NATIONAL TRANSPORT RESEARCH CENTRE

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FUNDAMENTAL TESTS

ON

SUBGRADE MATERIAL OF HIGHWAYS IN

ISLAMABAD

NTRC-217

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EXECUTIVE SUMMARY

Modern pavement structure consists of primarily three layers, sub-grade, sub-base and top asphaltic or concrete layer. Though, normally three main factors are ascribed for the structural failure of the pavement, namely Design Fault, Lack of Quality Control and Inadequate Maintenance, the design "Fault" in most of the instances is based on poor analysis of the materials and their strength. Due to poor material testing, failure in one layer can trigger the failure of whole pavement structure. In Pakistan apart from rutting and drainage problem, the third major cause of failure is subgrade failure.

National Transport Research Centre carried out analysis on subgrade samples collected from five different locations of various highways of the capital. The brief summary of the results is given below:

1. Physiomechanical properties of subgrade soils show that the soils are fine-grained and are a mixture of clay and silt in varying proportions. The soils have very low soil support values (CBR Values 2 - 6%). The soils are only stable when dry and unstable when wet. Poor drainage practices further aggravate the problem in Islamabad.

2. Silt and clay subgrades generally require a subbase, but when subgrade CBR-Value are so low, current practice is either to place a capping layer of selected fill on the weak soil to form a new "subgrade" upon which is then placed subbase material or provide chemical treatment (Stabilization) with lime or cement to alter the engineering properties of soil, like stiffness etc. to desirable standards.

3. This 'new subgrade/capping layer' not only protects the weak subgrade from adverse environmental effects, but provides a bed for full utilization of load distribution capability of subbase. This also fulfills the principle criterion of uniform lateral load distribution in the layered pavement system. It also prevents intrusion of soil into subbase and maintains its drainability.

Recommendations:

1) More rigorous tests on fine-grained soils like absorption, physiochemical activity, sensitivity etc. are essential to get a considerable insight into characteristic material properties.

2) Since use of CBR test is continuously declining therefore, stiffness models 'E' of the subgrade soil used in calculating the stresses and strains in the pavement and in the subgrade soil be directly measured to encompass soil characteristics.

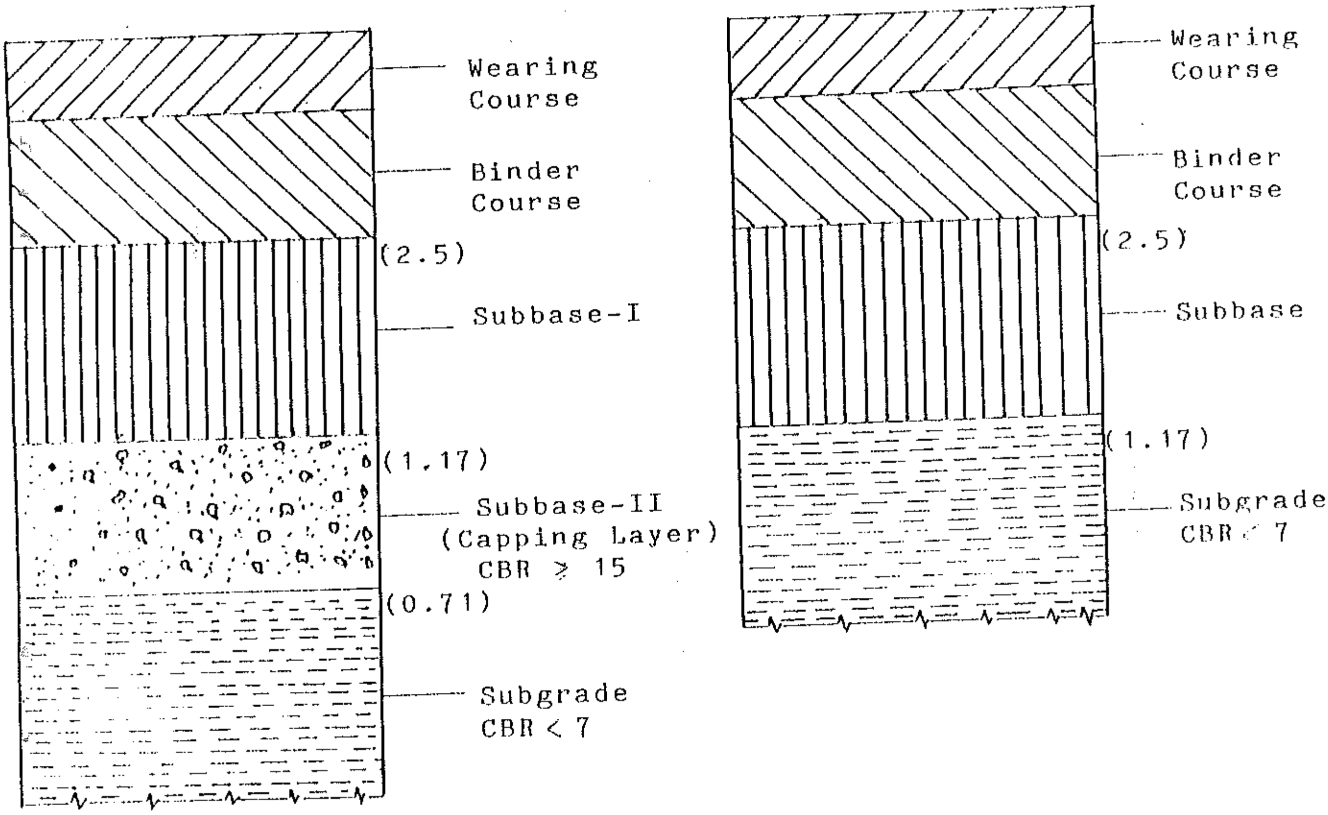
3) The high natural moisture content in the subgrade soil leads to the necessity for providing efficient drainage. Particularly drainage is very essential for fine-grained soils, as saturation closer to liquid limit causes a drastic reduction in soil stability triggering subgrade failure, which occurs more than often in Islamabad. Good drainage imply that the subgrades never get wetter than their equilibrium moisture contents beneath the finished pavement.

Table 1

Summary of Test Results

S.No	Location	NMC %	Sp.Gr	Sieve Analysis % (Passing)		Atterberg Limits %			Group Index	Moisture Density Relationship		California Bearing Ratio		Soil Type	Quality as Subgrade
				#04	#200	LL	PL	PI		MDD	OMC %	@0.1 "	@0.2 "		
1.	Kashmir H'way AGPR Office	20	2.63	95	92	27	17	10	8	115	15	5.2	5.5	A4	**Fair to Poor**
2.	Kashmir H'way Aabpara market	18	2.62	100	97	31	15	16	15	118	13	4.6	4.8	A6	
3.	Convention Centre R'bout	14	2.63	96	82	,28	18	10	7	117	14	5.6	5.8	A4	
4.	Faizabad Flyover	19	2.60	98	92	28	19	9	7	115	13	5.5	5.8	A4	
5.	NTRC Complex	15	2.70	97	91	32	20	12	10	112	16	4.8	5.0	A6	

THE CONCEPT OF CAPPING LAYER



* (Stress in psi) Typical stress values which depend on thickness and pavement material.

Source: Research on the Design of Flexible Road Pavements (Lee AR and Croney)

Fig. 1

1 : INTRODUCTION:

Structurally pavement consists of three primary layers, the bottom most layer of subgrade, the middle base layer and the top most sealing and load distributing layer of either asphaltic or cement concrete. Highway subgrade which is usually the original strata of the terrain, may be defined as the foundation on which the pavement and its other layers rest. The structural design of the pavement depends on the evaluation of the properties and strengths of subgrade, subbase and top layer apart from traffic loading and climatic conditions. Subgrade is the governing layer and the thickness and strengths of overlaying layers are all dependent on the subgrade strength. Higher subgrade strength lowers the pavement thickness.

Ever increasing number of vehicles and heavy axle loads impose larger and more numerous wheel loads on the roadway structure. In many instances, the pavement failure was triggered by subsidence and the fault lay in subgrade and not in the upper layers. This type of failure in turn normally leads to the conclusion that investigation into the properties of the subgrade soils and their performance under service conditions were not analyzed in detail under established procedures.

National Transport Research Centre at its materials testing laboratories carried out testing analysis of subgrade samples collected from four locations of the capital. The tests were performed in accordance with the AASHO/ASTM Standards.

2 : OBJECTIVE OF THE STUDY:

The fundamental objective of the study was to evaluate the subgrade properties of the highways in Islamabad and to give hands on experience to the newly inducted staff in the laboratories on sample collection and material testing. The roads selected are:

1. Kashmir Highway (AGPR Office)
2. Kashmir Highway (Aabpara Market)
3. Convention Centre round about
4. Faizabad Flyover
5. NTRC Complex

3 : METHODOLOGY:

The methodology adopted in this study to determine the physio-chemical properties of the subgrade material collected from various sections of the highways consisted of the following:-

I) Selection and identification of survey points/number and type of tests to be performed.
ii) Field sampling.
iii) Laboratory testing of sampled subgrade material.
iv) Analysis of data.
v) Results and recommendations.

4 : FIELD SAMPLING:

It is not often difficult to obtain representative sample of highway subgrade, but it involves experience and judgment rather than a typical formula. Samples of subgrade material were obtained from alongside the highways. The top layers were removed and the samples were collected from the subgrade level.

The samples were then secured in containers and plastic bags to preserve the original moisture content and to prevent loss of fines. The materials were processed in the laboratories to evaluate their physical properties in accordance with the established ASTM/AASHTO procedures.

5 : FIELD TESTING:

No field tests were carried out because typically in the field, field density, field moisture content and field CBR Values are determined and the subgrade samples were collected from outside the shoulders.

6 : LABORATORY TESTING:

Subgrade samples were tested as per ASTM/AASHTO procedures in the laboratory and following tests were carried out:

- I) Determination of moisture content of soil.
- ii) Sieve analysis of fine and coarse aggregates.
- iii) Atterberg limits & plasticity index of soils.
- iv) Moisture-Density relationships of soils.
- v) California Bearing Ratio of laboratory compacted soils.
- vi) Bulk specific gravity and density determination of soils.

7 : ANALYSIS OF TEST RESULTS

The summary of test results is shown in Table - 1, while the test results are discussed below in detail.

7.1 Discussion on Test Results

An analysis into test results collected from four highways of the capital show that the many engineering properties of soils are consistent with one another.

7.2 Natural Moisture Content

The natural moisture content values ranged between 15 - 20%. The samples were collected from the shoulder and also during the month of February, being a cold wet season, by virtue of this factor these values are high and above the optimum moisture content values. The detrimental effect of water above the optimum level on the properties and performance of subgrade is profound. Water content reduces the stability of subgrade. There are instances where water has contributed to pavement failure. Therefore, subgrade soils must be prevented from seepage and infiltration.

Table 7.1 shows generalized permeability values to highlight the severity of slow rate of water removal from these soils.

Table No. 7.1 Natural Moisture Content, Optimum Moisture Content Values

S. No	Location	NMC (%)	Optimum (%)	Soil Type	Coeff. of * Permeability Ft/day
1	Kashmir H'way AGPR Office	20	15	Silty Clay	.05
2	Kashmir H'way Aabpara Market	18	13	Clay	.0005
3	Convention Centre R'Bout	14	14	Silty Clay	.05
4	Faizabad Flyover	19	13	Silty Clay	.05
5	NTRC Complex	15	16	Clay	.005

* Generalized range values.

Table No. 7.2 Atterberg Limits & Soil Classification

Sl No	Location	Aterberg Limit			Degree of LL	Degree of Plasticity	Soil Type	
		LL	PL	PI			ASTM	Unified
1	Kashmir H'way AGPR Office	27	17	10	Low to Intermediate 25-35	Moderate (5-15)	A4	CL-ML
2	Kashmir H'way Aabpara Market	31	15	16		Plastic (16-35)	A6	CL-ML
3	Convetion Centre R'bout	28	18	10		Moderate	A4	CL-ML
4	Faizabad Flyover	28	19	9		Moderate	A4	CL-ML
5	NTRC Complex	32	20	12		Plastic	A6	CL-ML

7.3 Group Index

The group-index formula is devised for within-group evaluation. A group index of 0 indicate a good subgrade and a group index of 20 or greater indicates a very poor subgrade. The group index values ranged between 7 - 15.

Table No. 7.3 Group Index & Subgrade Quality

Sl No	Location	Group Index	Sub-grade Quality Scale 0-20
1	Kashmir H'way - AGPR Office	8	Fair
2	Kashmir H'way-Aabpara Market	15	Poor
3	Convetion Centre R'bout	7	Fair
4	Faizabad Flyover	7	Fair
5	NTRC Complex	10	Fair

* The above ratings assume good drainage conditions & through compaction of sub-grade.

The engineering properties of compressibility, permeability, rate of volume change, toughness and dry strength are more or less the same as liquid limit and plastic limit have a narrow range.

Clays must further be subclassified into Kaolinite, Illite or Montmorillonite etc. as their is a significant difference in their properties. A dry compacted montmorillonite soil can exert a pressure in excess of 5 tons/sq.ft. when restrained and moisted which is far more than enough pressure to disrupt pavement structures, while kaolinite in most cases behaves like silt.

7.4 Activity

Considerable additional insight can be gained by relating plasticity to particle-size distribution. It is known that different clay types differ in their ability to turn a soil plastic when present at a certain percentage content. Moreover, two soils with the same plasticity index or liquid limit may have widely different clay contents if the physio chemical activity of ratio of the plasticity index to the percent by weight of soil less than 0.002 mm. Activity has proved useful for characterizing the nature of the clay components of various soils. But this test cannot be carried out due to non-availability of sieves below #200.

7.5 Capillarity in Soils

Islamabad has a higher rainfall and water table. The capillary rise is more significant in silts (24 to 660 inches) and in clays (80 to 160 inches). Ground water table measurements are as essential as physical properties of sub-grade. Water removes from these soils slowly enough to keep them wet for significant periods, thereby greatly reducing their strength. Therefore good drainage is very essential.

7.6 Gradation and Classification of Soil

The particle-size distribution is the most significant analysis for subgrade soils. The sieve analysis show that the soils are composed of very fine particles of nearby equal size, around 82-97% passing No. 200 sieve. Therefore, by any standard the soils can be classified as fine-grained soils (more than 50% passing No. 200 sieve are fine grained). It may however, be noted that the size distribution in material less than No. 200 sieve is not significant in engineering work. The criteria delineated in unified soil classification system was applied after the data on grain size distribution and Atterberg limits were obtained. According to this system the soils can be precisely classified as a mixture of inorganic clay and silt of low plasticity (CL-ML) containing fractions of sand particles. The soils were classified as inorganic after 24 hour oven drying at 110 celsius & changes in liquid limit were well below 25%.

According to AASHO (M 145) sub-grade classification system the soils are A-4 and A-6 type i.e. a mixture of clay and silt.

Un fortunately these type of soils are not rated as good sub-grade soils, and A-6 soils are highly vulnerable to moisture changes. Generally, the quality of soil where percent fines exceed 15 and plasticity index exceeds 10 are regarded as fair to poor sub-grade material. Similarly, soils with flatter gradation curves are poorly graded soils and that these soils are susceptible to moisture variations and easily deformable under wheel loads.

Table No. 7.6 Gradation & Classification of Soils

Sl No	Location	SIEVE NUMBER (PASSING %)							
		4	10	20	40	60	140	200	PAN
1	Kashmir H'way AGPR Office	95	95	94	93	93	92	92	92
2	Kashmir H'way Aabpara Market	100	99	99	99	98	98	98	98
3	Convetion Centre R'bout	96	93	91	90	89	84	82	82
4	Faizabad Flyover	98	97	96	96	95	94	93	93
5	NTRC Complex	97	96	95	94	92	88	84	81

7.7 Moisture-Density (M-D)Relationship

Subgrade soil stabilization for pavement foundation is normally achieved by adding water to soil which facilitates compaction. The compacted subgrade must resist densification and deformation under repeated wheel loads. Subgrade volume must not change excessively during rainy season or dry season.

The famous modified proctor (modified AASHO) test was carried out on soils, giving a compactive effort of 56,300 ft. lb/ft-sec. The maximum dry density values ranges between and optimum moisture values ranged between 13-15 percent.

It is pertinent to point out that sub-grade is likely to become saturated through seepage and infiltration, and as cohesive soils are normally compacted at water content less than the plastic limit, future saturation may result in material closer to liquid limit, with consequent reduction in soil stability. Thus cohesive soils must not only be compacted to a required degree of stiffness but this deformation resistance must be maintained at an acceptable level during the life of the pavement. Moreover, a highly plastic clay soil may compact best at a relatively high water content with the kneading action of sheepfoot or prievmatric wheeled roller, whereas a granular soil may compact well and to a much higher density than the clay, at low water content with a vibratory roller

It is not uncommon to find five-ten distinct soil types along a kilometer of road.

Table No. 7.7 Moisture-Density (M-D) Relationship

Sl No	Location	Optimum Moisture Content %	Normal Range	Max. Dry Density	Normal Range	Compre-ssibility & Expansion	Field Comp-action	Value as Up-grade Material
1	Kashmir H'way AGPR Office	15	10-20	115	95-130		Sheep-foot	
2	Kashmir H'way Aabpara Market	13	10-30	118	95-120		or	Fair
3	Convetion Centre R'bout	14	10-20	117	95-130	Medium	Rubber	to
4	Faizabad Flyover	13	10-20	115	95-130		Tired	Poor
5	NTRC Complex	16	10-30	112	95-120		Roller	

Apart from moisture content, the maximum dry density is effected by a number of variables, including soil type, procedure of compaction, degree of compactive effort and the processing of soil during and after compaction. This makes very difficult the extrapolation of laboratory-compaction results to field situation. It is nevertheless valuable to study in laboratory-compaction properties of soils prepared under standard conditions as a starting point and guide to specifying field-compaction conditions. Reusing previously compacted soil during the test tends to increase dry density by a few pcf. but processing a sufficient quantity of soil to provide unused specimen for each moisture level is usually inconvenient.

7.8 CBR Values

The California Bearing Ratio test is entirely an emperical and inspite of its limited accuracy, it is the most widely used test for highway construction to give a reasonable measure of resistance to excessive deformation under load. The test is designed to indicate the relative stability of soil that has been constructed with a particular density and water content and that has adjusted to its environment beneath the pavement. The load penetration curves for soil samples were developed and these curves were compared to the standard curve to obtain the CBR values. Relative Bearing values defined as the load at 0.1 to 7 and also 2.1 to 7 respectively. Normally values ranges between 2 to 15 in unified system and 2-25% in AASHO system. The low CBR values are substaintiated by the fact that these soils are poorly graded. When sub-grade CBR-values are low, current practice is either to place a capping layer of selected fill on the weak soil to form a new "Sub-grade" upon which is than placed sub-base material or provide chemical treatment (stabilization) with lime or cement otherwise the thickness of sub-base will increase exorbitantly.

Table No. 7.8 California Bearing Ratio (CBR)

Sl No	Location	CBR @ 0.1 & 0.2		Qlty. As Sub-grade	Treatment
1.	Kashmir H'way-AGPR Office	5.2	5.5	Fair	Depends on Cost of
2.	Kashmir H'way-Aabpara Market	4.6	4.8	Poor	Required
3.	Convetion Centre R'bout	5.6	5.8	Poor	Required
4.	Faizabad Flyover	5.5	5.8	Poor	Required
5.	NTRC Complex	4.8	5.0	Poor	Required

The amount of volume change was recorded during the soaking period. The values ranged from 1 to 5 percent. Values exceeding 3 percent were rated as poor for subgrades.

7.9 Specific Gravity

Specific gravity is another toll in dealing with height volume relationships and is used for the conversion of solid weights to volumes and vice versa. The specific gravity values ranged between 2.60 to 2.70.

Table No. 7.9

S. No	Location	Specific Gravity
1	Kashmir H'way – AGPR Office	2.63
2	Kashmir H'way – Aabpara Market	2.62
3	Convetion Centre R'bout	2.63
4	Faizabad Flyover	2.60
5	NTRC Complex	2.7

7.10 Swelling Potential

Swelling with increasing moisture content is related to, mechanical, capillary and physiochemical effects. These factors also determine soil plasticity, therefore in the absence of exact analysis results relating swelling potential with plasticity index are in low-intermediate range.

8 : CONCLUSION AND RECOMMENDATIONS

An analysis into physiomechanical properties of sub-grade soils show that the soils are fine-grained and are a mixture of clay and silt in varying proportions. According to AASHO classification the soils are designated as A-4 and A-6 and CL-ML according to Unified system. The soils have low to intermediate plasticity values. These soils have very low soil support values (CBR Values 2-5%). Unfortunately, these soils are not rated as good sub-grade material, as fine-grained soils are only stable when dry and unstable when wet. Poor drainage practices further aggravate the problem is Islamabad.

When subgrade CBR-Values are so low, current practice is, after relative construction cost evaluation and maintenance performances, either to place a capping layer of selected fill on the weak soil to form a new "subgrade" upon which is than placed subbase material or provide chemical treatment (stabilization) with lime or cement to alter the engineering properties of soil, like strength, stiffness etc. To desirable standards, otherwise the thickness of subbase will increase enormously.

But, it is pertinent to point out that considerable variations in the characteristics of soil samples will be found in samples of apparently like soils taken from almost adjacent location. Therefore, this study only provides a guide and in no way be taken as a exhaustive study on subgrade soils of Islamabad.

It is pertinent to point out that drainage is very essential for fine-grained soils, as saturation closer to liquid limit causes a drastic reduction in soil stability triggering subgrade failure, which occurs more than often in Islamabad.

Subgrade is the foundation of the pavement structure therefore, extreme care must be taken during evaluation of the properties of subgrade material:-

i) Highway agencies must ensure that detailed procedures for the investigation of subgrade materials must be followed, as laid down in various establish manuals.

ii) Usually, Gradation upto #200 sieve, Moisture-Density, CBR, Atterberg Limits, specific gravity tests are carried out but it is very essential to determine material characteristics beyond #200 for fine-grained soils.

iii) Moisture-Density curves must be carried out as per field requirements.

iv) Activity, sensitive, swell potential etc. must be evaluated.

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