their repeated effect on pavement causes different types of stresses. There are also environmental effects such as temperature, frost heave and water which can affect hardly on the pavement.

Design of flexible pavement will take the procedures of calculating the different requirement of the pavement; thicknesses of layers, environmental conditions, traffic loads, reliability, Serviceability and others.

The basic equation for design of flexible pavement is below. [15]

$$\log_{10}(W_{18}) = Z_R S_o + 9.36\times\log_{10}(SN+1) - 0.2 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4+\frac{1094}{(SN+1)^{5.19}}} + 2.32\times\log_{10}(MR) - 8.0 --- (2.1)$$

Where:

W_{18} = 18-kip equivalent single axle load

Z_R = reliability

S_0 = overall standard deviation

SN = structural number

ΔPSI = design present serviceability loss

MR = resilient modulus of the subgrade

Design of flexible pavement can be achieved with different methods such as the Asphalt Institute Method, California Bearing Ratio method (CBR) and others.

In this thesis, AASHTO modified method will be only considered. The required structural number is obtained from the above equation or from the derived herein after chart in function of the ESAls, resilient modulus, reliability, serviceability loss and the standard deviation. The obtained structural number should be less than the calculated structural number from the pavement layers as it would be discussed later.

2.5.2 AASHTO design consideration [15]

1- Pavement performance

2- Road bed

3- Traffic

4- Material of construction

5- Environment

6- Drainage

7- Reliability

8- Life cycle time

2.5.3 Pavement Performance

Recent concept of pavement performance is related to both safety and structure.

Pavement performance considered in the AASHTO is related to structural performance only.

Safety performance can be found in other AASHTO publications. Frictional resistance is one of the safety aspects. The structural performance is related to cracking, rutting, raveling, faulting which affects the bearing capacity of a pavement. [15]

This structural performance is expressed by the present serviceability Index (PSI); how the road can serve the user. PSI scale ranges from 0-5. The value 5 represents the highest index of serviceability.

For design, initial and terminal values of PSI are selected.

Pi represents the PSI immediately after construction of the road. Pt represents the terminal PSI and is taken 2.5 for major roads and 2 for minor roads.

The loss of serviceability is used for design. It equals the difference of the initial and terminal serviceability index.

$\Delta\ PSI = PSI_i - PSI_t$ [15]

Table 2.11: Serviceability Factors [29]

Serviceability Factors		
	Flexible	**Rigid**
Initial serviceability	4.5	4.2
terminal serviceability	2.5	2.5
Design serviceability loss	2	1.7

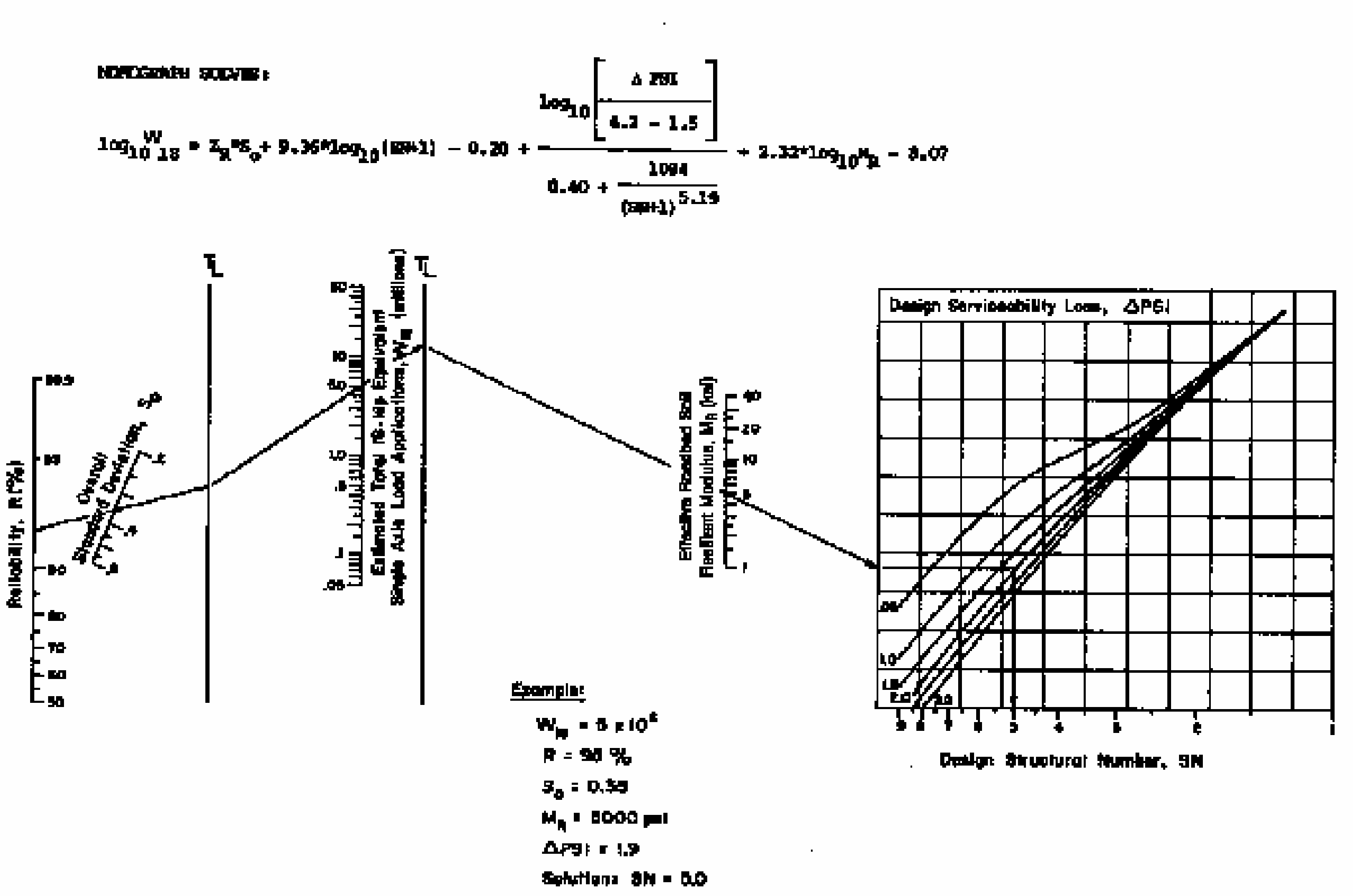


Fig 2.3: Design Chart of Flexible Pavement (15)

2.5.4 RELIABILITY (50-99.5) %

2.5.4.1 Definitions

1) It's defined as the probability that serviceability will be maintained in adequate levels from the user's point of view during the design period. [15] Or
2) It's defined as the probability that the section designed will perform satisfactory over the traffic environmental conditions during the design period. [15]

- It's taken against traffic predictions
- Higher levels of reliability mean less degree of risks of not performing the expectations.
- Higher levels of reliability means more pavement structure required.
- Levels of reliability increases as the use of road increases.

Table 2.12: Reliability levels [29]

Reliability %		
Classification	**Urban**	**Rural**
Interstate & Free way	95	90
Principal arterial, minor arterial	90	85
Collector	90	85
Local	80	80

2.5.4.2 Overall Standard Deviation

- It is a function of the reliability factor
- It accounts for both chance variation in traffic prediction and performance of pavement prediction for a given W_{18}.

Table 2.13: Overall standard deviation [29]

Overall standard deviation	
Flexible pavement	0.49
Rigid pavement	0.39

2.5.5 Material of construction

- Asphalt or Interlock is used for the surface layer. (layer coefficient is 0.42)
- Crushed aggregate base course is used for the base layer (layer coefficient is 0.14)

- kurkar is used for the sub base layer(layer coefficient is 0.09)
- Subgrade or roadbed is the natural ground or borrow compacted accepted material.

2.5.6 Total structural number of pavement SN

The total structural number of the pavement layers is calculated from the following equation:

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 - - - - - - - - 2.2$$

Where:

- a_1 = Surface layer coefficient
- a_2 = Base layer coefficient
- a_3 = Subbase layer coefficient
- D_1 = Surface layer depth (inch)
- D_2 = Base layer depth (inch)
- D_3 = Subbase layer depth (inch)
- m_2 = drainage factor of the base layer, is taken 1 in the Gaza Strip
- m_3 = drainage factor of the subbase layer, is taken 1 in the Gaza Strip

Table 2.14: layer coefficients (15)

Pavement layer	layer coefficient
asphalt	0.42
Crushed aggregate base course	0.14
kurkar	0.09

2.5.7 Drainage

Drainage conditions affect the performance of pavement. Poor drainage will increase the percentage of moisture in the pavement. Moisture existing will lead to pore pressure and decrease the pavement strength. Moisture causes additionally the expansion of soil which causes differential heaving.

Moisture sources are rainwater, runoff and high round water. Drainage of these sources is secured by surface drainage or subsurface drainage.

Drainage effect is interpreted by coefficients denoted in the structural number formula by m2 and m3, only for the base and subbase layers as indicated above.

Drainage coefficients depend on the saturation time of the pavement in the year.

Drainage coefficient may be more or less than one. It is taken one for the general conditions in the Gaza Strip

2.5.8 Environmental effects

Temperature may causes asphalt binder archeology and contraction and expansion of the pavement

Moisture change affects strength, durability and load bearing capacity.

Swelling and frost heave have an important effect on the subgrade bearing capacity.

As a result, environmental has important effects on the serviceability

2.5.9 Life cycle cost

- It refers to all cost and benefit, involved in the provision of a pavement during its complete life cycle.

- It includes construction, maintenance, and rehabilitation.

Different alternatives should be compared to find the most economical c

Summary

The different subjects related to subgrade preparation, either to the subgrade soil it self or to the factors affecting the subgrade bearing capacity were taken into consideration in collecting and presenting the literature review in this research. As a result soil classifications, subgrade properties and functions, traffic count and design of flexible pavement were the main topics focused on in Chapter 2.

3 CHAPTER THREE FIELD WORK

3.1 General

Any research will be considered useful, convincing and confident if it is supported by field practical works. In this thesis, the field work will take the procedures of preparing three types of work. The first type of field work refers to the traffic counts for different roads of different importance or classification over the Gaza Strip. The second type refers to the laboratory tests necessary to determine the bearing capacity of subgrade layer on which the pavement is constructed for a sample of roads over the area of the Gaza Strip. The third type refers to the costing of roads construction materials and the workmanship of road industry.

The count of vehicles for a chosen sample of road is carried out in the two directions during a period of about 24 hours. It includes not only the numbers and types of all vehicles passing on the road, but also the number, types and weights of truck axles. The objective is to find a reasonable list of classification of roads according to the expected ESAL in the design period.

Laboratory tests include sieve analysis, Uterberg Limits if any, and modified proctor and CBR test. This is to find a reasonable description of the subgrade soil and to determine the CBR value of the subgrade.

Preparing a data base for the cost of roads construction materials will be conducted in this thesis from different sources. Costing will include the total components of cost.

3.2 Traffic Count

3.2.1 General

Since the Gaza Strip had achieved great steps of progress in the industry of roads since the establishment of the Palestinian National Authority PNA in 1994, it was necessary to carry out the design according to comprehensive study with correct data, for both structural and geometrical design. Traffic count is essential for both types of design. For example structural design is based mainly on:

1- Traffic loads which will pass on the road during the design period, expressed in ESALs.

2- Bearing capacity of the subgrade supporting the required pavement expressed in the CBR or MR values.

3- Cost which is a function of the materials of construction.

As a result, traffic count is a practical and reliable way to find the expected ESAls during the design period. It should be carried out by qualified prepared persons. It should cover points of heavy traffic and specially trucks on the roads during a period of 24 hours continuously.

3.2.2 Objectives of the traffic counts

1- To determine the number of vehicles which pass over roads in a period of 24 hours if possible.

2- To find the number of each type of vehicles, mainly trucks, in order to calculate the equivalent single axle load ESAL within the period of design (20-25 years).

3- To find the Average Daily Truck Factor.

4- To list the roads in categories according to the ESAL.

3.2.3 Methodology of Count

3.2.3.1 General

Surveying of the existing vehicles used in the Gaza Strip specially trucks and knowing their axle loads is very essential to carry out the count process. For this, surveying of the existing truck types in the Gaza Strip is prepared. Great benefit was taken from a study made in 2003 by a group of B.Sc. graduates of the Civil Engineering Department in the Islamic University in Gaza. [(13)] The study includes surveying of the existing trucks used in the field of transportation in the Gaza Strip and the count of traffic on selected sample of roads in Gaza town.

Updating the surveying of data required for the process of traffic count was carried out by the researcher. New traffic count points distributed on the area of the Gaza Strip were considered. Finally, all counted points in the two times were considered and the outputs will be used in the process of listing roads.

The work carried out by the graduates will be denoted by phase 1 and the work carried out by the researcher will be denoted by phase 2.

3.2.3.2 Methodology main steps

1- Surveying of the existing vehicles in the Gaza Strip, specially trucks. It was conducted by the graduates of the Islamic University [13] in phase 1 and updated by the researcher in phase 2. Tables 3.1, to 3.6 are the updated data prepared in phase 2.

2- The axle type and weight of trucks, the corresponding truck equivalency factor and the ESAL of trucks are determined and indicated in Table 3.7.1-3.7.13. Summary of the vehicle ESALs prepared in phase 1 is indicated in Table 2.10 and the updated summary of phase 2 is indicated in Table 3.8.

3- Traffic count forms are prepared. It includes all the necessary information related to the number and weight of axle's loads, where:

a. Count form number 1 is used to count every vehicle for each hour (Table 3.11).

b. Count form number 2 is used to sum the total numbers in 24 hours and to calculate the ESAL for each road (Table 3.12). The date and day of count are documented in the count form.

4- Site locations of traffic count points are determined according to volume of traffic. Table 3.9 indicates locations of count points taken in phase 1 in 2003. Table 3.10 indicates the new count points taken in phase 2 by the researcher. Site plans for the count points in the two phases are attached in Appendix E

5- Two qualified persons were nominated and prepared.

6- They were familiar with all the listed types of vehicles.

7- Every one was responsible for the count in one of the two directions.

8- The count started at six o'clock in the morning and was extended to eleven o'clock in the evening and in some roads it was extended for 24 hours.

9- The results obtained are considered expressing the number of vehicles within 24 hours for the area where no traffic movement continues after that hour.

10- The total ESAL over the period of the design is calculated.

11- For the area of Gaza where the movement continues during the 24 hours, count for the remaining seven hours is executed for one or more of these roads and modification factors are derived and applied for the other roads.

12- Count is executed during the normal situation, while all the check points between Palestinian Governorates and the Palestinian occupied land in 1948 (Israeli side) and between the Palestinians themselves are opened.

3.2.4 Weights and dimensions of vehicles

For the existing vehicles in the Gaza Strip, especially trucks, it is very necessary to conduct an actual, reliable vehicle count. For this reason, the updated information's prepared by the researcher in phase 2 are summarized in Tables 3.1 to 3.6. Updated information was in Hebrew and translated to Arabic by a qualified person and then translated to English by the researcher.

Table 3.1: Permissible total lengths of Single Unit Trucks, Trailers, Full Trailers and busses (16)

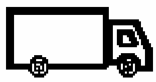
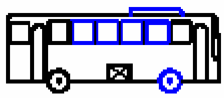
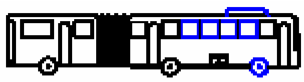
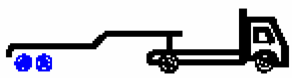
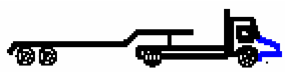
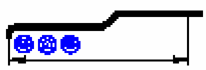
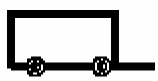
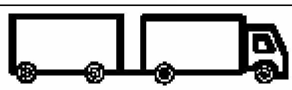
No	Vehicle Type Description	Form	Length m
1.	Commercial vehicle		12.00
2.	Bus		12.00
3.	Articulated bus		18.75
4.	Connected tractor: a. tractor on motor connected to semi trailer		16.50
	b. tractor behind motor connected to semi trailer		17.60
	semi trailer		12.00
5.	Trailer of two axles(single axle load)		12.00
6.	Single unit truck connected to trailer		18.75

Table 3.2: Permissible axle weights (kg), Amendment Number 314(B) [16]

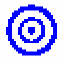
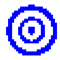
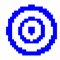
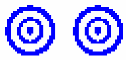
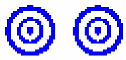
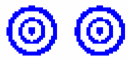
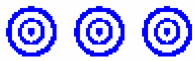
No	Description	Axle Load Type	Total weight (kg)
1	Front single Axle of a tractor connected to motor		7,500
2	Disconnected single Axle connected to motor		11,500
3	Disconnected single Axle disconnected to motor		10,000
4	Two axle tandem Load		18,000
5	Two axle tandem Load with air		19,000
6	Two axle tandem Load of a trailer with 1.8m spacing		20,000
7	Three axles Triple with tractor		24,000

Table 3.3: Permissible total weights of Single Unit Trucks, Trailers and Full Trailers

Amendment Number 314(A) (1) from Amendment Number 314(A) (16)

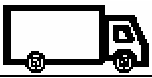
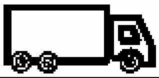
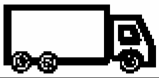
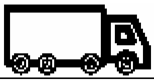
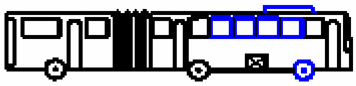
No	Description of vehicles and axles	Form and Axle Load Type	Total weight (kg)
1.	Single unit of two single axles		18,000
2.	Single unit of three axles, one single and two axles tandem		25,000
3.	Single unit of three axles, one single and two axles tandem with air		26,000
4.	Single unit of four axles, one front single, one rear single and two axles tandem		32,000
5.	Articulated bus		28,000

Table 3.4: Permissible total weights of Single Unit Trucks, Trailers and Full Trailers

Amendment Number 314(A) (2) from Amendment Number 314(A) [16]

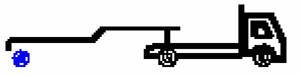
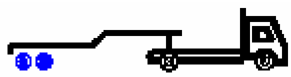
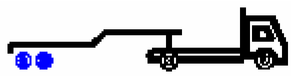
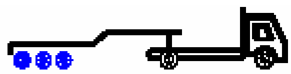
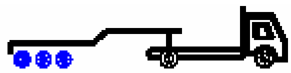
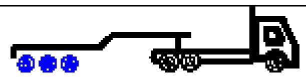
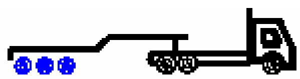
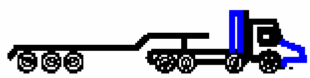
No	Description of vehicles and axles	Form and Axle Load Type	Total weight (kg)
1	Tractor of two single axles connected to a semi trailer of one single axle		28,000
2	Tractor of two single axles connected to a semi trailer of two axles tandem		36,000
3	Tractor of two single axles with air connected to a semi trailer of two axles tandem spaced 1.8m		38,000
4	Tractor of two single axles connected to a semi trailer of three axles triple		42,000
5	Tractor of two single axles with air connected to a semi trailer of three axles triple for sea containers transportation		43,000
6	Tractor of three axles, one single and two axles tandem connected to a semi trailer of two axles tandem		42,000
7	Tractor of three axles, one single and two axles tandem connected to a semi trailer of two axles tandem with air		43,000
8	Tractor of three axles, one single and two axles tandem connected to a semi trailer of three axles triple		48,000
9	Tractor of three axles, one single and two axles tandem connected to a semi trailer of three axles triple with air		50,000
10	Tractor of four axles, one front single, one rear single and two rear axles tandem connected to a semi trailer of three axles triple		55,000

Table 3.5: Permissible total weights of Single Unit Trucks, Trailers and Full Trailers

Amendment Number 314(A) (3) from Amendment Number 314(A) [16]

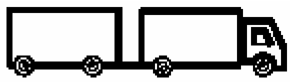
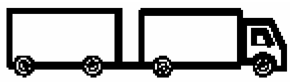
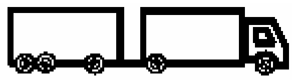
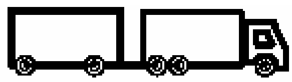
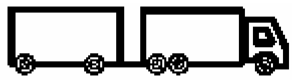
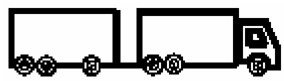
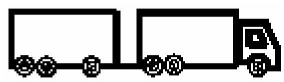
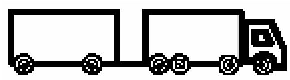
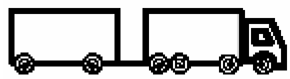
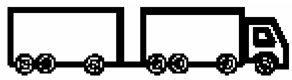
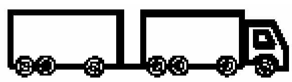
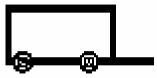
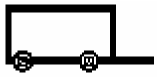
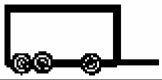
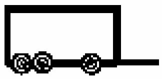
No	Description of vehicles and axles	Form and Axle Load Type	Total weight (kg)
1.	Commercial truck of two single axles connected to a trailer of two single axles		36000
2.	Commercial truck of two single axles connected to a trailer of two single axles with air		37000
3.	Commercial truck of two single axles connected to a trailer of three axles, one single and two axle tandem		43,000
4.	Commercial truck of three axles, one and two rear axle tandem with air connected to a trailer of two single axles		43,000
5.	Commercial truck of three axles, one and two rear axle tandem connected to a trailer of two single axles with air		45,000
6.	Commercial truck of three axles, one front single and two rear axle tandem with air connected to a trailer of three axles, one single axle and two axles tandem		50,000
7.	Commercial truck of three axles, one front single and two rear axle tandem with air connected to a trailer of three axles, one single axle and two axles tandem with air		53,000
8.	Commercial truck of four axles, one front single, one rear single and two rear axle tandem connected to a trailer of two single axles		50,000
9.	Commercial truck of four axles, one front single, one rear single and two rear axle tandem connected to a trailer of two single axles with air		51,000
10.	Commercial truck of four axles, one front single, one rear single and two rear axle tandem connected to a trailer of three axles, one single and two axles tandem		57,000
11.	Commercial truck of four axles, one front single, one rear single and two rear axle tandem connected to a trailer of three axles, one single and two axles tandem with air		59,000

Table 3.6: Permissible total weights of Single Unit Trucks, Trailers and Full Trailers

Amendment Number 314(A) (4) from Amendment Number 314(A) [16]

No	Description of vehicles and axles	Form and Axle Load Type	Total weight (kg)
12.	Trailer of two single axle load		18,000
13.	Trailer of two single axle load with air		19,000
14.	Trailer of three axles, one single and two axles tandem		25,000
15.	Trailer of three axles, one single and two axles tandem with air		27,000

3.2.5 Vehicles types, axles and EASLs

The following types of vehicles and their axle loads were surveyed and summarized in the tables below. Each type of vehicles was denoted by the letter X from X_1 to X_{16}, where X_1 represents the private cars, X_2 represents the light trucks and pickup and from X_3 to X_{15} represents the trucks according to their axles. X_{16} represent the agricultural tractor and its trailer. Pictures show different types of vehicles. Trucks, as told before, constitute the effective part of the ESALs of the roads during the design period :[13]

3.2.6 Truck equivalency factor of vehicles

Truck factor of vehicles from X_3 to X_{15} are calculated using Table 3.2 of the axle weights and the load equivalency factors mentioned in article 2.3.4 for all types of axles; single, tandem or tridem.

$$T.F = \sum N_i \times E ----3.1$$

Where:

T.F = Truck factor

N_i = number of axle type i (kg)

E = equivalency load factor according to axle type

For example:

T.F of X_8 = 2x0.76+2x2.43 = 6.38

Truck factor of vehicles from X3 to X_{15} are indicated in Tables 3.7.1 to 3.7.13, pictures of vehicles are attached to.

Truck factor summaries for the vehicles prepared in phase 2 is indicated in Table 3.8

Table3.7.1: Truck Factor for Two axles, four-tire single unit truck (X_3 - Total Wight 18.00 tonne)

Vehicle Description	Two Axle, four-tire single unit truck (Total Wight 18.00 tonne)	
Truck Parts	Head	Box
Axle type	single	single
Axle location	front	back
Axle Wight (tonne)	7.5	11
ESAL	0.76	3.93
Truck factor	4.69	

Table3.7.2: Truck Factor for Two axles, six-tire single unit truck (X_4 - Total Wight 25. tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 25.00 tonne)	
Truck Parts	Head	Box
Axle type	single	tandem
Axle location	front	back
Axle Wight (tonne)	7.5	18
ESAL	0.76	2.43
Average truck factor	3.19	

Table3.7.3: Truck Factor for Three Axles, single unit truck (X_5 - Total Wight 32.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 32.00 tonne)		
Truck Parts	Head		Box
Axle type	single	single	tandem
Axle location	front	back	back
Axle Wight (tonne)	7.5	7.5	18
ESAL	0.76	0.76	2.43
Truck factor	3.95		

Table3.7.4: Truck Factor for Three Axle, single unit truck (X_6 - Total Wight 44.0 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 44.00 tonne)		
Truck Parts	Head		Trailer Box
Axle type	single	tandem	tandem
Axle location	front	front	back
Axle Wight (tonne)	7.5	18	18
ESAL	0.76	2.43	2.43
Truck factor	5.62		

Table3.7.5: Truck Factor for Three Axle, single unit truck (X_7 - Total Wight 48.00 tonne

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 48.00 tonne)		
Truck Parts	Head		Trailer Box
Axle type	single	tandem	tridem
Axle location	front	front	back
Axle Wight (tonne)	7.5	18	25
ESAL	0.76	2.43	1.66
Truck factor	4.85		

Table3.7.6: Truck Factor for Four Axles, single unit truck (X_8 - Total Wight 49.00onne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 49.00 tonne)			
Truck Parts	Head		Trailer Box	
Axle type	single	single	tandem	tandem
Axle location	front	backt	front	backt
Axle Wight (tonne)	7.5	7.5	18	18
ESAL	0.76	0.76	2.43	2.43
Truck factor	6.38			

Table3.7.7: Truck Factor for Four Axles, single unit truck (X_9 - Total Wight 55.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 55.00 tonne)			
Truck Parts	Head		Trailer Box	
Axle type	single	single	tandem	trldem
Axle location	front	backt	front	backt
Axle Wight (tonne)	7.5	7.5	18	24
ESAL	0.76	0.76	2.43	1.66
Truck factor	5.61			

Table3.7.8: Truck Factor for Four Axles, trailer truck (X_{10} - Total Wight 37.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 37.00 tonne)			
Truck Parts	Head & Box		Trailer Box	
Axle type	single	single	single	single
Axle location	front	backt	front	back
Axle Wight (tonne)	7.5	11	10	10
ESAL	0.76	3.93	2.61	2.61
Truck factor	9.91			

Table3.7.9: Truck Factor for Four Axle, trailer truck (X_{11} - Total Wight 52.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 45.00 tonne)			
Truck Parts	Head & Box		Trailer Box	
Axle type	single	tandem	single	single
Axle location	front	backt	front	back
Axle Wight (tonne)	7.5	18	10	11
ESAL	0.76	2.43	2.61	3.93
Truck factor	9.73			

Table3.7.10: Average truck Factor for Four Axle, trailer truck (X_{12} - Total Wight 53.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 53.00 tonne)			
Truck Parts	Head & Box		Trailer Box	
Axle type	single	tandem	single	tandem
Axle location	front	backt	front	back
Axle Wight (tonne)	7.5	18	10	18
ESAL	0.76	2.43	2.61	2.43
Truck factor	8.23			

Table3.7.11: Truck Factor for Five Axle, trailer truck (X_{13} - Total Wight 63.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 53.00 tonne)				
Truck Parts	Head	Box		Trailer Box	
Axle type	single	single	tandem	single	tandem
Axle location	front	front	back	front	back
Axle Wight (tonne)	7.5	7.5	18	10	18
ESAL	0.76	0.76	4.17	2.61	2.43
Truck factor	8.99				

Table3.7.12: Truck Factor for Bus with two axle single unit truck (X_{14} - Total Wight 18.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 18.00 tonne)	
Bus	Single unit bus	
Axle type	single	single
Axle location	front	back
Axle Wight (tonne)	7.5	11
ESAL	0.76	3.93
Truck factor	4.69	

Table3.7.13: Average truck Factor for Loader with two axle single unit truck (IX_{15} - Total Wight 19.00 tonne)

vehicle Description	Two Axle, four-tire single unit truck (Total Wight 18.00 tonne)	
Loader	Single unit	
Axle type	single	single
Axle location	front	back
Axle Wight (tonne)	7.5	7.5
ESAL	0.76	0.76
Truck factor	1.59	

Table 3.8: Updated truck Factor summary for Vehicles, phase 2 (Equivalent ESALs)

No	Vehicle Symbol	Truck Factor
1	X_1^*	0.005
2	X_2^*	0. 1
3	X_3	4.688
4	X_4	3.189
5	X_5	3.946
6	X_6	5.618
7	X_7	4.848
8	X_8	6.378
9	X_9	5.606
10	X_{10}	9.908
11	X_{11}	9.728
12	X_{12}	8.228
13	X_{13}	8.986
14	X_{14}	4.688
15	X_{15}	1.592
16	X_{16}	0.3

* Truck factors of X_1, X_2 and X_{16} are assumed from the calculation of ESAls of light vehicles.

3.2.7 Site location of traffic count points

3.2.7.1 General

Traffic counts of roads in the Gaza Strip is very difficult not only for the local closures between the governorates that no one can expect due to the occupation authority, but also due to the closures of the entrances between the Gaza Strip and the occupied territories in 1948, where all goods and materials are imported in heavy trucks through these entrances to all cities in the Gaza Strip. All such entrances like Beit Hanoun, Al montar, Sofa and Rafah are governed by the Occupied Authority. These entrances are often closed for many days and opened for a few days. The movement of trucks is consequently governed by the occupation well. To make a correct count, regular and smooth movement of vehicles should be noticed which is not possible. Any how, Traffic counts were carried out during the time of opening and for the roads of different importance, outside and inside the cities.

General Plans are attached in Appendix E, to indicate the locations of traffic count points. Plan No KH.MSc Traffic1 represents the Gaza Strip and the traffic count points at Nuseirat Al Rashid Coastal Road, Salah Eddin Khan Younis Road. Plan No KH.MSc Traffic 2 represents the traffic count points at Gaza town. Plan No KH.MSc Traffic 3 represents the traffic count points at Bureij Camp.

3.2.7.2 Traffic count location

3.2.7.2.1 Traffic count locations, phase 1

The count was carried out in 2003 at Gaza city as a part of a study of a group of four students of the B.Sc. degree in the Civil Department at the Islamic university of Gaza [(13)]. The purpose of count was to determine the average truck factor of vehicles. The count period was limited due to the occupation and dangerous security case. It was from 6 or 7 o'clock in the morning to 18 or 19 o' clock in the evening in the two directions. The count includes 15 types of vehicles as described before. Roads locations, time and date of count are indicated in Table 3.9. This count will be modified and corrected by a modification factor to be considered as that of 24 hours count for each count point location. The new 24 hour count points will be considered references to obtain the modification factors and then to modify all count taken in phase 1.

Table 3.9: Roads, locations, date, and time of count at Gaza City, phase 1 [(13)]

No	Road name	Location of count	Date of count	Time of count
1	Jamal Abed El Nasser	50m east of Nagm El Arabi street crossing	5/4/2003	7:00-19:00
		30m east of Mostafa Hafed street crossing	7/4/2003	7:00-19:00
2	El Naser	30m north of Amin El Husseini street crossing	15/3/2003	7:00-18:00
		30m north of Al-Thoura street crossing	24/3/2003	7:00-18:00
3	Al-Jalaa	20m north of Tareg Bin Ziad street crossing	29/3/2003	7:00-21:00
		20m south of Omer Bin El Khatab street crossing	29/3/2003	7:00-21:00
4	Al-Rashid	30m south of road Number 8 crossing	12/4/2003	7:00-19:00
		30m south of road Number 8 crossing	5/3/2003*[1]	7:00-19:00
5	Salah Eddin	Infront of Alsakhra institution	7/5/2003*[2]	7:00-19:00
		30m south of Al Seddik Mosque	12/5/2003	7:00-19:00

*[1]: The count was implemented during the closure of the southern governorate

*[2]: The count was implemented during the closure of the entrances

3.2.7.2.2 Traffic count location, phase 2

Traffic count point's locations were chosen in different roads of different categories and included Gaza, Bureij, Nuseirat and Khan Younis. The purpose is to find road classifications according to the passing ESALs on the roads during the design period and according to AASHTO Modified of flexible pavements.

1- Al Jalaa Street, at the northern end in Gaza City.

2- Jamal Abdel Nasser Street (Al-Thlathini), in front of the Zaiton elementary school in Gaza City.

3- Palestine Road at Khaled El Hassan crossing in Gaza City

4- Khaled El Hassan Road at Palestine crossing in Gaza City

5- Al Rashid coastal Road, at the southern side or entrance of Wadi Gaza Bridge, at Nuseirat municipality.

6- Bureij Camp northern entrance of Al- Shohada road, just at the entry of the camp.

7- Al Kholafa Road, Bureij Camp, at Al Quds road crossing

8- Al Quds Road, Bureij Camp, at Al Kholafa road crossing

9- Abu Khaled Preparatory Girl School, Bureij camp, northern end

10- Big Mosque, Bureij camp, at Al Karama Road crossing

11- Salah Eddin Street, at the eastern road just 2km before the European Hospital, at Khan Younis governorates.

Table 3.10: Roads, locations, date, and time of count, phase 2

No	City	Road name	Location of count	Date of count	Time of count
1.	Gaza	Al- Jalaa south	End south	22/09/2004	6:00-23:00
2.		Al- Jalaa north	End south	22/09/2004	6:00-23:00
3.		Jamal A Ennaser	In front of Zieton school	20/09/2004	6:00-23:00
4.		Jamal A Ennaser	In front of Zieton school	20/09/2004	6:00-23:00
5.		Palestine	Khaled El Hassan crossing	24/08/2004	6:00-23:00
6.		Palestine	Khaled El Hassan crossing	24/08/2004	6:00-23:00
7.		Khaled El Hassan	Palestine crossing crossing	24/08/2004	6:00-23:00
8.		Khaled El Hassan	Palestine crossing crossing	24/08/2004	6:00-23:00
9.	Nuseirat	Al Rashid Coastal	South end of Gaza bridge	03/09/2004	6:00-23:00
10.		Al Rashid Coastal	South end of Gaza bridge	03/09/2004	6:00-23:00
11.	Bureij	Al-Shohada	Bureij entrance (western)	23/08/2004	6:00-23:00
12.		Al-Shohada	Bureij entrance (western)	23/8/2004	6:00-23:00
13.		Al Kholafa Bureij	Crossing with Al Quds	10/08/2005	6:00-23:00
14.		Al Kholafa Bureij	Crossing with Al Quds	10/08/2005	6:00-23:00
15.		Al Quds Bureij	Crossing with Al Kholafa	8/10/2005	6:00-23:00
16.		Al Quds Bureij	Crossing with Al Kholafa	8/10/2005	6:00-23:00
17.		Abu Khaled Prep Girl	start	4/8/2005	6:00-23:00
18.		Abu Khaled Prep Girl	start	4/8/2005	6:00-23:00
19.		Big Mosque	start	3/8/2005	6:00-23:00
20.		Big Mosque	start	3/8/2005	6:00-23:00
21.	Khan Younis	Salah Eddin	2km north of European H.	24/08/2004	6:00-23:00
22.		Salah Eddin		24/08/2004	6:00-23:00

3.2.8 Count results

3.2.8.1 General

Count is carried out for all types of vehicles by one qualified person for each direction of the road every hour. Count numbers are filled in form number 1 (Table 3.11) every hour. Total summation numbers are then transferred to form number 2 (Table 3.12). It is an excel worksheet that gives finally the total volume of traffic, total number of truck, percent of truck to the total number of vehicles, ESAL for each type of vehicles, daily equivalent single load and design ESAls. Listing of the resulting ESAls in a new worksheet from high great value to low value is prepared. The purpose of this descending listing of ESALs is to propose a road classification in the Gaza Strip to be used for the purpose of structural design of roads.

3.2.8.2 Considerations taken into account:

1- Count is calculated for a design period of 20 years

2- Lane coefficient is considered 0.8 for directions of two lanes and 0.7 for directions of three lanes or intended to be three in the near future.

3- Growth factor is taken zero due to an assumed optimistic scenario having the following:

- The expected distribution of traffic in new constructed roads in the design period.
- The truck weights are always considered full which is not real.
- The big values of daily ESALs reflect an up normal revolution of construction and development in the recent years.
- One of the purposes of calculating the ESALs was the road classification, where any growth factor will shift all categories up.

4- Results may be considered not reflecting the real situation due to the occupation, the dangerous security case and the repeated closures of check points of Beit Hanoun, Sofia, Carni and Rafah.

3.2.8.3 Results

Count form number 1 is filled for each type of vehicles from type X_1 to type X_{16} every hour. The total summation number during the 24 hour is determined and the count form number 2 represented in worksheet number 2 is completed. Modification factors are then multiplied by each item for each period of count. Chapter 4, data analysis, will explain the process of determination of the modification factors for the items; total number of truck, daily equivalent single axle load DESAls and total traffic number. Worksheets 4.1- 4.36 are attached in appendix A for finding the traffic count modification factors. Worksheets 4.1- 4.38 are attached in appendix B indicating the traffic count modified results.

Traffic count results will be used for:

1- Finding the design ESALs for each road direction

2- Classifications of roads according to their ESALs

3- Finding the minimum CBR values corresponding to each category of roads

Table 3.11: Worksheet 1, Traffic count Form No 1

Type	**Hour from----- to-------**	**total**
X1		
X2		
X3		
X4		
X5		
X6		
X7		
X8		
X9		
X10		
X11		
X12		
X13		
X14		
X15		
X16		

*X_i represents the vehicle type as explained in 3.2.5

Table 3.12: Worksheet 2, Traffic count Form No 2

Road Name: Location: Day:
Observer: study Direction: North Date: 29-03-2003

Period(H)	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15	x16
6--7																
7--8																
8--9																
9--10																
10--11																
11--12																
12--13																
13--14																
14--15																
15--16																
16--17																
17--18																
18--19																
19--20																
20--21																
21--22																
22--23																
23--24																
24--1																
1--2																
2--3																
3--4																
4--5																
5--6																
Total																
ESAL																
Des/ESAL																
T. ESAL																
T.ESAL/ L																
T.truck no																
% truck																
A Truck F																

Notes:.

3.3 Soil Tests

3.3.1 General

"The strength of the soil subgrade is the greatest factor in determining total thickness of pavement. Where feasible, resilient modulus or soaked California Bearing Ratio (CBR) laboratory tests should be conducted on subgrade soil to evaluate its strength. These tests should be conducted at the most probable field conditions of density and moisture anticipated during the design life of the pavement." (17)

Compaction of the subgrade soil during construction should be enough to find at least 95% of AASHTO T-99 or ASTM D 698 for cohesive clay soils and at least 95% of AASHTO T-180 or ASTM D 15777 for non cohesive (sandy and gravelly) soils.

The objective of the soil tests is to create a good sense or relation between the type and texture of soil subgrade and its bearing capacity represented in the CBR value.

3.3.2 Subgrade soil types

Good knowledge of the best methods and procedures of pavement construction, need certainly to know the types of subgrade soils in the Gaza Strip. Types of soil in Palestine and The Gaza Strip are indicated in fig 3.1 and 3.2 and briefed as follow:

3.3.2.1 Sandy soils

"Sandy soils are dune accumulations, regosols without defined profile. Texture in the upper layers is uniform of medium to coarse quartz sand with a very low water holding capacity." (14)

3.3.2.2 Loessial sandy soil

"Loessial sandy soil is found 5km from the sea inside in the central and southern part of the Gaza Strip. Loessial sandy soil forms a transitional zone between the sandy soil and the loess soil, usually with a calcareous loamy sand texture and a deep uniform pale brown soil profile." (14)

3.3.2.3 Loess soil

"Loess soil is found in the area between the city of Gaza and Wadi Gaza. Typical loess soil is brownish yellow- colored, silty to sand clay loams, often with an accumulation of clay and loam." (14)

3.3.2.4 Sandy Loess soil

Sandy loess soil is a transitional soil, characterized by a lighter texture. It is found in the depression between the kurkar ridges of Deir El Balah. Apparently, windblown sands have been mixed with loessial deposit. These soils have a rather uniform texture. (14)

3.3.2.5 Sandy soils over loess

"These are loess or loessial soils (sandy clay loam), which have been covered by a layer (0.2-0.5m) of dune sand. This soil is found east of Rafah and Khan Younis."(14)

3.3.2.6 Alluvial soil

"Alluvial and grumosolic soils, dominated by loamy clay texture are found on the slopes of the northern depression between Beit Hanouun Check point and Wadi Gaza. Most of all are dark brown to reddish brown in color with a well developed structure." (14)

3.3.3 Soil test used to determine the soil subgrade strength

The most common soil tests used to determine the soil subgrade strength or the bearing capacity of the soil are; California Bearing Ratio (CBR), Resistance value (R-value) and Resistance value (R-value) as explained before in Chapter 2.

CBR is widely used to describe and measure the bearing capacity of the subgrade as well as the base and subbase layers. This is generally for granular soil. (3)

The second part of field work in this thesis is represented in the soil tests conducted to describe the subgrade soil strength and nature. They should specifically include the sieve analysis, Modified Proctor for compaction, natural and optimum water content and California Bearing Capacity (CBR).

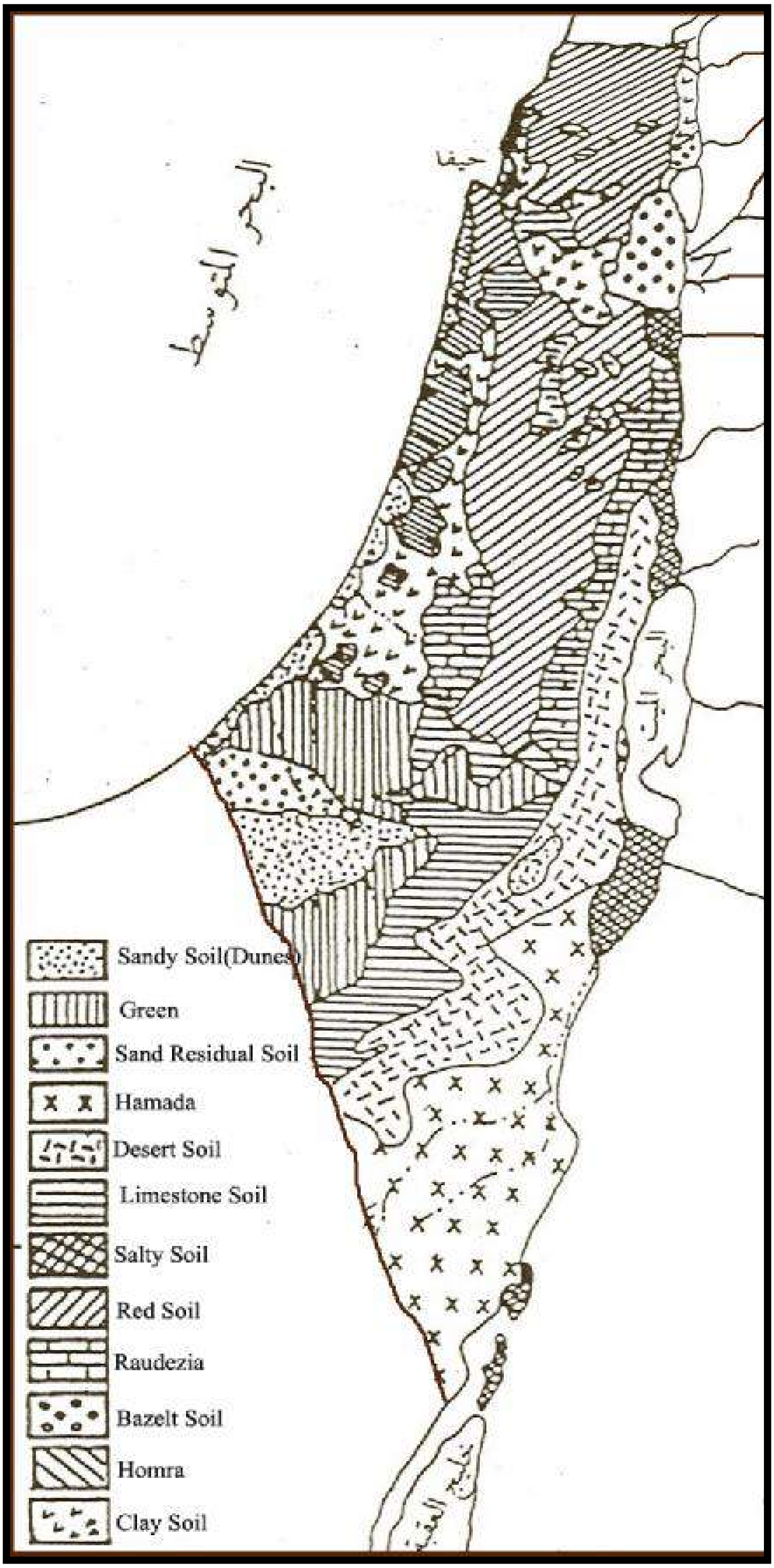


Fig 3.1: Types of soil in Palestine (14)

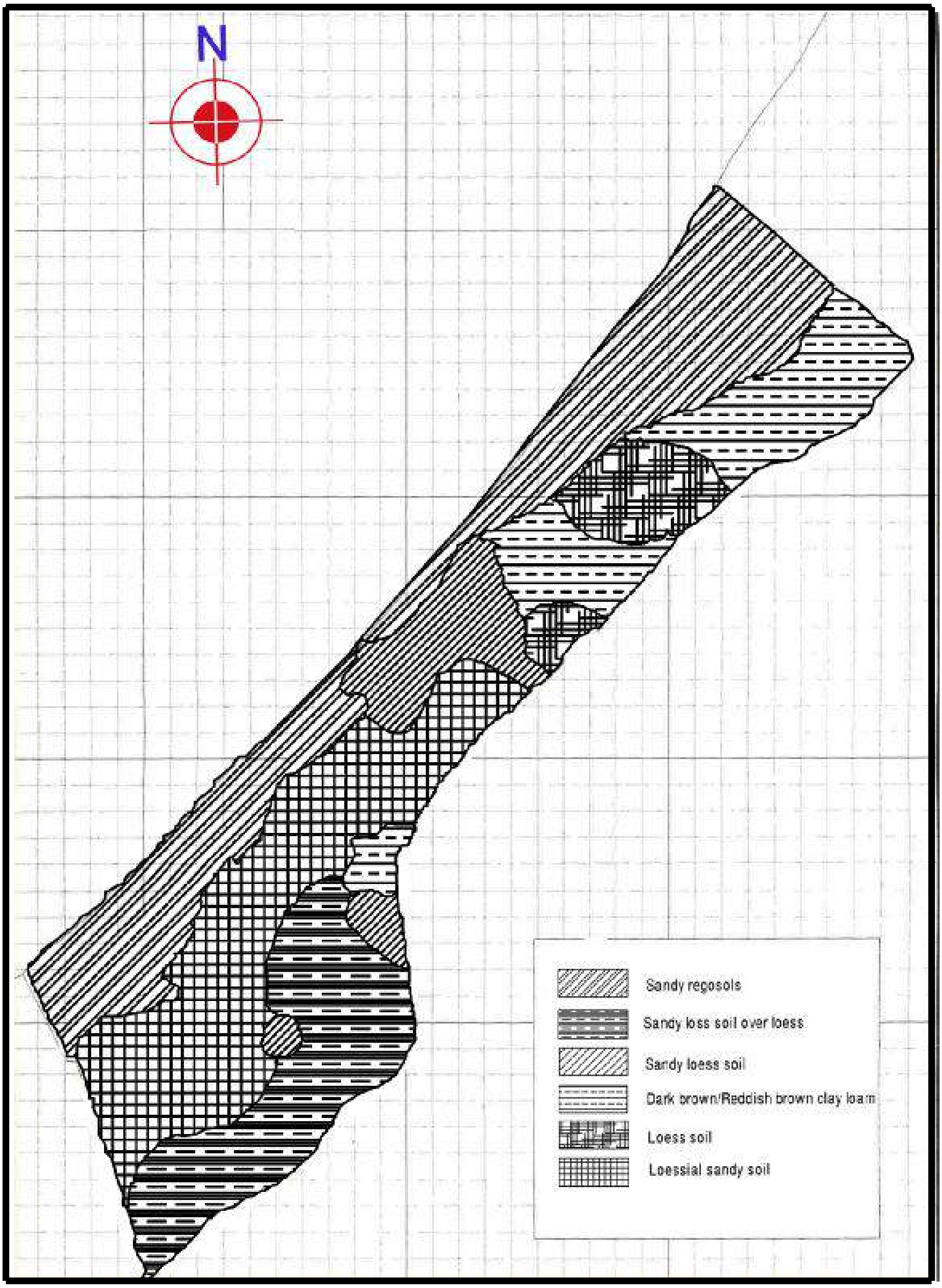


Fig: 3.2: Types of Soil in the Gaza Strip (14)

3.3.4 Methodology of soil test

1- Different locations are considered so as to cover the different types of subgrade soils over the area of the Gaza Strip.

2- Some locations were covered through coordination with the Material and Soil laboratory at the Islamic University by already conducted tests.

3- Other locations were covered through coordination with the Municipalities of Bureij, Nuseirat and Magazi from tests conducted for the purpose of roads construction projects.

4- Other locations were covered by the researcher who carried out some laboratory tests.

5- Sieve analysis, modified proctor and CBR are the tests conducted on non cohesive soils.

6- Sieve analysis, Uterberg Limits, modified proctor and CBR are the tests conducted on cohesive soils.

7- Summery of CBR results, soil types, depths and locations is prepared in table 3.18.

8- Site locations of tests are indicated on the attached plans in Appendix E, Drawing No KH.MSc CBR 01-07 General Plan for Gaza Strip and different plans for Gaza Town, Bureij Camp, Nuseirat Camp, Magazi Camp, Deir El Balah town and Camp, Khan Younis and Rafah.

9- Sheet results of conducted tests for the sieve analysis, compaction, Uterberg Limits and CBR are attached in appendix B

3.3.5 Objectives of conducting soil tests and collecting CBR results

1- To understand the practical side of test work of the subgrade soil

2- To have knowledge of soil types in the Gaza Strip

3- To have knowledge of CBR values of subgrade soils in the Gaza Strip

4- To have knowledge of CBR range of the subgrade soil in the Gaza Strip to determine the minimum CBR value for the road subgrade as it would be discussed later.

Table 3.13: summery of CBR values from different sites in the Gaza Strip*

No	Municipality	Test No.	Location	Depth	Classification	PI	CBR95%
1.	Nuseirat	1	Behind Municipality on Plan			N.P	21.4
2.	Nuseirat	2	Block D on Plan			N.P	20
3.	Nuseirat	3	Wad El Gshash Pubping Station				6.7
4.	Nuseirat	4	Nuseirat Plan	0.7	SC	8.9	7
5.	Nuseirat	5	Nuseirat Plan	0.7	SM	N.P	5
6.	Nuseirat	6	Nuseirat Plan	0.5	SM	N.P	25
7.	Nuseirat	7	Nuseirat Plan	0.8	SM	N.P	25
8.	Nuseirat	8	Nuseirat Plan	0.8	SP-SM	N.P	45
9.	Nuseirat	9	Nuseirat Plan	0.5	SM-SC	4.4	18
10.	Nuseirat	10	Nuseirat Plan	0.3	CL-ML	6.2	3
11.	Bureij Camp	1	Omar Mosques (Bureij Plan)	1	A-4(1)SSM		15
12.	Bureij Camp	2	Dear Yassin Road (Bureij Plan)	1	A-4(1)SSM	3	5
13.	Bureij Camp	3	AL Amal Road (Bureij Plan)	1.5	A-7-6(12)SCL	17	2
14.	Bureij Camp	4	AL Shohada Road (Bureij Plan)	1	A-2-4(0)SSM	N.P	10
15.	Bureij Camp	5	Mosaab& Khaled (Bureij Plan)	1	A-2-4(0)SSM	N.p	10
16.	Bureij Camp	6	Hiteen & Nazla (Bureij Plan)	1	A-7-6(12)SCL	18	2.4
17.	Bureij Camp	7	Hiteen Part 1 (Bureij Plan)	1	A-4(6)SCL	19	7
18.	Bureij Camp	8	Bissan Road (Bureij Plan)	1	A-7-6(12)SCL	17	2
19.	Bureij Camp	9	Hiteen Part 2 Bureij Plan)	1.5	A-7-6(12)SCL	17	2
20.	Bureij Camp	10	Al Quds Road (Bureij Plan)	1	A-4(7)SCL	9	3
21.	Bureij Camp	11	Dear Yasin & Safad (Bureij Plan)	1.5	A-7-6(12)SCL	19	3
22.	Bureij Camp	12	Huda Road (Bureij Plan)	1	A-7-6(12)SCL	10	2.4
23.	Bureij Camp	13	AL Awda Road (Bureij Plan)	1	A-4(5)SCL	8	7
24.	EL Magazi	1	Magazi Plan	0.5	A-4,SE-MC	5	21
25.	EL Magazi	2	Magazi Plan	0.5	A-2-4,SM	NP	25
26.	EL Magazi	3	Magazi Plan	0.5	A-4,SC-MC	6.9	20
27.	EL Magazi	4	Magazi Plan	0.5	A3,Fill SP-SM	NP	25
28.	EL Magazi	5	Magazi Plan	0.5	A-4,CL-ML	6.3	32
29.	EL Magazi	6	Magazi Plan	0.5	A-4,CL-ML	6.3	3.8
30.	EL Magazi	7	Magazi Plan	0.5	A-1-0,Fill SP-SM	NP	3.8
31.	EL Magazi	8	Magazi Plan				3.2
32.	EL Magazi	9	Magazi Plan				21
33.	EL Magazi	10	Magazi Plan				34
34.	EL Magazi	11	Magazi Plan				9.5
35.	EL Magazi	12	Magazi				20
36.	EL Magazi	13	Magazi				25
37.	EL Magazi	14	Magazi				32
38.	EL Magazi	15	Magazi				38
39.	EL Magazi	16	Magazi				31

*** Reference of the CBR values in table 3.18 are attached in appendix A, table 1**
*** Some information are not existing due to unavailability from the source**

Table 3.13: summery of CBR values from different sites in the Gaza Strip* (continued)

No	Municipality	Test No.	Location	Depth	Classification	PI	CBR95%
40.	Khan Younis	6	Rehousing Gaza Strip Plan	0.8			8.7
41.	Khan Younis	7	Rehousing Gaza Strip Plan	0.8			16.8
42.	Khan Younis	8	Rehousing Gaza Strip Plan	0.8		NP	22
43.	Rafah	1	Airport - Gaza Strip Plan		Brown sandy clay CL		2.3
44.	Rafah	2	Airport - Gaza Strip Plan		fine silty sand SM	NP	15.5
45.	Rafah	3	Airport - Gaza Strip Plan		fine silty sand SM	NP	22
46.	Rafah	4	Shapora - Gaza Strip Plan	0.8	silty sand	NP	32
47.	Rafah	5	Tal El Sultan - Gaza Strip Plan	0.8	sand	NP	34
48.	Rafah	19	Shapora - Gaza Strip Plan	0.8	SM Sand	NP	21
49.	Middle Area	9	Salah Eddin,Gaza Strip Plan	1.5	SM	NP	30
50.	Middle Area	10	Salah Eddin,Gaza Strip Plan	4	CL-ML	4.5	5
51.	Middle Area	11	Salah Eddin,Gaza Strip Plan	1.5	CL-ML	5	9
52.	Middle Area	12	Salah Eddin,Gaza Strip Plan	1.5	CL-ML	7	5
53.	Middle Area	13	Salah Eddin,Gaza Strip Plan	3	CL-ML	5	5
54.	Middle Area	14	Salah Eddin,Gaza Strip Plan	1	SM	NP	20
55.	Middle Area	15	Salah Eddin,Gaza Strip Plan		SC	10.8	11.14
56.	Al Zahra	16	AL Zahra(Gaza Strip Plan)	0.8	Kurkar	NP	31.5
57.	Gaza	17	Jdiada(Gaza Strip Plan)	0.8			4.1
58.	Beit Lahia	18	Sheakh Zaed(Gaza Strip Plan)	0.8	Sand backfill	NP	17.5
59.	Jabalia	1	UNRWA School Road Jab. Plan	0.8	Sand	NP	35.2
60.	Jabalia	2	Rail way Road Jab. PLan	0.8	Sand	NP	25.4
61.	Deir balah	1	On Plan	0.8	Fill,A-2-4SSM	NP	16.2
62.	Deir balah	2	On Plan	0.8	A-4SSM	NP	24
63.	Deir balah	3	On Plan	0.5	A-2-4SML	NP	22
64.	Deir balah	4	EL Bear Road	0.5	A-2-4SML	2.68	19
65.	Deir balah	5	On Plan	0.5	A-4SCL	7.8	6
66.	Deir balah	6	On Plan	0.5	A-7-5SCL	10.1	6.2
67.	Deir balah	7	Tunis Road	0.5	A-2-4SSP-SM	NP	26
68.	Deir balah	8	On Plan	0.8	A-3	NP	21.4
69.	Deir balah	9	On Plan	0.8	A-3	NP	18
70.	Deir balah	10	On Plan	0.8	A-3	NP	19.3
71.	Deir balah	11	On Plan	0.8	A-3	NP	20.8
72.	Deir balah	12	On Plan	0.8	A-3	NP	20
73.	Deir balah	13	On Plan	0.8	A-3	NP	17
74.	Khan Younis	1	Khan Younis Plan	0.8		NP	30
75.	Khan Younis	2	Khan Younis Plan	0.8		NP	25

*** Reference of the CBR values in table 3.18 are attached in appendix A, table 1**
*** Some information are not existing due to unavailability from the source**

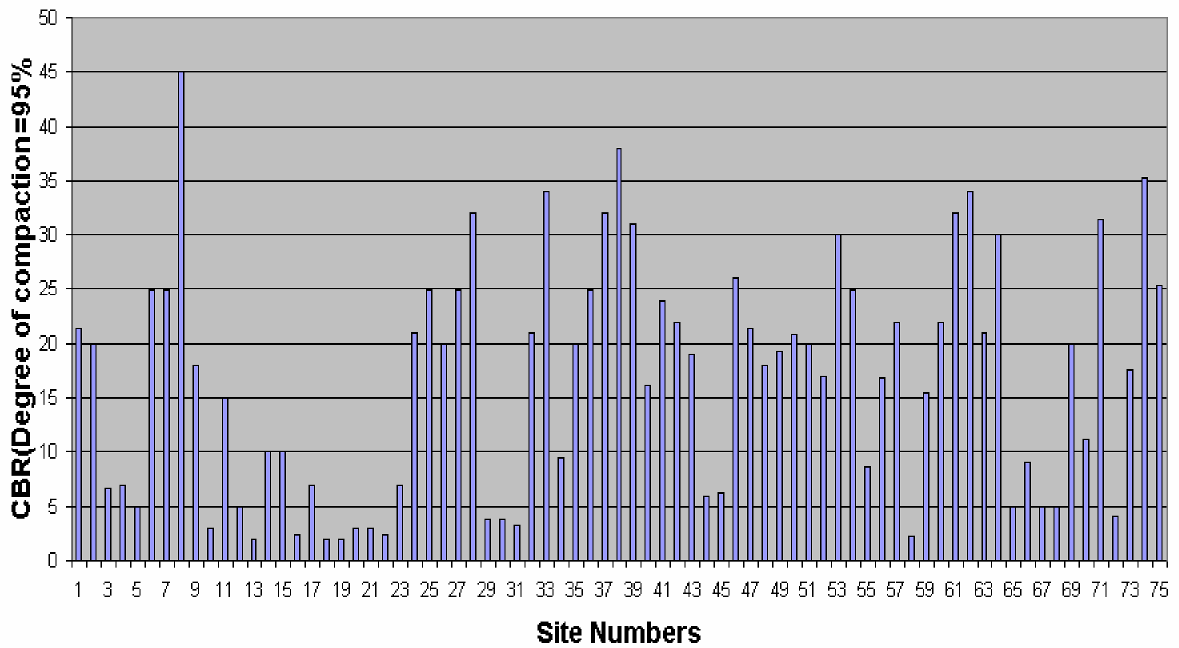


Fig 3.3: CBR Values of different Sites in the Gaza Strip

3.3.6 Analysis and discussion of the CBR values and soil types in the Gaza Strip

From the summary Table 3.13 of the CBR values of the subgrade, and from the above Figure 3.3, the following points could be noted:

1- the minimum CBR value is 2 and the maximum CBR value is 45

2- the percent of CBR values less than 3 is 7.9% and the percent Between 3 and 15 is 32.29% and that greater than 15% is 59.81%

3- From Figure 3.1 the area of clay soil constitute about 13.3% of the total area of the Gaza Strip and the area of clean sand 30.42%.

Accordingly the specification of roads industry regarding the subgrade preparation should be convenient to the existing natural soil. Knowing that the area of clay is very small it is not economical to consider the value 15% of the CBR as a mnimum value while the range of CBR between 5-15% is considered good (17) in many references as it will be indicated later on in Chapter 4, and while this range represents a considerable area of the Gaza strip.

3.4 Costing

3.4.1 General

Quality, time and cost are the main three factors that govern any project construction. Cost may be considered the most important factor of them. In the industry of roads, the cost of each layer of pavement constitutes an important component of the total cost. Available material in the local market affects the choice of the type of surface, base and sub base layers.

Subgrade strength expressed in CBR or MR also affects the choice of the pavement layers; surface base and sub base. Here in after analysis of the cost of the pavement layers, asphalt, crushed aggregate base course and kurkar. Cost of excavation, backfilling, and importing of subgrade material shall be considered in the process of costing.

Layers strengths expressed in layers coefficients affects also the process of choice of layer type.

3.4.2 Proposed allowable pavement layers

- Asphalt layer that may be applied in one or two layers from 4-6cm thickness as a surface layer.
- Inter lock block pavers is applied in a layers of 6 or 8cm as a surface layer.
- Crushed aggregate base course that may be applied in layers 10-15cm thickness as a base layer.
- Kurkar layer (selected approved granular material) may be applied in layers from 10-15cm thickness as a sub base layer.

The available material in the local market used to construct pavement layers and the proposed layers depths are indicated in the table 3.16.

Table 3.14: Proposed Layer depths

Layer type	Min depth cm	Max depth cm
Asphalt	4	10
Interlock block	11	13
Base coarse	10-15	30
kurkar	10-15	75

3.4.3 Construction cost analysis of a flexible pavement

Construction cost analysis will take the procedures of calculating the cost of:

3.4.3.1 Supply and install cost

1- Cost of supplied material for the layer.

2- Cost of workmanship (install).

3- Cost of losses

4- Cost of tests carried out on material of layer in both laboratory and field.

5- Cost of overheads and benefits which is taken 15% of the above total cost.

3.4.3.2 Excavation cost

Assumptions:

1- The design level of road is the same as that of the existing ground level.

2- Excavation depth is the total depth of pavement layers, surface, base and subbase.

3- The total cost of excavation includes excavation, loading and disposing.

4- The cost of excavation, loading and transportation of a truck of 15 m^3 is 100 NIS=22.9 $

As a result, the cost of excavation of 1 m^3 =22.9/15=1.53 $

The cost /1cm depth =1.53/100= 0.015 $

Supply cost of materials which constitute the pavement layers in the industry of roads in the Gaza Strip is indicated in Table 3.15 herein after.

Tables from 3.16-3.22 indicate the cost analysis of supplying and constructing pavement layers.

Table 3.15: Supply Cost of Pavement Materials

Description	Cost (NIS)	Cost (NIS)/1.17	Cost ($)
Interlock tiles 8cm black/m2	27	23.08	5.37
Interlock tiles 6cm black/m2	24	20.51	4.77
Interlock tiles 6cm red/m2	25	21.37	4.97
curb 100x30x15/mr	18	15.38	3.58
curb 100x25x17/mr	16	13.68	3.18
curb 100x20x10/mr	12	10.26	2.39
medium curb 100x25x23/mr	22	18.80	4.37
concrete B200/m3	215	183.76	42.74
concrete B250/m3	225	192.31	44.72
concrete B300/m3	235	200.85	46.71
Basecourse Gaza area /1 tonne	44	37.61	8.75
Basecourse middle area /1tonne	47	40.17	9.34
Clean sand m3	14	12.00	2.79
Kurkar m3	8.2	7.00	1.63
Asphalt tonne	316	270	60
Asphalt thick 1cm/m2	7.43	6.35	1.4
Steel (kg)	2.7	2.31	0.54

Table 3.16: Cost Estimate of Two Compacted Crushed Stone Base Course layers 2x15 cm

Description	Cost per m2 ($)
Supply	6.6
Construct	1.0
Losses (0.02 * 6.60)	0.13
Test	0.20
Sub-total	7.93
Profit 15%	1.19
Total	9.12 ≅ 9.00

Table 3.17: Cost Estimate of One Compacted Crushed Stone Base Course layer 15 cm

Description	Cost per m2 ($)
Supply	3.50
Construct	0.5
Losses (0.02 * 3.5)	0.07
Test	0.2
Sub-total	4.27
Profit 15%	0.63
Total	4.8 ≅ 4.8

Table 3.18: Cost Estimate of One Compacted Crushed Stone Base Course layer10 cm

Description	Cost per m2 ($)
Supply	2.3
Construct	0.5
Losses (0.02 * 2.3)	0.046
Test	0.20
Sub-total	3.05
Profit 15%	0.46
Total	3.5≅ 3.5

Table 3.19: Cost Estimate of one Compacted Kurkar Layer 15 Cm

Description	Cost per m2 ($)
Supply	0.45
Construct	0.5
Losses (0.02 * 0.45)	0.09
Test	0.1
Sub-total	1.14
Profit 15%	0.17
Total	1.3≅ 1.3

Table 3.20: Cost Estimate of Two Asphalt Layers 2x4cm

Description	Cost per m2 ($)
Supply	6
Construct two layers	0.8
Mco+RC2	0.5
Losses (6+0.5) * 0.02 =	0.13
Tests	0.2
Sub-total	7.63
Profit 15%	1.15
Total	8.77 ≅ 9.0

Table 3.21: Cost Estimate of Interlock Block Pavers layer 8cm on 5cm sand

Description	Cost per m2 ($)
Supply interlock 8cm	5.5
Sand + workmanship	1.0
Losses (6.5*0.02)	0.13
Tests	0.2
Sub-total	6.83
Profit 15%	1.03

Total	7.85 ≅ 8

Table 3.22: Cost Estimate of Interlock Block Pavers 6cm

Description	Cost per m2 ($)
Supply interlock 8cm	5
Sand + workmanship	1.0
Losses (6*0.02)	0.12
Tests	0.2
Sub-total	6.32
Profit 15%	0.95
Total	7.27 ≅ 7.5

Summary

The field works was the content of Chapter 3. It constitutes the source of data used in findings the research output. Traffic count was very necessary to find the daily and design ESAls for each counted road and consequently to make a road classification according to the expected total design ESAls within the design period (20 years). The count results obtained by the graduates [13] in phase 1 and the researcher in phase 2 were considered in preparing the final outputs of the research. Soil tests, especially CBR was the second part of the field work to be familiar with subgrade CBR values across the Gaza Strip. The last part of the field work was the costing of the material used in the construction of road pavements. It includes the supply and construction costs.

4 CHAPTER FOUR

DATA ANALYSIS

4.1 General

Collected data in this thesis is composed of three types related to three parts of the field works. Theoretical part of analysis includes the application of AASHTO Modified Equation representing the design chart of flexible pavement and the application of the structural Number equation used to find the total structural number and then the total thickness of the pavement.

Traffic count results, soil test and costing shall be analyzed individually and in combination if needed.

4.1.1 Traffic count analysis

It includes the procedures of:

- Calculating of the daily equivalent single axle loads (DESALs)
- Calculating of the the total design equivalent single axle loads (TDESALs)
- Calculating of the modification factors
- Calculating the daily average truck factor (ATF)
- study of the traffic counts results of the roads

4.1.2 Theoretical analysis

It includes the procedures of:

- Application and analysis of the AASHTO Modified equation
- Application and analysis of the structural number equation
- Rating of the CBR value and the ESALs.
- Finding the minimum CBR values before subgrade replacement

4.1.3 Soil test analysis

It includes the procedures of:

- Discussion of the different CBR values
- Classification of soil according to sieve, type and CBR

4.1.4 Cost analysis

It includes the procedures of:

- Calculating the cost and structural number SN of 1 cm depth of each layer of the pavement
- Comparison between the cost and the structural numbers SN of each layer
- Calculating the cost of the pavement

4.2 Traffic count analysis

Traffic count considered is the traffic count carried out by the graduates of the Islamic University in 2003, phase 1 and the traffic count carried out in 2004 & 2005 by the researcher, phase 2. Both count results in phase 1 and 2 shall be used in the resultant output of this thesis.

The main purpose of this thesis is to result in a road classification table for the Gaza strip in function of the ESAls of these roads. Traffic count analysis shall include the procedures of calculating the total design ESALds, truck percent and the average truck factor.

4.2.1 Calculating the daily equivalent single axle load (DESALs)

For each type of roads

$$DESALs = \sum_{i=1}^{i=16} X_i \times T.F \times M.D -------------- (4.1)$$

Where:

DESALs = daily equivalent single axle load

X_i = vehicle type from 1- 16

T.F = truck factor for each type of vehicles

M.D = Modification factor

$$TDESALs\ (million) = \sum_{i=1}^{i=16} X_i \times T.F \times M.D \times D_D \times D_L \times 365 \times 20 / 1000{,}000 ------- (4.2)$$

Where:

TDESALs = Total design equivalent single axle load per lane for the 20 years design period

X_i = vehicle type from 1- 16

T.F = truck factor for each type of vehicles

M.D = Modification factor = 1   for the 24 hour traffic count point (road)

D_D = Direction distribution factor

D_L = Lane distribution factor

Some considerations are taken in the process of count

- The count is carried out in each direction of the roads. This means that the directional distribution factor D_D is taken 1.
- The lane distribution factor D_L is taken 0.8 for two lane directions and 0.7 for three lane directions as indicated in Table 4.1. Some roads are given lane distribution factor equals to 0.7 assuming widening of the road to have three lanes for each direction like the Al Rashid coastal road.
- The growth factor is assumed zero due to:
    - expected distribution of vehicles in the future in more roads
    - The revolution development in the Gaza Strip in the recent years
    - The truck weights is always considered full

Table 4.1: Percent of 18-Kip ESAL in design lane ($D_{D)}$) [15]

Number of lanes in each direction	Percent of 18-Kip ESAL in design lane ($D_{D)}$
1	100
2	80-100
3	60-80
4	50-75

4.2.1.1 Traffic count, phase 1

It was carried out in 2003, the period of count was 12 hours (from 7-19), 12 hours (from 6-18) and 14 hours (from 7-21) as indicated in chapter 3, Table 3.13.

As noticed the count hours don't cover a complete day of 24 hours which may be considered arbitrary as a unit of the count, the reason was due to unsafe security situation in Al Aqsa Intifada and due to the other topics studied in their project.

This means that due to the Intifada the count even if it was carried out while the roads are opened between the governorates of Gaza, it wouldn't reflect the ideal volume or flow of traffic. The same note is applied to the count made by the researcher in phase 2. This due to non –uniform flow of trucks on the roads a cause to the check points distributed between the Gaza strip and the green line, from which all heavy trucks start their way. Heavy trucks wait in these check points for long time before loading and leaving, so any day could not be considered of the same intensity of traffic flow volume as the others days. And the traffic is not the same during the seven days of the week or even during the year.

To modify the count results made by the graduates, the count is multiplied by a modification factors represent the counted hours and the remaining uncounted hours.

4.2.1.2 Traffic count, phase 2

Traffic count carried out by the researcher was in 2004 and 2005. It includes 10 points of count. All points were count in the two directions. Six count points were counted during a period of 24 hours and the others were count for a period of 17 hours. Modification factors were derived to modify the count to represent 24 hours count. Populated areas were easier to carry out a complete day of count, where outside count points were unsafe to do so. Since the purpose of this thesis is to result in a classification list of roads in the Gaza strip could be used as a guide in the field of road industry, it was necessary to carry out the traffic count of some roads for 24 hours.

Traffic count points locations; date and time are indicated in Chapter 3, table3.13.

4.2.1.3 Modification factors

As mentioned before the count carried out by in phase 1 and part of the count carried out in phase 2 were during part of a day. To derive reasonable modification factors, traffic count during a period of 24 hours was carried out in phase 2 for some roads and considered as reference to determine these modification factors.

For the 24 hour count points, different periods similar to those of the existing uncompleted count points are derived. For each period and for each item of count; total vehicles number, ESALs or the truck number, modification factors are calculated and then the average modification factors are calculated.

$$M.F = \frac{count_{24h}}{count_{period}} ------4.3$$

Where

M.F = Modification factor

$Count_{24h}$ = Count of 24 hours

$Count_{period}$ = Count of period

Modification factors for each period of count are derived and multiplied by the count of this period to have the result of a 24 hour count for each traffic count point. The resultant count will be considered reflecting the count of 24 hours, and it will be used with that prepared in phase 2.

Regarding to the count form and the terms included such as; total number of vehicles, total ESALs, total design ESALs during the design period, number of truck, percentage of truck, and the average daily truck factor. Modification factors from one side for each term of count and from the other side for each period of count were derived to modify the existing count results to reflect the count of 24 hours.

24 hour count points are carried out for roads in the two directions. Each direction was considered as a reference, for each direction, five periods are derived as those counted for uncompleted directions. Any modification factor will represent one of the five existing count periods and one of the three items.

For each term:

$$M.F = \frac{count_{24h}}{count_{period}} ------4.3$$

$$A.M.F = \sum_{i=1}^{5} \frac{M.F}{5} --------4.4$$

Where:

A.M.F = Average modification factor

i = 5

Worksheets for the modification factors are numbered by 4.1-4.36 and attached in Appendix B. Average modification factors worksheet 4.37 is attached in Appendix B.

Tables 4.2, table 4.3 and table 4.4 represent the average modification factors for the ESALs, total vehicles numbers and the average truck factor for each period of indicated 5 periods.

Table 4.2: Average Modification Factors for the daily ESALs

No	Road	direction	Daily ESAls Modification Factors				
			7-21h	7-19h	6-18h	6-23h	6-21h
1	Al Jalaa	S	1.188	1.368	1.322	1.054	1.01
2	Al Jalaa	N	1.228	1.473	1.433	1.041	1.109
3	Palestine	S	1.36	1.488	1.313	1.144	1.222
4	palestine	N	1.337	1.394	1.701	1.13	1.337
5	Kh Al Hassan	W	1.085	1.141	1.33	1.017	1.085
6	Kh Al Hassan	E	1.371	1.341	1.761	1.088	1.37
	Average		**1.2615**	**1.3675**	**1.4767**	**1.079**	**1.1888**

Table 4.3: Average Modification Factors for Total Number of Vehicles

No	Road	Direction	Total Vehicle number Modification Factor				
			7-21h	7-19h	6-18h	6-23h	6-21h
1	Al Jalaa	S	1.312	1.537	1.17	1.13	1.237
2	Al Jalaa	N	1.299	1.508	1.51	1.123	1.231
3	Palestine	S	1.33	1.557	1.622	1.156	1.309
4	palestine	N	1.369	1.634	1.793	1.174	1.369
5	Kh Al Hassan	W	1.394	1.67	1.806	1.183	1.378
6	Kh Al Hassan	E	1.394	1.77	1.94	1.215	1.388
	Average		**1.3497**	**1.6127**	**1.6402**	**1.1635**	**1.3187**

Table 4.4: Average Modification Factors for Truck Number

No	Road	direction	Truck number Modification Factor				
			7-21h	7-19h	6-18h	6-23h	6-21h
1	Al Jalaa	S	1.243	1.471	1.412	1.032	1.117
2	Al Jalaa	N	1.203	1.4	1.322	1.042	1.105
3	Palestine	S	1.316	1.389	1.25	1.136	1.191
4	palestine	N	1.286	1.286	1.636	1.125	1.286
5	Kh Al Hassan	W	1.042	1.087	1.316	1	1.042
6	Kh Al Hassan	E	1.286	1.357	1.8	1.059	1.286
	Average		**1.2293**	**1.3317**	**1.456**	**1.0657**	**1.1712**

4.2.1.4 Resulting data analysis

All traffic count points' results, for roads in the two directions of each road are summarized. Each count form includes the total number of vehicles, the total equivalent single axle load; design ESALS, number of trucks, percentage of trucks and the average daily truck factor ADTF.

Summary tables 4.5 and 4.6 are then listed descendly in function of the ESALs and average truck factor. Tables indicating the relations between roads and each term are derived from the main summary table.

Tables are derived from this main table indicates the relation between road names and the total numbers of vehicles, truck number, percentage of trucks and the average truck factors as shown in tables 4.5 – table 4.9.

Table 4.5: Roads Directions Characteristics Summery List According Esals per Lane

No	Road	Dire -ction	Total traffic	Daily. ESAL	Design ESAL	truck No	% Truck	ATF	Design ESAL/L

1.	Al rashid Gaza	S	9922	2735.2	19.967	533	5.37%	0.276	13.977
2.	Al rashid Gaza	N	9443	2697.9	19.695	534	5.66%	0.286	13.786
3.	Jamal A. Najm-N.ED Gaza	E	14636	2466.7	18.007	529	3.61%	0.169	14.406
4.	Al rashid Nuseirat	N	6176	2001.2	14.609	393	6.37%	0.324	10.226
5.	Salah Eddin Khan Younis	N	5125	1900.8	13.876	429	8.36%	0.371	9.713
6.	Salah Eddin Khan Younis	S	5384	1894.1	13.827	418	7.76%	0.352	9.679
7.	Jamal A. Najm-N.ED Gaza	W	10689	2108.3	15.391	446	4.17%	0.197	12.313
8.	Jamal Abdel Nasser Gaza	E	9332	1738.6	12.692	366	3.92%	0.186	10.153
9.	Salah Eddin Gaza	S	7902	1859.6	13.575	409	5.17%	0.235	9.502
10.	Jamal Abdel Nasser Gaza	W	8818	1601.8	11.693	344	3.90%	0.182	9.355
11.	Al rashid Nuseirat	S	5615	1591.8	11.620	328	6%	0.283	8.134
12.	Salah Eddin Gaza	N	6752	1781.8	13.007	382	5.66%	0.264	9.105
13.	Al Jalaa -T .B. Ziad Gaza	N	12369	1499.2	10.944	310	2.50%	0.121	7.661
14.	Al Jalaa Gaza	N	9029	1415.0	10.329	353	3.91%	0.157	7.231
15.	Jamal A. N.-M.Hafed Gaza	E	13315	1406.8	10.270	278	2.09%	0.106	8.216
16.	Al Jalaa -O.B.Khatab Gaza	S	13312	1311.9	9.577	265	1.99%	0.099	6.704
17.	Al Jalaa -O.B.Khatab Gaza	N	11598	1265.2	9.236	262	2.26%	0.109	6.465
18.	Al Jalaa -T .B. Ziad Gaza	S	12493	1228.4	8.967	251	2.01%	0.098	6.277
19.	Al Jalaa Gaza	S	8270	1151.3	8.405	273	3.30%	0.139	5.883
20.	Jamal A. N.-M.Hafed Gaza	W	11783	888.6	6.487	167	1.41%	0.075	5.190
21.	Al-Nasser- Amin Gaza	S	15452	682.2	4.980	128	0.83%	0.044	3.984
22.	Al-Nasser- Amin Gaza	N	15828	657.7	4.801	118	0.75%	0.042	3.841
23.	Al-Nasser- Al-Thoura Gaza	N	10780	426.2	3.111	75	0.70%	0.040	2.489
24.	Al-Shohada bureij	W	4387	401.7	2.933	110	2.50%	0.092	2.346
25.	Al-Shohada bureij	E	3802	385.5	2.814	99	2.61%	0.101	2.251
26.	Al-Nasser- Al-Thoura Gaza	S	8972	287.8	2.101	128	1.43%	0.032	1.681
27.	Palestine Gaza	S	1185	113.2	0.826	25	2.11%	0.096	0.826
28.	Khaled Al hassan Gaza	W	1239	112.9	0.824	25	2.02%	0.091	0.824
29.	Al Quds Bureij	w	500	83.6	0.611	20	4.00%	0.167	0.611
30.	Khaled Al hassan Gaza	E	1174	83.5	0.609	18	1.53%	0.071	0.609
31.	Palestine Gaza	N	943	80.2	0.585	18	1.91%	0.085	0.585
32.	Al Kholafa Bureij	N	885	78.059	0.570	17	2%	0.088	0.570
33.	Al Quds Bureij Bureij	E	491	69.519	0.507	14	3%	0.142	0.507
34.	Al Kholafa Bureij	S	665	56.982	0.416	12	2%	0.086	0.416
35.	Abu Khaled Prep Girl Bureij	N	65	10.746	0.078	3	5%	0.165	0.078
36.	Abu Khaled Prep Girl Bureij	S	55	10.601	0.077	3	5%	0.193	0.077
37.	Big Mosque Bureij	W	32	5.318	0.039	1	3%	0.1662	0.039
38.	Big Mosque bureij	E	22	5.173	0.038	1	5%	0.235	0.038

Table 4.6: Roads Directions Characteristics Summery List According the ATF

No	Road	Direction	Total traffic	Daily ESAL	Design ESAL	truck No	% Truck	ATF	Design ESAL/L

1.	Salah Eddin Khan Younis	N	5125	1900.8	13.876	429	8.36%	0.371	9.713
2.	Salah Eddin Khan Younis	S	5384	1894.1	13.827	418	7.76%	0.352	9.679
3.	Al rashid Nuseirat	N	6176	2001.2	14.609	393	6.37%	0.324	10.226
4.	Al rashid Gaza	N	9443	2697.9	19.695	534	5.66%	0.286	13.786
5.	Al rashid Nuseirat	S	5615	1591.8	11.620	328	6%	0.283	8.134
6.	Al rashid Gaza	S	9922	2735.2	19.967	533	5.37%	0.276	13.977
7.	Salah Eddin Gaza	N	6752	1781.8	13.007	382	5.66%	0.264	9.105
8.	Salah Eddin Gaza	S	7902	1859.6	13.575	409	5.17%	0.235	9.502
9.	Big Mosque	E	22	5.173	0.038	1	5%	0.235	0.038
10.	Jamal A. Najm-N.ED Gaza	W	10689	2108.3	15.391	446	4.17%	0.197	12.313
11.	Abu Khaled Prep Girl	S	55	10.601	0.077	3	5%	0.193	0.077
12.	Jamal Abdel Nasser Gaza	E	9332	1738.6	12.692	366	3.92%	0.186	10.153
13.	Jamal Abdel Nasser Gaza	W	8818	1601.8	11.693	344	3.90%	0.182	9.355
14.	Jamal A. Najm-N.ED Gaza	E	14636	2466.7	18.007	529	3.61%	0.169	14.406
15.	Al Quds Bureij	w	500	83.6	0.611	20	4.00%	0.167	0.611
16.	Big Mosque	W	32	5.318	0.039	1	3%	0.1662	0.039
17.	Abu Khaled Prep Girl	N	65	10.746	0.078	3	5%	0.165	0.078
18.	Al Jalaa Gaza	N	9029	1415.0	10.329	353	3.91%	0.157	7.231
19.	Al Quds Bureij	E	491	69.519	0.507	14	3%	0.142	0.507
20.	Al Jalaa Gaza	S	8270	1151.3	8.405	273	3.30%	0.139	5.883
21.	Al Jalaa -T .B. Ziad Gaza	N	12369	1499.2	10.944	310	2.50%	0.121	7.661
22.	Al Jalaa -O.B.Khatab Gaza	N	11598	1265.2	9.236	262	2.26%	0.109	6.465
23.	Jamal A. N.-M.Hafed Gaza	E	13315	1406.8	10.270	278	2.09%	0.106	8.216
24.	Al-Shohada bureij	E	3802	385.5	2.814	99	2.61%	0.101	2.251
25.	Al Jalaa -O.B.Khatab Gaza	S	13312	1311.9	9.577	265	1.99%	0.099	6.704
26.	Al Jalaa -T .B. Ziad Gaza	S	12493	1228.4	8.967	251	2.01%	0.098	6.277
27.	Palestine	S	1185	113.2	0.826	25	2.11%	0.096	0.826
28.	Al-Shohada bureij	W	4387	401.7	2.933	110	2.50%	0.092	2.346
29.	Khaled Al hassan	W	1239	112.9	0.824	25	2.02%	0.091	0.824
30.	Al Kholafa	N	885	78.059	0.570	17	2%	0.088	0.570
31.	Al Kholafa	S	665	56.982	0.416	12	2%	0.086	0.416
32.	palestine	N	943	80.2	0.585	18	1.91%	0.085	0.585
33.	Jamal A. N.-M.Hafed Gaza	W	11783	888.6	6.487	167	1.41%	0.075	5.190
34.	Khaled Al hassan	E	1174	83.5	0.609	18	1.53%	0.071	0.609
35.	Al-Nasser- Amin Gaza	S	15452	682.2	4.980	128	0.83%	0.044	3.984
36.	Al-Nasser- Amin Gaza	N	15828	657.7	4.801	118	0.75%	0.042	3.841
37.	Al-Nasser- Al-Thoura Gaza	N	10780	426.2	3.111	75	0.70%	0.040	2.489
38.	Al-Nasser- Al-Thoura Gaza	S	8972	287.8	2.101	128	1.43%	0.032	1.681

Table 4.7: Roads List According the ESALS per Lane

No	Road	Total traffic	Daily ESAL	Design ESAL	truck No	% Truck	ATF	Design ESAL/Lane
1.	Al rashid Gaza Average	9682	2717	19.831	533	5.51%	0.281	13.881
2.	Jamal A Average	11429	1701.8	12.423	354.98	3%	0.152	9.939
3.	Salah Eddin Khan Average	5254	1897.5	13.851	423.2	8%	0.361	9.696
4.	Salah Eddin Gaza Average	7327	1820.7	13.291	395.6	5%	0.250	9.304
5.	Al rashid Nuseirat Average	5895	1796.5	13.114	361	0.061	0.304	9
6.	Al Jala Average	11178	1312	9.576	286	2.66%	0.121	6.703
7.	Al-Nasser Average	12758	513.5	3.748	112	0.92%	0.039	2.999
8.	Al-Shohada Bureij Average	4094	394	2.873	104	2.6%	0.096	2.299
9.	Khaled Al hassan Average	1207	98.200	0.717	21.5	2%	0.081	0.717
10.	Palestine Average	1064	96.685	0.706	21.5	2%	0.090	0.706
11.	Al Quds Bureij Average	496	76.581	0.559	17	3%	0.154	0.559
12.	Al Kholafa Average	775	67.521	0.493	14.5	2%	0.087	0.493
13.	Abu Khaled Prep Girl Average	60	10.674	0.078	3	5%	0.179	0.078
14.	Big Mosque Average	27	5.246	0.038	1	4%	0.201	0.038

Table 4.8: Roads List According the ATF

No	Road	Total traffic	Daily ESAL	Design ESAL	Truck No	% Truck	ATF	Design ESAL/Lane
1.	Salah Eddin Khan Average	5254	1897.5	13.851	423.2	8%	0.361	9.696
2.	Al rashid Nuseirat Average	5895	1796.5	13.11	361	0.061	0.304	9
3.	Al rashid Gaza Average	9682	2717	19.831	533	5.51%	0.281	13.881
4.	Salah Eddin Gaza Average	7327	1820.7	13.291	396	5%	0.250	9.304
5.	Big Mosque Average	27	5.246	0.038	1	4%	0.201	0.038
6.	Abu Khaled Prep Girl Average	60	10.674	0.078	3	5%	0.179	0.078
7.	Al Quds Bureij Average	496	76.581	0.559	17	3%	0.154	0.559
8.	Jamal A Average	11429	1701.8	12.423	355	3%	0.152	9.939
9.	Al Jala Average	11178	1312	9.576	286	2.66%	0.121	6.703
10	Al-Shohada Bureij Average	4094	394	2.873	104	2.6%	0.096	2.299
11	Palestine Average	1064	96.685	0.706	21.5	2%	0.090	0.706
12	Al Kholafa Average	775	67.521	0.493	14.5	2%	0.087	0.493
13	Khaled Al hassan Average	1207	98.200	0.717	21.5	2%	0.081	0.717
14	Al-Nasser Average	12758	513.5	3.748	112	0.92%	0.039	2.999

Table 4.9: Roads List According to ESALS Categories

No	Road	Total Traffic (No)	Daily ESAL (million)	Design ESAL (million)	truck (No)	% Truck	Average Truck factor ATF	Design ESAL/ Lane (million)
According to ESALS (≤0.05 Million)								
1	Big Mosque	27	5.246	0.038	1	4%	0.201	0.038
According to ESALS (0.05-0.1 Million)								
1	A. Khaled Prep Girl school	60	10.674	0.078	3	5%	0.179	0.078
According to ESALS (0.2-0.5 Million)								
1	Al Kholafa	775	67.521	0.493	14.5	2%	0.087	0.493
According to ESALS (0.5-0.75 Million)								
1	Khaled Al hassan	1207	98.200	0.717	21.5	2%	0.081	0.717
2	Palestine	1064	96.685	0.706	21.5	2%	0.090	0.706
3	Al Quds Bureij	496	76.581	0.559	17	3%	0.154	0.559
According to ESALS (2.0-5.0 Million)								
1	Al-Nasser	12758	513.5	3.748	112	9.2%	0.039	2.999
2	Al-Shohada Bureij	4094	394	2.873	104	2.6%	0.096	2.299
According to ESALS (5.0-10.0 Million)								
1	Jamal A Average	11429	1701.8	12.423	354.98	3%	0.152	9.939
2	Salah Eddin Khan	5254	1897.5	13.851	423.2	8%	0.361	9.696
3	Salah Eddin Gaza	7327	1820.7	13.291	395.6	5%	0.250	9.304
4	Al rashid Nuseirat	5895	1796.5	13.114	361	0.061	0.304	9
5	Al Jalaa	11178	1312	9.576	286	2.66%	0.121	6.703
According to ESALS (10.0-15.0 Million)								
1.	Al rashid Gaza	9682	2717	19.831	533	5.51%	0.281	13.881

4.3 Theoretical analysis

It includes the procedures of:

- § Application and analysis of the AASHTO modified equation
- § Application and analysis of the structural number equation
- § Calculation of the convenient replaced depth for poor subgrade soil

4.3.1 Application AASHTO modified equation(15)

The Basic equation used by AASHTO for design of flexible pavement is equation 2.1 as followed:

$$\log_{10}(W_{18}) = Z_R S_o + 9.36 \times \log_{10}(SN+1) - 0.2 + \frac{\log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.4 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(MR) - 8.07 - -(2.1)$$

Where:

W_{18} = 18-kip equivalent single axle load

Z_R = reliability

S_0 = overall standard deviation

SN = structural number

ΔPSI = design present serviceability loss

MR = resilient modulus of the subgrade

Equation 2.1 is used to determine the structural number of the pavement assuming the values of ESALS, serviceability, standard, derivation, reliability. The obtained structural number should be used as a reference to which checked the structural number obtained from the structural number equation 2.2.

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 - - - - - - - 2.2$$

Assumptions:

In order to deal with only two variables, the CBR value and the ESALs, the other values are fixed and assumed as follows:

Z_R = 0.95 for roads of ESALs > 0.5 million and 0.8 for roads of ESALs < 0.5 million

S_o = 0.35 for roads of ESALs > 0.5 million and 0.42 for roads of ESALs < 0.5 million

PSI = 4.5

TSI =2.5

ΔPSI = 2

Applying this equation with CBR and Total Design ESALs (million) values, worksheets 4.A.1 to 4.A.6 are obtained as indicated in appendix C, where 4.A.1means chapter4, AASHTO equation, and the worksheet number.

The estimated total 18 –kip equivalent single axle load is rated from 0.05X 10^6 to 50 X 10^6 and the CBR value and consequently the MR value is rated from 1.0 x 10^3 psi to 40x10^3 psi. The limits in the two cases are those indicated in the design chart of the monograph solves.

For each value of the proposed W_{18} the corresponding structural number is obtained by trials for the resilient modulus value MR (from 4.5 to 22.5) x10^3 psi.

4.3.2 Application of the structural number equation:

The structural number equation is applied so as to find the total structural number of the pavement in function of layer coefficients, layer depths and drainage coefficients.

Following the same procedures in the application of AASHTO modified equation, the estimated total 18 –kip equivalent single axle load is rated from 0.05 x 10^6 to 50 x 10^6 and the CBR value and consequently the MR value is rated from 4.5 x 10^3 psi to 40x10^3 psi. As a result, worksheets 4.S.1 to 4.S.5 are obtained as indicated in appendix C, where 4.S.1means chapter4, Structural equation, and the worksheet number.

For each value of W_{18} and MR the calculated structural number is obtained from equation 2.2 herein after. It should be greater than that obtained from the design chart or equation 2.1.

$$SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 ------- 2.2$$

Where:

- a_1 = Surface layer coefficient
- a_2 = Base layer coefficient
- a_3 = Subbase layer coefficient
- D_1 = Surface layer depth (inch)
- D_2 = Base layer depth (inch)
- D_3 = Subbase layer depth (inch)
- m_2 = drainage factor of the base layer, is taken 1 in the Gaza Strip
- m_3 = drainage factor of the subbase layer, is taken 1 in the Gaza Strip

The following notations are explained as follows:

ESALS= equivalent single axle lead ($x10^{6}$)

CBR = California bearing ratio.

MR= resilient modulus ($x10^3$ psi)

SN calculated = calculated structural number

SN required = required structural number (chart)

4.3.3 Application of the cost equation:

$$T.C = \sum C_i D_i + C_{exc} \sum D_i -------4.5$$

Where:

T.C = Total Cost ($)

Excavation depth = $\sum D_i = (D_1 + D_2 + D_{3+----})$

C_i = cost of the i layer per unit depth 1"

D_i = depth of the i layer per unit depth 1"

C_{exc}= cost of excavation per unit depth 1"

4.3.4 Worksheets data analysis

Regarding to worksheets 4.S.1-5 it is noticed that with small ESALs from $0.05x10^6$ to $0.2x10^6$, and with small CBR values of 3%, the pavement layers depths having a total structural number greater than that obtained from the chart are 3.2" , 6" , 0-12" of asphalt, base course and kurker receptively (SN calculated =3.26 > 3.22 of chart). This means that the maximum subbase depth of kurkar required is 30cm, which is a convenient depth for compaction also. In such conditions the existing subgrade could be used without replacement.

For ESAL equals $1x10^6$ the pavement layers depths are 3.2", 6", and 22" of asphalt, base course and kurker. This means that a sub base layer may reach 24" (60 cm kurker) with CBR value of 3% where with CBR 15%; the sub base layer depth is 6" (15cm). So if the subgrade soil of CBR 3% is replaced by a subgrade soil of CBR 15% or more for a depth 18" (45cm) as specified by UNRWA specification before 2001, kurkar layer needed as a sub base is 6˝ (15cm). This means that the total kurkar layer depth is 45+15 = 60 cm which is similar to that when CBR is 3%.

As a result for roads of ESALs equal or less than 1 million, replacement of subgrade soil is not recommended. Farther discussion will be later in this chapter and in chapter 5; Road classification

4.4 Calculation of the convenient replaced depth for poor subgrade soil

4.4.1 General

In the field of road pavement construction the natural ground soil, which means the subgrade soil, should be able to support safely and without critical deformation the expected traffic loads during the design period. If the subgrade is unable to do so, the top layer should be improved or replaced by another type of soil of bearing capacity enough to support such loads. The purpose here is to determine the minimum depth of replacement that could be considered a new subgrade with good bearing capacity. In other words the poor subgrade of CBR value less than 3% should be replaced by a new subgrade layer of CBR value greater than 3% with a depth enough to resist the overriding loads.

4.4.2 Subgrade CBR value

The soil bearing capacity is directly proportional to the soil CBR value. From Table 2.1 the CBR value 3% of a soil represents fine soil and more specifically clay soil (MR = 4500psi). Soil subgrade of CBR ≥ 3% could be classified as normal subgrade, as indicated in table 4.9 and 4.10, and could be used for roads of light traffic loads as it will be clarified later.

As mentioned before in Chapter 2 some references accepts subgrade soils of CBR values of at least 3% as follows:

1- "The subgrade must have a minimum CBR value of 5%. Engineering advice should be obtained where the subgrade does not meet this specification.[30]"

2- "Soils having Mr of 4500 psi (31Mpa) or less (CBR 3% or less) should be evaluated for either replacement with a material with higher bearing strength, installation of an aggregate subbase capping layer, improving by stabilization, or use of geotextile [17]".

3- Soils having Mr of 4500 psi (31Mpa) or less(CBR 3% or less) should be evaluated for either replacement with geotextile, a material with higher bearing strength, installation of an aggregate subbase capping (covering) layer, or improving by stabilization.[7]

4- Table 4.17 shows the different soil types with their CBR values

5- Table 4.18 shows the relation of CBR values with the subgrade conditions

Table 4.10: Relation between Soil Types and Bearing Values [19]

Type of soil	Subgrade strength	k- value range (pci)	MR (psi)	CBR %
Silts and clay of high compressibility natural density	Very low	50-100	1000-1900	<3
Fine grain soil, in which clay and silt size particles predominate(low compressibility)	low	100-150	1900-2900	3-5.5
Poorly graded sands & soils are predominantly sandy with moderate amounts of silts and clay	medium	150-220	2900 - 4300	5.5-12
Gravelly soil well grounded sand, and sand gravel mixtures relatively free of plastic fines	high	220-250	4300-4850	>12
Source: simplified guide for the design of concrete pavement, American concrete pavement association,1993				

Table 4.11: Relation between CBR values and subgrade conditions [18]

CBR value	Subgrade Strength	Comments
3% and less	Poor	Capping is required

3% - 5%	Normal	Widely encountered CBR range capping considered according to road category
5% - 15%	Good	"capping" normally unnecessary except in very heavily trafficked roads

4.4.3 Theoretical calculation

Since the pavement is composed of different layers with different materials, the stress on any layer could be determined using Odemark Equivalent thickness method to change the different pavement layers into one homogeneous layer. (2) The purpose here is to find the vertical stress on each layer which could help in proposing and determining the minimum required replaced depth of poor subgrade soil of CBR value less than 3%, which enable to consider the new replaced layer as a new good subgrade.

The general formula of Odemark method is:

$$h_e = n\left[h_1\left(\frac{E_1}{E_k}\right)^{0.33} + h_2\left(\frac{E_1}{E_k}\right)^{0.33} + - - - - + h_k\left(\frac{E_{k-1}}{E_k}\right)^{0.33}\right] - - - - - - - - (4.6)$$

Where:

h_e = equivalent depth > a (tire width 15cm)

n = 0.9

E_1 = modulus of elasticity of the first pavement layer (MN/m^2)

E_2 = modulus of elasticity of the second pavement layer (MN/m^2)

E_k = modulus of elasticity of the k pavement layer (MN/m^2)

$E_1 > E_2$

The vertical stress at any depth z of the homogenous pavement layer is

$$d_{subgrade} = px\left(1 - \frac{z^3}{\sqrt{\left(a^2 + z^2\right)^3}}\right) - - - - - - - - (4.7)$$

Where:

σ = vertical stress on any depth (MN/m^2)

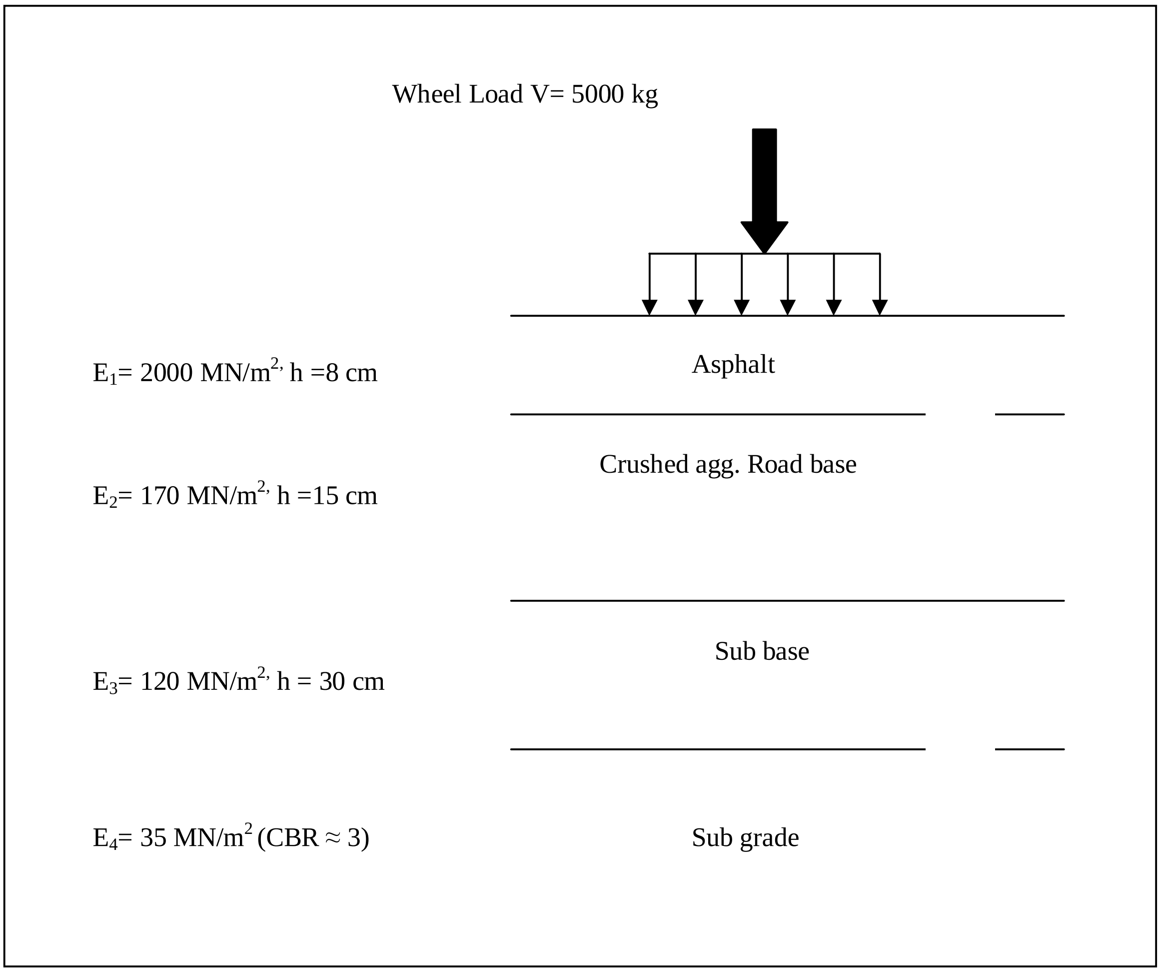
z = depth (m)

p = compressive stress at a depth zero

Assumption

- The pavement cross section indicated in Fig 4.1 below is subjected to a single axle load of 10 tonne, which means 5 tonne per each tire.
- The subgrade layer elastic modulus is $35 MN/m^2$ which represent a CBR value of about 3%, since the elastic modulus E = MR =1500 CBR (psi) = 10 CBR (MN/m^2)

Fig 4.1: Schematic Pavement Cross Section



Case 1:

Subgrade of CBR 3%, E=35, asphalt = 8cm, crushed aggregate base course = 15cm, replaced or subbase depth 30cm

Applying Odemark method:

$$h_e = 0.9\left[0.08x\left(\frac{2000}{35}\right)^{0.33} + 0.15\left(\frac{170}{35}\right)^{0.33} + ----+0.30\left(\frac{120}{35}\right)^{0.33}\right]$$

= 0.28+0.23+0.41 =0.92m

$$d_{subgrade} = 0.7x\left(1 - \frac{0.92^3}{\sqrt{\left(0.15^2 + 0.913^2\right)^3}}\right)$$ = 0.028 MN/m^2 =0.28 kg/ cm^2

Case 2:

Subgrade of CBR <1, E=10, asphalt = 8cm, crushed aggregate base course = 15, replaced or subbase depth 30cm

$h_e = 1.386m$, $d_{subgrade} = 0.12kg / cm^2$

Case 3:

Subgrade of CBR <1, E=10, asphalt = 8cm, crushed aggregate base course = 15, replaced or subbase depth 20cm

$h_e = 1.18m$, $d_{subgrade} = 0.17kg / cm^2$

4.4.4 Discussion of results

The purpose of this discussion is to assure that the subgrade bearing capacity with CBR values 3% is capable to support the stresses imposed by the traffic single wheel load of 5 tonne.

From the above results, having the pavement layers as indicated in the schematic figure 4.1, which represents the minimum layer depths of any road pavement cross section, regarding to the asphalt surface layer and base course subbase layer (8+15). It could be found from case 1 above, that the stress imposed by the tire load of a single axle load 10 tonne on both sides, and consequently on the subgrade soil is 0.28 kg/cm^2, from case 2, 0.12 kg/cm^2, and from case 3, 0.17 kg/cm^2. This means that with the same pavement layers the vertical stress on the subgrade is directly proportional to its strength (CBR). Also the vertical stress on the subgrade is inversely proportional to pavement layers depths.

From figure 4.2, the bearing value corresponding CBR 3% is about 8 psi which equals 0.56 kg/ cm^2 which is two times the stress imposed in case 1(0.28 kg/ cm^2)

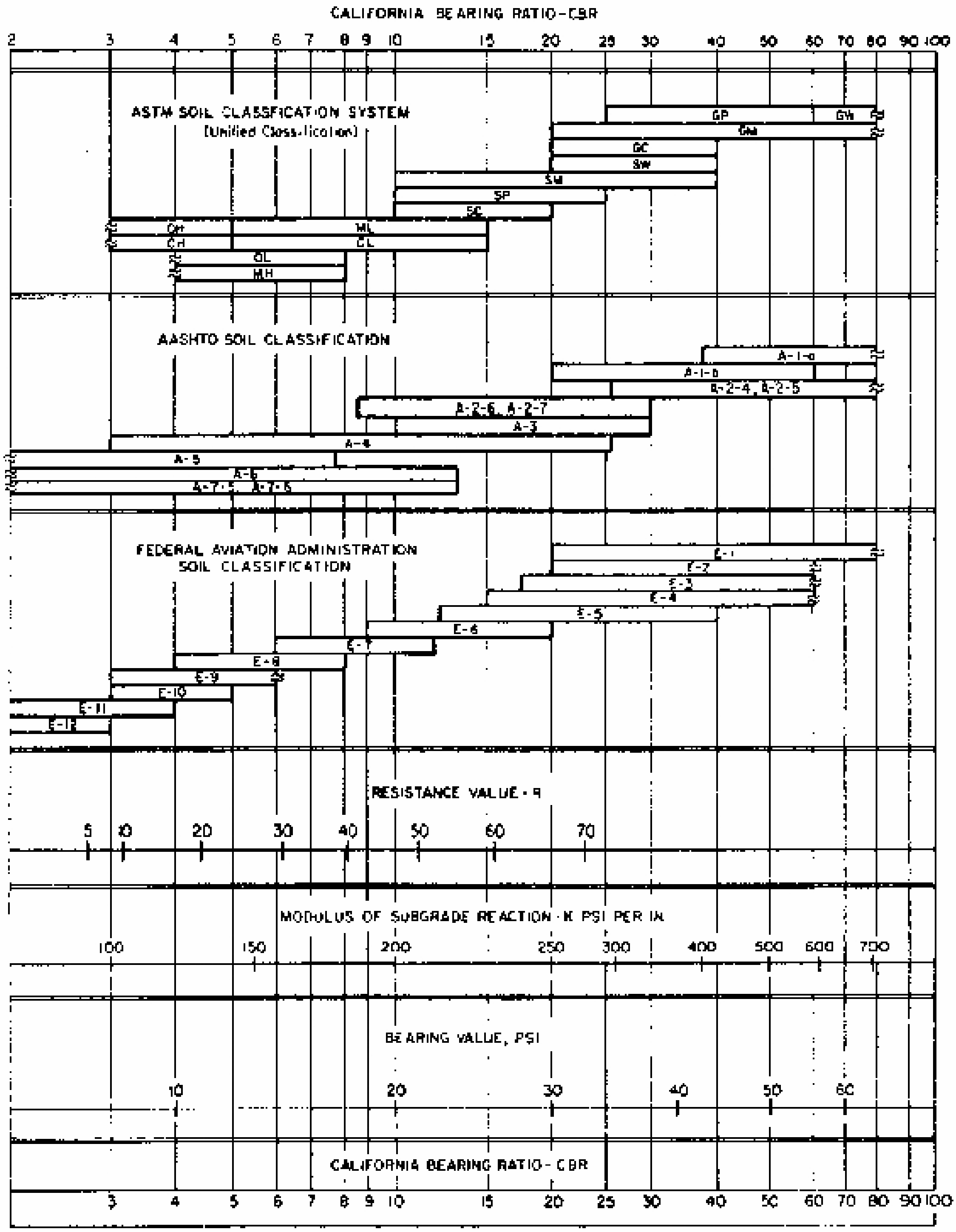


Fig 4.2: Approximate relationship between k values and other soil properties (1 psi = 6.9 kPa, 1 pci = 271.3 kN/m3). (After PCA (1966).)[20]

It means that there is a factor of safety of 2 between the applied stresses and the subgrade bearing capacity (0.56/0.28), which may be accepted.

Another justification is the Material and Soil Laboratory in the Islamic university, which clarified in one of the soil tests, that for a clay soil of subgrade CBR 6.7 for Nuseirat Pumping Station Road carried out under the request of the Special Environment Health Program at UNRWA Gaza, the soil bearing capacity is $70KN/m^2$ or 0.7 kg/ m^2 at a depth of 1.5m. [26] Of course, factor of safety was taken into consideration.

This means that small values of stresses on clay subgrade soils could be supported, where clay soil may have bearing capacity from 0.5- 1.0 kg/ cm2.

4.4.5 Minimum Subgrade CBR value

Considering the replaced layer as new subgrade with a depth of 30cm and CBR value greater than 15%, in this case, design procedures should follow another direction from the beginning. The resulting subbase layer would be less than that when the subgrade CBR was 3%. With different subgrade CBR values, the subgrade CBR value, for each category of design ESALs (million), at which the resulting subbase layer depth is equal to that of CBR value 15%, will be considered the minimum subgrade CBR value.

As a result for poor subgrade of CBR less than 3, the top layer of 30cm depth should be replaced with granular backfill material of CBR greater than 15 as indicated in Figure 4.3.

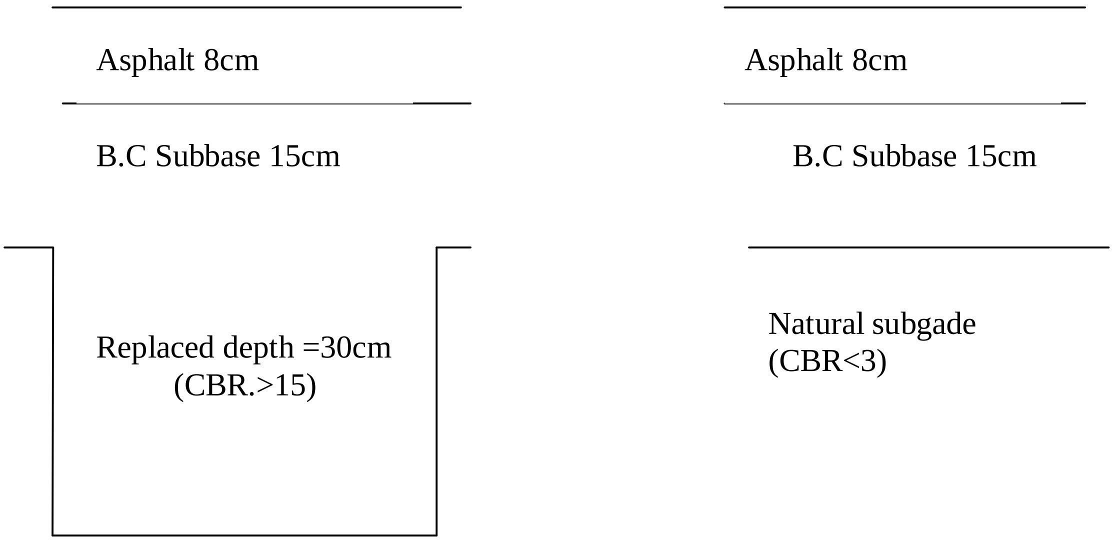


Fig 4.3: Schematic of Pavement Cross Section without and with replacement

For subgrade soil having CBR values from 3-15, replacement should be related to the expected ESALs of the roads during the design period. The minimum CBR values corresponding to the categories of ESALs are determined from worksheets 4S1-5 and indicated in table 4.12 and Figure 4.4. Table 4.13 indicates the Proposed range of the minimum CBR values with the corresponding design ESALs million.

Table 4.12: Relationship between the minimum CBR values and the design ESALs million

ESALs (million))	Recommended minimum CBR Value before replacement (%)
0.05	3
0.1	3
0.2	3
0.3	3
0.5	4
0.75	4
1	4
2	5
3	6
5	6
10	6
15	6
20	6
30	7
50	8

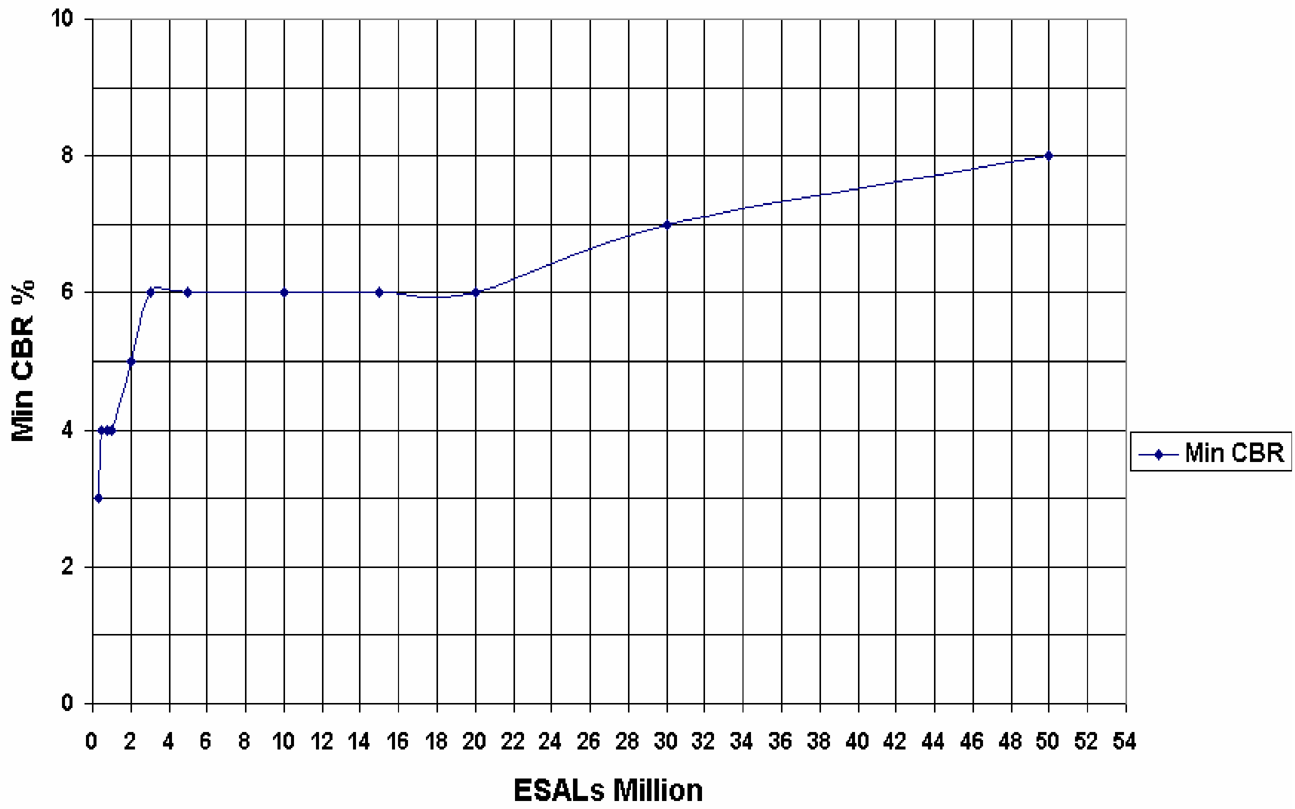


Fig 4.4 : Min CBR -Design ESALs

Table 4.13: Proposed minimum CBR values and the design ESALs million

No	ESALs (million)	Recommended minimum CBR value before replacement (%)
1.	≤0.3	3
2.	0.3< ESAL ≤ 1	4
3.	1< ESAL ≤ 2	5
4.	2< ESAL ≤ 20	6
5.	20< ESAL ≤ 30	7
6.	30< ESAL ≤ 50	8

For example in worksheet 4S3, with ESALs category 2, pavement layers corresponding to CBR 5 are 3.2", 6", 18" and those of CBR 15 are; 3.2", 6", 6". It is clear that the difference is 6" which is the agreed replaced depth. So, the minimum CBR value is 5%

From this table the minimum CBR value of subgrade soil could be used without replacement is the value 10

Herein below examples of pavement layers from worksheet 4S1-5, based on the assumption that the replaced depth is 30cm.

First example:

Having a pavement with the given data:

- assumed replaced depth is 30cm

- Reliability = 0.8
- S0 = 0.42
- PSI = 4.5
- TSI =2.5
- ΔPSI = 2

Option 1:

- 8cm asphalt layer, a1=0.42
- 15 cm crushed aggregate base course, a2=0.14
- 45cm kurkar, a3=0.09
- drainage factors m2&m3=1
- CBR =3%
- ESAL = 0.2x106
- Calculated SN = 3.22
- Required SN chart = 3.26

Option 2:

- 8cm asphalt layer
- 15 cm crushed aggregate base course
- 15cm kurkar
- CBR =15%
- ESAL = 0.2x106
- Calculated SN = 2.184
- Required SN chart = 1.76

From option 1 the subbase layer depth needed to fulfill the required structural number is found 30cm of kurkar on a subgrade of CBR value equals 3%.

In option 2 with CBR 15%, the subbase layer depth needed to fulfill the required structural number is found zero. This means that replacing the upper 30cm according to the proposed specifications in this thesis, to have a new CBR greater than 15.will lead to the same in option 1, where subgrade CBR equals 3% and the subbase layer equals 30cm.

So the first option is the same as the second. The excavation depth also is the same.

Second example:

Having a pavement with the given data:

- assumed replaced depth is 45cm

§ - Reliability = 0.95

§ - S0 = 0.35

§ - PSI = 4.5

§ - TSI =2.5

§ - ΔPSI = 2

Option 1:

§ - 8cm asphalt layer, a1=0.42

§ - 15 cm crushed aggregate base course, a2=0.14

§ - 60cm kurkar, a3=0.09

§ - Drainage factors m2 & m3 = 1

§ - CBR =3

§ - ESAL = 1x106

§ - Calculated SN = 4.34

§ - Required SN chart = 4.11

Option 2:

§ - 8cm asphalt layer

§ - 15 cm crushed aggregate base course

§ - 15cm kurkar

- § - CBR =15
- § - ESAL = 1x106
- § - Calculated SN = 2.7
- § - Required SN chart = 2.3

From option 1 the subbase layer depth needed to fulfill the required structural number is found 55(30+25)cm of kurkar on a subgrade of CBR value equals 3%.

In option 2 with CBR 15%, the subbase layer depth needed to fulfill the required structural number is found 15cm. This means that replacing the upper 30cm according to the proposed specifications in this thesis, to have a new CBR greater than 15.will save 10cm, where subgrade CBR equals 15% and the subbase layer equals (30+15) cm.

So the second option is better than the first. The excavation depth also is less.

Third example:

Having a pavement with the given data:

- assumed replaced depth is 30cm

- § Reliability = 0.95
- § S0 = 0.35
- § PSI = 4.5
- § TSI =2.5
- § ΔPSI = 2

Option 1:

- § 8cm asphalt layer, a1=0.42
- § 15 cm crushed aggregate base course, a2=0.14
- § 45cm kurkar, a3=0.09
- § drainage factors m2&m3=1
- § CBR =3
- § ESAL = 2x106
- § Calculated SN = 4.7

- Required SN chart = 4.54

Option 2:

- 8cm asphalt layer
- 15 cm crushed aggregate base course
- 15cm kurkar
- CBR =15
- ESAL =2x106
- Calculated SN = 2.72
- Required SN chart = 2.57

From option 1 the subbase layer depth needed to fulfill the required structural number is found 70(30+40) cm of kurkar on a subgrade of CBR value equals 3%.

In option 2 with CBR 15%, the subbase layer depth needed to fulfill the required structural number is found 15cm. This means that replacing the upper 30cm according to the proposed specifications in this thesis, to have a new CBR greater than 15.will save 25cm, where subgrade CBR equals 15% and the subbase layer equals (30+15) cm.

So the second option is better than the first. The excavation depth also is less.

From the above examples, if the replaced depth is bigger, the value of the minimum CBR value decrease, and vise versa.

This means that, replacement of subgrade soil of CBR less than 15 is recommended if the CBR value is below the minimum nominated in table 4.11. It is evident that there is a relationship between the CBR value, ESALs and the replaced depths.

Accordingly, and from the above discussions the replacement of poor subgrade (CBR<3) layers is accepted for all categories of roads.

Analysis of the two variables; CBR and the ESALs is carried out in the application of the structural number equation and AASHTO modified equation. The total cost of pavement will be an important factor in the design tables.

4.5 Cost analysis

Comparison between the costs of pavements is the way that leads to choose the economical one. Finding the cost of the unit depth of pavement layers is very essential for the process of cost analysis.

4.5.1 Cost of the unit depth of each layer of a pavement

Cost of pavement layers is estimated using the cost analysis of all components of construction and consequently the cost of the unit depth of each layer (1cm) is determined.

The structural number per cm is found, and since the structural number of asphalt is the biggest, it is used as a reference unit depth for the structural number. The equivalent depth of the base and sub base layers with the cost is found too.

Table 4.12 indicate the pavement layers depths, cost per cm and the cost of the equivalent depths

Table 4.14: Layers' Structural Numbers SN per Cm, Equivalent Depth

Layer type	Layer coefficient "a" (1/inch)	SN/1cm (1/cm)	Equivalent depth of 1cm of asphalt	Cost of Equivalent depth to 1cm of asphalt (m^2)
Asphalt	0.42	0.168	1	1.4
Base coarse	0.14	0.056	3	0.96
kurkar	0.09	0.036	4.667	0.42

Table 4.15: Layers' Depths and Costs

task	Layer depth "d" inch	Cost ($ /m^2)	Cost ($/cm)	Cost of Equivalent depth to 1cm of asphalt (m^2)
Asphalt	3.2 (8)	11.2	1.4	1.4
Base coarse	6 (15)	4.8	0.32	0.96
kurkar	6 (15)	1.3	0.09	0.42
excavation	15.2 (38)	0.57	0.015	

4.5.2 Data analysis

From the above analysis in the above tables, it is clear that the strength expressed in the corresponding structural number (SN) of 1 cm of asphalt is the same as that of 3 cm of Crushed aggregate base course as the same as 4.667 cm of kurkar. The corresponding cost of each is 1.4, 0.96 and 0.42 $. That is to say the kurkar is the most economical used layer within the pavement.

As a result, the kurkar layer should be the deepest layer as could as possible. The asphalt layer depth should be selected as minimum as possible, which could be applied in an acceptable workability. It is proposed 8cm in two layers in minimum, or one layer of at least 5cm. The crushed aggregate base course layer could be taken 15 cm which could be the minimum well compacted layer. For side walk, crushed aggregate base course layer could be taken 10cm. The required remaining depth of the pavement should be selected kurkar. This is not absolutely, asphalt layer may be increased to 9-10 cm and the crushed aggregate base course layer could be two layers of 30 cm depth. This depends on the existing situation on the ground.

SUMMARY

Data analysis includes not only the data collected within the field work but also the analysis of results of the applications of the basic AASHTO modified design equation and the total structural number equation. The required replaced depth was also an important part of the data analysis section. The minimum CBR value and the corresponding ESAl table was an important output of this research as well as the road classification table.

5 CHAPTER FIVE

ROADS CLASSIFICATIONS

5.1 General

Roads classification differs from one country to another slightly with respect to laws and rules of that country. Roads are generally classified according to different criteria. The first criterion is the site location of road, rural or urban. The second criterion is the function describing the service introduced and the mutual relation with other roads such as; arterial, collector, local or residential. This classification will reflect the expected volume and types of traffic that pass through these roads during the design period.

Other criteria obtained from traffic count output are used in classification and can be considered functional of the classification such as type, volume of traffic, percent of heavy trucks, average truck factor and the equivalent single axle load (ESALs).

5.2 Road description

- § Highways: are roads that provide primary transportation routes between geographical locations such as cities and towns. They are characterized by varying traffic volume, heavy loading and widely varying speeds. They may be called interstate or express. (21)
- § Arterials: are roads provide service to large areas and usually connect other arterial roads. They are characterized by high traffic volume, heavy loading and widely varying speeds. (21)
- § Rural: are roads providing access to adjacent pro arterial routes in the rural areas. They are low car and light traffic with some busses and local farm traffic. Speed varies from low to high speeds as highways. (22)
- § Local: are roads surrounding and connecting residential roads.
- § Collectors: are roads connecting residential roads with arterial routes. They may have significant traffic. (23)
- § Residential streets: are roads to provide access to adjacent residential properties. They are of low speeds, low traffic volume and light traffic. (24)

- Residential driveways: are small pavement section for automobile use and parking with an occasional medium truck. They are of low speed and low volume of traffic. [25]

5.3 Necessity of road classification

Roads network generally consist of different classes of roads. Road network could be radial, grid or in the form of a tree. In each type of road networks, all road classes could be found, interstate, highway or expressway, arterial, collector, local and residential. Road classes directly could give an impression of the road importance concerning the function and traffic volume and types. This could affect the structural and geometrical design of the road.

In this thesis, focus will be given to the low category classes of roads, residential and local roads.

These two categories constitute the highest percent of roads area in any developed city. For example, the hatched zone from the North Remal in Gaza town as shown on Figure 5.1 is taken herein after as a case study.

5.4 Case study

The purpose of the case study is to find low categories roads area as a percent of the other types and of he total developed area. The area is surrounded by the roads; Al Nasser road from the west, Al Galaa Road from the east, Omar El Mokhtar from the south and Abu Jehad from the north. The internal roads are considered local and in the same time residential roads according to their functions and locations. The surrounding roads are considered either collectors or arterials roads. The area of the internal local roads and the area of the surrounding roads are calculated as well as the total area of the zone. Table 5.1 indicates the areas calculated. The total roads areas, locals and collectors are 338,700 m^2. They are 25% of the total case study area (1,343,300 m^2). The area of local or residential roads is 221,500 m^2, which is about 16.5% of the total area. Regarding to these reasons, design and construction of these two categories should be carried out seriously and precisely to the point satisfying all necessary requirement of design without any excessive cost.

Cost of roads construction is one the most governing factors in the infrastructure developing projects.

Trying to give such categories of roads the complete requirement of design, safety and bearing capacity, without extra depths of pavement layers, considerable saving of money could be obtained.

Fig 5.1: North Remal - Gaza - Case Study

Table 5.1: Case Study Roads Categories Areas

No	description	Area m^2	%
1.	Total area of zone	1,343,000	100
2.	Internal local roads(residential)	221,500	16.49
3.	Surrounding external roads	117,200	8.73
4.	Total roads area	338,700	25.22
5.	Building area	10,043,000	74.78

Saved money means also saving time and consequently this means additional development of more areas, enhancing the economical situation, achieving welfares and progress to the country.

5.5 External guide classification tables

The main variable considered in the proposed classification in this thesis is the ESAls used for design. Tables herein after indicate different road classifications from different sources. Such tables may be used as a guide for the proposed road classification

Table 5.2: Road Classification According To Esals [26]

Street Classification	Average daily traffic(ADT)	Design lane 18-Kip ESAL	
		18-Kip ESAL	Million
Major Arterial	50000	1,000,0000	10
Minor Arterial	20000	4,000,000	4
Collector	10000	1,000,000	1
Local	1600	100,000	0.1
Cal-de-sac	400	10,000	0.01

Table 5.3: Road Classification According To ESALs [27]

Equivalent (18kip) daily load application (ESAL)		ESALs(20 year)	
Classification	18-Kip ESAL		Million
Local	1 5 10	7,300 36,500 73,000	≈ 0.01 ≈ 0.05 ≈ 0.1
Minor Collector	30 50	219,000 365,000	≈ 0.5 ≈ 0.75
Major Collector	100	730,000	≈ 1
Minor Arterial	200	1,460,000	≈ 1.5
Major Arterial	200(minimum)	>1,460,000	> 1.5

Table 5.4: Road Classification According To ESALs(million) (17)

Road Class	EALs*(million)	Reliability factor	Design EALs* (million)**
Arterial or Major Streets			
Urban	7.5	3.775	28.4
Rural	3.6	2.929	10.6
Major Collector			
Urban	2.8	2.929	8.3
Rural	1.5	2.39	3.5
Minor Collector			
Urban	1.3	2.39	3.0
Rural	0.55	2.39	1.3
Commercial / Multifamily			
local	0.43	2.010	0.84
Urban	0.28	2.010	0.54
Rural			

- *Assume a 20 year design life
- ** Adjusted EALs = F_R x EALs

Table 5.5: Design Catalog Vehicle Classification (28)

Vehicle Category	Gross Vehicle weight Range Ibs	Assumed ESALs per Vehicles	Representative Vehicles
Cars and light Trucks	0-14000	0.0007	Cars, SUVs, pickup trucks, ambulances, delivery vehicles
Medium Trucks and busses	14001-33000	0.25	City cargo van, delivery truck, wrecker, school bus
Heavy Trucks and busses	Over 33000	1.0	Simi tractor trailer, concrete mixer, dump truck, fire truck, city bus

Table5.6: Traffic Volume for Driveways (25)

Vehicle type	Vehicles per day	Vehicles per year	ESALs
Cars and light Trucks	10	3650	negligible
Medium Trucks and busses	occasional	10	negligible
Heavy Trucks and busses	negligible	negligible	negligible
Total	10	3660	negligible

Table 5.7: Traffic Volume for Residential Streets [24]

Vehicle type	Vehicles per day	Vehicles per year	ESALs (psi)
Cars and light Trucks	500	200000	140
Medium Trucks and busses	10	4000	80
Heavy Trucks and busses	1	365	365
Total	510	204000	585

Table5.8: Traffic Volume for Collector Streets [23]

Vehicle type	Vehicles per day	Vehicles per year	ESALs (psi)
Cars and light Trucks	3500	1300000	900
Medium Trucks and busses	100	36500	9000
Heavy Trucks and busses	200	7000	10000
Total	3620	204000	190,000

Table5.9: Road Classification According To ESALs(million) [*]

Road class	ESALs (18 Kip)	ESALs (million)
Driveways	negligible	negligible
Residential Streets	585	0.012
Collector Streets	190,000	3.8
Arterial & highway	According design	According design

* Table 5.9 is prepared from tables 5.5, 5.6, 5.7 and 5.8

Table 5.10: Typical Truck Factor for Deferent Classes of Highway, All Trucks Combined (After Asphalt Institute MS-1)

Types of facilities	Truck factors	
	Average	Range
Interstate rural	0.49	0.34-.77
Other rural	0.31	0.20-.52
All rural	0.42	0.29-0.67
All urban	0.30	0.154-0.59
All system	0.40	0.27-0.63

From the discussion of the three examples in chapter 4 and from the count results findings represented in the summary of results form of the worksheets number 4.1-4.36 the following table is proposed for road classification.

Table 5.11: Road Classification Summary from Tables 5.2, 5.3, 5.4, and 5.9

ESALs (million)						
No	Road class	Table 5.4	Table 5.8	Table 5.10		Table 5.15
				urban	rural	
1	Cal-de sac	0.01				
1	residential					0.012
2	Local		0.01 0.05 0.10	0.84	0.54	
3	Minor collector	0.1	0.2 0.5	3	1.3	
4	Major collector	1	0.75	8.3	3.5	3.8
5	Minor arterial	4	1.5			
6	Major arterial	10	>1.5	28.4	10.6	
7	interstate					

From classification of roads indicated in the tables 5.2, 5.3, 5.4, and 5.9, the proposed table 5.11 represents the summary of those tables. The purpose of the summary, with the aid of traffic count output summary for roads indicated in table 4.5, chapter 4, is to result in a suitable classification of roads in the Gaza Strip in function of the ESALs.

From table 5.11 which represents the road classification summary after some institutes and from table 5.12 that represent the traffic count output list, the ESALs values for each class of roads shall be discussed taking into consideration the function and location of each road and then the classes of roads shall be confirmed in the proposed classification table 4.13.

Table 5.12: Roads list according to ESALs (million) and function

(Traffic count output, average of south and north)

No	Road	ESALs (million)
Residential B, ESALs for Roads < 0.05 million		
1	Big Mosque	0.038
Residential A, ESALs for Roads from 0.05 -0.1 million		
1	Abu Khaled Prep Girl School(average)	0.078
Local B, ESALs for Roads from 0.2-0.5 million		
1	Al Kholafa	0.493
Local C, ESALs for Roads from 0.5-0.75 million		
1	Khaled El Hassan	0.717
2	Palestine	0.706
2	Al Quds	0.559
Major Collector, ESALs for Roads from 2.0-5.0 million		
1	Al Nasser	2.999
2	Al Shohada Bureij	2.29
Minor Arterial, Average ESALs for Roads from 5-10 million		
1	Jamal A Average	9.939
2	Salah Eddin Khan Average	9.696
3	Salah Eddin Gaza Average	9.304
4	Al rashid Nuseirat Average	9
5	Al Jala Average	6.703
Major Arterial, ESALs for Roads from 10-15 million		
1	Al Rashid Gaza	13.881

Table 5.13: Proposed Road Classification according to ESALs

Road class	Total Design ESALs(million)
Residential	Up to 0.10.
Residential A	0.05-0.10.
Residential B	< 0.05
Local	0.1 < ESAL≤ 1
Local A	0.75 - 1
Local B	0.5 – 0.75
Local C	0.2 - 0.5
Local D	0.1 - 0.2
Minor Collector	1< ESAL≤2
Major Collector	2 < ESAL≤ 5
Minor Arterial	5 < ESAL≤ 10
Major Arterial	10< ESAL≤15
Inter governorates	15 < ESAL≤30

5.6 Roads Classifications

5.6.1 Residential roads (proposed ESALs from 0.01-0.1 million):-

From table 5.11, the ESALs is 0.012 for residential and 0.01 for cal –de sac, and from the traffic count output which lists tables according to ESALs as indicated in table 5.12 for the Big Mosque Road (ESALs = 0.038 million) and for Abu Khaled Prep Girl Road (ESALs = 0.078 million), and from the actual function of these roads as access to the residents houses or buildings, where these two roads are about 5-7 m width and about 150 m length. So, they could be classified as residential roads easily with the ESALs range from 0.01-0.1. Thus the residential is confirmed in the proposed table

5.6.2 Local roads (proposed ESALs from 0.1-1 million):-

From table 5.11, the ESALs is 0.01, 0.05, 0.1, 0.84, and 0.54 and from the traffic count output which lists according to ESALs as indicated in table 5.12 for road Al Kholafa (ESALs=0.493 million) and for roads; Khaled El Hassan, Palestine and Al Quds (ESALs = 0.717, 0.706 &0.559 million), also from the actual function of these roads where Palestine and khaled Al Hassan roads as shown on Gaza road map are in the north Remal of Gaza town. They are local roads, constituting part of the grid roads of the area. They have the same importance as the others. They differ from AL-Jalaa road, EL- Nasser, Jamal A.EL-Nasser roads that are considered main collectors or even arterials connecting the blocks of the city. While Al Quds and Al Kholafa Roads in Bureij Camp are also part of the grid roads in the camp, they could not be considered main collector or arterial. The convenient classification is local roads with the ESALs range from 0.1-1. The big values of ESALs of Gaza roads refer relatively to their existence in Gaza town as a big town.

The value of 0.1from table 5.11 also supports the proposed classification, where the value 0.1 -0.2 is proposed for local D category.

Local categories are given 4 intervals, first due to the relatively big percent of such categories and second to the variance range of importance, population and area of towns having these local roads.

5.6.3 Minor collector (proposed ESALs from 1-2 million):-

From table 5.11 the ESALs are 0.1, 0.2, 0.5, 3, and 1.3 and from the traffic count output which lists tables according to ESALS as indicated in the road directions summery table 4.5 for all roads Al Nasser Gaza Road in one of its count points has a value of ESALs = 1.68 million within this range while the average is 3 million and lies in the second class of major collector. The proposed range of ESAL for this class is 1-2. This range is closed of that in table 5.11 and could be accepted for this class.

5.6.4 Major collectors (proposed ESAL from 2-5 million):-

From table 5.11 the EASLs for the major collectors are 1, 0.75, 8.3, 3.5 and 3.8. and from the traffic count output which lists tables according to ESALS as indicated in table 5.12 for Al Nasser Gaza and Al Shohada Bureij (ESALs = 3.0 &2.299 million) and from the actual function of Al Nasser Gaza road and Al Shohada Bureij road where many roads are collected in. they could be classified as major collector roads.

For the specified nominated roads AL-Nasser (Gaza) and AL-shuhada (Bureij), the real function of these roads is major collector. AL-Nasser road is actually major collector in Gaza, where all the perpendicular roads are collected in this road. AL-Shuhada Bureij road also is the main entrance of Bureij camp and is considered the main collector in the camp.

5.6.5 Minor arterial (Proposed ESALs is from 5-10 million)

From table 5.11 the ESALs are 4, 1.5, 10 and 28.4. The two values 10 and 28.4 are considered for the categories minor arterial, major arterial and interstate roads. From the traffic count output which lists tables according to ESALS table 5.12 for Jamal A. El Nasser Gaza, Salah Eddin Khan Younis, Salah Eddin Gaza, Al Rashid Nuseirat and Al Jala Gaza (ESALs = 9.939, 9.696, 9.304, 9 & 6.703 million) the proposed range of ESALs is from 5-10. In the detailed results of the traffic count points in the summary table 4.5, in different points of count and in different directions there are different values of the ESALs which reflect really the difference in the quantity and type of traffic counted there. That is to say for Salah Eddin Gaza, Al Rashid Nuseirat and Salah Eddin Khan Younis there are count points which has ESALs values greater than 10 out of their class from 5-10. This is due to the interference and random movement of traffic.

Salah Eddin Gaza, Al Rashid Nuseirat and Salah Eddin Khan Younis roads physically could be considered minor, major arterial or inter governorates as supported in table 5.11 classification, where they connects the southern governorate with Gaza.

5.6.6 Major arterial (proposed ESAL is from 10-15 million).

From tabe 5.11, the ESALs are 10, >1.5 (which may be 5-20), 10.6 and 28.4. From table 5.12, the proposed range for the ESALs is from 10-15. The average value of the traffic count output of ESALs is 13.881 for road Al Rashid Gaza. The proposed range is close to that of table 5.11 and this road is really major arterial road. Al Rashid Gaza road could be considered not only a major arterial but also an inter governorate road since it connect Gaza with the South.

5.6.7 Inter governorate (proposed ESAL 15-25 million)

From table 5.11 ESAL is 10.6 and 28.4 for rural and urban roads respectively. The interstate road in Gaza strip is considered urban road generally. The proposed range is from 15-25 which is considered suitable with the values obtained from the summary table 4.5. The average values of the traffic count output list according to ESALs are below 15.

As mentioned above, AL Rashid Nuseiret, Salah Eddin Khan Younis, Salah Eddin Gaza and AL Rashid Gaza roads could be classified regarding to their locations and functions as inter governorate roads as well as they could be considered major arterial roads.

Table 5.14: Road list according to ATF (average of south and north)

No	Road	ATF
1	Salah Eddin Khan Younis	0.361
2	Al rashid Nuseirat	0.304
3	Al rashid Gaza	0.281
4	Salah Eddin Gaza	0.250
5	Big Mosque	0.201
6	Abu Khaled Prep Girl	0.179
7	Al Quds Bureij	0.154
8	Jamal A El Nasser	0.152
9	Al Jalaa	0.121
10	Al-Shohada bureij	0.096
11	Palestine	0.090
12	Al Kholafa	0.087
13	Khaled Al hassan	0.081
14	Al-Nasser Average	0.039

From the comparison between table 5.10: "classification of roads according to the ATF" and table 5.14: "classification of roads according to the ATF", closed results could be obtained. The roads Al Rashid Nuseirat, Salah Eddin Khan Younis, Al rashid Gaza and Salah Eddin Gaza have ATF from 0.25 to 0.361 which are close to the range of table 5.10 which is from 0.34 – 0.77 as for the interstate roads. For all urban roads from table 5.16, the range of ATF is 0.154 – 0.59 which is very close to the proposed classification of roads from 0.039 to 0.25

5.7 Confirmation

Regarding to the above discussion the proposed classification table 4.13 is confirmed. The categories are residential B, & A, local D, C, B, & A, minor collector, major collector, minor arterial, major arterial and intergovernorates.

Summary

Road classification was proposed taking into consideration the traffic count results, including the total design ESAL within the design period, external guide classification and actual function of the studied roads, if it was residential or local or others. A case study was considered to indicate that low categories roads such as residential and local constitute the highest percent of area with respect to the others. This will lead to focus more and more these categories to have more saving in cost, time and resources

6 CHAPTER SIX

DESIGN TABLES AND CHARTS

6.1 Background

Regarding to the application of AASHTO modified equation and the structural number equation in chapter 4, worksheets 4A1-7 and worksheets 4S1-5, design tables 6.1-5 are prepared.

As shown in these tables, the first columns represent the design ESALs million during the design period per lane, it is rating from 0.05-50 million. The second column represents the CBR values rating, from 3-15. Column 3 represents the Resilient modules MR. MR is calculating from the relation MR= 1500 CBR (psi). It is rating from 4.5 – 225X10 kip. The fourth column represents the depth of the asphalt layer (d1, inches). Column 5 represents the depth of the base course layer (d2, inches). Column 6 represents the depth of the sub base layer. (kurkar, d2, inches). Column 7 represents the structural number calculated from the layers through equation 2.2

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 ------- 2.2$$

Column 8 represents the required structural number obtained from AASHTO equation or the chart. Column 9 represents the cost of the pavement construction for all layers using equation: 4.5

$$T.C = \sum C_iD_i + C_{exc}\sum D_i ------- 4.5$$

Since the rating of the ESALS does not cover the whole values and gaps exist in between the values, charts are prepared as another alternative for the purpose of design. Charts in appendix D from chart 1 to chart 19. For example when the ESAL value is 13 or 7 or 4, charts are used to find the required structural number. The calculated structural number is obtained from pavement layers either from tables or calculated from proposed layers depths. Other charts are used to find the cost of pavement construction, knowing the CBR or MR values.

Chart 1 represents MR, ESALs and SN. Chart 2 represents CBR, ESAls and SN. Chart 3 represent MR, ESALs and cost chart 4represent CBR, ESALs and cost. Chart 5 represents minimum CBR and ESALs.

Charts 6-19 represent CBR, SN and cost for each category of ESALs.

6.2 Procedures

6.2.1 Tables

- For Tables 6.1 – 6.5, knowing the CBR or MR value with the specified design ESAls per lane, the proposed layer depths of the pavement, calculated structural number, the required structural number and the total cost of the pavement construction are found easily.

6.2.2 Charts (attached in appendix D)

- For charts 6.1 – 6.2, knowing the CBR or MR value, from the X-axes, vertical line is drawn to meet the curve of the structural number of the specified design ESAls per lane in a point from which horizontal line is drawn to meet the Y- axes in a point express the value of structural number SN.
- The same procedures are executed to find the cost in function of the CBR or MR value for charts 6.3 – 6.4.
- For charts 6.6 – 6.19, knowing the CBR value on the right Y-axes, horizontal line is drawn to meet the line representative to the CBR in a point from which vertical line is drawn to meet the curves of the required SN and the cost in two points, from each one a horizontal line is drawn to meat the left Y-axes to determine the value of the required structural number SN and the total cost $.
- In case of having values of ESAls or CBR in between the proposed values in the tables or in the harts, interpolation is used to represent such values.
- Chart 6.5 is used to determine the minimum CBR value below which the subgrade soil should be replaced or improved.

Design charts from 6.1 to 6.19are attached in appendix D

Table 6.1: Structural Design of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3
Cost=c1d1+c2d2+c3d3+c4 (d1+d2+d3)
Where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor is taken 1
m3 = drainage factor is taken 1

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs (million)	CBR	MR(kip)	d1"	d2"	d3"	SN Calc.	SN Chart	$ cost
0.05	3	4.5	2.4	6	10	2.748	2.58	16.1492
0.05	4	6	2.4	6	6	2.388	2.32	15.0972
0.05	5	7.5	2.4	6	0	1.848	2.1	13.5192
0.05	6	9	2.4	6	0	1.848	1.97	13.5192
0.05	7	10.5	2.4	6	0	1.848	1.86	13.5192
0.05	8	12	2.4	6	0	1.848	1.76	13.5192
0.05	9	13.5	2.4	6	0	1.848	1.68	13.5192
0.05	10	15	2.4	6	0	1.848	1.61	13.5192
0.05	11	16.5	2.4	6	0	1.848	1.55	13.5192
0.05	12	18	2.4	6	0	1.848	1.5	13.5192
0.05	13	19.5	2.4	6	0	1.848	1.45	13.5192
0.05	14	21	2.4	6	0	1.848	1.4	13.5192
0.05	15	22.5	2.4	6	0	1.848	1.36	13.5192
0.1	3	4.5	2.4	6	12	2.928	2.88	16.6752
0.1	4	6	2.4	6	10	2.748	2.53	16.1492
0.1	5	7.5	2.4	6	6	2.388	2.34	15.0972
0.1	6	9	2.4	6	0	1.848	2.2	13.5192
0.1	7	10.5	2.4	6	0	1.848	2.08	13.5192
0.1	8	12	2.4	6	0	1.848	1.98	13.5192
0.1	9	13.5	2.4	6	0	1.848	1.89	13.5192
0.1	10	15	2.4	6	0	1.848	1.82	13.5192
0.1	11	16.5	2.4	6	0	1.848	1.75	13.5192
0.1	12	18	2.4	6	0	1.848	1.69	13.5192
0.1	13	19.5	2.4	6	0	1.848	1.64	13.5192
0.1	14	21	2.4	6	0	1.848	1.59	13.5192
0.1	15	22.5	2.4	6	0	1.848	1.55	13.5192
0.2	3	4.5	3.2	6	12	3.264	3.22	19.5056
0.2	4	6	3.2	6	10	3.084	2.9	18.9796
0.2	5	7.5	3.2	6	6	2.724	2.67	17.9276
0.2	6	9	3.2	6	6	2.724	2.5	17.9276
0.2	7	10.5	3.2	6	6	2.724	2.36	17.9276
0.2	8	12	3.2	6	6	2.724	2.25	17.9276
0.2	9	13.5	3.2	6	0	2.184	2.15	16.3496
0.2	10	15	3.2	6	0	2.184	2.06	16.3496
0.2	11	16.5	3.2	6	0	2.184	1.99	16.3496
0.2	12	18	3.2	6	0	2.184	1.92	16.3496
0.2	13	19.5	3.2	6	0	2.184	1.86	16.3496
0.2	14	21	3.2	6	0	2.184	1.81	16.3496
0.2	15	22.5	3.2	6	0	2.184	1.76	16.3496

Table 6.2: Structural Design of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3
Cost=c1d1+c2d2+c3d3+c4 (d1+d2+d3)
Where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor is taken 1
m3 = drainage factor is taken 1

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs (million)	CBR	MR(kip)	d1"	d2"	d3"	SN Calc.	SN Chart	$ cost
0.5	3	4.5	3.2	6	18	3.804	3.7	21.0836
0.5	4	6	3.2	6	14	3.444	3.35	20.0316
0.5	5	7.5	3.2	6	10	3.084	3.09	18.9796
0.5	6	9	3.2	6	10	3.084	2.88	18.9796
0.5	7	10.5	3.2	6	6	2.724	2.72	17.9276
0.5	8	12	3.2	6	6	2.724	2.59	17.9276
0.5	9	13.5	3.2	6	6	2.724	2.48	17.9276
0.5	10	15	3.2	6	6	2.724	2.39	17.9276
0.5	11	16.5	3.2	6	6	2.724	2.3	17.9276
0.5	12	18	3.2	6	6	2.724	2.23	17.9276
0.5	13	19.5	3.2	6	0	2.184	2.16	16.3496
0.5	14	21	3.2	6	0	2.184	2.1	16.3496
0.5	15	22.5	3.2	6	0	2.184	2.05	16.3496
0.75	3	4.5	3.2	6	20	3.984	3.94	21.6096
0.75	4	6	3.2	6	18	3.804	3.88	21.0836
0.75	5	7.5	3.2	6	16	3.624	3.59	20.5576
0.75	6	9	3.2	6	14	3.444	3.365	20.0316
0.75	7	10.5	3.2	6	12	3.264	3.18	19.5056
0.75	8	12	3.2	6	10	3.084	3.03	18.9796
0.75	9	13.5	3.2	6	10	3.084	2.905	18.9796
0.75	10	15	3.2	6	10	3.084	2.8	18.9796
0.75	11	16.5	3.2	6	6	2.724	2.7	17.9276
0.75	12	18	3.2	6	6	2.724	2.61	17.9276
0.75	13	19.5	3.2	6	6	2.724	2.54	17.9276
0.75	14	21	3.2	6	6	2.724	2.47	17.9276
0.75	15	22.5	3.2	6	6	2.724	2.405	17.9276
1	3	4.5	3.2	6	22	4.164	4.11	22.1356
1	4	6	3.2	6	18	3.804	3.72	21.0836
1	5	7.5	3.2	6	14	3.444	3.44	20.0316
1	6	9	3.2	6	12	3.264	3.22	19.5056
1	7	10.5	3.2	6	10	3.084	3.05	18.9796
1	8	12	3.2	6	10	3.084	2.9	18.9796
1	9	13.5	3.2	6	6	2.724	2.78	17.9276
1	10	15	3.2	6	6	2.724	2.67	17.9276
1	11	16.5	3.2	6	6	2.724	2.58	17.9276
1	12	18	3.2	6	6	2.724	2.5	17.9276
1	13	19.5	3.2	6	6	2.724	2.43	17.9276
1	14	21	3.2	6	6	2.724	2.36	17.9276
1	15	22.5	3.2	6	6	2.724	2.3	17.9276

Table 6.3: Structural Design of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3
Cost=c1d1+c2d2+c3d3+c4 (d1+d2+d3)
Where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor is taken 1
m3 = drainage factor is taken 1

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs (million)	CBR	MR(kip)	d1”	d2”	d3”	SN Calc.	SN Chart	$ cost
2	3	4.5	3.2	6	28	4.704	4.54	23.7136
2	4	6	3.2	6	24	4.344	4.13	22.662
2	5	7.5	3.2	6	18	3.804	3.82	21.0836
2	6	9	3.2	6	16	3.624	3.58	20.5576
2	7	10.5	3.2	6	16	3.624	3.39	20.5576
2	8	12	3.2	6	12	3.264	3.24	19.5056
2	9	13.5	3.2	6	12	3.264	3.1	19.5056
2	10	15	3.2	6	10	3.084	2.98	18.9796
2	11	16.5	3.2	6	10	3.084	2.88	18.9796
2	12	18	3.2	6	6	2.724	2.79	17.9276
2	13	19.5	3.2	6	6	2.724	2.71	17.9276
2	14	21	3.2	6	6	2.724	2.64	17.9276
2	15	22.5	3.2	6	6	2.724	2.57	17.9276
3	3	4.5	3.2	6	30	4.884	4.8	24.2396
3	4	6	3.2	6	24	4.344	4.37	22.6616
3	5	7.5	3.2	6	22	4.164	4.05	22.1356
3	6	9	3.2	6	18	3.804	3.81	21.0836
3	7	10.5	3.2	6	16	3.624	3.61	20.5576
3	8	12	3.2	6	14	3.444	3.44	20.0316
3	9	13.5	3.2	6	14	3.444	3.3	20.0316
3	10	15	3.2	6	12	3.264	3.17	19.5056
3	11	16.5	3.2	6	10	3.084	3.06	18.9796
3	12	18	3.2	6	10	3.084	2.97	18.9796
3	13	19.5	3.2	6	10	3.084	2.88	18.9796
3	14	21	3.2	6	10	3.084	2.81	18.9796
3	15	22.5	3.2	6	6	2.724	2.74	17.9276
5	3	4.5	3.2	6	34	5.244	5.15	25.2916
5	4	6	3.2	6	30	4.884	4.7	24.2396
5	5	7.5	3.2	6	24	4.344	4.37	22.6616
5	6	9	3.2	6	22	4.164	4.1	22.1356
5	7	10.5	3.2	6	18	3.804	3.89	21.0836
5	8	12	3.2	6	18	3.804	3.72	21.0836
5	9	13.5	3.2	6	16	3.624	3.56	20.5576
5	10	15	3.2	6	16	3.624	3.43	20.5576
5	11	16.5	3.2	6	14	3.444	3.32	20.0316
5	12	18	3.2	6	12	3.264	3.21	19.5056
5	13	19.5	3.2	6	12	3.264	3.12	19.5056
5	14	21	3.2	6	10	3.084	3.04	18.9796
5	15	22.5	3.2	6	10	3.084	2.96	18.9796

Table 6.4: Structural Design of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3
Cost=c1d1+c2d2+c3d3+c4 (d1+d2+d3)
Where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor is taken 1
m3 = drainage factor is taken 1

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs (million)	CBR	MR(kip)	d1"	d2"	d3"	SN Calc.	SN Chart	$ cost
10	3	4.5	3.2	6	40	5.784	5.66	26.8696
10	4	6	3.2	6	34	5.244	5.18	25.2916
10	5	7.5	3.2	6	30	4.884	4.82	24.2396
10	6	9	3.2	6	26	4.524	4.54	23.1876
10	7	10.5	3.2	6	24	4.344	4.32	22.6616
10	8	12	3.2	6	22	4.164	4.13	22.1356
10	9	13.5	3.2	6	22	4.164	3.96	22.1356
10	10	15	3.2	6	18	3.804	3.82	21.0836
10	11	16.5	3.2	6	18	3.804	3.7	21.0836
10	12	18	3.2	6	16	3.624	3.58	20.5576
10	13	19.5	3.2	6	16	3.624	3.49	20.5576
10	14	21	3.2	6	14	3.444	3.39	20.0316
10	15	22.5	3.2	6	14	3.444	3.31	20.0316

15	3	4.5	4	12	30	6.06	5.96	32.098
15	4	6	4	12	24	5.52	5.46	30.52
15	5	7.5	4	12	20	5.16	5.1	29.468
15	6	9	4	12	16	4.8	4.81	28.416
15	7	10.5	4	12	14	4.62	4.57	27.89
15	8	12	4	12	12	4.44	4.37	27.364
15	9	13.5	4	12	10	4.26	4.2	26.838
15	10	15	4	12	10	4.26	4.06	26.838
15	11	16.5	4	12	6	3.9	3.92	25.786
15	12	18	4	12	6	3.9	3.81	25.786
15	13	19.5	4	12	6	3.9	3.7	25.786
15	14	21	4	12	6	3.9	3.61	25.786
15	15	22.5	4	12	6	3.9	3.52	25.786

20	3	4.5	4.8	12	28	6.216	6.2	34.4024
20	4	6	4	12	28	5.88	5.7	31.572
20	5	7.5	4	12	22	5.34	5.3	29.994
20	6	9	4	12	18	4.98	5	28.942
20	7	10.5	4	12	16	4.8	4.76	28.416
20	8	12	4	12	14	4.62	4.56	27.89
20	9	13.5	4	12	12	4.44	4.38	27.364
20	10	15	4	12	10	4.26	4.24	26.838
20	11	16.5	4	12	10	4.26	4.1	26.838
20	12	18	4	12	6	3.9	3.98	25.786
20	13	19.5	4	12	6	3.9	3.87	25.786
20	14	21	4	12	6	3.9	3.77	25.786
20	15	22.5	4	12	6	3.9	3.68	25.786

Table 6.5: Structural Design of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3

Cost=c1d1+c2d2+c3d3+c4 (d1+d2+d3)
Where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor is taken 1
m3 = drainage factor is taken 1

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs (million)	CBR	MR(kip)	d1"	d2"	d3"	SN Calc.	SN Chart	$ cost
30	3	4.5	4	12	36	6.6	6.52	33.676
30	4	6	4	12	30	6.06	5.99	32.098
30	5	7.5	4	12	24	5.52	5.59	30.52
30	6	9	4	12	24	5.52	5.29	30.52
30	7	10.5	4	12	18	4.98	5.04	28.942
30	8	12	4	12	18	4.98	4.83	28.942
30	9	13.5	4	12	12	4.44	4.64	27.364
30	10	15	4	12	12	4.44	4.49	27.364
30	11	16.5	4	12	12	4.44	4.35	27.364
30	12	18	4	12	12	4.44	4.23	27.364
30	13	19.5	4	12	10	4.26	4.11	26.838
30	14	21	4	12	10	4.26	4.01	26.838
30	15	22.5	4	12	6	3.9	3.91	25.786

50	3	4.5	4	12	42	7.14	6.95	35.254
50	4	6	4	12	36	6.6	6.38	33.676
50	5	7.5	4	12	30	6.06	5.97	32.098
50	6	9	4	12	28	5.88	5.65	31.572
50	7	10.5	4	12	22	5.34	5.39	29.994
50	8	12	4	12	22	5.34	5.17	29.994
50	9	13.5	4	12	18	4.98	4.98	28.942
50	10	15	4	12	18	4.98	4.82	28.942
50	11	16.5	4	12	16	4.8	4.66	28.416
50	12	18	4	12	16	4.8	4.53	28.416
50	13	19.5	4	12	12	4.44	4.42	27.364
50	14	21	4	12	12	4.44	4.31	27.364
50	15	22.5	4	12	10	4.26	4.21	26.838

Table 6.6: Resilient Modulus MR, ESALs and Cost

MR(kip)	$ Cost (0.05)	$ Cost (0.1)	$ Cost (0.2)	$ Cost (0.5)	$ Cost (0.75)	$ Cost (1.0)	$ Cost (2.0)	$ Cost (3.0)	$ Cost (5.0)	$ Cost (10.0)	$ Cost (15)	$ Cost (20)
4.5	16.1	16.7	19.5	21.1	21.6	22.1	23.7	24.2	25.3	26.9	32.1	32.6
6	15.1	16.1	19.0	20.0	21.1	21.1	22.7	22.7	24.2	25.3	30.5	31.6
7.5	13.5	15.1	17.9	19.0	20.6	20.0	21.1	22.1	22.7	24.2	29.5	30.0
9	13.5	13.5	17.9	19.0	20.0	19.5	20.6	21.1	22.1	23.2	28.4	28.9
10.5	13.5	13.5	17.9	17.9	19.5	19.0	20.6	20.6	21.1	22.7	27.9	28.4
12	13.5	13.5	17.9	17.9	19.0	19.0	19.5	20.0	21.1	22.1	27.4	27.9
13.5	13.5	13.5	16.3	17.9	19.0	17.9	19.5	20.0	20.6	22.1	26.8	27.4
15	13.5	13.5	16.3	17.9	19.0	17.9	19.0	19.5	20.6	21.1	26.8	26.8
16.5	13.5	13.5	16.3	17.9	17.9	17.9	19.0	19.0	20.0	21.1	25.8	26.8
18	13.5	13.5	16.3	17.9	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8
19.5	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8
21	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.0	20.0	25.8	25.8
22.5	13.5	13.5	16.3	16.3	17.9	17.9	17.9	17.9	19.0	20.0	25.8	25.8

Table 6.7: CBR, ESALs and Cost

CBR	$ Cost (0.05)	$ Cost (0.1)	$ Cost (0.2)	$ Cost (0.5)	$ Cost (0.75)	$ Cost (1.0)	$ Cost (2.0)	$ Cost (3.0)	$ Cost (5.0)	$ Cost (10.0)	$ Cost (15)	$ Cost (20)
3	16.1	16.7	19.5	21.1	21.6	22.1	23.7	24.2	25.3	26.9	32.1	32.6
4	15.1	16.1	19.0	20.0	21.1	21.1	22.7	22.7	24.2	25.3	30.5	31.6
5	13.5	15.1	17.9	19.0	20.6	20.0	21.1	22.1	22.7	24.2	29.5	30.0
6	13.5	13.5	17.9	19.0	20.0	19.5	20.6	21.1	22.1	23.2	28.4	28.9
7	13.5	13.5	17.9	17.9	19.5	19.0	20.6	20.6	21.1	22.7	27.9	28.4
8	13.5	13.5	17.9	17.9	19.0	19.0	19.5	20.0	21.1	22.1	27.4	27.9
9	13.5	13.5	16.3	17.9	19.0	17.9	19.5	20.0	20.6	22.1	26.8	27.4
10	13.5	13.5	16.3	17.9	19.0	17.9	19.0	19.5	20.6	21.1	26.8	26.8
11	13.5	13.5	16.3	17.9	17.9	17.9	19.0	19.0	20.0	21.1	25.8	26.8
12	13.5	13.5	16.3	17.9	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8
13	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8
14	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.0	20.0	25.8	25.8
15	13.5	13.5	16.3	16.3	17.9	17.9	17.9	17.9	19.0	20.0	25.8	25.8

Table 6.8: Resilient Modulus MR, ESALs and Structural number SN

MR	SN (0.05)	SN (0.1)	SN (0.2)	SN (0.5)	SN (0.75)	SN (1.0)	SN (2.0)	SN (3.0)	SN (5.0)	SN (10.0)	SN (15)	SN (20)
4.5	2.58	2.88	3.22	3.7	3.94	4.11	4.54	4.8	5.15	5.66	5.96	6.2
6	2.32	2.53	2.9	3.35	3.88	3.72	4.13	4.37	4.7	5.18	5.46	5.7
7.5	2.1	2.34	2.67	3.09	3.59	3.44	3.82	4.05	4.37	4.82	5.1	5.3
9	1.97	2.2	2.5	2.88	3.365	3.22	3.58	3.81	4.1	4.54	4.81	5
10.5	1.86	2.08	2.36	2.72	3.18	3.05	3.39	3.61	3.89	4.32	4.57	4.76
12	1.76	1.98	2.25	2.59	3.03	2.9	3.24	3.44	3.72	4.13	4.37	4.56
13.5	1.68	1.89	2.15	2.48	2.905	2.78	3.1	3.3	3.56	3.96	4.2	4.38
15	1.61	1.82	2.06	2.39	2.8	2.67	2.98	3.17	3.43	3.82	4.06	4.24
16.5	1.55	1.75	1.99	2.3	2.7	2.58	2.88	3.06	3.32	3.7	3.92	4.1
18	1.5	1.69	1.92	2.23	2.61	2.5	2.79	2.97	3.21	3.58	3.81	3.98
19.5	1.45	1.64	1.86	2.16	2.54	2.43	2.71	2.88	3.12	3.49	3.7	3.87
21	1.4	1.59	1.81	2.1	2.47	2.36	2.64	2.81	3.04	3.39	3.61	3.77
22.5	1.36	1.55	1.76	2.05	2.405	2.3	2.57	2.74	2.96	3.31	3.52	3.68

Table 6.9: CBR, ESALs and Structural number SN

CBR	SN (0.05)	SN (0.1)	SN (0.2)	SN (0.5)	SN (0.75)	SN (1.0)	SN (2.0)	SN (3.0)	SN (5.0)	SN (10.0)	SN (15)	SN (20)
3	2.58	2.88	3.22	3.7	3.94	4.11	4.54	4.8	5.15	5.66	5.96	6.2
4	2.32	2.53	2.9	3.35	3.88	3.72	4.13	4.37	4.7	5.18	5.46	5.7
5	2.1	2.34	2.67	3.09	3.59	3.44	3.82	4.05	4.37	4.82	5.1	5.3
6	1.97	2.2	2.5	2.88	3.365	3.22	3.58	3.81	4.1	4.54	4.81	5
7	1.86	2.08	2.36	2.72	3.18	3.05	3.39	3.61	3.89	4.32	4.57	4.76
8	1.76	1.98	2.25	2.59	3.03	2.9	3.24	3.44	3.72	4.13	4.37	4.56
9	1.68	1.89	2.15	2.48	2.905	2.78	3.1	3.3	3.56	3.96	4.2	4.38
10	1.61	1.82	2.06	2.39	2.8	2.67	2.98	3.17	3.43	3.82	4.06	4.24
11	1.55	1.75	1.99	2.3	2.7	2.58	2.88	3.06	3.32	3.7	3.92	4.1
12	1.5	1.69	1.92	2.23	2.61	2.5	2.79	2.97	3.21	3.58	3.81	3.98
13	1.45	1.64	1.86	2.16	2.54	2.43	2.71	2.88	3.12	3.49	3.7	3.87
14	1.4	1.59	1.81	2.1	2.47	2.36	2.64	2.81	3.04	3.39	3.61	3.77
15	1.36	1.55	1.55	2.05	2.405	2.3	2.57	2.74	2.96	3.31	3.52	3.68

7 CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusion

Regarding to the aim and main objects of the thesis we can match the following outputs:

7.1.1 Road classification

Classification of roads in function of the ESALs in the Gaza strip is prepared as shown in Table 5.13

Table 5.13: Proposed Road Classification According to ESALs

Road class	Total Design ESALs(million)
Residential	Up to 0.10.
Residential A	0.05-0.10.
Residential B	< 0.05
Local	0.1 < ESAL≤ 1
Local A	0.75 - 1
Local B	0.5 – 0.75
Local C	0.2 - 0.5
Local D	0.1 - 0.2
Minor Collector	1< ESAL≤2
Major Collector	2 < ESAL≤ 5
Minor Arterial	5 < ESAL≤ 10
Major Arterial	10< ESAL≤15
Inter governorates	15 < ESAL≤30

The low ESALs categories represented in residential and local roads were focused and given more intervals since they constitute the high percent of area of all road categories.

7.1.2 Amendment of specifications

Amendment of the specifications of road constructions of the different national and international institutes was one of the main objectives of this thesis. Amendment will deal with the subject of subgrede preparation. The amended specification should specify the minimum bearing capacity of the different type of subgrede soil represented in the CBR value required to meet the ESALs of the road during the design period across the area of the Gaza strip and should give general brief comparison on the cost of the different layers of the road pavement. In other words amendment of specification should include roads classification according to the ESALs, the minimum subgrade CBR values as shown in Table 7.1 below, which combined the minimum subgrade CBR value Table 4.11 and the road classification Table 5.13. Chart 4.2, in Chapter 4, also is an interpretation of Table 4.11.

Table 4.11: Minimum Subgrade CBR Values and the Total Design ESALs Million

No	ESALs (million)	Recommended minimum CBR value before replacement (%)
1	≤0.3	3
2	0.3< ESAL ≤ 1	4
3	1< ESAL ≤ 2	5
4	2< ESAL ≤ 20	6
5	20< ESAL ≤ 30	7
6	30< ESAL ≤ 50	8

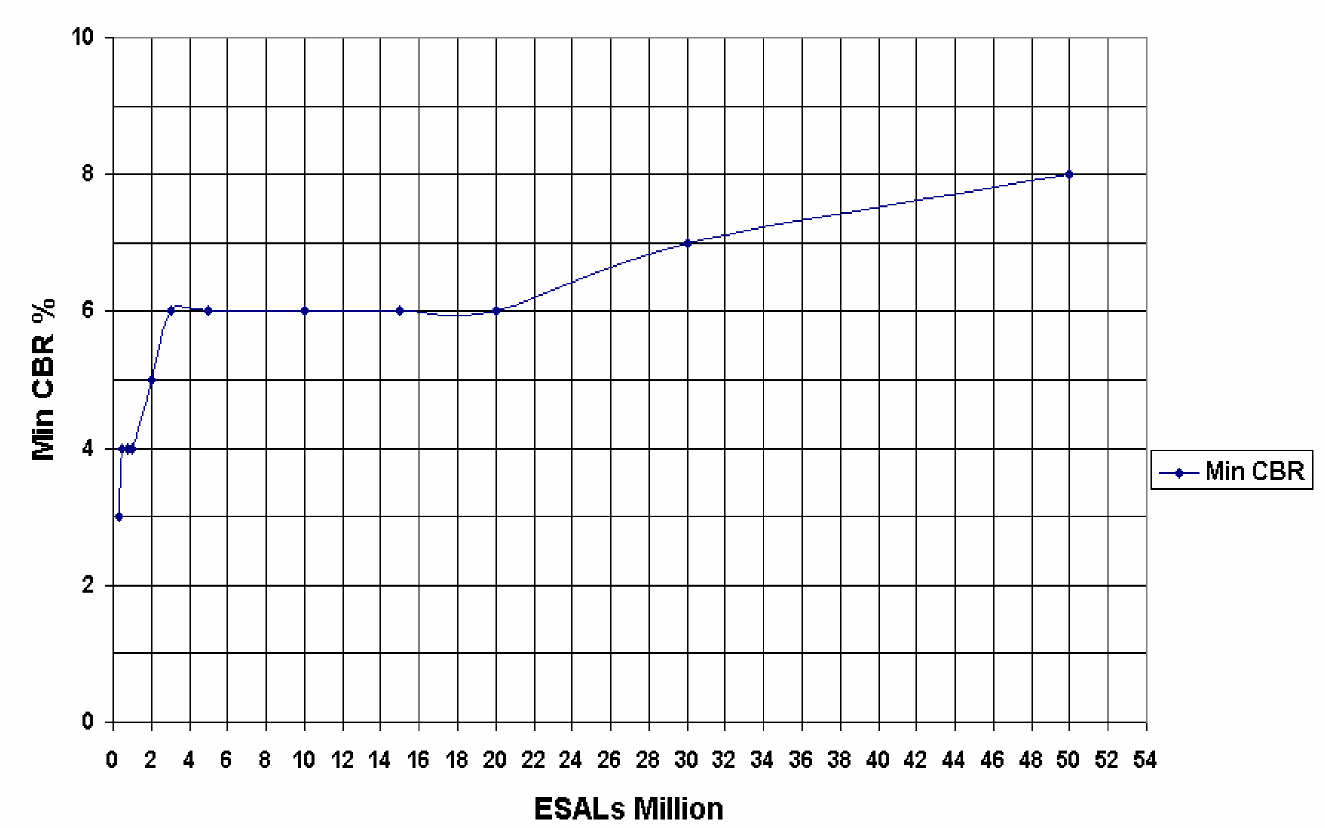


Fig 4.4 : Min CBR -Design ESALs

Table 7.1: Road classification and the minimum subgrade CBR value with the ESALs (million)

Road class No	Road class	ESALs million	Minimum CBR
1	Local & Residential	≤0.3	3
2	Local	0.3< ESAL ≤ 1	4
3	Minor collector	1< ESAL ≤ 2	5
4	Major collector, arterial. & inter governorates	2< ESAL ≤ 20	6
5	inter governorates	20< ESAL ≤ 30	7
6	inter governorates	30< ESAL ≤ 50	8

7.1.3 Proposed specification for subgrade preparation

7.1.3.1 General

The "Subgrade" is the in situe material upon which the pavement structure is placed, or it is the bottom of the excavation for the pavement, or top of the fill. Subgrade is the most important factor in pavement performance which the processes of determination of the total thickness of pavement relay on.

7.1.3.2 Excavation

Contractor shall include excavation as required to provide a smooth, gentle slope to meet the existing adjacent ground surfacing. For the sub-grade preparation he shall scarify a layer of an adequate area and suitable depth not less than 300 mm, and the soil shall pulverized, mixed, shaped, compacted and finished, all in accordance with the Specifications.

After the completion of compaction, subgrade should conform to levels, grades, horizontal alignment, vertical alignment and cross section according to the drawings or as approved by the director of work or his representative.

7.1.3.3 Subgrade Bearing Capacity

Before road construction, subgrade soil should be tested to determine the CBR in accordance of AASHTO 193. At least one bore hole should be considered for every 100m of the road length or as approved by the director of work or his representative. The absolute minimum CBR value is 3 for all road categories, below which subgrade soil should be replaced or improved. The minimum CBR value for the different roads categories should be according to Table 4.18 which should be included in the specifications.

When the upper 300 mm below the subgrade elevation of earth cut is found to be incapable of compaction as specified and failed to satisfy the minimum absolute CBR value 3, or the corresponding value indicated in Table 4.18 with respect to road categories, the contractor shall replace the upper 300 mm of the subgrade layer with a selected granular material of minimum CBR 30. Classification of roads shall be the responsibility of the designer, the director of work or his representative

7.1.3.4 COMPACTION

Enough compaction should be carried out to a reasonable depth. Compaction of the subgrade soil during construction should be at least 95% of AASHTO T-193. Generally reasonable depth of compaction is between 6-12 inches (15-30cm). Due to the variation of density of soil with water content, laboratory tests on the subgrade soil with different water content are carried out to determine the optimum water content to meet the maximum dry density required for specifications.

7.1.4 Cost analysis

On the level of cost analysis, and taking into consideration the bearing capacity or the strength of the pavement layers, expressed in structural number SN, cost analysis in Chapter 4 was made. It was clarified that the kurker layer depth needed to give the same structural number as that of asphalt or base course layer is of the most economical cost of the other layers.

7.1.5 Design tables

Regarding to the design tables, the application of the AASHTO modified equation solver and the structural number equation with the cost and total cost of layers, establish a very useful design tables. Design and cost charts were derived from these tables could be used also.

Design table with schematic sections of pavement layers is also derived from those tables.

These tables enable the designer to deal directly with the subgrade soil replacement or improvement.

As noted in the first sentence of the introduction in this thesis the progress and welfare of any country depends on the development of infrastructure assists especially the transportation and more and more on the road net work .

Construction of a complete road net work in the next future, especially with the intention to build a new port on Gaza coastal and with the development of the residential areas of cities, continuous rehabilitation and maintenance of road net work, all this will push towards the big care with this vital sector in the society. It is the road industry sector.

7.2 Recommendations

Passing through this thesis, especially Chapter 3, 4 and 5, the following recommendations could be noted.

7.2.1 Traffic count

1- The count should be carried out by a group of qualified persons, 4 persons for each point of count continuously for 24 hours. The first two persons should carry out the count during the first 12 hours from 5 o'clock in the morning to 5 o'clock in the evening and next two persons should complete the count in the next 12 hours from 5 o'clock in the evening to 5 o'clock in the morning.

2- The count shall include the status of trucks, whatever the truck is empty or loaded.

3- Traffic count points on roads shall be chosen carefully where heavy trucks are expected.

4- Surveying of the existing heavy and light trucks should be prepared. Up-to-date information could be found in the ministry of transportation or in the consultant engineer office, Mr. Wael daoud who works for the ministry.

Light traffic of weights from 4.5 tonne to 18.o tonne constitutes a big category of vehicles. They should be classified in groups 4.5 -9.0, 9 – 14, 14 – 18tonne. ESALs are calculated for each group and they should be included in the future traffic count.

5- More count point shall be chosen for the residential, local and collector roads, since they constitute the biggest percent of the area of roads.

6- Count point shall cover all the roads categories of the Gaza strip.

7.2.2 Regulations and rules

Strict specific traffic regulations and rules should be applied on people, roads, and vehicles, especially heavy trucks.

For example, some roads should be forbidden against heavy trucks of total weight greater than 20 tonne.

Overloaded trucks should be subjected to strict punishment.

Any forbidden pulled material on roads, like steel reinforcement or wood should be subjected to strict punishment.

7.2.3 Costing

1- Updating the cost of supplying and constructing pavement layers.

2- Trials should be carried out to find alternatives for the base layer and for the subbase layer (kurkar)

3- Sub base kurkar layer should be the deepest layer, since the cost of the unit structural number of kurkar layer is the lowest

.

7.2.4 Laboratory tests

1- CBR tests for all roads, especially dust roads should be made and a map of the Gaza stripe could be used with the aid of GIS to indicate the values of CBR or at least the type of soil according to one of the international classification systems.

7.2.5 Design

1- It's strongly recommended for design to find the expected ESALs during the design period. Knowing of the road class may lead to ESALs prediction. Traffic count could be very useful when design is required for the reconstruction or rehabilitation of important roads.

2- As mentioned above Sub base kurkar layer should be the deepest layer.

7.2.6 Construction

1- Compaction of the subgrade layer is very important in the construction stages of road; it should be at least 95 % of AASHTO T-99 or ASTM D 698 for cohesive clay soil or at least 95% of AASHTO T-180 or ASTM D15777 for non cohesive soil (sandy and gravelly).

For the soundness and durability of pavement, compaction of sub base, base and surface layers also is very important

2- Levels and alignment of the subgrade should be implemented carefully.

7.2.7 General

Farther study on the same subject could support and enhance the results and conclusions obtained in this thesis.

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APPENDICES

Table 4.4: Roads characteristics summery list according the Design ESALs/Lane

Road	Directio	T.traffic	Daily.ESAL	Design ESAL	truck No	%Truck	**ATF**	D.ESAL/L
Salah Eddin Khan Younis	N	5125	1900.8	13.876	429	8.36%	**0.371**	9.713
Salah Eddin Khan Younis	S	5384	1894.1	13.827	418	7.76%	**0.352**	9.679
Al rashid Nuseirat	N	6176	2001.2	14.609	393	6.37%	**0.324**	10.226
Al rashid Gaza	N	9443	2697.9	19.695	534	5.66%	**0.286**	13.786
Al rashid Nuseirat	S	5615	1591.8	11.620	328	6%	**0.283**	8.134
Al rashid Gaza	S	9922	2735.2	19.967	533	5.37%	**0.276**	13.977
Salah Eddin Gaza	N	6752	1781.8	13.007	382	5.66%	**0.264**	9.105
Salah Eddin Gaza	S	7902	1859.6	13.575	409	5.17%	**0.235**	9.502
Big Mosque	E	22	5.173	0.038	1	5%	**0.235**	0.038
Jamal A. Najm-N.ED Gaza	W	10689	2108.3	15.391	446	4.17%	**0.197**	12.313
Abu Khaled Prep Girl	S	55	10.601	0.077	3	5%	**0.193**	0.077
Jamal Abdel Nasser Gaza	E	9332	1738.6	12.692	366	3.92%	**0.186**	10.153
Jamal Abdel Nasser Gaza	W	8818	1601.8	11.693	344	3.90%	**0.182**	9.355
Jamal A. Najm-N.ED Gaza	E	14636	2466.7	18.007	529	3.61%	**0.169**	14.406
Al Quds Bureij	w	500	83.6	0.611	20	4.00%	**0.167**	0.611
Big Mosque	W	32	5.318	0.039	1	3%	**0.1662**	0.039
Abu Khaled Prep Girl	N	65	10.746	0.078	3	5%	**0.165**	0.078
Al Jalaa Gaza	N	9029	1415.0	10.329	353	3.91%	**0.157**	7.231
Al Quds Bureij	E	491	69.519	0.507	14	3%	**0.142**	0.507
Al Jalaa Gaza	S	8270	1151.3	8.405	273	3.30%	**0.139**	5.883
Al Jalaa -T .B. Ziad Gaza	N	12369	1499.2	10.944	310	2.50%	**0.121**	7.661
Al Jalaa -O.B.Khatab Gaza	N	11598	1265.2	9.236	262	2.26%	**0.109**	6.465
Jamal A. N.-M.Hafed Gaza	E	13315	1406.8	10.270	278	2.09%	**0.106**	8.216
Al-Shohada bureij	E	3802	385.5	2.814	99	2.61%	**0.101**	2.251
Al Jalaa -O.B.Khatab Gaza	S	13312	1311.9	9.577	265	1.99%	**0.099**	6.704
Al Jalaa -T .B. Ziad Gaza	S	12493	1228.4	8.967	251	2.01%	**0.098**	6.277
Palestine	S	1185	113.2	0.826	25	2.11%	**0.096**	0.826
Al-Shohada bureij	W	4387	401.7	2.933	110	2.50%	**0.092**	2.346
Khaled Al hassan	W	1239	112.9	0.824	25	2.02%	**0.091**	0.824
Al Kholafa	N	885	78.059	0.570	17	2%	**0.088**	0.570
Al Kholafa	S	665	56.982	0.416	12	2%	**0.086**	0.416
palestine	N	943	80.2	0.585	18	1.91%	**0.085**	0.585
Jamal A. N.-M.Hafed Gaza	W	11783	888.6	6.487	167	1.41%	**0.075**	5.190
Khaled Al hassan	E	1174	83.5	0.609	18	1.53%	**0.071**	0.609
Al-Nasser- Amin Gaza	S	15452	682.2	4.980	128	0.83%	**0.044**	3.984
Al-Nasser- Amin Gaza	N	15828	657.7	4.801	118	0.75%	**0.042**	3.841
Al-Nasser- Al-Thoura Gaza	N	10780	426.2	3.111	75	0.70%	**0.040**	2.489
Al-Nasser- Al-Thoura Gaza	S	8972	287.8	2.101	128	1.43%	**0.032**	1.681

Table 4.4: Roads characteristics summery list according the ATFM1

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al Jalaa -T .B. Ziad Gaza	N	12369	1499.2	**10.944**	310	2.50%	0.121	**7.661**
Al Jalaa Gaza	N	9029	1415.0	**10.329**	353	3.91%	0.157	**7.231**
Al Jalaa -O.B.Khatab Gaza	S	13312	1311.9	**9.577**	265	1.99%	0.099	**6.704**
Al Jalaa -O.B.Khatab Gaza	N	11598	1265.2	**9.236**	262	2.26%	0.109	**6.465**
Al Jalaa -T .B. Ziad Gaza	S	12493	1228.4	**8.967**	251	2.01%	0.098	**6.277**
Al Jalaa Gaza	S	8270	1151.3	**8.405**	273	3.30%	0.139	**5.883**
Al Jala Average		11178	1312	**9.576**	286	2.66%	0.121	**6.703**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al rashid Gaza	S	9922	2735.2	**19.967**	533	5.37%	0.276	**13.977**
Al rashid Gaza	N	9443	2697.9	**19.695**	534	5.66%	0.286	**13.786**
Al rashid Gaza Average		9682	2717	**19.831**	533	5.51%	0.281	**13.881**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al-Nasser- Amin Gaza	S	15452	682.2	**4.980**	128	0.83%	0.044	**3.984**
Al-Nasser- Amin Gaza	N	15828	657.7	**4.801**	118	0.75%	0.042	**3.841**
Al-Nasser- Al-Thoura Gaza	N	10780	426.2	**3.111**	75	0.70%	0.040	**2.489**
Al-Nasser- Al-Thoura Gaza	S	8972	287.8	**2.101**	128	1.43%	0.032	**1.681**
Al-Nasser Average		12758	513.5	**3.748**	112	0.92%	0.039	**2.999**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al rashid Nuseirat	N	6176	2001.2	**14.609**	393	6.37%	0.324	**10.226**
Al rashid Nuseirat	S	5615	1591.8	**11.620**	328	6%	0.283	**8.134**
Al rashid Nuseirat Average		5895	1796.5	**13.11468975**	361	0.061	0.304	**9**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Jamal A. Najm-N.ED Gaza	E	14636	2466.7	**18.007**	529	3.61%	0.169	**14.406**
Jamal A. Najm-N.ED Gaza	W	10689	2108.3	**15.391**	446	4.17%	0.197	**12.313**
Jamal Abdel Nasser Gaza	E	9332	1738.6	**12.692**	366	3.92%	0.186	**10.153**
Jamal Abdel Nasser Gaza	W	8818	1601.8	**11.693**	344	3.90%	0.182	**9.355**
Jamal A. N.-M.Hafed Gaza	E	13315	1406.8	**10.270**	278	2.09%	0.106	**8.216**
Jamal A. N.-M.Hafed Gaza	W	11783	888.6	**6.487**	167	1.41%	0.075	**5.190**
Jamal A Average		11429	1701.8	**12.423**	354.98	3%	0.152	**9.939**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Salah Eddin Gaza	S	7902	1859.6	**13.575**	409	5.17%	0.235	**9.502**
Salah Eddin Gaza	N	6752	1781.8	**13.007**	382	5.66%	0.264	**9.105**

Salah Eddin Gaza Average		7327	1820.7	**13.291**	395.6	5%	0.250	**9.304**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Salah Eddin Khan Younis	N	5125	1900.8	**13.876**	429	8.36%	0.371	**9.713**
Salah Eddin Khan Younis	S	5384	1894.1	**13.827**	418	7.76%	0.352	**9.679**
Salah Eddin Khan Younis Average		5254	1897.5	**13.851**	423.2	8%	0.361	**9.696**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Palestine	S	1185	113.2	**0.826**	25	2.11%	0.096	**0.826**
palestine	N	943	80.2	**0.585**	18	1.91%	0.085	**0.585**
Palestine Average		1064	96.685	**0.706**	21.5	2%	0.090	**0.706**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Khaled Al hassan	W	1239	112.9	**0.824**	25	2.02%	0.091	**0.824**
Khaled Al hassan	E	1174	83.5	**0.609**	18	1.53%	0.071	**0.609**
Khaled Al hassan Average		1207	98.200	**0.717**	21.5	2%	0.081	**0.717**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Abu Khaled Prep Girl	N	65	10.746	**0.078**	3	5%	0.165	**0.078**
Abu Khaled Prep Girl	S	55	10.601	**0.077**	3	5%	0.193	**0.077**
Abu Khaled Prep Girl Average		60	10.674	**0.078**	3	5%	0.179	**0.078**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al Kholafa	N	885	78.059	**0.570**	17	2%	0.088	**0.570**
Al Kholafa	S	665	56.982	**0.416**	12	2%	0.086	**0.416**
Al Kholafa Average		775	67.521	**0.493**	15	2%	0.087	**0.493**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	**ATF**	D.ESAL/L
Al-Shohada bureij	E	3802	385.5	**2.814**	99	2.61%	**0.101**	2.251
Al-Shohada bureij	W	4387	401.7	**2.933**	110	2.50%	**0.092**	2.346
Al-Shohada bureij average		4094	**393.594**	**2.873**	104	**0.026**	**0.096**	**2.299**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al Quds Bureij	w	500	83.6	**0.611**	20	4.00%	0.167	**0.611**
Al Quds Bureij	E	491	69.519	**0.507**	14	3%	0.142	**0.507**
Al Quds Bureij Average		496	76.581	**0.559**	17	3%	0.154	**0.559**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Big Mosque	W	32	5.318	**0.039**	1	3%	0.1662	**0.039**
Big Mosque	E	22	5.173	**0.038**	1	5%	0.235	**0.038**

Big Mosque Average		27	5.246	**0.038**	1	4%	0.201	**0.038**

Road	**Directio**	**T.traffic**	**Daily.ESAL**	**Design ESAL**	**truck N**	**%Truck**	**ATF**	**D.ESAL/L**
Salah Eddin Khan Younis Average		5254	1897.5	13.851	423.2	8%	**0.361**	9.696
Al rashid Nuseirat Average		5895	1796.5	13.11468975	361	0.061	**0.304**	9
Al rashid Gaza Average		9682	2717	19.831	533	5.51%	**0.281**	13.881
Salah Eddin Gaza Average		7327	1820.7	13.291	395.6	5%	**0.250**	9.304
Big Mosque Average		27	5.246	0.038	1	4%	**0.201**	0.038
Abu Khaled Prep Girl Average		60	10.674	0.078	3	5%	**0.179**	0.078
Al Quds Bureij Average		496	76.581	0.559	17	3%	**0.154**	0.559
Jamal A Average		11429	1701.8	12.423	354.98	3%	**0.152**	9.939
Al Jala Average		11178	1312	9.576	286	2.66%	**0.121**	6.703
Al-Shohada bureij average		4094	393.594	2.873	104	0.026	**0.096**	2.299
Palestine Average		1064	96.685	0.706	21.5	2%	**0.090**	0.706
Al Kholafa Average		775	67.521	0.493	14.5	2%	**0.087**	0.493
Khaled Al hassan Average		1207	98.200	0.717	21.5	2%	**0.081**	0.717
Al-Nasser Average		12758	513.5	3.748	112	0.92%	**0.039**	2.999

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Big Mosque Average		27	5.246	**0.038**	1	4%	0.201	**0.038**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Abu Khaled Prep Girl Average		60	10.674	**0.078**	3	5%	0.179	**0.078**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al Kholafa Average		775	67.521	**0.493**	14.5	2%	0.087	**0.493**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Khaled Al hassan Average		1207	98.200	**0.717**	21.5	2%	0.081	**0.717**
Palestine Average		1064	96.685	**0.706**	21.5	2%	0.090	**0.706**
Al Quds Bureij Average		496	76.581	**0.559**	17	3%	0.154	**0.559**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al-Nasser Average		12758	513.5	**3.748**	112	0.92%	0.039	**2.999**
Al-Shohada bureij average		4094	393.594	**2.873**	104	0.026	0.096	**2.299**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Jamal A Average		11429	1701.8	**12.423**	354.98	3%	0.152	**9.939**
Salah Eddin Khan Younis Average		5254	1897.5	**13.851**	423.2	8%	0.361	**9.696**
Salah Eddin Gaza Average		7327	1820.7	**13.291**	395.6	5%	0.250	**9.304**
Al rashid Nuseirat Average		5895	1796.5	**13.11468975**	361	0.061	0.304	**9**
Al Jala Average		11178	1312	**9.576**	286	2.66%	0.121	**6.703**

Road	Directio	T.traffic	Daily.ESAL	**Design ESAL**	truck No	%Truck	ATF	**D.ESAL/L**
Al rashid Gaza Average		9682	2717	**19.831**	533	5.51%	0.281	**13.881**

Worksheet 1: Application of AASHTO Modfied Equation for Flexible Pavement, ESALS=0.05-50(million psi, CBR=3-15

AASHTO Modefied Equation

log10 (W18) = $Z_R S_0$ + 9.36*log10 (SN+1) – 0.2 + log10 (ΔPSI /4.2-1.5) / (0.4+1094/ (SN+1)5.19) +2.32x log10 (MR) -8.07

Where:
W_{18} = 18-kip equivalent single axle load
Z_R = reliability — 0.95 for ESAL>0.5 million, 0.80 for ESAL<1million
S_0 = overall standard deviation — 0.42
SN = structural number
ΔPSI = design present serviceability loss — 2
MR = resilient modulus of the subgrade soil

W_{18}	$log_{10}(W_{18})$	$Z_R S_0$	9.36*log_{10}(SN+1))	$(SN+1)^{5.19}$	M_R	log_{10}(MR)	ΔPSI	4.2-1.5	1094/(SN+1)5.19	SN	eqn right side	log_{10}(h5/i5)	0.4+E11	log10(h5/i5)/F11
0.05	-1.30103	0.336	5.184345129	749.2951271	4.5	0.653212514	2	2.7	1.460038856	2.58	-1.304272293	-0.130333768	1.860038856	-0.070070455
0.05	-1.30103	0.336	4.877852463	506.6483754	6	0.77815125	2	2.7	2.159288479	2.32	-1.301762418	-0.130333768	2.559288479	-0.050925783
0.05	-1.30103	0.336	4.599145454	354.9500086	7.5	0.875061263	2	2.7	3.082124168	2.1	-1.3421418	-0.130333768	3.482124168	-0.037429386
0.05	-1.30103	0.336	4.425000366	284.1881546	9	0.954242509	2	2.7	3.849562278	1.97	-1.32582694	-0.130333768	4.249562278	-0.030669928
0.05	-1.30103	0.336	4.27158607	233.6359729	10.5	1.021189299	2	2.7	4.682498103	1.86	-1.318898399	-0.130333768	5.082498103	-0.025643643
0.05	-1.30103	0.336	4.126909008	194.2308165	12	1.079181246	2	2.7	5.632473876	1.76	-1.324995861	-0.130333768	6.032473876	-0.02160536
0.05	-1.30103	0.336	4.007341672	166.7322385	13.5	1.130333768	2	2.7	6.561418533	1.68	-1.323006285	-0.130333768	6.961418533	-0.0187223
0.05	-1.30103	0.336	3.899755149	145.3329982	15	1.176091259	2	2.7	7.527540294	1.61	-1.322153762	-0.130333768	7.927540294	-0.016440631
0.05	-1.30103	0.336	3.805216089	128.8082075	16.5	1.217483944	2	2.7	8.493247609	1.55	-1.318876523	-0.130333768	8.893247609	-0.014655363
0.05	-1.30103	0.336	3.724718481	116.2274327	18	1.255272505	2	2.7	9.412579926	1.5	-1.310331621	-0.130333768	9.812579926	-0.013282314
0.05	-1.30103	0.336	3.64259455	104.6578908	19.5	1.290034611	2	2.7	10.45310575	1.45	-1.310534043	-0.130333768	10.85310575	-0.012008891
0.05	-1.30103	0.336	3.558777222	94.03647575	21	1.322219295	2	2.7	11.6337835	1.4	-1.31850467	-0.130333768	12.0337835	-0.010830656
0.05	-1.30103	0.336	3.490456348	86.1813505	22.5	1.352182518	2	2.7	12.69416171	1.36	-1.316433789	-0.130333768	13.09416171	-0.009953579

0.1	-1	0.336	5.511464952	1137.723309	4.5	0.653212514	2	2.7	0.96156947	2.88	-1.002805203	-0.130333768	1.36156947	-0.095723187
0.1	-1	0.336	5.127171242	696.547473	6	0.77815125	2	2.7	1.570603645	2.53	-1.067656864	-0.130333768	1.970603645	-0.066139007
0.1	-1	0.336	4.902266929	522.6899656	7.5	0.875061263	2	2.7	2.093018944	2.34	-1.053870433	-0.130333768	2.493018944	-0.052279494
0.1	-1	0.336	4.728203797	418.5317289	9	0.954242509	2	2.7	2.613899794	2.2	-1.035197809	-0.130333768	3.013899794	-0.043244228
0.1	-1	0.336	4.572834706	343.2244507	10.5	1.021189299	2	2.7	3.187418605	2.08	-1.028336914	-0.130333768	3.587418605	-0.036330795
0.1	-1	0.336	4.438664232	289.1894269	12	1.079181246	2	2.7	3.782987545	1.98	-1.022793335	-0.130333768	4.182987545	-0.031158058
0.1	-1	0.336	4.314003808	246.6378943	13.5	1.130333768	2	2.7	4.43565253	1.89	-1.024574523	-0.130333768	4.83565253	-0.026952674
0.1	-1	0.336	4.214331654	217.1665201	15	1.176091259	2	2.7	5.037608926	1.82	-1.015105574	-0.130333768	5.437608926	-0.023968949
0.1	-1	0.336	4.112154014	190.6060498	16.5	1.217483944	2	2.7	5.73958697	1.75	-1.018511661	-0.130333768	6.13958697	-0.021228426
0.1	-1	0.336	4.022481341	169.9864614	18	1.255272505	2	2.7	6.435806659	1.69	-1.018352781	-0.130333768	6.835806659	-0.019066333
0.1	-1	0.336	3.946212756	154.2142054	19.5	1.290034611	2	2.7	7.094028706	1.64	-1.012298629	-0.130333768	7.494028706	-0.017391683
0.1	-1	0.336	3.868485792	139.6451239	21	1.322219295	2	2.7	7.834143934	1.59	-1.013793898	-0.130333768	8.234143934	-0.015828454
0.1	-1	0.336	3.805216089	128.8082075	22.5	1.352182518	2	2.7	8.493247609	1.55	-1.006375832	-0.130333768	8.893247609	-0.014655363

Worksheet 1: Application of AASHTO Modfied Equation for Flexible Pavement, ESALS=0.05-50(million psi, CBR=3-15

AASHTO Modefied Equation

log10 (W18) = Z_RS_0 + 9.36*log10 (SN+1) – 0.2 + log10 (ΔPSI /4.2-1.5) / (0.4+1094/ (SN+1)5.19) +2.32x log10 (MR) -8.07

Where:
W_{18} = 18-kip equivalent single axle load
Z_R = reliability 0.95
S_0 = overall standard deviation 0.35
SN = structural number
ΔPSI = design present serviceability loss 2
MR = resilient modulus of the subgrade soil

W_{18}	$log_{10}(W_{18})$	Z_RS_0	9.36*log_{10}(SN+1))	$(SN+1)^{5.19}$	M_R	log_{10}(MR)	ΔPSI	4.2-1.5	1094/(SN+1)5.19	SN	eqn right side	log_{10}(h5/i5)	0.4+E11	log10(h5/i5)/F11
0.2	-0.69897	0.336	5.852924541	1759.428492	4.5	0.653212514	2	2.7	0.621792818	3.22	-0.693176434	-0.130333768	1.021792818	-0.127554007
0.2	-0.69897	0.336	5.532364722	1168.490835	6	0.77815125	2	2.7	0.93625039	2.9	-0.693861313	-0.130333768	1.33625039	-0.097536936
0.2	-0.69897	0.336	5.285274361	852.3478568	7.5	0.875061263	2	2.7	1.283513522	2.67	-0.696001222	-0.130333768	1.683513522	-0.077417714
0.2	-0.69897	0.336	5.092476895	666.3664913	9	0.954242509	2	2.7	1.641739214	2.5	-0.691515163	-0.130333768	2.041739214	-0.06383468
0.2	-0.69897	0.336	4.926535636	539.1391252	10.5	1.021189299	2	2.7	2.02916084	2.36	-0.691959014	-0.130333768	2.42916084	-0.053653824
0.2	-0.69897	0.336	4.791228259	453.6016686	12	1.079181246	2	2.7	2.411807706	2.25	-0.685423555	-0.130333768	2.811807706	-0.046352305
0.2	-0.69897	0.336	4.664186783	385.6841346	13.5	1.130333768	2	2.7	2.836518026	2.15	-0.687708623	-0.130333768	3.236518026	-0.040269749
0.2	-0.69897	0.336	4.546352552	331.8136161	15	1.176091259	2	2.7	3.297031668	2.06	-0.694369352	-0.130333768	3.697031668	-0.035253625
0.2	-0.69897	0.336	4.452282323	294.2615155	16.5	1.217483944	2	2.7	3.717781437	1.99	-0.68880638	-0.130333768	4.117781437	-0.031651454
0.2	-0.69897	0.336	4.35598349	260.2177989	18	1.255272505	2	2.7	4.204170524	1.92	-0.694092062	-0.130333768	4.604170524	-0.028307763
0.2	-0.69897	0.336	4.27158607	233.6359729	19.5	1.290034611	2	2.7	4.682498103	1.86	-0.695177275	-0.130333768	5.082498103	-0.025643643
0.2	-0.69897	0.336	4.199891154	213.1993127	21	1.322219295	2	2.7	5.131348625	1.81	-0.690122829	-0.130333768	5.531348625	-0.023562747
0.2	-0.69897	0.336	4.126909008	194.2308165	22.5	1.352182518	2	2.7	5.632473876	1.76	-0.69163291	-0.130333768	6.032473876	-0.02160536

0.5	-0.301	0.336	6.29083595	3077.427871	4.5	0.65321251	2	2.7	0.355491679	3.7	-0.30022618	-0.130334	0.755492	-0.172515161
0.5	-0.301	0.336	5.976259445	2059.487895	6	0.77815125	2	2.7	0.531200015	3.35	-0.29239289	-0.130334	0.9312	-0.139963237
0.5	-0.301	0.336	5.725730163	1495.698192	7.5	0.87506126	2	2.7	0.731430984	3.09	-0.29332145	-0.130334	1.131431	-0.115193742
0.5	-0.301	0.336	5.511464952	1137.723309	9	0.95424251	2	2.7	0.96156947	2.88	-0.30441561	-0.130334	1.361569	-0.095723187
0.5	-0.301	0.336	5.340281917	914.3613454	10.5	1.0211893	2	2.7	1.196463527	2.72	-0.30619796	-0.130334	1.596464	-0.081639052
0.5	-0.301	0.336	5.195684039	760.2215705	12	1.07918125	2	2.7	1.439054142	2.59	-0.30548547	-0.130334	1.839054	-0.070870001
0.5	-0.301	0.336	5.069181723	646.8391177	13.5	1.13033377	2	2.7	1.691301546	2.48	-0.30476578	-0.130334	2.091302	-0.062321844
0.5	-0.301	0.336	4.962669175	564.5942277	15	1.17609126	2	2.7	1.937674787	2.39	-0.2985527	-0.130334	2.337675	-0.055753593
0.5	-0.301	0.336	4.853290477	491.0066205	16.5	1.21748394	2	2.7	2.228075864	2.3	-0.30573962	-0.130334	2.628076	-0.049592849
0.5	-0.301	0.336	4.766135609	439.2998863	18	1.25527251	2	2.7	2.490326162	2.23	-0.30072528	-0.130334	2.890326	-0.045093101
0.5	-0.301	0.336	4.677071093	392.0811459	19.5	1.29003461	2	2.7	2.790238734	2.16	-0.30490253	-0.130334	3.190239	-0.040853923
0.5	-0.301	0.336	4.599145454	354.9500086	21	1.32221929	2	2.7	3.082124168	2.1	-0.30473517	-0.130334	3.482124	-0.037429386

0.5	-0.301	0.336	4.539046496	326.2241936	22.5	1.35218252	2	2.7	3.353521969	2.05	-0.29861912	-0.130334	3.753522	-0.03472306

Worksheet 1: Application of AASHTO Modified Equation for Flexible Pavement, ESALS=0.05-50(million psi, CBR=3-15

AASHTO Modefied Equation

log10 (W18) = $Z_R S_0$ + 9.36*log10 (SN+1) – 0.2 + log10 (ΔPSI /4.2-1.5) / (0.4+1094/ (SN+1)5.19) +2.32x log10 (MR) -8.07

Where:

W_{18} = 18-kip equivalent single axle load
Z_R = reliability 0.95
S_0 = overall standard deviation 0.35
SN = structural number
ΔPSI = design present serviceability loss 2
MR = resilient modulus of the subgrade soil

W_{18}	$log_{10}(W_{18})$	$Z_R S_0$	9.36*log_{10}(SN+1))	$(SN+1)^{5.19}$	M_R	$log_{10}(MR)$	ΔPSI	4.2-1.5	1094/(SN+1)5.19	SN	eqn right side	log_{10}(h5/i5)	0.4+E11	log10(h5/i5)/F11
0.75	-0.1249	0.336	6.485047164	3943.442485	4.5	0.65321251	2	2.7	0.277422583	3.93	-0.12589635	-0.130334	0.677423	-0.192396551
0.75	-0.1249	0.336	6.158986673	2600.633476	6	0.77815125	2	2.7	0.420666738	3.55	-0.12851692	-0.130334	0.820667	-0.158814489
0.75	-0.1249	0.336	5.910313678	1893.185464	7.5	0.87506126	2	2.7	0.577862033	3.28	-0.12682861	-0.130334	0.977862	-0.133284415
0.75	-0.1249	0.336	5.70580367	1458.125765	9	0.95424251	2	2.7	0.750278218	3.07	-0.12766001	-0.130334	1.150278	-0.1133063
0.75	-0.1249	0.336	5.542774449	1184.124511	10.5	1.0211893	2	2.7	0.923889329	2.91	-0.12051401	-0.130334	1.323889	-0.098447631
0.75	-0.1249	0.336	5.394555038	979.9673527	12	1.07918125	2	2.7	1.116363721	2.77	-0.12169599	-0.130334	1.516364	-0.085951521
0.75	-0.1249	0.336	5.263061211	828.5142196	13.5	1.13033377	2	2.7	1.320435997	2.65	-0.12432069	-0.130334	1.720436	-0.075756244
0.75	-0.1249	0.336	5.150137385	717.2741052	15	1.17609126	2	2.7	1.52521887	2.55	-0.12302905	-0.130334	1.925219	-0.067698157
0.75	-0.1249	0.336	5.045752285	627.776353	16.5	1.21748394	2	2.7	1.742658822	2.46	-0.12451302	-0.130334	2.142659	-0.060828055
0.75	-0.1249	0.336	4.950660315	556.0036908	18	1.25527251	2	2.7	1.967612838	2.38	-0.12615607	-0.130334	2.367613	-0.055048598
0.75	-0.1249	0.336	4.865590022	498.777998	19.5	1.29003461	2	2.7	2.193360582	2.31	-0.12578639	-0.130334	2.593361	-0.050256709
0.75	-0.1249	0.336	4.791228259	453.6016686	21	1.32221929	2	2.7	2.411807706	2.25	-0.12157528	-0.130334	2.811808	-0.046352305
0.75	-0.1249	0.336	4.715480793	411.7879606	22.5	1.35218252	2	2.7	2.656707103	2.19	-0.12409438	-0.130334	3.056707	-0.042638619

1	0	0.336	6.622856848	4702.07134	4.5	0.65321251	2	2.7	0.23266342	4.1	-0.00169819	-0.130334	0.632663	-0.206008067
1	0	0.336	6.299475691	3111.562351	6	0.77815125	2	2.7	0.351591862	3.71	-0.00262371	-0.130334	0.751592	-0.173410298
1	0	0.336	6.050338877	2263.78584	7.5	0.87506126	2	2.7	0.483261261	3.43	-0.00107869	-0.130334	0.883261	-0.147559702
1	0	0.336	5.843280417	1737.897176	9	0.95424251	2	2.7	0.629496391	3.21	-0.0034765	-0.130334	1.029496	-0.126599539
1	0	0.336	5.675729577	1403.199059	10.5	1.0211893	2	2.7	0.779647045	3.04	0.00040336	-0.130334	1.179647	-0.110485394
1	0	0.336	5.532364722	1168.490835	12	1.07918125	2	2.7	0.93625039	2.9	0.00452828	-0.130334	1.33625	-0.097536936
1	0	0.336	5.394555038	979.9673527	13.5	1.13033377	2	2.7	1.116363721	2.77	-0.00302214	-0.130334	1.516364	-0.085951521
1	0	0.336	5.285274361	852.3478568	15	1.17609126	2	2.7	1.283513522	2.67	0.00238837	-0.130334	1.683514	-0.077417714
1	0	0.336	5.172974503	738.4958202	16.5	1.21748394	2	2.7	1.481389562	2.57	-0.00573802	-0.130334	1.88139	-0.069275269
1	0	0.336	5.080845996	656.5441952	18	1.25527251	2	2.7	1.666300621	2.49	-0.00399769	-0.130334	2.066301	-0.063075899
1	0	0.336	4.998484353	591.0108997	19.5	1.29003461	2	2.7	1.851065692	2.42	-0.00053405	-0.130334	2.251066	-0.057898696

1	0	0.336	4.926535636	539.1301252	21	1.32221929	2	2.7	2.02916084	2.36	-0.00643058	-0.130334	2.429161	-0.053653824
1	0	0.336	4.840953605	483.333292	22.5	1.35218252	2	2.7	2.26344847	2.29	-0.00491717	-0.130334	2.663448	-0.048934218

Worksheet 1: Application of AASHTO Modified Equation for Flexible Pavement, ESALS=0.05-50(million psi , CBR=3-15

AASHTO Modefied Equation

log10 (W18) = $Z_R S_0$ + 9.36*log10 (SN+1) – 0.2 + log10 (∆PSI /4.2-1.5) / (0.4+1094/ (SN+1)5.19) +2.32x log10 (MR) -8.07

Where:

W_{18} = 18-kip equivalent single axle load
Z_R = reliability 0.95
S_0 = overall standard deviation 0.35
SN = structural number
∆PSI = design present serviceability loss 2
MR = resilient modulus of the subgrade soil

W_{18}	$log_{10}(W_{18})$	$Z_R S_0$	$9.36*log_{10}(SN+1))$	$(SN+1)^{5.19}$	M_R	$log_{10}(MR)$	ΔPSI	4.2-1.5	1094/(SN+1)5.19	SN	eqn right side	$log_{10}(h5/i5)$	0.4+E11	log10(h5/i5)/F11
2	0.30103	0.3325	6.959251398	7224.631144	4.5	0.65321251	2	2.7	0.151426416	4.54	0.30084693	-0.130334	0.551426	-0.236357499
2	0.30103	0.3325	6.646698537	4847.402974	6	0.77815125	2	2.7	0.225687859	4.13	0.30620466	-0.130334	0.625688	-0.208304775
2	0.30103	0.3325	6.393320278	3507.632848	7.5	0.87506126	2	2.7	0.311891252	3.82	0.3028814	-0.130334	0.711891	-0.183081009
2	0.30103	0.3325	6.185700874	2690.86451	9	0.95424251	2	2.7	0.40656079	3.58	0.3004515	-0.130334	0.806561	-0.161591997
2	0.30103	0.3325	6.013467909	2159.687229	10.5	1.0211893	2	2.7	0.506554831	3.39	0.30135887	-0.130334	0.906555	-0.143768213
2	0.30103	0.3325	5.872144418	1803.137293	12	1.07918125	2	2.7	0.6067203	3.24	0.30888118	-0.130334	1.00672	-0.129463733
2	0.30103	0.3325	5.735656899	1514.775305	13.5	1.13033377	2	2.7	0.722219326	3.1	0.30439194	-0.130334	1.122219	-0.116139301
2	0.30103	0.3325	5.614905555	1298.354071	15	1.17609126	2	2.7	0.842605283	2.98	0.30104977	-0.130334	1.242605	-0.104887506
2	0.30103	0.3325	5.511464952	1137.723309	16.5	1.21748394	2	2.7	0.96156947	2.88	0.30280452	-0.130334	1.361569	-0.095723187
2	0.30103	0.3325	5.416063005	1007.250519	18	1.25527251	2	2.7	1.08612503	2.79	0.30309481	-0.130334	1.486125	-0.087700406
2	0.30103	0.3325	5.329339794	901.6761676	19.5	1.29003461	2	2.7	1.213295903	2.71	0.30393282	-0.130334	1.613296	-0.080787268
2	0.30103	0.3325	5.251908951	816.8008502	21	1.32221929	2	2.7	1.339371769	2.64	0.3070262	-0.130334	1.739372	-0.074931519
2	0.30103	0.3325	5.172974503	738.4958202	22.5	1.35218252	2	2.7	1.481389562	2.57	0.30326268	-0.130334	1.88139	-0.069275269

3	0.47712	0.3325	7.14568602	9166.241317	4.5	0.65321251	2	2.7	0.119350993	4.8	0.47268397	-0.130334	0.519351	-0.250955077
3	0.47712	0.3325	6.832559314	6145.631881	6	0.77815125	2	2.7	0.178012615	4.37	0.47488419	-0.130334	0.578013	-0.225486028
3	0.47712	0.3325	6.582807299	4467.68199	7.5	0.87506126	2	2.7	0.244869712	4.05	0.47334075	-0.130334	0.64487	-0.202108684
3	0.47712	0.3325	6.384877915	3470.027738	9	0.95424251	2	2.7	0.315271255	3.81	0.47900467	-0.130334	0.715271	-0.182215862
3	0.47712	0.3325	6.212240662	2783.606249	10.5	1.0211893	2	2.7	0.393015356	3.61	0.4795477	-0.130334	0.793015	-0.164352137
3	0.47712	0.3325	6.0595046	2290.433119	12	1.07918125	2	2.7	0.477638919	3.44	0.47720009	-0.130334	0.877639	-0.148505001
3	0.47712	0.3325	5.929264744	1939.55136	13.5	1.13033377	2	2.7	0.564047966	3.3	0.47894481	-0.130334	0.964048	-0.135194278
3	0.47712	0.3325	5.804473475	1653.888111	15	1.17609126	2	2.7	0.661471591	3.17	0.47271927	-0.130334	1.061472	-0.122785923
3	0.47712	0.3325	5.695803674	1439.627435	16.5	1.21748394	2	2.7	0.759918833	3.06	0.47050187	-0.130334	1.159919	-0.112364559
3	0.47712	0.3325	5.604679143	1281.512156	18	1.25527251	2	2.7	0.853678988	2.97	0.47545032	-0.130334	1.253679	-0.103961038

3	0.47712	0.3325	5.511464952	1137.728209	19.5	1.29003461	2	2.7	0.96156947	2.88	0.47112206	-0.130334	1.361569	-0.095723187
3	0.47712	0.3325	5.437457772	1035.143653	21	1.32221929	2	2.7	1.056858144	2.81	0.47804431	-0.130334	1.456858	-0.089462223
3	0.47712	0.3325	5.362078197	940.1639955	22.5	1.35218252	2	2.7	1.163626777	2.74	0.47828814	-0.130334	1.563627	-0.083353503

AASHTO Modefied Equation

log10 (W18) = $Z_R S_0$ + 9.36*log10 (SN+1) – 0.2 + log10 (∆PSI /4.2-1.5) / (0.4+1094/ (SN+1)5.19) +2.32x log10 (MR) -8.07

Where:
W_{18} = 18-kip equivalent single axle load
Z_R = reliability 0.95
S_0 = overall standard deviation 0.35
SN = structural number
∆PSI = design present serviceability loss 2
MR = resilient modulus of the subgrade soil

W_{18}	$log_{10}(W_{18})$	$Z_R S_0$	9.36*log_{10}(SN+1))	$(SN+1)^{5.19}$	M_R	log_{10}(MR)	∆PSI	4.2-1.5	1094/(SN+1)5.19	SN	eqn right side	log_{10}(h5/i5)	0.4+E11	log10(h5/i5)/F11
5	0.69897	0.3325	7.383871084	12424.01168	4.5	0.65321251	2	2.7	0.088055294	5.15	0.69477698	-0.130334	0.488055	-0.267047136
5	0.69897	0.3325	7.074988649	8375.109636	6	0.77815125	2	2.7	0.130625156	4.7	0.6971765	-0.130334	0.530625	-0.245623049
5	0.69897	0.3325	6.832559314	6145.631881	7.5	0.87506126	2	2.7	0.178012615	4.37	0.69971542	-0.130334	0.578013	-0.225486028
5	0.69897	0.3325	6.622856848	4702.07134	9	0.95424251	2	2.7	0.23266342	4.1	0.6931914	-0.130334	0.632663	-0.206008067
5	0.69897	0.3325	6.451930921	3780.184342	10.5	1.0211893	2	2.7	0.289403876	3.89	0.69453724	-0.130334	0.689404	-0.189052851
5	0.69897	0.3325	6.308097107	3146.001844	12	1.07918125	2	2.7	0.347742962	3.72	0.6999947	-0.130334	0.747743	-0.174302902
5	0.69897	0.3325	6.167910927	2630.434751	13.5	1.13033377	2	2.7	0.415900831	3.56	0.6930431	-0.130334	0.815901	-0.159742169
5	0.69897	0.3325	6.050338877	2263.78584	15	1.17609126	2	2.7	0.483261261	3.43	0.6938109	-0.130334	0.883261	-0.147559702
5	0.69897	0.3325	5.94812787	1986.829712	16.5	1.21748394	2	2.7	0.550625951	3.32	0.69808752	-0.130334	0.950626	-0.137103104
5	0.69897	0.3325	5.843280417	1737.897176	18	1.25527251	2	2.7	0.629496391	3.21	0.69141309	-0.130334	1.029496	-0.126599539
5	0.69897	0.3325	5.755437942	1553.518936	19.5	1.29003461	2	2.7	0.704207702	3.12	0.6927845	-0.130334	1.104208	-0.118033743
5	0.69897	0.3325	5.675729577	1403.199059	21	1.32221929	2	2.7	0.779647045	3.04	0.69529295	-0.130334	1.179647	-0.110485394
5	0.69897	0.3325	5.59442694	1264.847058	22.5	1.35218252	2	2.7	0.864926706	2.96	0.69095377	-0.130334	1.264927	-0.103036617

10	1	0.3325	7.707718785	18785.86726	4.5	0.65321251	2	2.7	0.058235267	5.66	1.00124637	-0.130334	0.458235	-0.284425442
10	1	0.3325	7.403652127	12741.78245	6	0.77815125	2	2.7	0.085859259	5.18	1.00320887	-0.130334	0.485859	-0.268254162
10	1	0.3325	7.159679136	9331.474859	7.5	0.87506126	2	2.7	0.11723763	4.82	1.00034082	-0.130334	0.517238	-0.251980445
10	1	0.3325	6.959251398	7224.631144	9	0.95424251	2	2.7	0.151426416	4.54	0.99923652	-0.130334	0.551426	-0.236357499
10	1	0.3325	6.794532878	5854.386243	10.5	1.0211893	2	2.7	0.186868436	4.32	1.0041086	-0.130334	0.586868	-0.222083453
10	1	0.3325	6.646698537	4847.402974	12	1.07918125	2	2.7	0.225687859	4.13	1.00459425	-0.130334	0.625688	-0.208304775
10	1	0.3325	6.509708492	4069.582911	13.5	1.13033377	2	2.7	0.268823618	3.96	0.99971267	-0.130334	0.668824	-0.194870165
10	1	0.3325	6.393320278	3507.632848	15	1.17609126	2	2.7	0.311891252	3.82	1.00127099	-0.130334	0.711891	-0.183081009
10	1	0.3325	6.29083595	3077.427871	16.5	1.21748394	2	2.7	0.355491679	3.7	1.00538354	-0.130334	0.755492	-0.172515161

10	1	0.3325	6.185700874	2690.80451	18	1.25527251	2	2.7	0.40656079	3.58	0.99884109	-0.130334	0.806561	-0.161591997
10	1	0.3325	6.105025752	2427.495927	19.5	1.29003461	2	2.7	0.450670169	3.49	1.007193	-0.130334	0.85067	-0.153213047
10	1	0.3325	6.013467909	2159.687229	21	1.32221929	2	2.7	0.506554831	3.39	0.99974846	-0.130334	0.906555	-0.143768213
10	1	0.3325	5.938707249	1963.075632	22.5	1.35218252	2	2.7	0.557288768	3.31	1.00212184	-0.130334	0.957289	-0.136148854

AASHTO Modefied Equation

log10 (W18) = $Z_R S_0$ + 9.36*log10 (SN+1) – 0.2 + log10 (∆PSI /4.2-1.5) / (0.4+1094/ (SN+1)5.19) +2.32x log10 (MR) -8.07

Where:

W_{18}	**= 18-kip equivalent single axle load**	
Z_R	**= reliability**	0.95
S_0	**= overall standard deviation**	0.35
SN	**= structural number**	
∆PSI	**= design present serviceability loss**	2
MR	**= resilient modulus of the subgrade soil**	

W_{18}	$log_{10}(W_{18})$	$Z_R S_0$	9.36*log_{10}(SN+1))	$(SN+1)^{5.19}$	M_R	$log_{10}(MR)$	ΔPSI	4.2-1.5	1094/(SN+1)5.19	SN	eqn right side	log_{10}(h5/i5)	0.4+E11	log10(h5/i5)/F11
15	1.17609	0.3325	7.886822483	23612.49906	4.5	0.65321251	2	2.7	0.046331394	5.96	1.17276431	-0.130334	0.446331	-0.292011206
15	1.17609	0.3325	7.583776368	16036.39586	6	0.77815125	2	2.7	0.068219818	5.46	1.17322706	-0.130334	0.46822	-0.278360214
15	1.17609	0.3325	7.350687256	11908.63114	7.5	0.87506126	2	2.7	0.091866142	5.1	1.17835126	-0.130334	0.491866	-0.264978126
15	1.17609	0.3325	7.152688599	9248.560186	9	0.95424251	2	2.7	0.118288683	4.81	1.17756177	-0.130334	0.518289	-0.251469447
15	1.17609	0.3325	6.981204627	7429.993998	10.5	1.0211893	2	2.7	0.147241034	4.57	1.1746986	-0.130334	0.547241	-0.238165197
15	1.17609	0.3325	6.832559314	6145.631881	12	1.07918125	2	2.7	0.178012615	4.37	1.17327378	-0.130334	0.578013	-0.225486028
15	1.17609	0.3325	6.701791296	5200.646724	13.5	1.13033377	2	2.7	0.210358453	4.2	1.1731292	-0.130334	0.610358	-0.213536436
15	1.17609	0.3325	6.590848838	4513.788257	15	1.17609126	2	2.7	0.24236848	4.06	1.17898491	-0.130334	0.642368	-0.202895647
15	1.17609	0.3325	6.476793362	3902.104388	16.5	1.21748394	2	2.7	0.280361541	3.92	1.17229066	-0.130334	0.680362	-0.191565455
15	1.17609	0.3325	6.384877915	3470.027738	18	1.25527251	2	2.7	0.315271255	3.81	1.17739426	-0.130334	0.715271	-0.182215862
15	1.17609	0.3325	6.29083595	3077.427871	19.5	1.29003461	2	2.7	0.355491679	3.7	1.17370109	-0.130334	0.755492	-0.172515161
15	1.17609	0.3325	6.212240662	2783.606249	21	1.32221929	2	2.7	0.393015356	3.61	1.17793729	-0.130334	0.793015	-0.164352137
15	1.17609	0.3325	6.13209575	2512.861061	22.5	1.35218252	2	2.7	0.435360322	3.52	1.17563817	-0.130334	0.83536	-0.156021019

20	1.30103	0.3325	8.024632167	28155.00809	4.5	0.65321251	2	2.7	0.03885632	6.2	1.30560014	-0.130334	0.438856	-0.296985055
20	1.30103	0.3325	7.732060153	19378.86004	6	0.77815125	2	2.7	0.056453269	5.7	1.31433521	-0.130334	0.456453	-0.285535842
20	1.30103	0.3325	7.481827543	14079.18293	7.5	0.87506126	2	2.7	0.077703373	5.3	1.30163558	-0.130334	0.477703	-0.272834097
20	1.30103	0.3325	7.283495704	10929.61816	9	0.95424251	2	2.7	0.100094988	5	1.2992203	-0.130334	0.500095	-0.260618026
20	1.30103	0.3325	7.117554445	8842.858771	10.5	1.0211893	2	2.7	0.123715648	4.76	1.30035001	-0.130334	0.523716	-0.248863613
20	1.30103	0.3325	6.973900049	7361.022891	12	1.07918125	2	2.7	0.148620649	4.56	1.30253426	-0.130334	0.548621	-0.237566283
20	1.30103	0.3325	6.8401221	6205.260394	13.5	1.13033377	2	2.7	0.176302029	4.38	1.29884113	-0.130334	0.576302	-0.226155318
20	1.30103	0.3325	6.732940846	5411.645997	15	1.17609126	2	2.7	0.202156608	4.24	1.3075276	-0.130334	0.602157	-0.216444969

20	1.30103	0.3325	6.629856848	4702.07134	16.5	1.21748394	2	2.7	0.23266342	4.1	1.30391153	-0.130334	0.632663	-0.206008067
20	1.30103	0.3325	6.526066648	4155.471317	18	1.25527251	2	2.7	0.263267369	3.98	1.30429625	-0.130334	0.663267	-0.196502609
20	1.30103	0.3325	6.435271077	3700.626962	19.5	1.29003461	2	2.7	0.295625582	3.87	1.30328942	-0.130334	0.695626	-0.187361954
20	1.30103	0.3325	6.350932028	3322.847325	21	1.32221929	2	2.7	0.329235711	3.77	1.30225426	-0.130334	0.729236	-0.178726531
20	1.30103	0.3325	6.273501185	3010.065717	22.5	1.35218252	2	2.7	0.363447214	3.68	1.30234717	-0.130334	0.763447	-0.170717459

AASHTO Modefied Equation

log10 (W18) = $Z_R S_0$ + 9.36*log10 (SN+1) – 0.2 + log10 (∆PSI /4.2-1.5) / (0.4+1094/ (SN+1)5.19) +2.32x log10 (MR) -8.07

Where:
W_{18} = 18-kip equivalent single axle load
Z_R = reliability 0.95
S_0 = overall standard deviation 0.35
SN = structural number
∆PSI = design present serviceability loss 2
MR = resilient modulus of the subgrade soil

W_{18}	$\log_{10}(W_{18})$	$Z_R S_0$	9.36*$\log_{10}$(SN+1))	$(SN+1)^{5.19}$	M_R	$\log_{10}$(MR)	ΔPSI	4.2-1.5	1094/(SN+1)5.19	SN	eqn right side	$\log_{10}$(h5/i5)	0.4+E11	log10(h5/i5)/F11
30	1.47712	0.3325	8.201398988	35283.41336	4.5	0.65321251	2	2.7	0.03100607	6.52	1.47695774	-0.130334	0.431006	-0.302394276
30	1.47712	0.3325	7.904306365	24145.51885	6	0.77815125	2	2.7	0.045308614	5.99	1.47943537	-0.130334	0.445309	-0.292681894
30	1.47712	0.3325	7.664767481	17783.42066	7.5	0.87506126	2	2.7	0.061517973	5.59	1.47500724	-0.130334	0.461518	-0.282402368
30	1.47712	0.3325	7.475370041	13963.58233	9	0.95424251	2	2.7	0.078346657	5.29	1.47924548	-0.130334	0.478347	-0.272467188
30	1.47712	0.3325	7.310505745	11313.10223	10.5	1.0211893	2	2.7	0.096702034	5.04	1.47976662	-0.130334	0.496702	-0.262398298
30	1.47712	0.3325	7.166657673	9414.988615	12	1.07918125	2	2.7	0.116197698	4.83	1.48037008	-0.130334	0.516198	-0.252488086
30	1.47712	0.3325	7.031972413	7927.541965	13.5	1.13033377	2	2.7	0.1379999	4.64	1.47459064	-0.130334	0.538	-0.24225612
30	1.47712	0.3325	6.922397144	6892.558609	15	1.17609126	2	2.7	0.1587219	4.49	1.48015759	-0.130334	0.558722	-0.233271272
30	1.47712	0.3325	6.8173914	6027.762449	16.5	1.21748394	2	2.7	0.181493549	4.35	1.48031793	-0.130334	0.581494	-0.224136224
30	1.47712	0.3325	6.725175808	5358.259779	18	1.25527251	2	2.7	0.204170765	4.23	1.48418462	-0.130334	0.604171	-0.215723395
30	1.47712	0.3325	6.630819625	4750.118803	19.5	1.29003461	2	2.7	0.230310029	4.11	1.47942268	-0.130334	0.63031	-0.206777241
30	1.47712	0.3325	6.550481114	4287.042582	21	1.32221929	2	2.7	0.255187575	4.01	1.48160399	-0.130334	0.655188	-0.198925885
30	1.47712	0.3325	6.468522766	3861.116842	22.5	1.35218252	2	2.7	0.283337709	3.91	1.47735509	-0.130334	0.683338	-0.190731123

50	1.69897	0.3325	8.427436324	47087.47447	4.5	0.65321251	2	2.7	0.023233355	6.95	1.69744158	-0.130334	0.423233	-0.307947772
50	1.69897	0.3325	8.125007547	32004.60842	6	0.77815125	2	2.7	0.034182577	6.38	1.69263651	-0.130334	0.434183	-0.30018194
50	1.69897	0.3325	7.892658803	23789.10583	7.5	0.87506126	2	2.7	0.045987437	5.97	1.69306452	-0.130334	0.445987	-0.292236412
50	1.69897	0.3325	7.7016106	18639.93266	9	0.95424251	2	2.7	0.058691199	5.65	1.69381049	-0.130334	0.458691	-0.284142728
50	1.69897	0.3325	7.539488032	15154.77364	10.5	1.0211893	2	2.7	0.072188475	5.39	1.69512656	-0.130334	0.472188	-0.276020647
50	1.69897	0.3325	7.397069135	12635.13834	12	1.07918125	2	2.7	0.086583935	5.17	1.69541498	-0.130334	0.486584	-0.267854648
50	1.69897	0.3325	7.269923082	10741.85152	13.5	1.13033377	2	2.7	0.10184464	4.98	1.69508803	-0.130334	0.501845	-0.259709396

Worksheet 1: Application of AASHTO Modified Equation for Flexible Pavement, ESALS=0.05-50(million psi , CBR=3-15

50	1.69897	0.3325	7.159679136	9331.474859	15	1.17609126	2	2.7	0.11723762	4.82	1.69873041	-0.130334	0.517238	-0.251980445
50	1.69897	0.3325	7.046361796	8074.530473	16.5	1.21748394	2	2.7	0.135487754	4.66	1.69003192	-0.130334	0.535488	-0.243392622
50	1.69897	0.3325	6.951907229	7157.204585	18	1.25527251	2	2.7	0.152852973	4.53	1.69089183	-0.130334	0.552853	-0.235747613
50	1.69897	0.3325	6.870233322	6448.46426	19.5	1.29003461	2	2.7	0.169652797	4.42	1.69681852	-0.130334	0.569653	-0.2287951
50	1.69897	0.3325	6.786884717	5797.497425	21	1.32221929	2	2.7	0.188702111	4.31	1.69554177	-0.130334	0.588702	-0.221391713
50	1.69897	0.3325	6.70960109	5252.76273	22.5	1.35218252	2	2.7	0.208271353	4.21	1.69489541	-0.130334	0.608271	-0.214269122

design table 6.1

Structural Design of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3

Cost=c1d1+c2d2+c3d3+c4(d1+d2+d3)

where:

d1= surface layer depth (asphalt) inches

d2= base layer depth (base course) inches

d3 = sub base layer depth (kurkar) inches

a1 = Surface layer coefficient

a2 = Base layer coefficient

a3 = Subbase layer coefficient

m2 = drainage factor

m3 = drainage factor

c1=asphalt cost per inch

c2=basecourse cost per inch

c3=kurkar cost per inch

c4=total excavation cost per inch

ESALs	CBR	MR	d1	d2	d3	SN Calc.	SN Chart	cost
0.05	3	4.5	2.4	6	10	2.748	2.58	16.1492
0.05	4	6	2.4	6	6	2.388	2.32	15.0972
0.05	5	7.5	2.4	6	0	1.848	2.1	13.5192
0.05	6	9	2.4	6	0	1.848	1.97	13.5192
0.05	7	10.5	2.4	6	0	1.848	1.86	13.5192
0.05	8	12	2.4	6	0	1.848	1.76	13.5192
0.05	9	13.5	2.4	6	0	1.848	1.68	13.5192
0.05	10	15	2.4	6	0	1.848	1.61	13.5192
0.05	11	16.5	2.4	6	0	1.848	1.55	13.5192
0.05	12	18	2.4	6	0	1.848	1.5	13.5192
0.05	13	19.5	2.4	6	0	1.848	1.45	13.5192
0.05	14	21	2.4	6	0	1.848	1.4	13.5192
0.05	15	22.5	2.4	6	0	1.848	1.36	13.5192
0.1	3	4.5	2.4	6	12	2.928	2.88	16.6752
0.1	4	6	2.4	6	10	2.748	2.53	16.1492
0.1	5	7.5	2.4	6	6	2.388	2.34	15.0972
0.1	6	9	2.4	6	0	1.848	2.2	13.5192
0.1	7	10.5	2.4	6	0	1.848	2.08	13.5192
0.1	8	12	2.4	6	0	1.848	1.98	13.5192
0.1	9	13.5	2.4	6	0	1.848	1.89	13.5192
0.1	10	15	2.4	6	0	1.848	1.82	13.5192
0.1	11	16.5	2.4	6	0	1.848	1.75	13.5192
0.1	12	18	2.4	6	0	1.848	1.69	13.5192
0.1	13	19.5	2.4	6	0	1.848	1.64	13.5192
0.1	14	21	2.4	6	0	1.848	1.59	13.5192
0.1	15	22.5	2.4	6	0	1.848	1.55	13.5192

0.2	3	4.5	3.2	6	12	3.264	3.22	19.5056
0.2	4	6	3.2	6	10	3.084	2.9	18.9796
0.2	5	7.5	3.2	6	6	2.724	2.67	17.9276
0.2	6	9	3.2	6	6	2.724	2.5	17.9276
0.2	7	10.5	3.2	6	6	2.724	2.36	17.9276
0.2	8	12	3.2	6	6	2.724	2.25	17.9276
0.2	9	13.5	3.2	6	0	2.184	2.15	16.3496
0.2	10	15	3.2	6	0	2.184	2.06	16.3496
0.2	11	16.5	3.2	6	0	2.184	1.99	16.3496
0.2	12	18	3.2	6	0	2.184	1.92	16.3496
0.2	13	19.5	3.2	6	0	2.184	1.86	16.3496
0.2	14	21	3.2	6	0	2.184	1.81	16.3496
0.2	15	22.5	3.2	6	0	2.184	1.76	16.3496

design table 6.2

Structural Design Tables of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3

Cost=c1d1+c2d2+c3d3+c4(d1+d2+d3)

where:

d1= surface layer depth (asphalt) inches

d2= base layer depth (base course) inches

d3 = sub base layer depth (kurkar) inches

a1 = Surface layer coefficient

a2 = Base layer coefficient

a3 = Subbase layer coefficient

m2 = drainage factor

m3 = drainage factor

c1=asphalt cost per inch

c2=basecourse cost per inch

c3=kurkar cost per inch

c4=total excavation cost per inch

ESALs	CBR	MR	d1	d2	d3	SN Calc.	SN Chart	cost
0.5	3	4.5	3.2	6	18	3.804	3.7	21.0836
0.5	4	6	3.2	6	14	3.444	3.35	20.0316
0.5	5	7.5	3.2	6	10	3.084	3.09	18.9796
0.5	6	9	3.2	6	10	3.084	2.88	18.9796
0.5	7	10.5	3.2	6	6	2.724	2.72	17.9276
0.5	8	12	3.2	6	6	2.724	2.59	17.9276
0.5	9	13.5	3.2	6	6	2.724	2.48	17.9276
0.5	10	15	3.2	6	6	2.724	2.39	17.9276
0.5	11	16.5	3.2	6	6	2.724	2.3	17.9276
0.5	12	18	3.2	6	6	2.724	2.23	17.9276
0.5	13	19.5	3.2	6	0	2.184	2.16	16.3496
0.5	14	21	3.2	6	0	2.184	2.1	16.3496
0.5	15	22.5	3.2	6	0	2.184	2.05	16.3496

0.75	3	4.5	3.2	6	20	3.984	3.93	21.6096
0.75	4	6	3.2	6	18	3.804	3.55	21.0836
0.75	5	7.5	3.2	6	16	3.624	3.28	20.5576
0.75	6	9	3.2	6	14	3.444	3.07	20.0316
0.75	7	10.5	3.2	6	12	3.264	2.91	19.5056
0.75	8	12	3.2	6	10	3.084	2.77	18.9796
0.75	9	13.5	3.2	6	10	3.084	2.65	18.9796
0.75	10	15	3.2	6	10	3.084	2.55	18.9796
0.75	11	16.5	3.2	6	6	2.724	2.46	17.9276
0.75	12	18	3.2	6	6	2.724	2.38	17.9276
0.75	13	19.5	3.2	6	6	2.724	2.31	17.9276
0.75	14	21	3.2	6	6	2.724	2.25	17.9276
0.75	15	22.5	3.2	6	6	2.724	2.19	17.9276

1	3	4.5	3.2	6	22	4.164	4.1	22.1356
1	4	6	3.2	6	18	3.804	3.71	21.0836
1	5	7.5	3.2	6	14	3.444	3.43	20.0316
1	6	9	3.2	6	12	3.264	3.21	19.5056
1	7	10.5	3.2	6	10	3.084	3.04	18.9796
1	8	12	3.2	6	10	3.084	2.9	18.9796
1	9	13.5	3.2	6	6	2.724	2.77	17.9276
1	10	15	3.2	6	6	2.724	2.67	17.9276
1	11	16.5	3.2	6	6	2.724	2.57	17.9276
1	12	18	3.2	6	6	2.724	2.49	17.9276
1	13	19.5	3.2	6	6	2.724	2.42	17.9276
1	14	21	3.2	6	6	2.724	2.36	17.9276
1	15	22.5	3.2	6	6	2.724	2.29	17.9276

design table 6.3

Structural Design of Flexible Pavement
SN=a1d1+a2d2m2+a3d3m3
Cost=c1d1+c2d2+c3d3+c4(d1+d2+d3)
where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor
m3 = drainage factor

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs	CBR	MR	d1	d2	d3	SN Calc.	SN Chart	cost
2	3	4.5	3.2	6	28	4.704	4.54	23.7136
2	4	6	3.2	6	24	4.344	4.13	22.662
2	5	7.5	3.2	6	18	3.804	3.82	21.0836
2	6	9	3.2	6	16	3.624	3.58	20.5576
2	7	10.5	3.2	6	16	3.624	3.39	20.5576
2	8	12	3.2	6	12	3.264	3.24	19.5056
2	9	13.5	3.2	6	12	3.264	3.1	19.5056
2	10	15	3.2	6	10	3.084	2.98	18.9796
2	11	16.5	3.2	6	10	3.084	2.88	18.9796
2	12	18	3.2	6	6	2.724	2.79	17.9276
2	13	19.5	3.2	6	6	2.724	2.71	17.9276
2	14	21	3.2	6	6	2.724	2.64	17.9276
2	15	22.5	3.2	6	6	2.724	2.57	17.9276

3	3	4.5	3.2	6	30	4.884	4.8	24.2396
3	4	6	3.2	6	24	4.344	4.37	22.6616
3	5	7.5	3.2	6	22	4.164	4.05	22.1356
3	6	9	3.2	6	18	3.804	3.81	21.0836
3	7	10.5	3.2	6	16	3.624	3.61	20.5576
3	8	12	3.2	6	14	3.444	3.44	20.0316
3	9	13.5	3.2	6	14	3.444	3.3	20.0316
3	10	15	3.2	6	12	3.264	3.17	19.5056
3	11	16.5	3.2	6	10	3.084	3.06	18.9796
3	12	18	3.2	6	10	3.084	2.97	18.9796
3	13	19.5	3.2	6	10	3.084	2.88	18.9796
3	14	21	3.2	6	10	3.084	2.81	18.9796
3	15	22.5	3.2	6	6	2.724	2.74	17.9276

5	3	4.5	3.2	6	34	5.244	5.15	25.2916
5	4	6	3.2	6	30	4.884	4.7	24.2396
5	5	7.5	3.2	6	24	4.344	4.37	22.6616
5	6	9	3.2	6	22	4.164	4.1	22.1356
5	7	10.5	3.2	6	18	3.804	3.89	21.0836
5	8	12	3.2	6	18	3.804	3.72	21.0836
5	9	13.5	3.2	6	16	3.624	3.56	20.5576
5	10	15	3.2	6	16	3.624	3.43	20.5576
5	11	16.5	3.2	6	14	3.444	3.32	20.0316
5	12	18	3.2	6	12	3.264	3.21	19.5056
5	13	19.5	3.2	6	12	3.264	3.12	19.5056
5	14	21	3.2	6	10	3.084	3.04	18.9796
5	15	22.5	3.2	6	10	3.084	2.96	18.9796

design table 6.4

Structural Design of Flexible Pavement

SN=a1d1+a2d2m2+a3d3m3
Cost=c1d1+c2d2+c3d3+c4(d1+d2+d3)
where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor is taken 1
m3 = drainage factor is taken 1

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs	CBR	MR	d1	d2	d3	SN Calc.	SN Chart	cost
10	3	4.5	3.2	6	40	5.784	5.66	26.8696
10	4	6	3.2	6	34	5.244	5.18	25.2916
10	5	7.5	3.2	6	30	4.884	4.82	24.2396
10	6	9	3.2	6	26	4.524	4.54	23.1876
10	7	10.5	3.2	6	24	4.344	4.32	22.6616
10	8	12	3.2	6	22	4.164	4.13	22.1356
10	9	13.5	3.2	6	22	4.164	3.96	22.1356
10	10	15	3.2	6	18	3.804	3.82	21.0836
10	11	16.5	3.2	6	18	3.804	3.7	21.0836
10	12	18	3.2	6	16	3.624	3.58	20.5576
10	13	19.5	3.2	6	16	3.624	3.49	20.5576
10	14	21	3.2	6	14	3.444	3.39	20.0316
10	15	22.5	3.2	6	14	3.444	3.31	20.0316

15	3	4.5	4	12	30	6.06	5.96	32.098
15	4	6	4	12	24	5.52	5.46	30.52
15	5	7.5	4	12	20	5.16	5.1	29.468
15	6	9	4	12	16	4.8	4.81	28.416
15	7	10.5	4	12	14	4.62	4.57	27.89
15	8	12	4	12	12	4.44	4.37	27.364
15	9	13.5	4	12	10	4.26	4.2	26.838
15	10	15	4	12	10	4.26	4.06	26.838
15	11	16.5	4	12	6	3.9	3.92	25.786
15	12	18	4	12	6	3.9	3.81	25.786
15	13	19.5	4	12	6	3.9	3.7	25.786
15	14	21	4	12	6	3.9	3.61	25.786
15	15	22.5	4	12	6	3.9	3.52	25.786

20	3	4.5	4.8	12	28	6.216	6.2	34.4024
20	4	6	4	12	28	5.88	5.7	31.572
20	5	7.5	4	12	22	5.34	5.3	29.994
20	6	9	4	12	18	4.98	5	28.942
20	7	10.5	4	12	16	4.8	4.76	28.416
20	8	12	4	12	14	4.62	4.56	27.89
20	9	13.5	4	12	12	4.44	4.38	27.364
20	10	15	4	12	10	4.26	4.24	26.838
20	11	16.5	4	12	10	4.26	4.1	26.838
20	12	18	4	12	6	3.9	3.98	25.786
20	13	19.5	4	12	6	3.9	3.87	25.786
20	14	21	4	12	6	3.9	3.77	25.786
20	15	22.5	4	12	6	3.9	3.68	25.786

design table 6.5

Structural Design of Flexible Pavement
SN=a1d1+a2d2m2+a3d3m3
Cost=c1d1+c2d2+c3d3+c4(d1+d2+d3)
where:
d1= surface layer depth (asphalt) inches
d2= base layer depth (base course) inches
d3 = sub base layer depth (kurkar) inches
a1 = Surface layer coefficient
a2 = Base layer coefficient
a3 = Subbase layer coefficient
m2 = drainage factor
m3 = drainage factor

c1=asphalt cost per inch
c2=basecourse cost per inch
c3=kurkar cost per inch
c4=total excavation cost per inch

ESALs	CBR	MR	d1	d2	d3	SN Calc.	SN Chart	cost
30	3	4.5	4	12	36	6.6	6.52	33.676
30	4	6	4	12	30	6.06	5.99	32.098
30	5	7.5	4	12	24	5.52	5.59	30.52
30	6	9	4	12	24	5.52	5.29	30.52
30	7	10.5	4	12	18	4.98	5.04	28.942
30	8	12	4	12	18	4.98	4.83	28.942
30	9	13.5	4	12	12	4.44	4.64	27.364
30	10	15	4	12	12	4.44	4.49	27.364
30	11	16.5	4	12	12	4.44	4.35	27.364
30	12	18	4	12	12	4.44	4.23	27.364
30	13	19.5	4	12	10	4.26	4.11	26.838
30	14	21	4	12	10	4.26	4.01	26.838
30	15	22.5	4	12	6	3.9	3.91	25.786
ESALs	CBR	MR	d1	d2	d3	SN Calc.	SN Chart	cost
50	3	4.5	4	12	42	7.14	6.95	35.254
50	4	6	4	12	36	6.6	6.38	33.676
50	5	7.5	4	12	30	6.06	5.97	32.098
50	6	9	4	12	28	5.88	5.65	31.572
50	7	10.5	4	12	22	5.34	5.39	29.994
50	8	12	4	12	22	5.34	5.17	29.994
50	9	13.5	4	12	18	4.98	4.98	28.942
50	10	15	4	12	18	4.98	4.82	28.942
50	11	16.5	4	12	16	4.8	4.66	28.416
50	12	18	4	12	16	4.8	4.53	28.416
50	13	19.5	4	12	12	4.44	4.42	27.364
50	14	21	4	12	12	4.44	4.31	27.364
50	15	22.5	4	12	10	4.26	4.21	26.838

design table 6.6

Table 6.6: Resilient Modulus MR, ESALs and Cost table

MR	cost(0.05	cost(0.1)	cost(0.2)	cost(0.5)	cost(0.75	cost(1.0)	cost(2.0)	cost(3.0)	cost(5.0)	cost(10.0	cost(15)	cost(20)	cost(30)	cost(50)
4.5	16.1	16.7	19.5	21.1	21.6	22.1	23.7	24.2	25.3	26.9	32.1	32.6	33.676	35.254
6	15.1	16.1	19.0	20.0	21.1	21.1	22.7	22.7	24.2	25.3	30.5	31.6	32.098	33.676
7.5	13.5	15.1	17.9	19.0	20.6	20.0	21.1	22.1	22.7	24.2	29.5	30.0	30.52	32.098
9	13.5	13.5	17.9	19.0	20.0	19.5	20.6	21.1	22.1	23.2	28.4	28.9	30.52	31.572
10.5	13.5	13.5	17.9	17.9	19.5	19.0	20.6	20.6	21.1	22.7	27.9	28.4	28.942	29.994
12	13.5	13.5	17.9	17.9	19.0	19.0	19.5	20.0	21.1	22.1	27.4	27.9	28.942	29.994
13.5	13.5	13.5	16.3	17.9	19.0	17.9	19.5	20.0	20.6	22.1	26.8	27.4	27.364	28.942
15	13.5	13.5	16.3	17.9	19.0	17.9	19.0	19.5	20.6	21.1	26.8	26.8	27.364	28.942
16.5	13.5	13.5	16.3	17.9	17.9	17.9	19.0	19.0	20.0	21.1	25.8	26.8	27.364	28.416
18	13.5	13.5	16.3	17.9	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8	27.364	28.416
19.5	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8	26.838	27.364
21	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.0	20.0	25.8	25.8	26.838	27.364
22.5	13.5	13.5	16.3	16.3	17.9	17.9	17.9	17.9	19.0	20.0	25.8	25.8	25.786	26.838

Table 6.7:CBR, ESALs and Cost table

CBR	cost(0.05	cost(0.1)	cost(0.2)	cost(0.5)	cost(0.75	cost(1.0)	cost(2.0)	cost(3.0)	cost(5.0)	cost(10.0	cost(15)	cost(20)	cost(30)	cost(50)
3	16.1	16.7	19.5	21.1	21.6	22.1	23.7	24.2	25.3	26.9	32.1	32.6	33.676	35.254
4	15.1	16.1	19.0	20.0	21.1	21.1	22.7	22.7	24.2	25.3	30.5	31.6	32.098	33.676
5	13.5	15.1	17.9	19.0	20.6	20.0	21.1	22.1	22.7	24.2	29.5	30.0	30.52	32.098
6	13.5	13.5	17.9	19.0	20.0	19.5	20.6	21.1	22.1	23.2	28.4	28.9	30.52	31.572
7	13.5	13.5	17.9	17.9	19.5	19.0	20.6	20.6	21.1	22.7	27.9	28.4	28.942	29.994
8	13.5	13.5	17.9	17.9	19.0	19.0	19.5	20.0	21.1	22.1	27.4	27.9	28.942	29.994
9	13.5	13.5	16.3	17.9	19.0	17.9	19.5	20.0	20.6	22.1	26.8	27.4	27.364	28.942
10	13.5	13.5	16.3	17.9	19.0	17.9	19.0	19.5	20.6	21.1	26.8	26.8	27.364	28.942
11	13.5	13.5	16.3	17.9	17.9	17.9	19.0	19.0	20.0	21.1	25.8	26.8	27.364	28.416
12	13.5	13.5	16.3	17.9	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8	27.364	28.416
13	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.5	20.6	25.8	25.8	26.838	27.364
14	13.5	13.5	16.3	16.3	17.9	17.9	17.9	19.0	19.0	20.0	25.8	25.8	26.838	27.364
15	13.5	13.5	16.3	16.3	17.9	17.9	17.9	17.9	19.0	20.0	25.8	25.8	25.786	26.838

design table 6.7

Table 6.8:Resilient Modulus MR, ESALs and Structural number SN

MR	SN(0.05)	SN(0.1)	SN(0.2)	SN(0.5)	SN(0.75)	SN(1.0)	SN(2.0)	SN(3.0)	SN(5.0)	SN(10.0)	SN(15)	SN(20)	SN(30)	SN(50)
4.5	2.58	2.88	3.22	3.7	3.93	4.1	4.54	4.8	5.15	5.66	5.96	6.2	6.52	6.95
6	2.32	2.53	2.9	3.35	3.55	3.71	4.13	4.37	4.7	5.18	5.46	5.7	5.99	6.38
7.5	2.1	2.34	2.67	3.09	3.28	3.43	3.82	4.05	4.37	4.82	5.1	5.3	5.59	5.97
9	1.97	2.2	2.5	2.88	3.07	3.21	3.58	3.81	4.1	4.54	4.81	5	5.29	5.65
10.5	1.86	2.08	2.36	2.72	2.91	3.04	3.39	3.61	3.89	4.32	4.57	4.76	5.04	5.39
12	1.76	1.98	2.25	2.59	2.77	2.9	3.24	3.44	3.72	4.13	4.37	4.56	4.83	5.17
13.5	1.68	1.89	2.15	2.48	2.65	2.77	3.1	3.3	3.56	3.96	4.2	4.38	4.64	4.98
15	1.61	1.82	2.06	2.39	2.55	2.67	2.98	3.17	3.43	3.82	4.06	4.24	4.49	4.82
16.5	1.55	1.75	1.99	2.3	2.46	2.57	2.88	3.06	3.32	3.7	3.92	4.1	4.35	4.66
18	1.5	1.69	1.92	2.23	2.38	2.49	2.79	2.97	3.21	3.58	3.81	3.98	4.23	4.53
19.5	1.45	1.64	1.86	2.16	2.31	2.42	2.71	2.88	3.12	3.49	3.7	3.87	4.11	4.42
21	1.4	1.59	1.81	2.1	2.25	2.36	2.64	2.81	3.04	3.39	3.61	3.77	4.01	4.31
22.5	1.36	1.55	1.76	2.05	2.19	2.29	2.57	2.74	2.96	3.31	3.52	3.68	3.91	4.21

Table 6.9:CBR, ESALs and Structural number SN

CBR	SN(0.05)	SN(0.1)	SN(0.2)	SN(0.5)	SN(0.75)	SN(1.0)	SN(2.0)	SN(3.0)	SN(5.0)	SN(10.0)	SN(15)	SN(20)	SN(30)	SN(50)
3	2.58	2.88	3.22	3.7	3.93	4.1	4.54	4.8	5.15	5.66	5.96	6.2	6.52	6.95
4	2.32	2.53	2.9	3.35	3.55	3.71	4.13	4.37	4.7	5.18	5.46	5.7	5.99	6.38
5	2.1	2.34	2.67	3.09	3.28	3.43	3.82	4.05	4.37	4.82	5.1	5.3	5.59	5.97
6	1.97	2.2	2.5	2.88	3.07	3.21	3.58	3.81	4.1	4.54	4.81	5	5.29	5.65
7	1.86	2.08	2.36	2.72	2.91	3.04	3.39	3.61	3.89	4.32	4.57	4.76	5.04	5.39
8	1.76	1.98	2.25	2.59	2.77	2.9	3.24	3.44	3.72	4.13	4.37	4.56	4.83	5.17
9	1.68	1.89	2.15	2.48	2.65	2.77	3.1	3.3	3.56	3.96	4.2	4.38	4.64	4.98
10	1.61	1.82	2.06	2.39	2.55	2.67	2.98	3.17	3.43	3.82	4.06	4.24	4.49	4.82
11	1.55	1.75	1.99	2.3	2.46	2.57	2.88	3.06	3.32	3.7	3.92	4.1	4.35	4.66
12	1.5	1.69	1.92	2.23	2.38	2.49	2.79	2.97	3.21	3.58	3.81	3.98	4.23	4.53
13	1.45	1.64	1.86	2.16	2.31	2.42	2.71	2.88	3.12	3.49	3.7	3.87	4.11	4.42
14	1.4	1.59	1.81	2.1	2.25	2.36	2.64	2.81	3.04	3.39	3.61	3.77	4.01	4.31
15	1.36	1.55	1.76	2.05	2.19	2.29	2.57	2.74	2.96	3.31	3.52	3.68	3.91	4.21

design table 6.8

layer	SN/inc	Cost	depth (2.5cm)
Asphal	0.42	1.4	2.5
Base c	0.14	0.32	2.5
kurkar	0.09	0.09	2.5

aspha	aspha	aspha	aspha	aspha	aspha

layer	SN/inc	Cost/in	depth (cm)
Asphal	0.42	3.5	1
Base c	0.14	0.8	1
kurkar	0.09	0.225	1
exc		0.038	

design table 6.9

design table 6.10

design table 6.11

design table 6.12

3.93
3.55
3.28
3.07
3.18
3.03
2.65
2.55
2.46
2.38
2.31
2.25
2.19

4.1
3.71
3.43
3.21
3.04
2.9
2.77
2.67
2.57
2.49
2.42

design table 6.13

2.36	
2.29	

California Bearing Capacity Test (CBR), Apparatus

California Bearing Capacity Test (CBR), Apparatus

California Bearing Capacity Test (CBR), Apparatus

Sieve Analysis