Design And Analysis Of Heavy Load Pavement For Cost Effective Port Operation Of The Nigerian West-East Coastal Shelf

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ABSTRACT: The intensity of traffic and container loads in operation of ports necessitates the provision of zero or low maintenance heavy load pavements which can be in any of four main forms of pavement construction:- asphalt, concrete block, rigid concrete and reinforced concrete pavements. This paper, therefore, presents a construction/maintenance life cycle cost based pavement structure that reflects on construction materials, methods, port operational techniques and environment for the selection of the most appropriate for Nigerian coastal shelf. Primary data on cargo handling and container traffic statistics (for both export and import) were deduced from the operational and data sourced from the management of Nigerian Ports Authority and the Federal Office of Statistics in Lagos. Further, the length of the Nigerian west-east territorial costal shelf (between Lagos and Calabar), types of handling equipment available at the ports, available materials and construction technology prevailing at the ports environment were also extracted from other relevant sources. The British Ports Federation (BPF) Manual (1989) and the Nigeria Highway Design Manual (1972) were used for the design purposes. Design by Charts were employed with the aid of a Microsoft Excel software while the construction cost analysis was carried out for each pavement type at varying California Bearing Ratio (CBR) values of 1%, 3%, 5%, 10% and 30% for the possible native (subgrade) soils or as modified in bounded forms. The results of the design indicated that the rigid concrete and reinforced concrete pavements are better in technical terms since they can both be placed on soils with very low CBR values. However, the reinforced concrete pavement stands as the best choice economically with reasonably satisfactory technical capability because for all the subgrade CBR values and subbase thicknesses its construction cost is least. The cost of constructing the base course of reinforced concrete pavement on a soil of 10% CBR and 300mm thick subbase, for instance, is ₦5,950.00/m^2 of pavement as compared to costs of asphalt, and rigid concrete pavements which are ₦6,800.00/m^2 and ₦7,761.25/m^2 respectively.

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Key words: Ports, Container terminal, Heavy load pavement, Cargo handling operation, California Bearing Ratio, Design charts.

1.0 INTRODUCTION

Ports are important and intermodal transfer/operational facility for a marine transportation system. Over 96% or 3.6billion tons of international cargo moved through the ports of the world in 1978 (Bruun, 1981), which do come in various physical forms of liquid bulk, dry bulk, parcel or pseudo bulk, or containerized break bulk. Of all the componenting elements of a port, the pavement is about the most extensive in fixed land area and physical presentation. Its provision demands much heavily in investment. The terminal surface (or port pavement) constitute the base of all operations as it makes up for about 5 to 25% of the total budget (De-Heer, 1994). The marine economy is such a risky enterprise that cannot tolerate lost or idle time for frequent maintenance activities and hence the most strategic handling of the desirable pavement is for the initial construction cost to be usually very high with very low or zero maintenance cost.

Also a cost-effective pavement practice for a growing marine industry with selection of the pavement types from the list of asphalt, rigid concrete, reinforced concrete and concrete blocks shall be appropriate. The choice of the construction technology and maintenance practice of heavy load pavements is more appropriate for Nigerian ports, prevailing marine traffic and environment. Apart from traffic, the other major inputs in pavement design, construction, maintenance and operation are the physical strength and elastic properties of all the components (Yoder and Witczak (1975), Theyse et al (2007) and Jimoh (1987)).

This paper investigated the sensitivity of the performance of heavy load pavement within the Nigerian ports for changing materials, construction and maintenance options for a 25 years period, with a view to selecting the most cost effective combinations. The objectives, therefore, are (a) compilation of existing forms of pavements in Nigerian port areas, (b) development of unit cost data for construction, maintenance and replacement practices for various pavements in Nigeria, (c) compilation of a catalogue of lifespans of the various pavement structures, (d) carrying out cost-effective analysis for a 25-year construction and maintenance life, (e) selection of the most economical and cost effective heavy load pavement appropriate for Nigerian ports and hence (f) recommend a draft of design/analytical procedure for heavy load pavement in Nigerian marines.

MATERIALS AND METHODS

Study Area

The Nigerian west-east territorial costal shelf stretches from Badagry (Bight of Benin) to Calabar (Bight of Bonny) with a total length of 771.38km. Figure 1 shows the shelf while Table 1 presents the breakdown of the length of the various segments of the shelf. The coordinates of Bight of Benin is N6 01 52.9; E4 50 35.1 and that of Bight of Bonny is N4 43 37.8; E8 31 35.5 (Germin Corporation, 1995-2002). Port facility plans and development is highly dominated by non-Nigerians (foreigners) unlike the highways. There are seventeen (17) ports along the Nigerian west-east territorial coastal shelf where marine activities are in operation. The four major flagship of the port operation are Lagos Port Complex (Apapa and Tin Can Island), Portharcourt Port Complex, Bonny and the Forcados Ports where the volume of the cargoes handling are up to 15% to 56%.

Table 1: Distances Along Nigerian Territorial Coastal Shelf

LOCATION	LEG LENGTH (Km)	DISTANCE (Km)
INTLBR	0	
LAGOS	78.13	78.13
BHTFB	64.86	142.99
BHGTF1	47.46	190.45
001	57.79	248.24
GLFGNE	35.71	283.95
GLFGN1	52.81	236.76
GLFGN	50.67	387.43
GLFGN3	44.87	432.30
GLFGN4	29.18	461.48
GLFGN5	24.48	485.96
GLFGN6	26.67	512.63
BHGTF2	33.33	545.96
BHGTF3	38.19	584.15
BHGTF4	51.19	635.34
BHGTF5	35.21	670.55
002	50.49	721.04
BHGTF6	18.93	739.97
INTLB1	31.41	771.38

Deskwork

The basic method adopted for this study is in two stages: (i) capture of statistical data on the operation of marine traffic in Nigerian ports system as well as costal material properties using secondary sources and (ii) application for the design of various surface terminal pavements in relation to each container handling system, loadings and pavement materials using Microsoft Excel software and in accordance with British Ports Association analytical procedure.

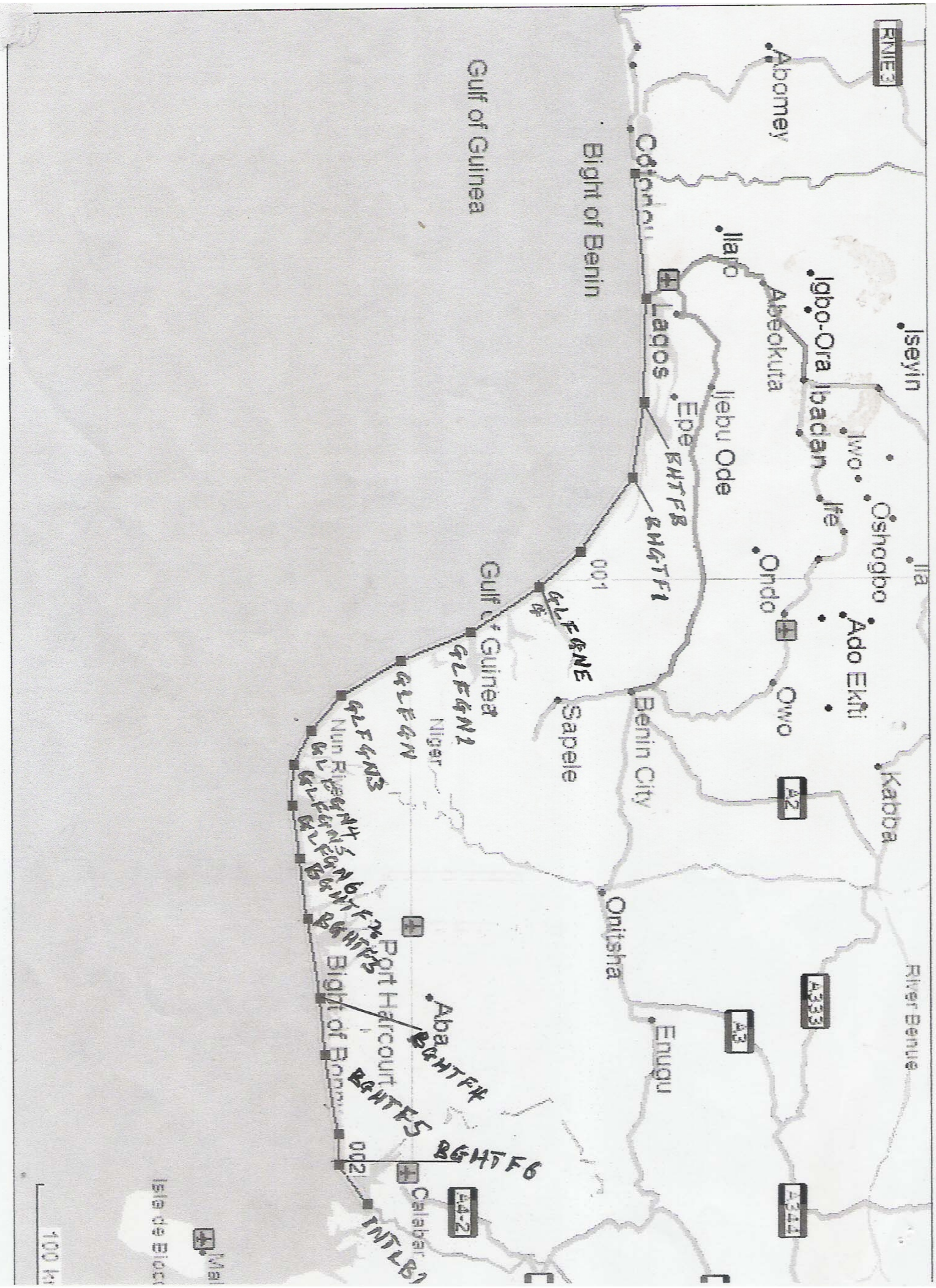

Figure 1: Map Showing Distances along Nigerian Territorial Costal Shelf

Data Presentation

The statistics acquired from the Nigerian Ports Authority, Apapa and Federal Office of Statistics, Lagos which reflected the desirable factors of traffic type, quantity, growth and handling technology are summarized in Tables 2, 3 and 4. Figures 2 and 3 present the ten-year (1988-1998) trend for cargo handling at the ports on the west-east territorial coastal shelf on annual basis.

Table 2 – Foreign Trade Cargo Handled at Nigerian Ports : Cargo Loaded' 000 Tonnes

Ports	1988	%	1989	%	1990	%	1991	%	1992	%	1993	%
Apapa	271	0.43	261	0.35	303	0.39	201	0.26	178	0.26	259	0.31
Tin-Can Island	179	0.28	138	0.18	155	0.20	134	0.17	192	0.28	172	0.20
P-Harcourt	546	0.87	361	0.48	81	0.10	113	0.14	121	0.18	65	0.08
Okrika	375	0.59	637	0.84	1150	1.47	1066	1.36	714	1.04	583	0.69
Fed. Light Terminal.	59	0.09	57	0.08	367	0.47	345	0.44	310	0.45	297	0.35
Bonny	18646	29.6	20212	26.5	18828	24.1	20006	25.5	20384	29.6	17439	20.7
Brass	5552	8.80	6844	9.07	8326	10.7	7787	9.95	7955	11.5	7417	8.81
Warri	283	0.45	69	0.09	71	0.09	98	0.12	1403	2.00	48	0.06
Koko	5	-	123	0.16	1	-	-	-	-	-	-	-
Sapele	3	-	3	3.00	8	0.01	15	0.02	18	0.03	4	0.01
Escravos	6396	10.5	7427	9.82	7865	10.1	8774	11.2	7411	10.8	8861	10.5
Forcados	16821	26.7	24543	32.5	24363	31.2	22853	29.1	24600	35.7	23915	28.4
Pennington	2974	4.72	3012	3.99	2791	3.58	2908	3.70	2617	3.80	3564	4.23
Calabar	13	0.02	10	0.01	14	0.02	14	0.02	6	0.01	3	-
Qua-Ibo	9386	14.9	10328	13.6	11423	14.7	12370	15.7	1569	2.28	19741	23.4
Merryland (Bonny)	-	-	376	0.50	860	1.10	825	1.05	581	0.84	668	0.79
Antan	1605	2.55	1138	1.51	1388	1.78	1024	1.36	895	1.30	1196	1.42
Total	63036	100	75429	100	77994	100	78594	100	68954	100	84232	100

Ports	1994	%	1995	%	1996	%	1997	%	1998	%
Apapa	85	0.09	103	0.12	153	0.18	159	8.32	144	0.14
Tin-Can Is.	85	0.09	85	0.09	93	0.11	94	4.92	119	0.19
P-Harcourt	51	0.06	59	0.07	152	0.18	207	10.8	161	0.16
Okrika	574	0.67	2974	3.33	421	0.49	511	26.7	1094	1.09
Fed. Light Terminal.	261	0.30	171	0.19	146	0.17	123	6.43	338	0.34
Bonny	19133	22.2	17464	19.6	12398	14.5	-	-	18727	18.7
Brass	6849	7.94		7.85		8.95	-	-	6480	6.46

			7005		7642					
Warri	68	0.08	978	1.10	23	0.03	13	0.68	29	0.01
Koko	1	-	4	0.01	-	-	-	-	-	-
Sapele	3	0.01	2	-	7	0.01	11	0.58	11	-
Escravos	12328	14.3	10990	12.3	11676	13.7	-	-	15510	15.5
Forcados	22704	26.5	25719	28.8	24003	28.1	-	-	18341	18.3
Pennington	2832	3.28	2762	3.10	3664	4.29	-	-	2853	2.84
Calabar	8	0.01	9	0.01	4	-	1	0.01	37	0.00
Qua-Ibo	20377	23.6	19671	22.1	24279	28.5	-	-	29470	29.4
Merryland (Bonny)	120	0.14	307	0.34	273	0.32	301	15.7	-	-
Antan	498	0.58	617	0.69	-	-	-	-	401	0.40
Total	86305	100	89212	100	85350	100	1912	100	100373	100

Source: Nigerian Ports Authority

Table 3 – Foreign Trade Cargo Handled at Nigerian Ports : Cargo Unloaded' 000 Tonnes

Ports	1988	%	1989	%	1990	%	1991	%	1992	%	1993	%
Apapa	3050	46.3	3698	54.0	2768	45.8	4168	51.7	6082	55.3	6083	55.6
Tin-Can Island.	1713	26.3	1522	22.5	1659	27.5	1388	17.2	2301	20.3	1857	16.1
P-Harcourt	793	12.2	591	8.78	765	12.7	1144	14.2	1278	11.6	1405	12.8
Okrika	209	3.2	138	2.04	8	0.13	-	-	74	0.67	-	-
Fed.Light Term.	97	1.49	131	1.94	288	4.77	336	4.17	546	4.96	306	2.80
Warri	562	8.62	576	8.53	446	7.38	612	7.59	535	4.86	430	3.93
Koko	21	0.32	21	0.31	16	0.26	31	0.38	24	0.22	28	0.26
Sapele	31	0.48	46	0.68	27	0.45	35	0.43	82	0.75	107	0.98
Escravos	-	-	-	-	-	-	-	-	-	-	-	-
Calabar	78	1.20	69	1.02	48	0.79	43	0.53	29	0.26	55	0.50
Merryland (Bonny)	-	-	8	0.12	17	0.28	-	-	48	0.44	135	1.23
Container Terminal											-	-
Roro											-	-

Fed. Ocean Term*											-	-
Total	6517	100	6749	100	6042	100	8064	100	10999	100	10942	100

Ports	1994	%	1995	%	1996	%	1997	%	1998	%
Apapa	4120	51.7	4786	51.7	3943	43.9	3526	38.1	5621	43.6
Tin-Can Island.	1528	19.1	1340	14.5	1717	19.1	1984	21.5	2791	21.7
P-Harcourt	776	9.74	916	9.89	1088	12.1	1064	11.5	1281	9.94
Okrika	-	-	27	0.29	115	1.28	66	0.71	482	3.74
Fed.Light Term.	146	1.83	24	0.26	442	4.92	608	6.58	306	2.37
Warri	266	3.34	374	4.04	335	3.73	298	3.23	344	2.67
Koko	26	0.33	24	0.26	31	0.35	54	0.58	90	0.70
Sapele	94	1.18	94	1.01	110	1.22	152	1.65	264	2.05
Escravos	-	-	-	-	-	-	-	-	-	-
Calabar	23	0.29	154	1.66	34	0.38	52	0.56	119	0.92
Merryland (Bonny)	-	-	198	2.14	79	0.88	-	-	-	-
Container Terminal	608	7.63	778	8.40	779	8.67	993	10.8	1198	9.29
Roro	381	4.78	325	3.51	225	2.51	239	2.59	268	2.08
Fed. Ocean Term*	-	-	-	-	-	-	-	-	168	1.30
Total	7968	100	9262	100	8982	100	9234	100	12892	100

Source: Nigerian Ports Authority

Table 4: Yearly Totals of Cargoes Handled at Nigerian Ports

Year	Total Cargo Loaded '000' Tonnes	Total Cargo Unloaded '000' Tonnes
1998	63,036	6,517
1989	75,429	6,749
1990	77,994	6,042
1991	78,594	8,064
1992	68,954	10,999
1993	84,232	10,942
1994	86,305	7,968
1995	89,212	9,262
1996	85,350	8,982
1997	1,912	9,234
1998	100,373	12,892

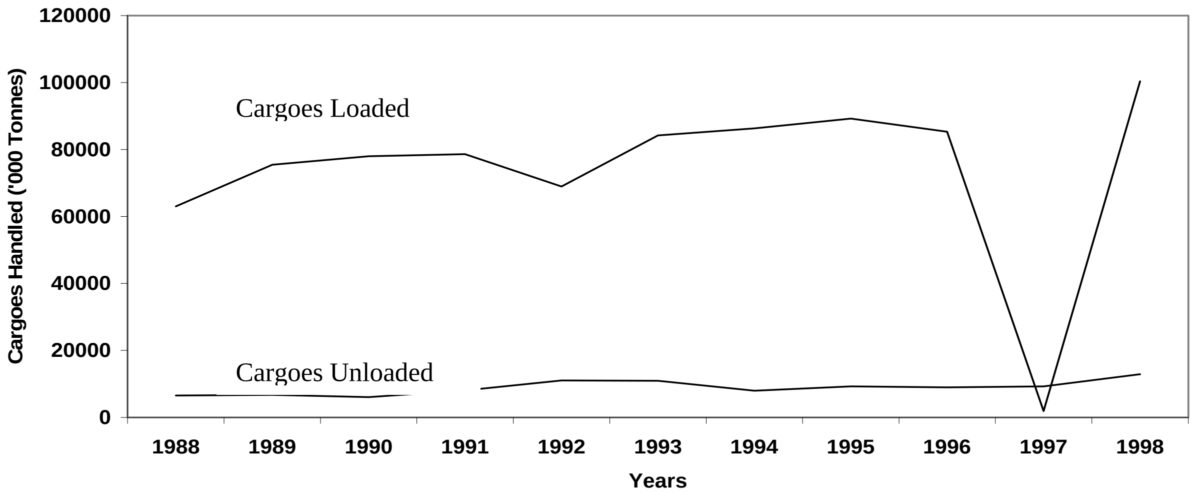

Figure 2: Yearly Totals of Cargoes Handled at Nigerian West-East Coastal Ports

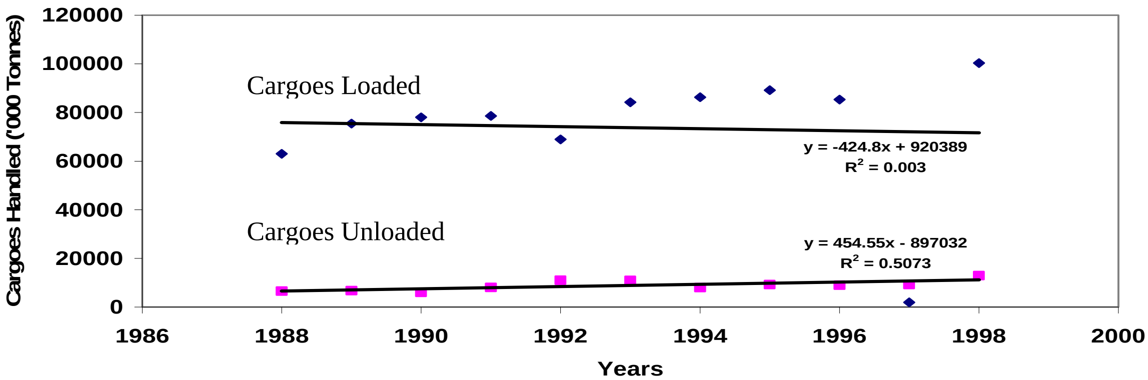

Figure 3: Trend (Best Fit) of Yearly Totals of Cargoes Handled at Nigerian West-East Coastal Ports

Material Characteristics

In order to ensure the coverage of entire length of the Nigerian costal native soils, the profiles and properties of soils within the Lagos and Port Harcourt port complexes were used as representatives. These are shown in Table 5 below.

Table 5: Characteristics of Soil Materials at Lagos and Port Harcourt Ports

Properties	Characteristic Values at		Range (%)
	Lagos	Port Harcourt	
Natural Moisture Content (%)	51	39.1	39.1 – 51.0
Liquid Limit (%)	42	48	42 - 48
Plastic Limit (%)	19	25.5	19.0 - 25.5
Plasticity Index (%)	23	22.5	22.5 – 23.0
Dry Density (kN/m^3)	14.4	13.0^3	13.0 – 14.4
Specific Gravity	2.52	2.60	2.52 – 2.60
Clay Content (%)	36	33.5	33.5 – 36.0

Source: Progress Engineers (2001) and Bugo-Tech (2000).

Elastic constants (that is, elastic modulus and Poisson's ratio) have to be assigned to the components of the pavement, that is, the subgrade, the subbase, the base and the surface. This is because the design criteria and analysis are based upon elastic theory. The strength of the subgrade is, commonly, referred to in terms of its California Bearing Ratio (CBR) and there is a relationship developed between elastic modulus, Poisson's ratio and CBR. As advised (Overseas Road Note 31, 2003), it is false economy to minimize the extent of preliminary investigations to determine the variability in material properties. Variability in material properties is, generally, much greater than desired in design processes and must, therefore, be taken into account explicitly during pavement design. The materials characteristics for the pavement which constitutes subgrade, subbase, base and surfacing were determined and obtained as follows:

3.1 Subgrade: The subgrade strength is characterised by its California Bearing Ratio (CBR). British Ports Federation design charts are produced for CBR values of 1%, 3%, 5%, 10% and 30% which represent the likelihood of CBR values for very poor to very good subgrade which can prevail in tropical/subtropical regions. According to

Heukelom and Foster (1960), the subgrade is assumed to be semi-infinite and its elastic modulus is equal to ten times its CBR value. That is,

$E_g = 10 \text{ x CBR}^{-1}$ (N/mm^2) ……………………. (1)

CBR of deep organic clay stratum in Nigerian coasts is 5-10% (Ajayi, 1983).

Poisson's ratio, ν, is calculated from $\nu = 0.82 - 0.1\log E_g$ (Barber,1980)…………… (2)

where, E_g = elastic modulus of the subgrade (N/mm^2)

<u>3.2 Subbase:</u> The elastic modulus the subbase is calculated from the thickness of the subbase and the elastic modulus of the subgrade (Shell Pavement Design Manual, 1978) from the expression,

$E_s = 0.2H_s^{0.45} \text{ x } E_g$ (N/mm^2)…………………….. (3)

where, E_s = elastic modulus of the subbase (N/mm^2), H_s = thickness of the subbase (mm) and E_g = elastic modulus of the subgrade (N/mm^2).

The Poisson's ratio for the subbase is calculated using equation (2) taken CBR value as 30% and the compressive strength as 12N/mm^2 (Nigerian Highway Design Manual, 1997).

<u>3.3 Base:</u> The CBR, the elastic modulus and the compressive strength for the base course is taken as 80%, 1000N/mm^2 and 12N/mm^2 respectively. Relevant clauses of the Nigerian Specification for Construction Technology requires compaction on lifts of not more than 150mm to 200mm. Hence, the probable sizes of the subbase and base courses could be either 150mm or 200mm or any of their multiples.

Data Analysis and Design

The BPA manual (1990) gave a realistic method of assessing the damaging effect of container handling equipment which reflects those parameters particular to container terminal pavements as (a) very heavy wheel loads up to 25tons, (b) wide area of operation, (c) severe dynamics, (d) wide range of equipment types and sizes. For each wheel on one side of the plant, the damaging effect is calculated from equation proposed by Heukelom and Klomp, (1978):

$$D = \left(\frac{W}{12,000}\right)^{3.75} * \left(\frac{P}{0.8}\right)^{1.25} \quad \text{……………………………..} \; 4$$

where, D = pavement damage; W = wheel load (kg); P = tyre pressure (N/mm^2) which gives pavement damage, D, in the units of Port Area Wheel Load (PAWL).

Based on the deductions from the information in Tables 1-3, the design life of the pavement at Apapa port is 4,131,818 passes and the number of repetitions of a straddle carrier over a period of 25years is 3,888,000. This value can be halved and for a critical handling facility like the Apapa port, a value of 2,000,000 repetitions and a life of 25years are adopted for the design (BPF Manual, 1989). The use of BPF Charts was considered for the pavement design (see the Appendix for the Charts). The design approach for heavy load pavement is to compute strains resulting from a defined loading regime and to determine the permissible strains which the pavement construction materials can withstand. A pavement is deemed to be correctly designed when actual and permissible strains are similar. The allowable strain is given by:

$$\varepsilon_v = \frac{21600}{N^{0.28}} \quad \text{in microstrain……………………(5)}$$

where, N = number of repetitions of applied load = 2 x 10^6; => E_v = 372microstrain.

The allowable base horizontal tensile strain is given by:

$$\varepsilon_h = \frac{F_c x 993500}{6xE_b^{1.022} x N^{0.052}} \quad \text{in microstrain………………..(6)}$$

where, for:

<u>Asphalt Pavement :</u>

F_c = characteristic compressive strength of base material in microstrain = 12N/mm^2 (BPA Manual)

Since F_c > 7N/mm^2 ; $E_b = 16800 \text{ x } F_c^{0.25}$ = 31268N/mm^2 => E_h = 24 microstrain

Concrete Block Pavement:
F_c = characteristic compressive strength of base material in microstrain = 6N/mm^2 (BPA manual)
Since $F_c < 7N/mm^2$; $E_b = 4000 \times F_c^{0.25} = 24000N/mm^2$ => E_h = 16 microstrain

Rigid Concrete Pavement :
F_c = characteristic compressive strength of base material in microstrain = 18N/mm^2 (BPA manual)
Since $F_c > 7N/mm^2$; $E_b = 16800 \times F_c^{0.25} = 34604N/mm^2$ => E_h = 32 microstrain.

Reinforced Concrete Pavement:
F_c = characteristic compressive strength of base material in microstrain = 24N/mm^2 (BPA manual)
Since $F_c > 7N/mm^2$; $E_b = 16800 \times F_c^{0.25} = 37185N/mm^2$ => E_h = 40 microstrain.

RESULTS

Design by use of Charts

Asphalt Pavement with Granular Base

For an asphalt surfaced flexible pavement required to withstand 2.000,000 Effective repetitions of LCI-C plant on a subgrade of 10% CBR.

Effective depth of pavement = 2664.0mm.

Assumed thickness of subbase = 300mm.

From chart C of the Appendix, 2×10^6 repetitions correspond with a permissible compressive vertical microstrain of 375. From Chart 8 of the Appendix, 375 microstrain corresponds with granular base thickness of 500mm. The results for other CBR values for asphalt pavement as well as design output for Concrete Block, Rigid and Reinforced Concrete pavements are shown in Tables 6-9. Charts A, B, C and 6-15 used for asphalt pavement with granular base are presented in the Appendix.

Table 6: Design Output for Asphalt Pavement with Granular Base

Subgrade CBR (%)	300mm Subbase Thickness		600mm Subbase Thickness	
	Chart No.	Base Thickness (mm)	Chart No.	Base Thickness (mm)
1	6	No practical solution	11	No practical solution
3	7	No practical solution	12	Not required
5	8	No practical solution	13	Not required
10	9	500	14	Not required
30	10	Not required	15	Not required

Table 7: Design Output for Concrete Block Pavement

Subgrade CBR (%)	300mm Subbase Thickness		600mm Subbase Thickness	
	Chart No.	Base Thickness (mm)	Chart No.	Base Thickness (mm)
1	21	No practical solution	26	No practical solution
3	22	No practical solution	27	No practical solution
5	23	No practical solution	28	No practical solution
10	24	No practical solution	29	270
30	25	No practical solution	30	Not required

Table 8: Design Output for Rigid Concrete Pavement

Subgrade CBR (%)	300mm Subbase Thickness		600mm Subbase Thickness	
	Chart No.	Base Thickness (mm)	Chart No.	Base Thickness (mm)
1	36	325	41	290
3	37	300	42	280
5	38	275	43	270
10	39	250	44	240
30	40	100	45	0

Table 9: Design Output for Rigid Concrete Pavement

Subgrade CBR (%)	300mm Subbase Thickness		600mm Subbase Thickness	
	Chart No.	Base Thickness (mm)	Chart No.	Base Thickness (mm)
1	36	245	41	205
3	37	205	42	200
5	38	200	43	190
10	39	175	44	110
30	40	0	45	0

Table 10: Prices of Base Course Materials as at August, 2008.

Material	Price
Granular Materials	₦5,000.00/m^3
Crushed Granite	₦3,500.00/ton
Cement	₦1,800.00/bag
Sharp Sand	₦1,845.00/m^3
12mm Iron rod	₦2,200.00/length

4.2 Cost Data Collection and Analysis

Field (market) survey conducted to obtain prices of materials (Ilorin, Nigeria (2010)) required for construction, maintenance and rehabilitation of heavy load pavements are shown in Table 10. The costs of producing concrete mixes of 1:4:8 and 1:1:2 were calculated as ₦13,600.00/m^3 and ₦31,045.00/m^3 respectively from Table 10. Table 11 shows the cost of materials required for the base course of one square metre (1m^2) spot on each pavement type at CBR values of 1%, 3%, 5%, 10% and 30%.

Table 11: Cost Analysis

Pavement	Quantity(m^3) for subbase thickness of		Cost / m^3 (₦)	Amount (₦) for subbase thickness of	
	300mm	600mm		300mm	600mm
CBR = 1%					
Asphalt (Granular Base)	-	-	13,600.00	-	
Concrete Blocks	-	-	4,500.00	-	
Rigid Concrete	0.325	0.290	31,045.00	10,089.63	9003.05
Reinforced Concrete	0.245	0.205	34,000.00	8330.00	6,970.00
CBR = 3%					
Asphalt (Granular Base)	-	-	13,600.00	-	-
Concrete Blocks	-	-	4,500.00	-	-
Rigid Concrete	0.300	0.280	31,045.00	9,313.50	8,694.00
Reinforced Concrete	0.205	0.200	34,000.00	6,970.00	6,800.00
CBR = 5%					
Asphalt (Granular Base)	-	-	13,600.00	-	-
Concrete Blocks	-	-	4,500.00	-	-
Rigid Concrete	0.275	0.270	31,045.00	8,537.38	8,382.15
Reinforced Concrete	0.200	0.190	34,000.00	6,800.00	6,460.00
CBR = 10%					
Asphalt (Granular Base)	0.500	-	13,600.00	6,800.00	-
Concrete Blocks	-	0.270	4,500.00	-	1,215.00
Rigid Concrete	0.250	0.240	31,045.00	7,761.25	7,450.80
Reinforced Concrete	0.175	0.110	34,000.00	5,950.00	3,740.00
CBR = 30%					
Asphalt (Granular Base)	-	-	13,600.00	-	-
Concrete Blocks	-	-	4,500.00	-	-
Rigid Concrete	0.100	0	31,045.00	3,104.50	0
Reinforced Concrete	0	0	34,000.00	0	0

Discussions

The results obtained for the design method and pavements using different CBR values are discussed to reveal the changes in material specification, construction technology and corresponding maintenance requirements due to the sensitivity of the performance of heavy load pavement. Charts were employed in the design of the component layers for the four pavements under consideration. The design results show that asphalt pavement on granular base with subgrade CBR values of 1%, 3% and 5% and subbase thickness of 300mm and also with CBR value of 1% and subbase thickness of 600mm did not produce any thickness of base course. This is because asphalt surfacing on such soils and thicknesses are not practical solutions. Asphalt pavement placed on soils of 30% CBR and 300mm thick subbase and on soils of 3%, 5%, 10% and 30% and 600mm thick subbase will not require the provision of a base course (see Table 6).

The results also show that it will not be practically wise to construct a concrete block pavement on all the five sugrade CBR values and 300mm thick subbase as well as soils with CBR values of 1%, 3% and 5% and 600mm thick. However a soil of 30% CBR and subbase thickness of 600mm will not require a base course to carry a concrete block pavement (Table 7). In the case of rigid concrete pavement, with subbase thicknesses of 300mm and 600mm and for all CBR values, its construction is practically possible with resulting base thicknesses reducing with increase in subgrade CBR values (Table 8). Table 9 shows that reinforced concrete pavement is an improvement over the rigid concrete pavement as the resulting base thicknesses in the former are less than those of the latter for all CBR values and subbase thicknesses.

Tables 12 and 13 presented graphically in Figures 4 and 5 also show clearly that for all pavements, the base course thicknesses decrease with increase in the subgrade CBR values, thickness of subbase course not withstanding. This implies that a better subgrade will require a less pavement thickness. It is also evident that concrete block and reinforced concrete will produce pavements of least thicknesses.

The traditional approach adopted for the design in this paper involves selecting a container handling equipment (in this case a straddle carrier) according to operational requirements, then design a pavement system to withstand the damage afflicted by the selected equipment. The choice will be a compromise between the technicality and economy of the design method. The most important thing is to be aware of the available choices of the relevant factors and adopt them appropriately.

Table 12: Design Results by Analysis Technique

Pavement Type	Base Thickness(m) for 300 mm subbase	Base Thickness(m) for 600 mm subbase
CBR = 1%		
Asphalt (Granular Base)	-	-
Concrete Blocks	-	-
Rigid Concrete	0.325	0.290
Reinforced Concrete	0.245	0.205
CBR = 3%		
Asphalt (Granular Base)	-	-
Concrete Blocks	-	-
Rigid Concrete	0.300	0.280
Reinforced Concrete	0.205	0.200
CBR = 5%		
Asphalt (Granular Base)	-	-
Concrete Blocks	-	-
Rigid Concrete	0.275	0.270
Reinforced Concrete	0.200	0.190
CBR = 10%		
Asphalt (Granular Base)	0.500	-
Concrete Blocks	-	0.270
Rigid Concrete	0.250	0.240
Reinforced Concrete	0.175	0.110
CBR = 30%		
Asphalt (Granular Base)	-	-
Concrete Blocks	-	-
Rigid Concrete	0.100	0
Reinforced Concrete	0	0

Table 13: CBR Values versus Base and Subbase Thicknesses

Asphalt Pavement with Granular Base		
CBR (%)	Base Thickness(m) for 300 mm subbase	Base Thickness(m) for 600 mm subbase
1	-	-
3	-	-
5	-	-
10	0.500	-
30	-	-
Concrete Block Pavement with Lean Concrete Base		
CBR (%)	Base Thickness(mm)	Subbase Thickness(mm)
1	-	-
3	-	-
5	-	-
10	-	0.270
30	-	-
Rigid Concrete Pavement		
CBR (%)	Base Thickness(mm)	Subbase Thickness(mm)
1	0.325	0.290
3	0.300	0.280
5	0.275	0.270
10	0.250	0.240
30	0.100	0
Reinforced Concrete Pavement		
CBR (%)	Base Thickness(mm)	Subbase Thickness(mm)
1	0.245	0.205
3	0.205	0.200
5	0.200	0.190
10	0.175	0.110
30	0	0

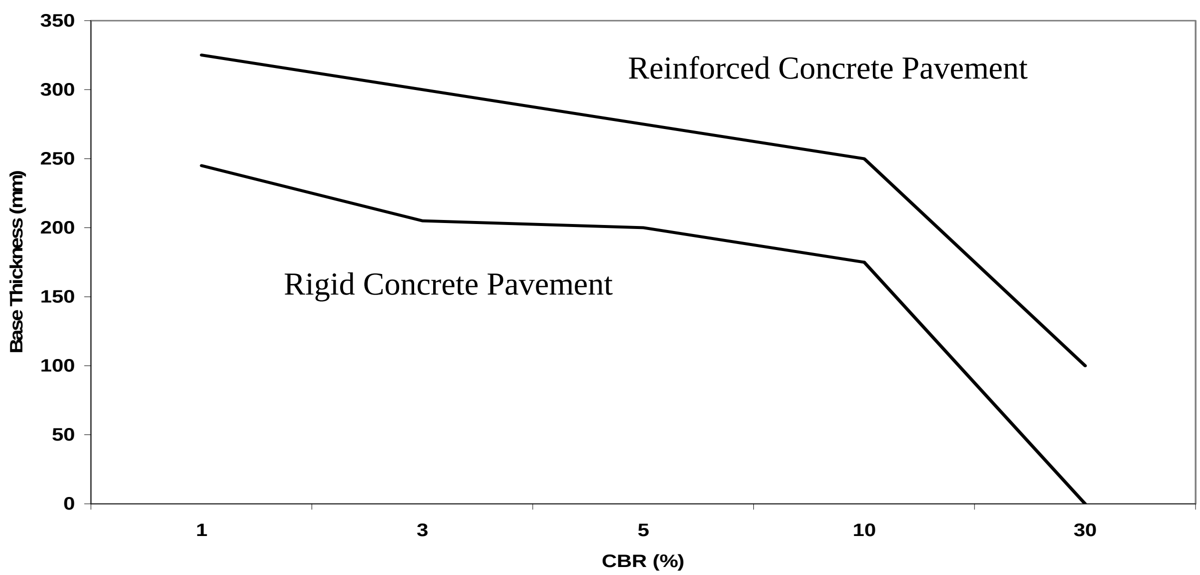

Figure 4: Base Thickness Versus Subgrade CBR (300mm Subbase Thickness)

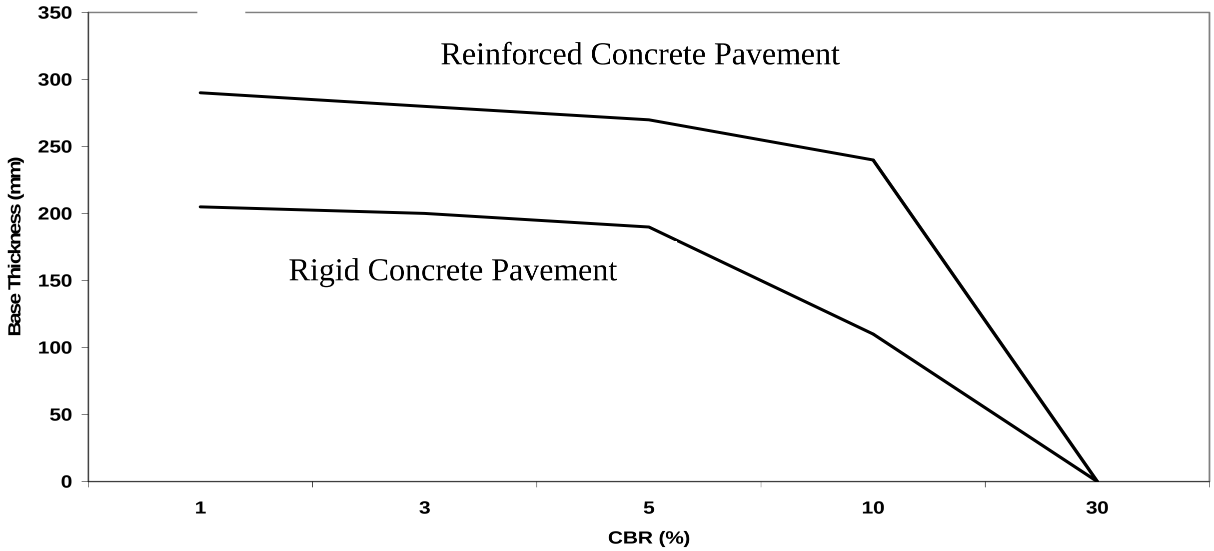

Figure 5: Base Thickness Versus Subgrade CBR (600mm Subbase Thickness

CONCLUSIONS

The following conclusions can be made from this study:- The results indicate that rigid concrete and reinforced concrete pavements are better practically than other types of pavements. However, the reinforced concrete pavement stands as the best choice economically. This is because for all the subgrade CBR values and subbase thicknesses its construction cost is least. For instance, the cost of constructing the base course of reinforced concrete pavement on a soil of 10% CBR and 300mm thick subbase is ₦5,950.00/m^2 of pavement as compared to costs of asphalt, and rigid concrete pavements which are ₦6,800.00/m^2 and ₦7,761.25/m^2 respectively. In addition reinforced concrete pavement on a subgrade CBR of over 30% and for 300mm and 600mm subbase thicknesses will not require the provision of a base course. This implies that a better subgrade will require less pavement thickness.

Cost analysis shows that all pavement types are cheaper to build on subgrades with CBR values of 30% and for all the CBR values, reinforced concrete pavement is the best choice economically having met all safety conditions. The ideal pavement for marine traffic does not require maintenance or repair and it must be cheap. In real life, a sound compromise has to be found both in the technical and economic fields. An unsuitable pavement will have a negative impact on terminal operations. Hence, selection of suitable and economically feasible pavement is of utmost importance.

RECOMMENDATIONS

The economically and cost effective, fortified pavement for marine operation at the coastal areas is the reinforced concrete pavement with the least construction costs for all subgrade CBR values and subbase thicknesses. It is advisable that reinforced concrete pavement be adopted for Nigeria Port Pavements because of the justifiable cost effectiveness.

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This paper cannot be put together without the tremendous background information made available by various research workers, authors of excellent books and articles which have been referred to and listed in my references. I thank them. My special thanks to Dr. Y.A. Jimoh, a senior lecturer in the Civil Engineering Department, University of Ilorin, Ilorin, Nigeria for his immense contribution to this paper.

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APPENDIX

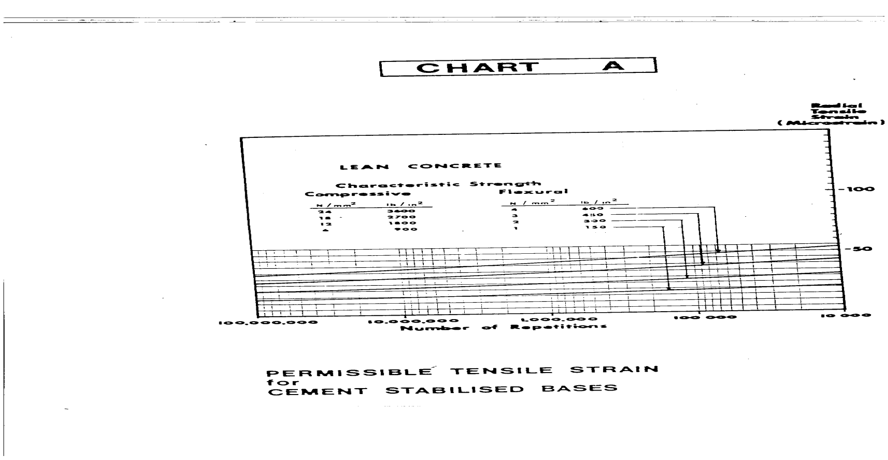
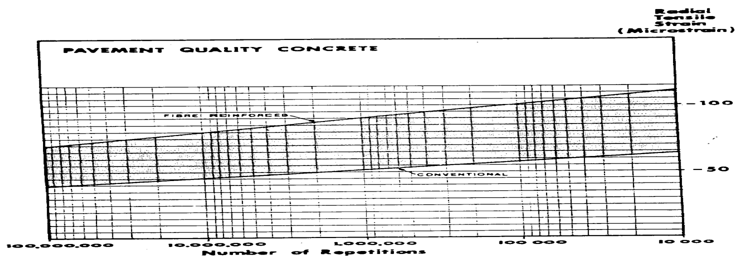
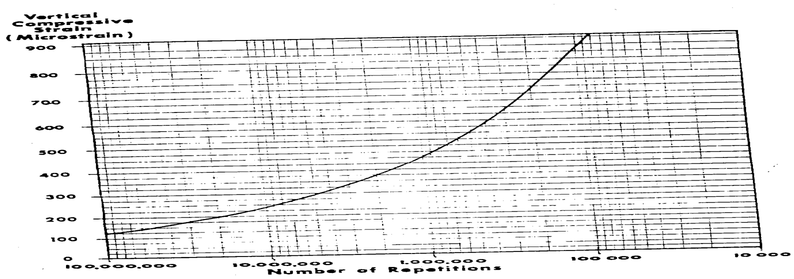


CHART B



PERMISSIBLE TENSILE STRAIN for RIGID CONCRETE SLABS

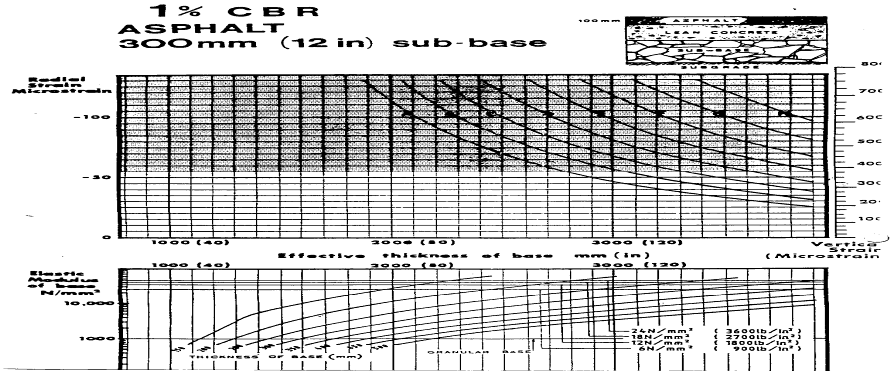
CHART C



PERMISSIBLE COMPRESSIVE STRAIN for GRANULAR BASES

CHART No. 6

1% CBR
ASPHALT
300mm (12 in) sub-base



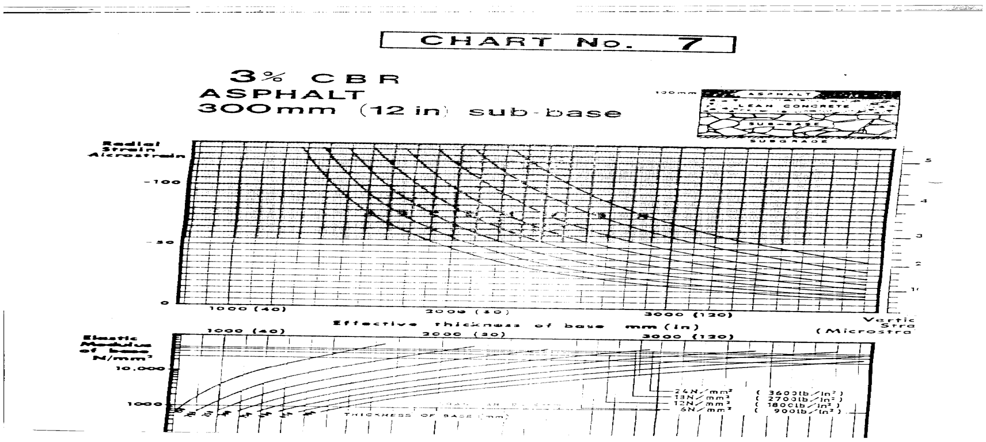


CHART No. 7
3% CBR
ASPHALT
300mm (12 in) sub-base
ASPHALT
LEAN CONCRETE
SUB-BASE
SUBGRADE
Radial Strain Microstrain
1000 (40)
2000 (80)
3000 (120)
Effective thickness of base mm (in)
Elastic Modulus of base N/mm²
10,000
1000
24N/mm² (3600lb/in²)
18N/mm² (2700lb/in²)
12N/mm² (1800lb/in²)
6N/mm² (900lb/in²)

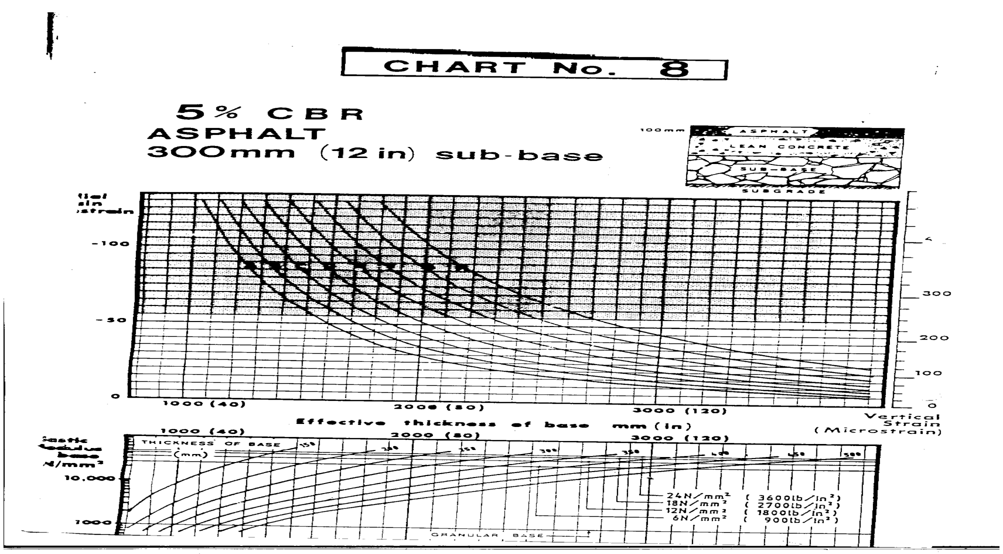


CHART No. 8
5% CBR
ASPHALT
300mm (12 in) sub-base
ASPHALT
LEAN CONCRETE
SUB-BASE
SUBGRADE
-100
-50
0
300
200
100
1000 (40)
2000 (80)
3000 (120)
Effective thickness of base mm (in)
Vertical Strain (Microstrain)
THICKNESS OF BASE (mm)
10,000
1000
24N/mm² (3600lb/in²)
18N/mm² (2700lb/in²)
12N/mm² (1800lb/in²)
6N/mm² (900lb/in²)
GRANULAR BASE

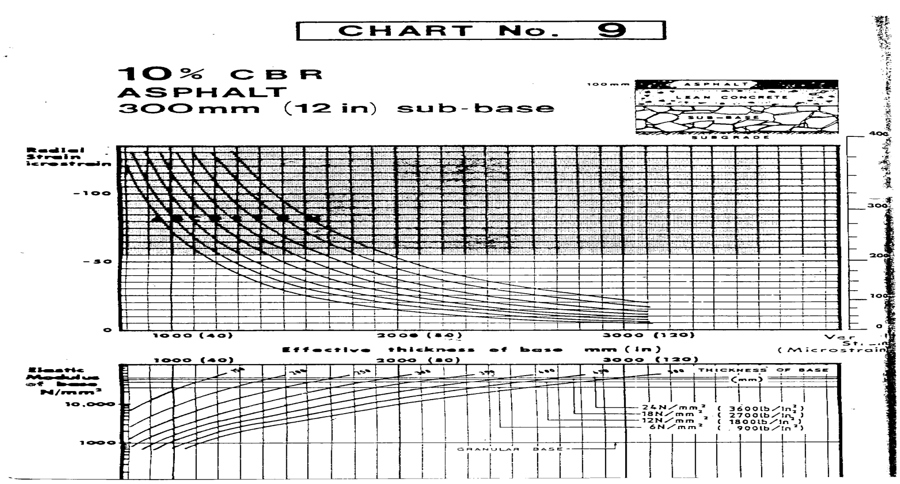


CHART No. 9
10% CBR
ASPHALT
300mm (12 in) sub-base
ASPHALT
LEAN CONCRETE
SUB-BASE
SUBGRADE
Radial Strain Microstrain
-100
-50
0
1000 (40)
2000 (80)
3000 (120)
Effective thickness of base mm (in)
(Microstrain)
Elastic Modulus of base N/mm²
THICKNESS OF BASE (mm)
10,000
1000
24N/mm² (3600lb/in²)
18N/mm² (2700lb/in²)
12N/mm² (1800lb/in²)
6N/mm² (900lb/in²)
GRANULAR BASE

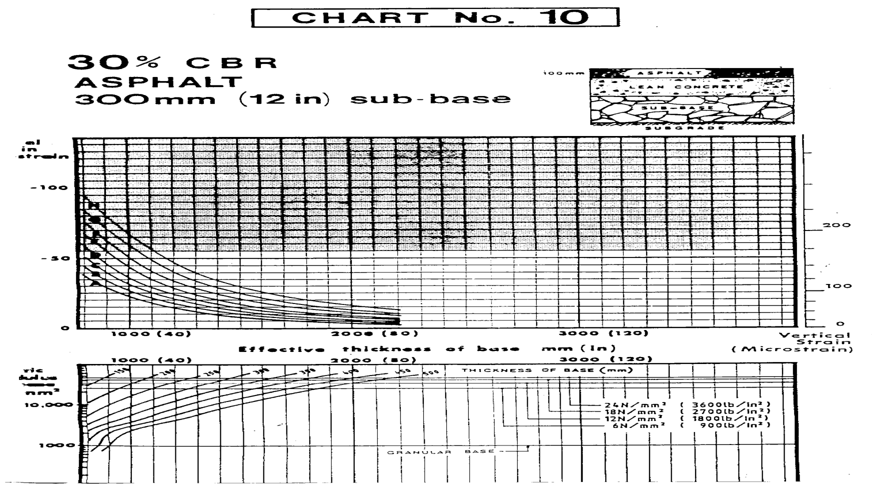


CHART No. 10
30% CBR
ASPHALT
300mm (12 in) sub-base
ASPHALT
LEAN CONCRETE
SUB-BASE
SUBGRADE
1000 (40)
2000 (80)
3000 (120)
Effective thickness of base mm (in)
Vertical Strain (Microstrain)
THICKNESS OF BASE (mm)
24N/mm² (3600lb/in²)
18N/mm² (2700lb/in²)
12N/mm² (1800lb/in²)
6N/mm² (900lb/in²)
GRANULAR BASE

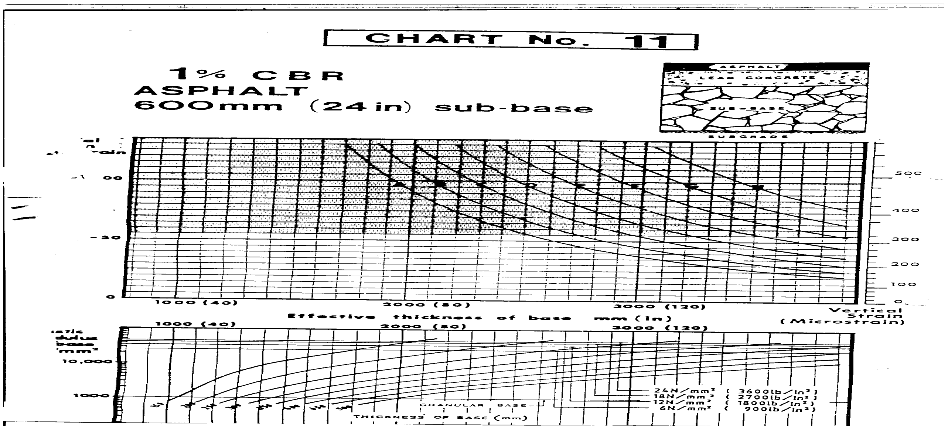


CHART No. 11
1% CBR
ASPHALT
600mm (24 in) sub-base
ASPHALT
LEAN CONCRETE
SUB-BASE
SUBGRADE
1000 (40)
2000 (80)
3000 (120)
Effective thickness of base mm (in)
Vertical Strain (Microstrain)
24N/mm² (3600lb/in²)
18N/mm² (2700lb/in²)
12N/mm² (1800lb/in²)
6N/mm² (900lb/in²)
GRANULAR BASE
THICKNESS OF BASE (mm)

CHART No. 12

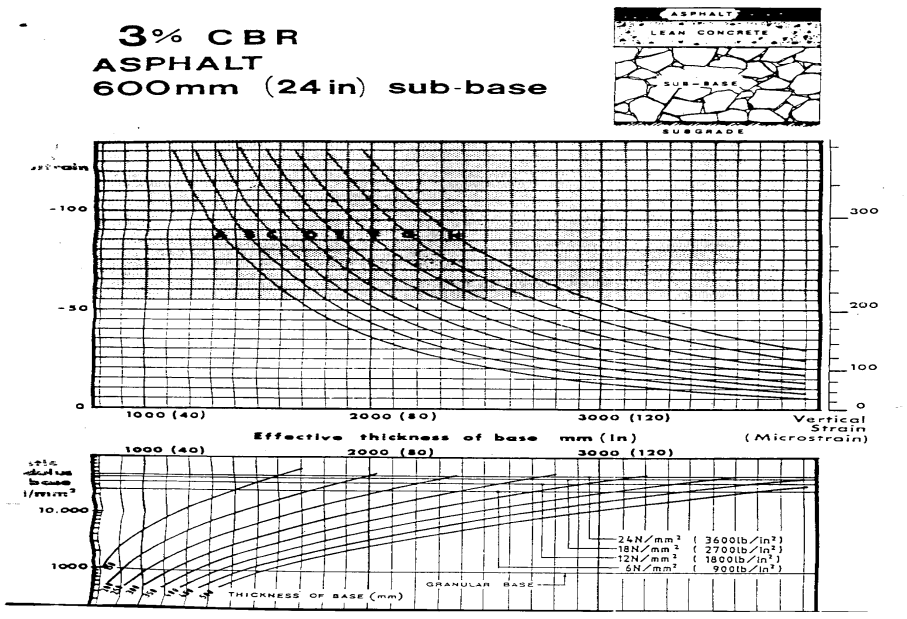
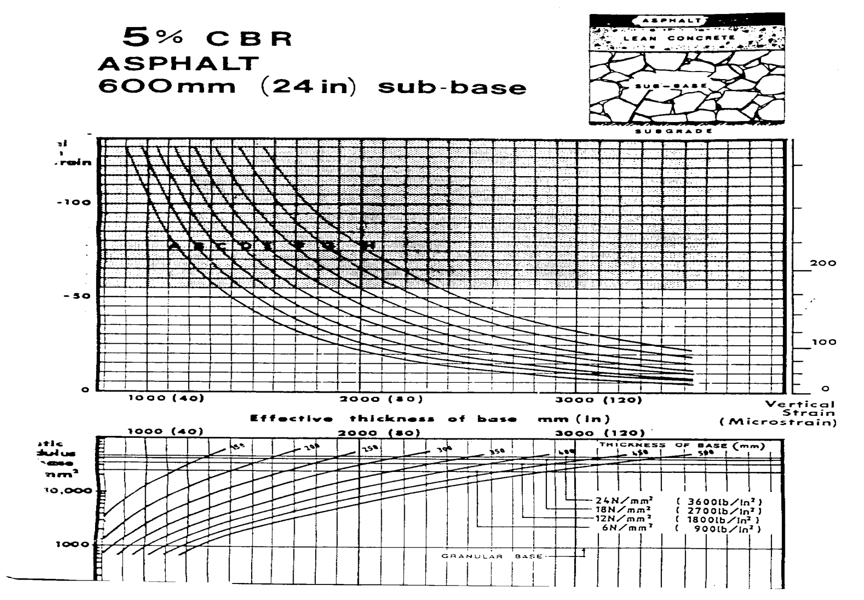


CHART No. 13



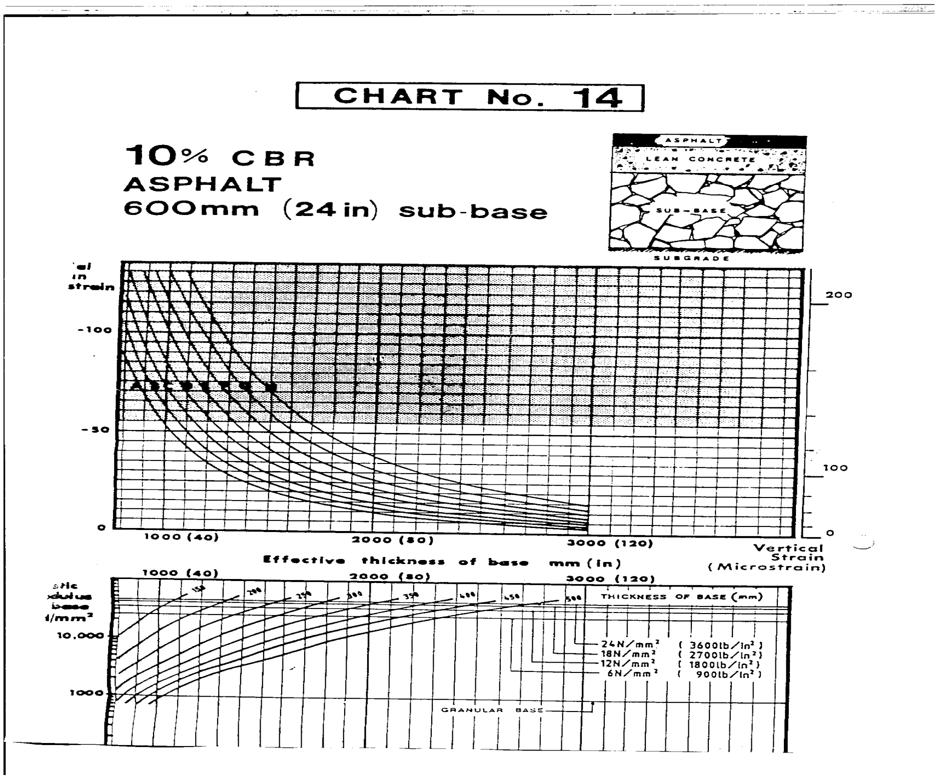


CHART No. 14
10% CBR
ASPHALT
600mm (24 in) sub-base
ASPHALT
LEAN CONCRETE
SUB-BASE
SUBGRADE
-100
-50
0
200
100
0
1000 (40)
2000 (80)
3000 (120)
Effective thickness of base mm (in)
Vertical Strain (Microstrain)
THICKNESS OF BASE (mm)
10,000
1000
24N/mm² (3600lb/in²)
18N/mm² (2700lb/in²)
12N/mm² (1800lb/in²)
6N/mm² (900lb/in²)
GRANULAR BASE

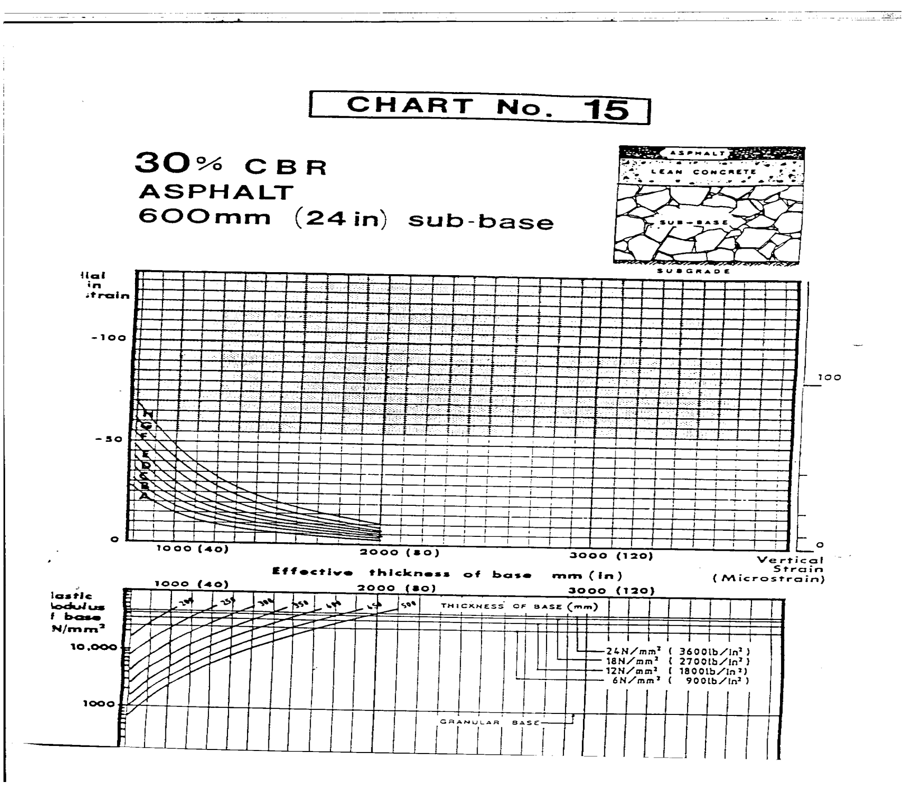


CHART No. 15
30% CBR
ASPHALT
600mm (24 in) sub-base
ASPHALT
LEAN CONCRETE
SUB-BASE
SUBGRADE
-100
-50
0
100
0
1000 (40)
2000 (80)
3000 (120)
Effective thickness of base mm (in)
Vertical Strain (Microstrain)
THICKNESS OF BASE (mm)
10,000
1000
24N/mm² (3600lb/in²)
18N/mm² (2700lb/in²)
12N/mm² (1800lb/in²)
6N/mm² (900lb/in²)
GRANULAR BASE

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