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New Concepts In Sub-grade Design

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Contents

EXECUTIVE SUMMARY

One of the important aspect in the pavement design is the sub-grade moisture content for determining its strength. The Engineers in Pakistan generally use soaked CBR values which results in an uneconomical (thicker) pavement in most cases.

This study introduces Equilibrium Moisture Content concept, coupled with ISO-CBR curves for the quantification of sub-grade strength. The Equilibrium Moisture Content is not subject to seasonal change and measured away from the pavement edge after the construction of the road.

To determine the practical application of the concept, three soils samples from the vicinity of Rawalpindi-Islamabad were used. The samples were compacted with varying moisture contents and ISO-CBR charts were produced by plotting dry densities verses moisture content, with CBR values marked at each point. These charts can serve as ready-reckoner for determination of sub-grade CBR at a particular moisture content. With the help of these charts, the design strength of sub-grade can be determined for the local soils. The method produces a thinner pavement as compared to soaked CBR value.

Although wide spread use of the method has the potential of bringing about considerable savings, most

pavements fail prematurely even with thicker layers on account of the use of soaked CBR values, mainly due to poor quality control practices. There is therefore need to bring about improvement in quality control, which incidently does not entail any additional cost, to take advantage of more economical design concepts developed during last two decades.

1. INTRODUCTION

1.1 GENERAL

The objective of pavement design is to produce an engineering structure that will distribute traffic loads efficiently. Bituminous pavements have essentially three components as shown in Fig. 1.1.

- The Pavement Foundation (Sub-grade)
- The Road Base
- The Surfacing

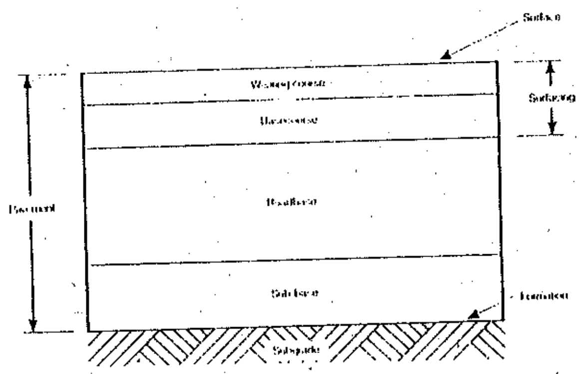


Fig. 1.1 Structural layers in a bituminous pavement

Generally pavement design methods can be placed in to three main categories:

1.1.1 MECHANISTIC OR ANALYTICAL METHODS: In these type of pavement design methods after the establishment of design loads, the stresses and strains in the pavement caused by the applied traffic loading on the selected pavement are analysed. The designer must then nominate the worst pavement condition acceptable over the design life of pavement. It leads to set of defined failure criteria. The calculated values are then compared with these criteria. The example of such design method is the Shell's Pavement Design Method (SPDM), based on BISTRO Computer Programme.

1.1.2 EMPERICAL METHODS: Design methods falling in this category relate the pavement thickness to strength of the subgrade, proposed materials and anticipated traffic during the life of the pavement. Examples of such design method are CBR method developed by the California state highway department during the 1930's in which the strength of the sub-grade and unbound granular materials is measured by the CBR test. The total thickness of the pavement is related to the soaked CBR value of the subgrade for the particular wheel load as shown in Fig. 1.1.2

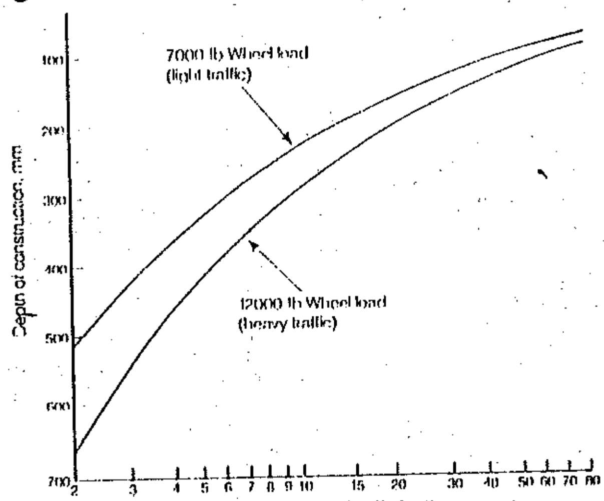


Fig. 1.1.2 California bearing ratio design curves.

The other example of such design method is Road Note 29 design procedure produced bythe Transport and Road Research Laboratories (TRL) for the design of flexible pavements.

1.1.3 SEMI - EMPERICAL DESIGN METHODS: In such type of pavement design methods the recommendations derived from the structural performance of the experimental roads, for pavements with different types of road bases are used. The basic design provide reference structures, having an 85% probability of survival which can be modified using analytical approach. Thus such design methods recognise the variability in the road structure and the uncertainties of traffic forecasts. Examples of such method are LR1132 and AASHTO Design Guide, 1986 and Road Note 31.

1.2 OVERSEAS ROAD NOTE 31

The current Road Note 31, a design guide for the structural design of bitumen surfaced roads in tropical and sub-tropical countries, lies in the third category of pavement design methods which based on [1]:

i) The results of full-scale experiments where all factor effecting performance have been accurately measured and their variability quantified.

ii) Studies of the performance of as-built existing road network.

1.2.1 THE DESIGN PROCESS: There are three main steps to be followed in designing a new road pavement by this method. These are:

i) Estimating the amount of traffic and the cumulative number of equivalent standard axles that will use the road over the selected design life.

ii) Assessing the strength of the sub-grade soil over which the road is to be built.

iii) Selecting the most economical combination of pavement materials and layer thicknesses that will provide satisfactory service over the design life of the pavement. (It is usually necessary to assume that an appropriate level of maintenance is also carried out).

1.3 APPLICATION OF THE ROAD NOTE 31 TO PAKISTAN

Unfortunately due to the non-availability of any pavement design method in our country, the road engineers mostly used the AASHTO Design Guide, 1986 or the Road Note 31 for the pavement designs in Pakistan. Few aspects of design which have to be considered for designing any pavement in tropical country are as follows:

i) The influence of tropical climates (i.e. more rain and high temperature) on moisture conditions in sub-grades.

ii) The severe conditions developed on imposed bituminous surfacing materials by the tropical climate and the implications of this for design of such bituminous surfacing.

iii) The high axle loads and Tyre pressures which are very common in our country.

Except the third factor mentioned above, most of the factors are covered in the design method of RN 31.

1.3.1 AXLE LOADS: In the design method traffic loading is expressed in terms of equivalent standard axles, on the same basis as that used in AASHTO method. When over all volumes of traffic are low and axle loads are modest, the introduction in to the traffic stream, of a small proportion of vehicles with more than 20 tonnes axle load can double or treble the damaging power of the traffic. This conclusion arises from the assumption that an axle load of 20 tonnes is roughly 260 times as damaging as one axle of 5 tonnes using the 4th power law. Similarly as per AASHTO equivalence factors the damaging effect of 20 tonnes

Similarly as per AASHTO equivalance factors the damaging effect of 20 tonnes axle load is 300 times more as compare to 5 tones axle load. The maximum axle loads used in AASHTO road test were 13.6 tonnes for single axle, and 21.8 tones for tandem axle sets. In Pakistan, single axle load in excess of 20 tonnes are not uncommon, (NTRC No.   et.al 1995) hence it is necessary to extrapolate well beyond the AASHTO test results to derive the load equivalance factors for these loads. This results the total number of ESAL's during the design life (mostly taken 10 years) exceeds the highest class of traffic i.e. T-8 ranges 17-30x10^6 ESAL's, on the major highways in Pakistan. Therefore, the guide suffers the disadvantages that it cannot be applied with confidence to design situations that lie out the range conditions with which it has been derived. Nevertheless it does offer the designer a wide choice of pavement material options and is suitable for the design of medium and lightly traffic roads in Pakistan.

2. OBJECTIVE OF THE STUDY

The objective of this study is to analyse the second aspect of the pavement design by RN 31 i.e. the assessment of the strength of the sub-grade soil over which the road is to built, which results to develop charts for e.g. Fig. 2.1 for different types of soil, commonly used in subgrade here in Pakistan. This relates the moisture/density properties of the particular soil to its CBR.

Using charts of this type for local soils, appropriate CBR design values can be derived from a knowledge of the likely state to compaction and the equilibrium moisture conditions likely to occur under the new pavement.

The literature review section of the study will cover the new research happening in all over the world relating to CBR testing and equilibrium in moisture condition. The scope of the study also covers to provide knowledge to our road engineers in Pakistan about the research happening in the field of pavement engineering in other parts of the world.

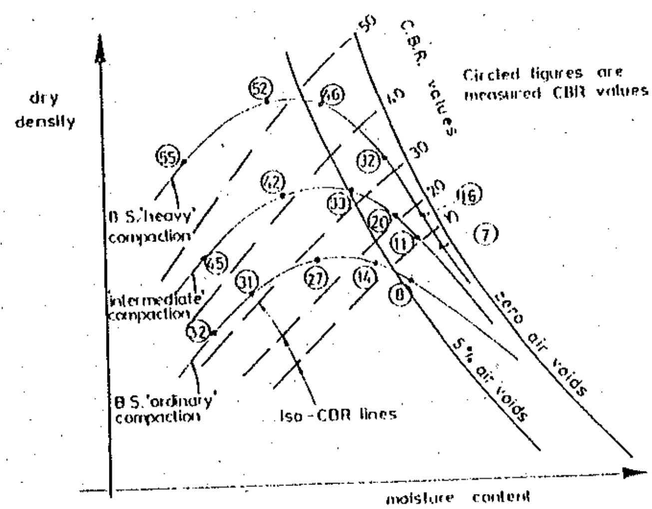


Fig.2.1 Construction of ISO-CBR lines from test on compactedsamples.

3. LITERATURE REVIEW

Sub-grade is the most important component in any pavement, as it provides the foundations to the upper layers. The strength of road sub-grade is commonly assesed in terms of California Bearing Ratio (CBR) and this is dependent on the type of soil, its moisture content and density.

3.1 THE SUB-GRADE MOISTURE CONTENT

Historically engineers used the optimum moisture content as the design moisture content for subgrade which leads to serious faulty results. Now a days road engineers preferred to determine design parametres on material brought to the appropriate moisture content i.e. the Equilibrium Moisture Content . The optimum Moisture Content is the moisture in soil where the maximum density achieved for a particular compactive affort. The OMC is not easy to determine accurately and has a co-effecient of variation of about 20% although it has been suggested that the value can be as high as 45% (Ingles and Moble et.al. 1975) or as low as 10% (Smith, Pratt and Crews et.al. 1983).Moisture content under road pavement will vary seasonably, annually and over longer periods. Second variations in moisture content are commonly located in the upper 1 to 2 m. Significant moisture changes will only occur immediately after rainfall if very permeable layer exist. Otherwise the changes will be very slow. Most of the changed moisture content occurs in the metre or so of pavement width at the edge of pavement surface (Morris and Gray et.al. 1976). The estimation of moisture content for design purposes is often based on the equilibrium moisture content. This is the stable (i.e. not subject to seasonal change) moisture content found away from the pavement edge some time after construction. It is therefore the appropriate value for design and construction of much of roadway. The Equilibrium Moisture Content depend on climate, soil type, water table depth and soil water composition [2].

The estimation of the design sub-grade moisture content can be done by following three methods:

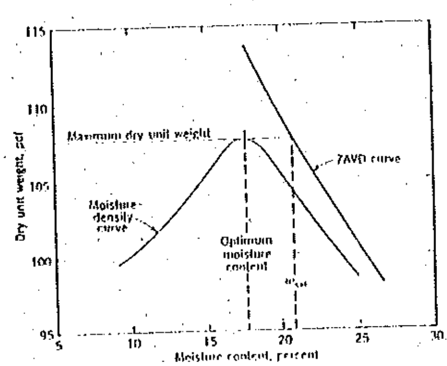
i) Measure the moisture content in sub-grades below existing pavements in similar situation at the time of year when the water table is at its highest level. When no suitable road is available in the vicinity, moisture content in the sub-grade under an impermeable pavement can be estimated from the knowledge of water table, section and soil moisture content (Russam and Croney et. al 1960).

ii) When the water table is not near the ground surface and where the annual rainfall is greater than 25mm per year, the design moisture content can be taken as the optimum moisture content obtained by standard tests.

iii) In region where the climate is dry and annual rainfall is less than 25mm per year for design purposes, a value of 80% of the optimum moisture content can be adopted.

3.2 THE SUB-GRADE STRENGTH

For any pavement design, the sub-grade whether in cut or fill should be well compacted to utilize its full strength and to economise thereby on the overall thickness of pavement requirement. Proper determination of sub-grade strength in either form of pavement (flexible or rigid) plays a very important role in the design and performance of any pavement. An objective of compac- tion is to rapidly pack a maximum of soil solids in a unit volume. With few exception, soil water content remains constant and the compaction consitsof expeliing air as solids assure positions or orientation favorable for tight packing. The amount of packing is measured in terms of dry unit weight (dry density). The degree of compaction depends primarily on three factors: (1) Soil moisture contents during compaction (2) Soil type (3) Nature and amount of compactive effort. In the laboratory, one may examine the effect of any one of the three factors by holding the other two constants. The particular soil type and compactive effort, as the water content of the soil increases, the achieved dry density will increase as well. Soon, however, a point is reached where increasing water content has an adverse effect, causing dry density to decrease. Thus, there is an optimum water content at which a maximum dry density may be reached [3]. A typical moisture density curve is shown in Fig 3.2.



Typical moisture-density curve developed by soil compaction and ZAVD (zero air voids density) curve for $G_s = 2.70$.

Fig.3.2 A Typical Moisture Density Curve

The purpose of compaction is to provide soil with stability. For fine grained subgrade soils, an index of stability is resistance to excessive deformation under load or pressure. CBR is probably the most widly used index of stability. The CBR test will clearly be a measure of both the vertical stiffness and the shear strength of the material being tested. The CBR test has received most validation as a subgrade test and has an overall coefficiant of variation of about 20%. However, at one location the coefficiant as high as 60% (Smith and Pratt et.al 1983).

The main problem with it are reproducing the correct moisture and density and eliminating material over 19 mm. The soaked CBR, for instance, is the appropriate test for a material likely to be saturated in service. As such it remains the basic test conditions in many countries. But now a days, most of the design methods, as TRL RN31, or Australian Road Design practice insist that in most cases, CBRs should be conducted at the anticipated (unsaturated) moisture contents (Lonton, et.al 1952). The unquestioning use of the soaked CBR thus tends to sidestep the more desirable determination of inservice moisture conditions (equilibrium moisture content).

There are circumstances where soil sub-grade are likely to be very wet i.e. when there is water table immediately under the pavement, in this case, the procedure of soaking is supposed to be right. However, it should be realised that soaking for four days may be un-realistically severe moisture condition in certain cases. Cases falling in this category are briefed as follows:

i) Sub-grade of roads where a comparatively thick bituminous surfacing of impermeable nature is provided on top, such as well laid and sealed dense carpet, and where simultantously (a) water table is too deep to affect the sub-grade adversely (i.e. greater than one metre in sands and three metre in clay) and (b) well shaped verges exists facilitating quick drainage of surface water to the side drains.

ii) Sub-grade in areas where climate is arid through out the year i.e. annual rain fall is of order of 50 cm or less and water table is too deep to affect the sub-grade adversely. In the above situation, it is anticipated that the most severe moisture condition in the field will be far behind that of sample at the end of four days soaking resulting in unduly conservative designs if soaking procedure is adopted [4].

Even a simple design method as the CBR method is open to misuse. In the original formulation of the method, the CBR of the sub-grade material is obtained after four days of soaking. A condition which is very unlikely to apply under a properly built road. Thus the measured CBR is merely used as an index of strength to classify the material. On the other hand, the pavement performance data on which the design thicknesses are based were obtained from in service pavement. Under such pavement, the in-situ CBR of the sub-grade (which is related to the actual supporting value of the sub-grade) would have been much higher than the soaked CBR value[5].

4. METHODOLOGY

The procedure recommended by the TRL for relating CBR values to variation in density and moisture content for a particular type of soil is out lined in the following para's.

4.1 SOIL TYPE

In this study the different types of soil, commonly used in subgrade in the vicinity of Islamabad/Rawalpindi have been selected. The specification are given table 4.1.

Table 4.1 Specification of Soil Used

SOIL TYPE	SPECIFICATIONS	AASHTO CLASSIFICATION
Soil Type I	Morethan 35% passing #200 Sieve with P.I.< 15	**A - 6**
Soil Type II	Morethan 35% passing #200 sieve with P.I.>15	**A - 4**
Soil Type III	Lessthan 50% passing #200 sieve with P.I <10	**A - 2-4**

4.2 COMPACTION LEVELS

Each soil sample has been subjected to compaction test in a 152 mm diameter CBR mould at three different compaction levels as described in table 4.2.

TABLE 4.2 COMPACTION LEVELS USED

LEVEL	TYPE OF COMP.	MASS (kg)	DROP (mm)	NO.OF LAYERS	BLOWS/ LAYERS	COMP. EFFORT
I	ASTM Ordinary (D698-78)	2.49	305	3	56	12,400 ft-lb/ cu.ft
II	Interme-diate	2.49	305	5	56	26,400 ft-lb/cu.ft
III	ASTM Modified (D1557-78)	4.54	457	5	56	56,300 ft-lb/cu.ft

4.3 ISO-CBR DEMARCATION

Finally by drawing the CBR on the moisture/density graph of each soil type at three different compaction levels, charts has been produced for the determination of design CBR of sub-grade at any moisture condition. Therefore by Knowing the moisture conditions under the pavement after construction i.e Equilibrium Moisture Content, the design CBR for the sub-grade can be calculate from the ISO-CBR charts for the above mentioned soil type.

5. RESULTS

Three different types of soil, mostly used in the construction of sub-grade in the vicinity of Rawalpindi Islamabad region , the samples were collected and tested as per ASTM standards for the phsysical testing while Moisture- density-CBR relationship for each soil type has been found as per TRL method.
Physical properties of all the three soil types have been determined as per ASTM standards and placed in Table.5.1-a & 5.2-b.

5.1 PHYSICAL PROPERTIES OF SOILS

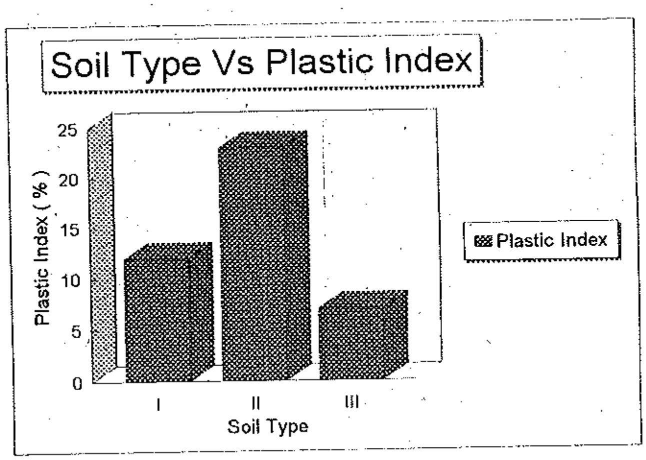
Table.5.1-a PHYSICAL PROPERTIES OF SOIL

Soil Type	Location	Sample Description
I	Kashmir Highway, Islamabad	Yellowish Brown, Silty Clay Soil.
II	Islamabad Highway, Islamabad	Redish Brown Clayey Soil.
III	Chak Belli Khan Road R.Pindi	Lean Sandy Silt,

Table.5.1-b PHSYSICAL PROPERTIES OF SOIL

Soil Type	Passing #200 Sieve	Atterberg's Limits L.L	Atterberg's Limits P.L	P.I (%)	Sp.Gravity
I	90 %	30 %	18 %	12	2.615
II	85 %	33 %	10 %	23	2.701
III	40 %	18 %	11 %	7	2.721

It is tried in the study to select the three different type of soil, for this purpose the soil type I , has been choosen as clayey material with low plasticity, while the soil of type II was with high plastic Index. The Soil Type III was a soil with enough sandy matetrial . Specific Gravity for each type of soil was determined which range from 2.615 to 2.721. Similarly the plastic Index of soils range from 7 % to 23 %. While the percentage of material passing No.200 # range from 40 % to 90 %. Soil Type I was collected from the Kashmir highway , Soil type II was collected from Islamabad Highway , While the Sandy Soil Type III was retained from Chak belli Khan Road Rawalpindi.



5.2 COMPACTION IN RELATION TO SOIL TYPE

In order to find out the effect of compactive effort on the soil type, all the three soils were tested under standard compaction level, results of the test are placed in Table.5.2 & fig.5.2. Is is found that the dry densities varies from 94 lb/cu.ft to 115 lb/cu.ft. under the same compactive effort, similarly the maximum dry density in Soil Type I was observed as 108 lb/cu.ft, at Optimum Moisture Content of 17 %, in the case of Soil Type II the Maximum dry density of 106 lb/cu.ft at a Optimum Moisture Content of 13% was observed, while in the case of Soil Type III, the Maximum Dry density of 115 lb.cu.ft was find at a Optimum Moisture Content Of 13%.

Table.5.2 Compaction In Relation to Soils Type For Level I

Sp.gravity	2.72								
M.Content	5%	7%	9%	11%	13%	15%	17%	19%	21%
	Dry Density (lb/cu.ft)								
Soil I	94	95	99	100	104	105	107	106	104
Soil II	92	94	96	102	106	104	102	99	97
Soil III	105	108	110	112	115	113	110	108	106
ZAVD	149	143	136	131	125	121	116	112	108

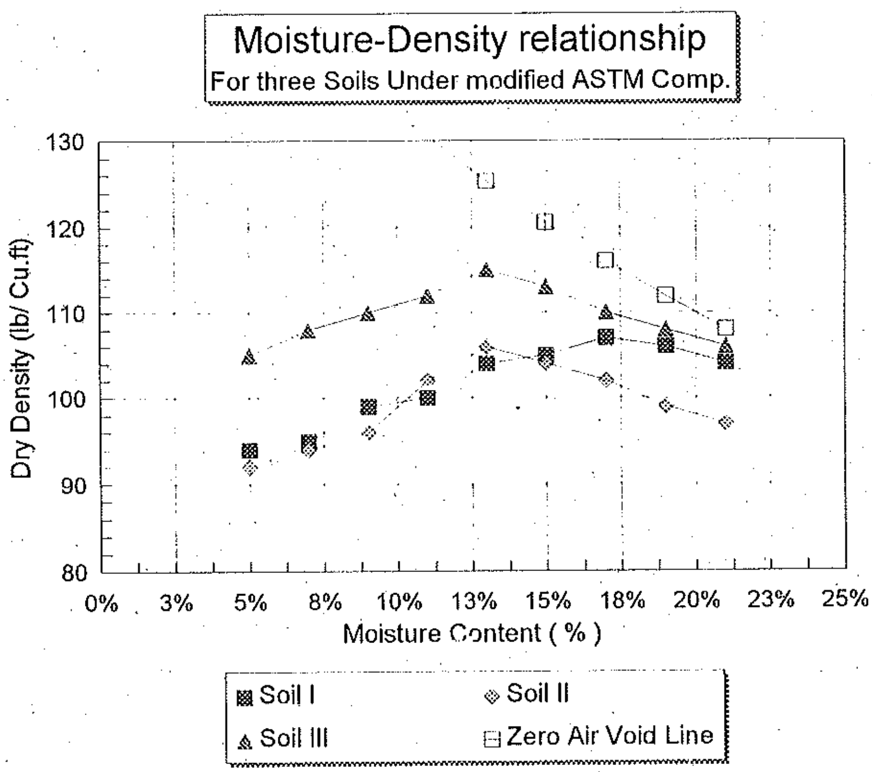


Fig.5.2

5.3 THE FAMILY OF CURVES METHOD

In the laboratory, in order to observe the behavior of each soil, it is of cosiderable advantage to study the influence of molding moisture content and dry density on the stability of soil.This can be done utilizing the family -of-curves method of compaction-data analysis developed by Turnball and McRae[6].By this method the usual moisture-density curves are developed for the soil, but for three levels of compactive efforts, CBR values are than plotted on each point as shown in Fig.5.3.It is customery to compact the soil in cylinderical mold using a drop hammer.If the number of hammer blows applied per layer is varied, or the weight of the hammer is changed to establish compaction curves for different levels of compactive effort, results similar to Fig.5.3-a to Fig.5.3-c will be obtained.

Table. 5.3-a Moisture-Density-CBR Relationship of Soil Type I

Sp.gravity	2.72								
M.Content	5%	7%	9%	11%	13%	15%	17%	19%	21%
Dry Density (lb/cu.ft)									
Comp.I	94	95	99	100	104	105	107	106	104
Comp.II	97	100	102	105	108	110	111	109	105
Comp.III	103	105	109	115	118	117	114	112	107
ZAVD	149	143	136	131	125	121	116	112	108
C.B.R (%)									
Comp.I	36	34	33	31	24	25	18	15	12
Comp.II	54	52	49	47	42	40	20	15	14
Comp.III	91	85	78	68	62	60	30	25	20

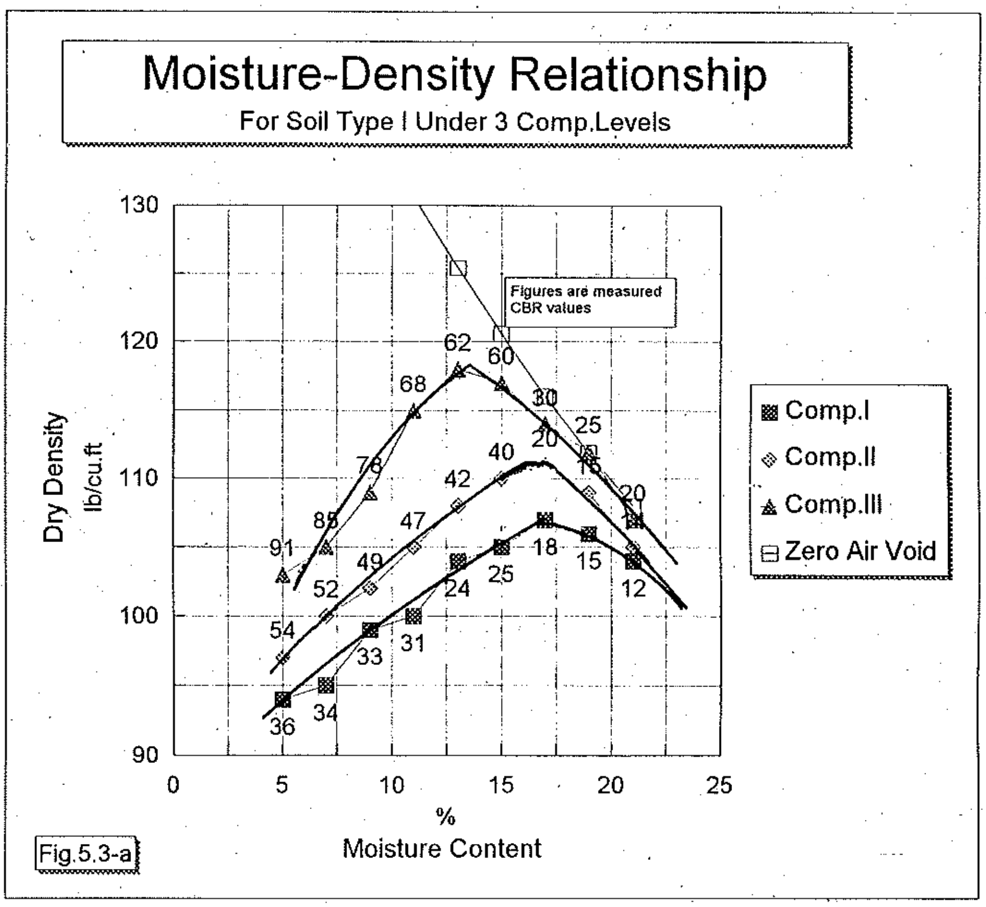


Fig.5.3-a

Table. 5.3-b Moisture-Density-CBR Relationship Of Soil Type II

Sp.gravity	2.72								
M.Content	5%	7%	9%	11%	13%	15%	17%	19%	21%
	Dry Density (lb/cu.ft)								
Comp.I	92	94	96	102	106	104	102	99	97
Comp.II	101	102	104	105	108	110	106	103	102
Comp.III	116	120	122	120	116	113	110	108	105
ZAVD	149	143	136	131	125	121	116	112	108
	C.B.R (%)								
Comp.I	30	20	15	12	10	8	5	5	5
Comp.II	40	38	36	26	24	18	12	8	5
Comp.III	84	86	88	48	15	10	8	5	5

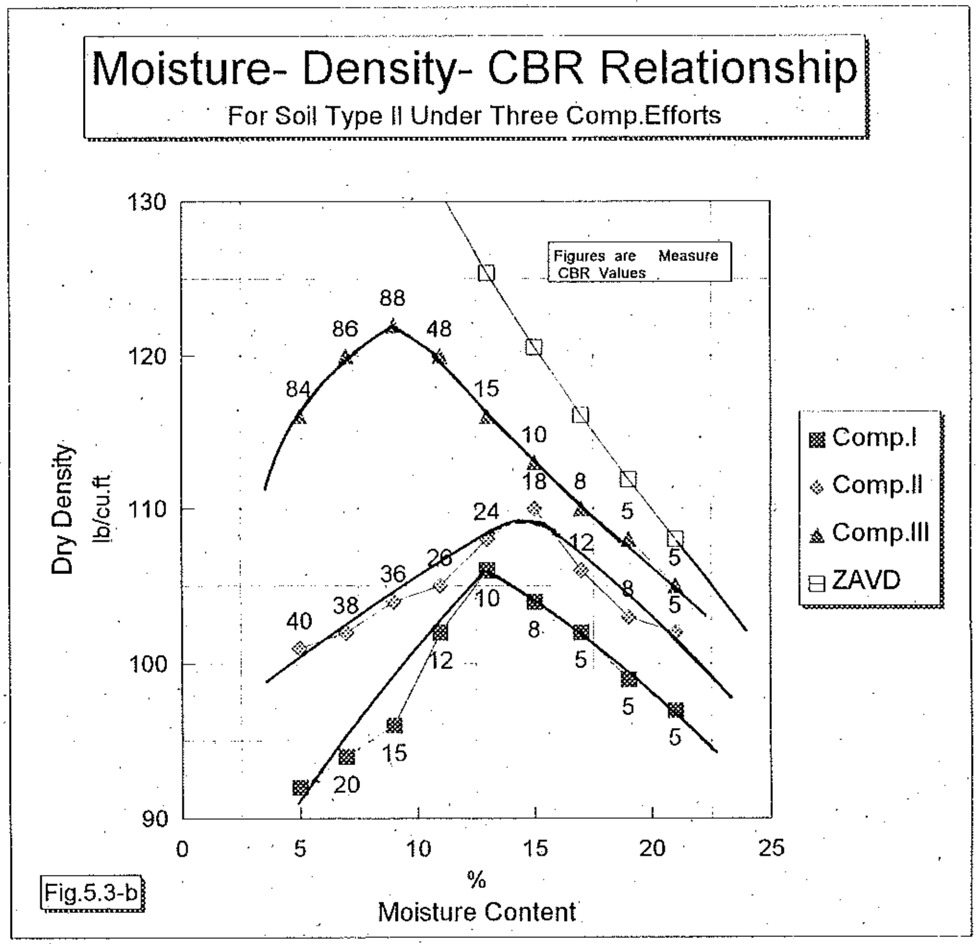
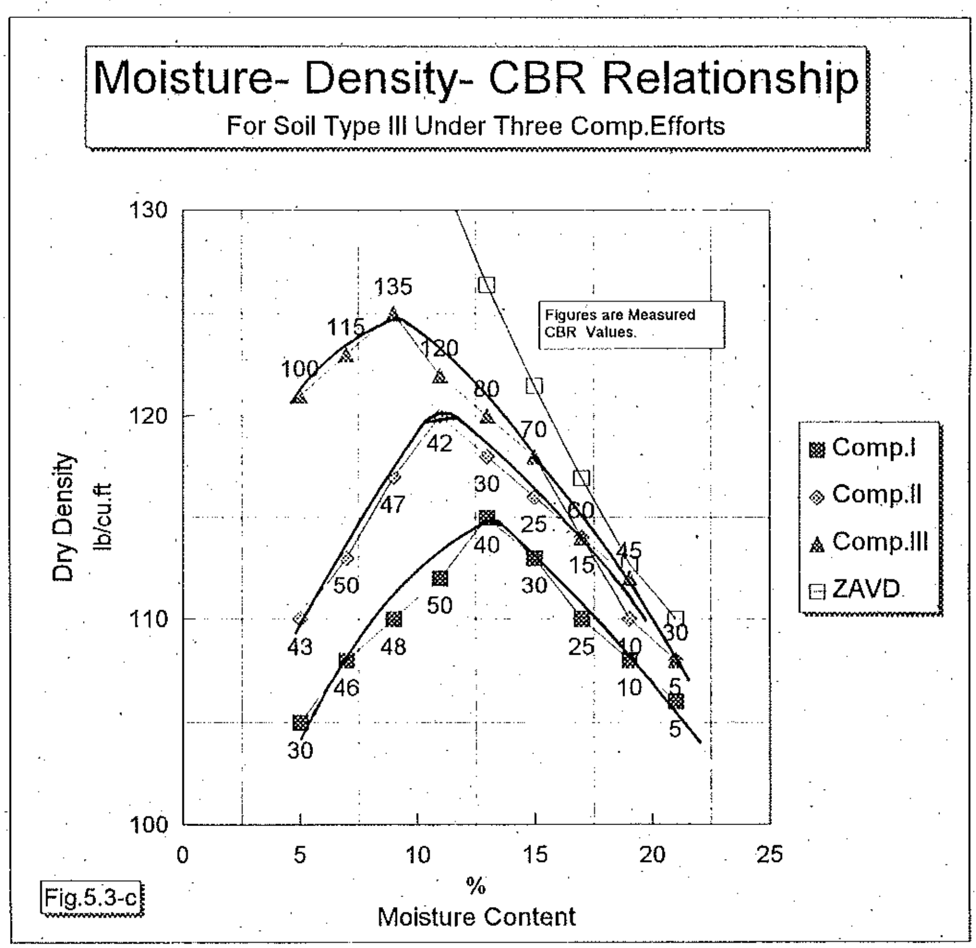


Fig.5.3-b

Table. 5.3-c Moisture-Density-CBR Relationship Of Soil Type III

Sp.gravity	2.75								
M.Content	5%	7%	9%	11%	13%	15%	17%	19%	21%
				Dry Density (lb/cu.ft)					
Comp.I	105	108	110	112	115	113	110	108	106
Comp.II	110	113	117	120	118	116	114	110	108
Comp.III	121	123	125	122	120	118	114	112	108
ZAVD	151	144	138	132	126	121	117	113	110
				C.B.R (%)					
Comp.I	30	46	48	50	40	30	25	10	5
Comp.II	43	50	47	42	30	25	15	10	5
Comp.III	100	115	135	120	80	70	60	45	30



5.4 INTERPRETATION OF RESULTS

Curves in Fig.5.3-a to Fig.5.3-c show tthe effects of moulding moisture content and compacted density on the stability (strength) of the soil. Thus, if a CBR value of 20 % is sought as a minimum and if the soil to be compacted has a moisture content of 18 5, therfore by consulting Fig.5.3-a for Soil type I, a compacted dry density of at least 112 lb/cu.ft is called for. Conversely, if it is determined that a density of 110 lb/cu.ft was achieved in the field at a moisture content of 15%, then by consulting Fig.5.3-a for soil type I, a CBR of 40% value might be expected.

The family permits an evaluation of the extent to which control of water content or dry density or both is necessary in compacting a given degree of stability.

A common practical use of such curves is easily given in Fig.5.3-a, the compactive level III represents the " Modified AASHTO " compactive effort, thus, maximum modified density for soil type III is about 122 pcf. It is common in Highways construction to specify 95% "Modified AASHTO" density for the subgrade requirement, in this case 116 pcf. This density can then be plotted on Fig.5.4 as shown and at glance the engineer can make recommendations as to allowable range of compaction in order to achieve a certain minimum CBR.

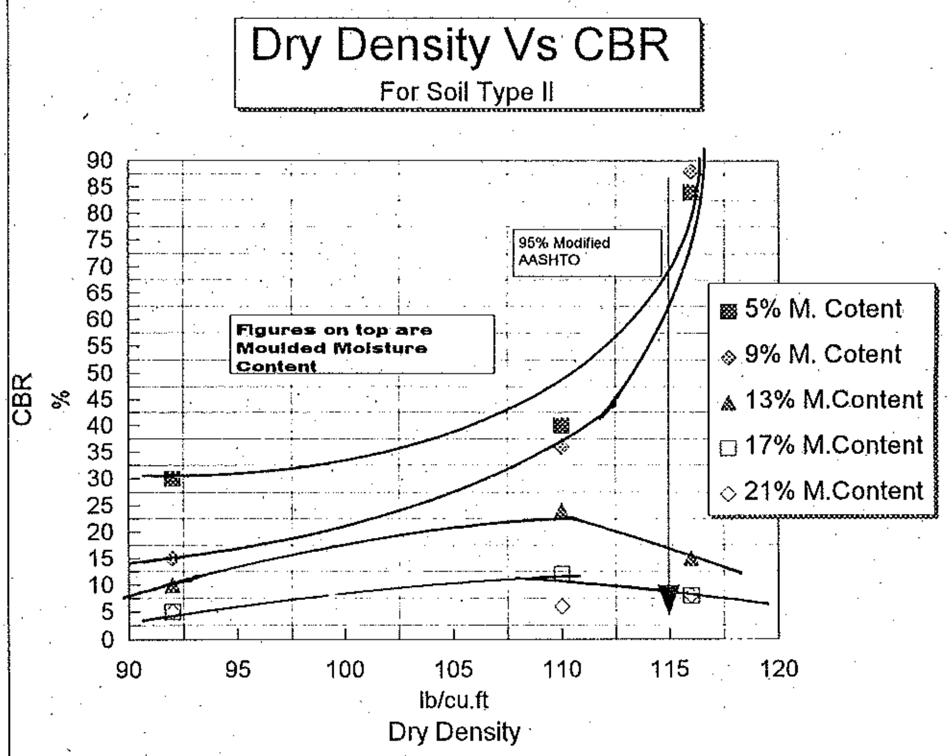


Fig.5.4

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