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TITLE: Use of Soft Limestone for Road-Base Construction in Belize

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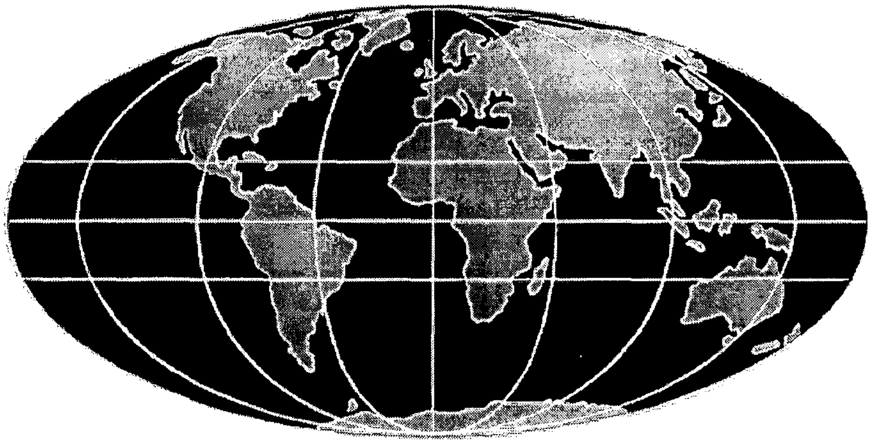

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PA3450/99

PA3450/99 WOODBRIDGE, M E (1999). **Use of soft limestone for road-base construction in Belize.** *Seventh International Conference on Low-Volume Roads, Baton Rouge, Louisiana, USA. 23 - 26 May 1999*

Use of Soft Limestone for Road-Base Construction in Belize

M. E. WOODBRIDGE

The results of a highway experiment, constructed in May 1978 in northern Belize, designed to investigate the suitability of locally occurring calcareous materials, known as marls, for road bases are discussed. The marls comprise high-purity carbonate materials containing mainly silt-sized particles and fall outside the grading, plasticity, and strength specifications normally required for road bases. Three marls, each with slightly different characteristics, were substituted as road base for crushed stone. One of the marls was also stabilized with ordinary portland cement. Detailed monitoring was then undertaken periodically to determine their performance. The road pavement was constructed on an embankment to ensure good drainage. A good quality surface dressing seal has been maintained. After 19 years of traffic, measured at 1.3 million equivalent standard axles, the marl road bases have performed at least as well as the crushed stone. The cement-stabilized marl road base performed exceptionally well. Stabilization would enable the use of more plastic marls.

Belize is a small country situated on the Caribbean coast of Central America. Nearly 23 000 km^2 in area, it is about 1/10th the size of the United Kingdom and has a common border with Mexico and Guatemala. It became fully independent in 1981, although it has been internally self-governing since 1964. The country has four main highways (Figure 1) totaling 600 km and now built to bituminous standard.

Belize has a subtropical climate with a pronounced wet season. Data supplied by Belize Sugar Industries (BSI) indicate that average annual rainfall for the period 1974–1989 was 1364 mm, of which 72 percent (983 mm) fell between June and October. Monthly day maxima temperatures vary from 30°C to 35°C and night minima temperatures vary from 15°C to 25°C. Relative humidity usually exceeds 80 percent.

In December 1973 Sir William Halcrow and Partners (the consultant) were appointed under United Kingdom technical aid to carry out a feasibility study for improvement of the Northern Highway. They initially considered using marl for road base because of the good performance of existing marl pavements in Belize and Mexico, but marl was eventually rejected because of the low wet strength, poor grading, and relatively high plasticity; crushed stone was used as road base instead.

The Transport Research Laboratory (TRL) was invited to carry out further investigations. A full laboratory investigation was carried out and a field trial was constructed in May 1978, using three marls substituted for the crushed stone road base used in the main contract, including one marl stabilized with cement. The performance of the four trial sections was compared with a control section of crushed stone. Monitoring visits were made in March 1979, October 1980, March 1984, October 1989, November 1992, and September 1997. This report describes the following:

- Selection, engineering classification, and composition of the marls;
- Design parameters and construction of the road trial;
- Results of the monitoring visits; and
- Engineering criteria for future use of the marls.

SELECTION, ENGINEERING CLASSIFICATION, AND COMPOSITION

Selection

The marl occurs ubiquitously in northern Belize and the Yucatan beneath a thin layer of clay. It is underlain by limestone at depths varying from 4 to 9 m. The consultant identified several marl borrow areas for fill material from which TRL selected three for road bases: Tower Hill (or Texaco Pit), San Victor (or Buena Vista North), and Santa Cruz.

Engineering Classification of the Selected Marls

Compaction

Laboratory compaction tests were carried out in 1978 on samples taken from stockpiles. The results are presented in Table 1. The unsoaked California bearing-ratio (CBR) values of the marls are very high and comparable to the crushed stone but their soaked CBR values are much lower. This characteristic caused them to be rejected for road base.

Grading

Figure 2 presents the results of gradings carried out on the stockpiled marls. All were outside the recommended grading envelope for mechanically stable natural gravel. Gradings determined on marl samples taken after compaction (Figure 3) were even finer grained than the stockpiled marl samples and therefore further outside the recommended grading envelope. This reduction in grain size was undoubtedly caused during construction of the trial sections. Normally such a feature would be associated with significant deficiencies in performance.

Plasticity

Atterberg limits were determined on the fraction passing the British standard (BS) 425-μm sieve (*1*) of the stockpiled marls and the results

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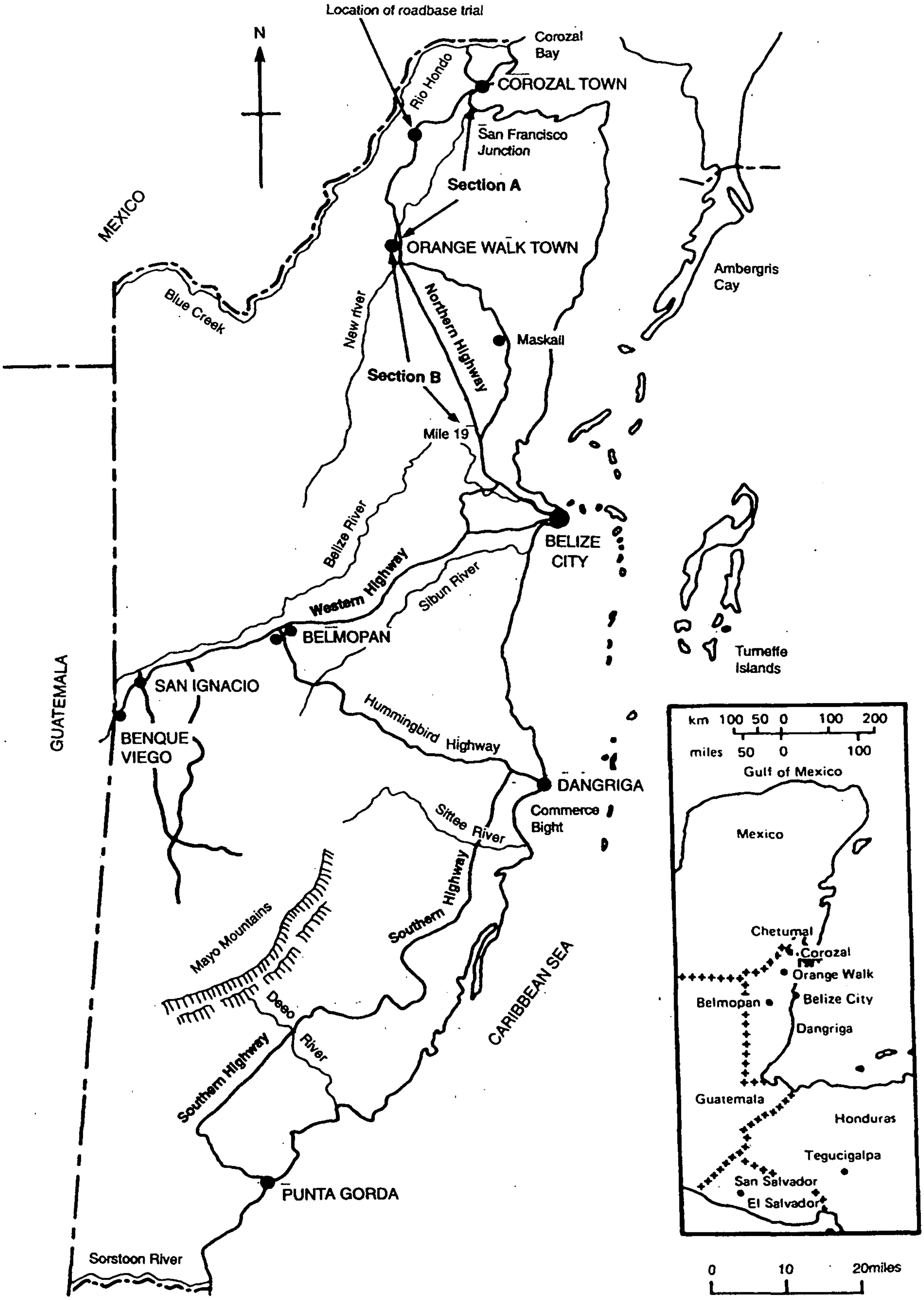


FIGURE 1 Belize: Marl road-base trial, general location.

TABLE 1 Laboratory Compaction Characteristics of the Selected Marls

LOCATION	SECTION 1		SECTION 2		SECTION 3		SECTIONS 4 (&5)	
MATERIAL	CRUSHED STONE, SAN ANTONIO		MARL, TOWER HILL		MARL, SAN VICTOR		MARL, SANTA CRUZ	
	1978	1984	1978	1984	1978	1984	1978	1984
BS (Heavy) Compaction								
Max. Dry Density Mg/m³ (MDD)	2.24	2.24	1.97	2.00	1.67	1.65	1.70	1.70
Optimum Moisture Content % (OMC)	4.0	5.5	9.5	9.2	16.0	16.0	16.0	15.6
CBR %								
at OMC		140	130	180	140	150	130	160
Soaked (4 days)		140	50	40	60	30	40	50
BS (Light) Compaction								
Max. Dry Density, Mg/m³	2.15	2.17	1.86	1.89	1.51	1.61	1.62	1.63
Optimum Moisture Content % (OMC)	9.0	8.0	11.0	12.6	21.0	20.3	18.0	16.0
CBR %								
At OMC		120	35	18	45	14	25	15
Soaked (4 days)		80	16	11	16	5	16	8

are presented in Table 2. The marls had a high proportion of fines but did not show high plasticity. According to TRL *Road Note 31* (*2*), the plasticity index of the material passing the BS 425-μm sieve should not exceed 6 for road base and the liquid limit should not exceed 25. Under these criteria, the marls were of marginal quality for road-base materials. [In the fourth edition of TRL *Road Note 31* (*3*), the quantity of plastic material, expressed as the plasticity modulus or the product of the plasticity index and percentage passing the BS 425-μm sieve, is specified, with a limit of 90: the marls have much higher values.]

Swell was measured during determination of soaked CBR: values of 0.1 percent were recorded, indicating that the fines were nonswelling.

Chemical and Petrologic Composition

The chemical and mineral constituents of the marls were determined and are indicated in Table 3. The results confirmed that the marls consist almost entirely of calcium carbonate and that the crushed stone is dolomite. In fact, the materials are not marls, which are calcareous clays or shales, but limestones. The term marl is retained, however, because that is how they are known locally.

Although the marls have a high fines content, the high carbonate content has resulted in low plasticity and a softness of the constituent particles. The chemical composition has also profoundly affected the subsequent performance of the marls. In terms of grain size, they are akin to silt or loess, but, whereas loess typically comprises hard particles of rounded silica between 0.15 and 0.075 mm and is liable to have a low shear strength because of the poor grading and particle shape, the marl comprises soft particles that break down and lock together on compression or compaction, giving high strength en masse. This is the feature that has led to the good performance of the marl, as discussed below.

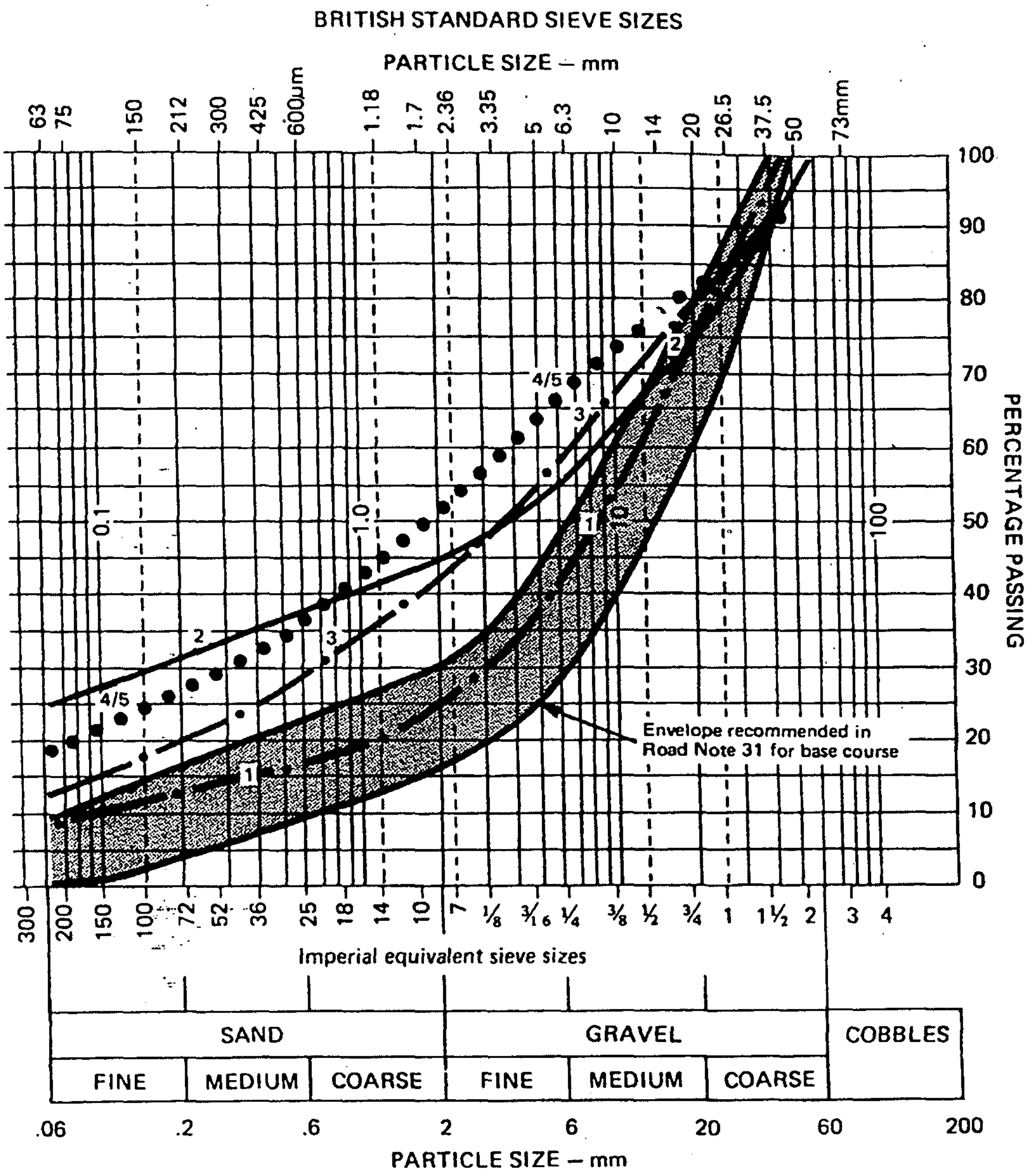
Thin sections of the marls were examined (Figures 4 and 5) and showed fine-grained calcareous particles agglomerated around a harder particle or a shell fragment. The larger particles were porous, allowing the resin with which the slides were made to permeate them quite easily. The microporosity and softness are important features of the marls. When compacted, the marl particles meld together to form a strong and compact mass. Water can, however, permeate them quite easily and, although the carbonate minerals do not have the property of accommodating water within them, as clay minerals do, the water instead forms a surrounding film, which reduces the mass strength. Microfossils occur, chiefly foraminifera, which are of marine origin. The marls are typical of the oozes, which have a widespread occurrence in the tropical oceans of today. They are also physicochemically similar to the Middle and Upper Chalk of western Europe (*4*). Chalk is obviously more indurated but, when broken down into its elemental silt- and clay-sized particles, has liquid and plastic limits of 27 and 21, respectively, and therefore a plasticity index of 6. It also has a notoriously low wet strength in its disaggregated state.

ROAD DESIGN AND CONSTRUCTION

Design

The consultant assembled data from a variety of sources and estimated a cumulative figure of 0.5 million equivalent standard axles (esa) for the heaviest trafficked lane, south to Orange Walk town, for the 10-year design life.

Low areas existed along the road alignment of Section A, which were seasonally inundated. To raise the pavement above flood level, construction of an embankment was proposed, elevated from 400 to 800 mm above ground level. The proposed embankment fill was the marl obtained from appropriately spaced borrow pits along the road alignment. Soaked CBR values of this marl at BS (heavy) compaction were at least 10 percent, indicating its suitability for fill, according to the third edition of *Road Note 31* (*2*).



Note: 1: Section One, San Antonio crushed stone
2: Section Two, Tower Hill or Texaco Pit marl
3: Section Three, San Victor marl
4 and 5: Sections Four and Five, Santa Cruz or Buena Vista North marl

FIGURE 2 Belize: Marl road-base trial, grading of stockpiled marls before construction (May 1978).

For subbase, the marl from the Santa Cruz borrow pit satisfied the minimum design CBR value of 25 percent.

For road base, the materials were required to have a minimum soaked CBR value of 80 percent at BS (light) compaction. The marl was thus precluded for use as road base. The only material available at that time that satisfied this specification was the crushed stone from the San Antonio quarry.

The target dry densities relative to the maximum dry density, BS (heavy) compaction, were 90 percent for the embankment fill and 95 percent for both the subbase and the road base.

The proposed surfacing consisted of a prime coat blinded with stone dust followed by an "inverted" double surface dressing—that is, a larger-sized stone layer laid over a smaller-sized stone layer, applied over the central 6.7 m of carriageway. The road shoulders, each 1.83 m wide, were to be left unsealed. The surface dressing consisted of 13-mm chippings, followed by 20-mm chippings, both obtained from the San Antonio quarry. This stone had aggregate impact values ranging from 19 to 26 percent but was not of ideal quality for surfacing aggregate because it was susceptible to polishing. However, there was no alternative source.

Construction

The TRL experimental sections were constructed in May 1978 during the main contract. Embankment and subbase construction was

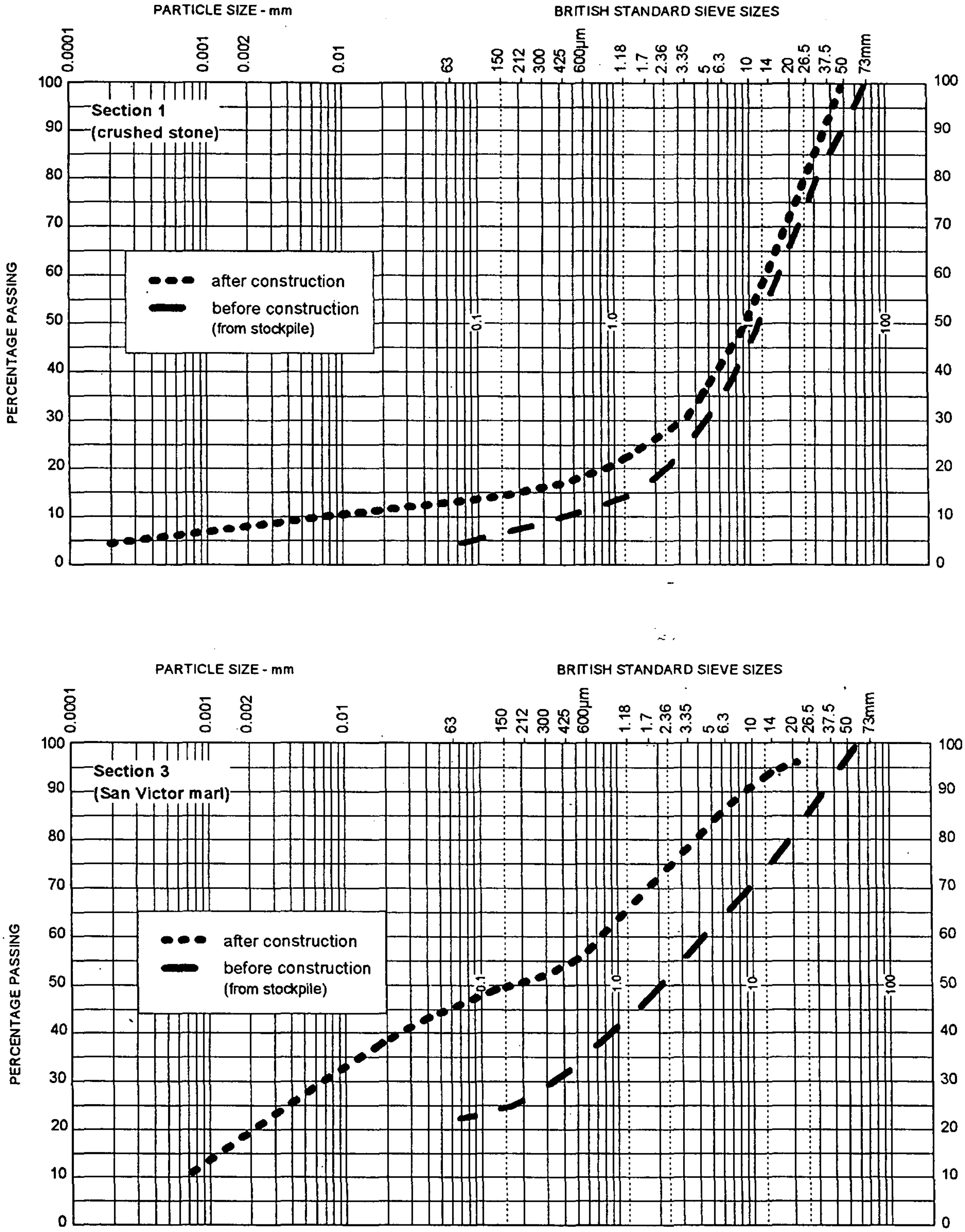


FIGURE 3 Belize: Marl road-base trial, grading of marls before (1978) and after (1984 and 1989) construction.

TABLE 2 Atterberg Limits of Stockpiled Marls

	SECTION 1 Crushed Stone	SECTION 2 Marl, Tower Hill	SECTION 3 Marl, San Victor	SECTION 4 Marl, Sta. Cruz
Mass percentage passing 425 micrometer sieve	17	75	55	62
Liquid limit	n/p	24	29	29
Plastic limit	n/p	15	23	23
Plasticity Index	-	9	6	6
Plasticity modulus	-	675	330	372

carried out by the contractor. The marls used for road base were then laid under TRL supervision.

Five sections, each 106.7 m (350 ft) long, were laid. Each included a 15.2-m (50-ft) transition zone between sections, leaving 91.4 m (300 ft) for monitoring purposes. Section 1 was a control where the road base consisted of the crushed stone used in the main contract; Section 2 was marl from the Texaco Pit; Section 3 was marl from the San Victor pit; Section 4 was marl from the Santa Cruz pit; and Section 5 was the Santa Cruz marl stabilized with cement.

The experimental site was located in a low swampy area. From 600 to 750 mm of marl fill was laid and compacted followed by 100-mm-thick subbase of Santa Cruz marl. Construction of the marl road bases was then completed under TRL supervision. Section 5, the cement-stabilized road base, was laid separately. After the marl had been dumped and spread, Mexican portland cement bags were placed at a predetermined spacing equivalent to 5 percent by weight. The cement was manually spread and mixed into the marl with a grader. Water was then added before further mixing and spreading and the material was then compacted with smooth-wheeled rollers for 1.5 h. The total time taken for the cement-stabilizing operation was 3 h.

The compacted marl road-base thickness was later checked and found to be within ±5 mm of the design thickness of 150 mm, except Section 5, whose mean thickness was 180 mm.

After the road bases had been constructed, a prime coat of MC 30 was applied at 0.61 L/m^2 on Sections 1 to 4. On the cement-stabilized section, a higher viscosity prime, MC 3000, was used to facilitate curing. This prime was slow to harden and also slightly damaged by unauthorized traffic, so it was decided to apply the first layer of binder and surface dressing chippings before it had hardened.

TABLE 3 Chemical Composition of Crushed Stone and Marls

Description	San Antonio Dolomite	Tower Hill or Texaco Pit Marl	San Victor Marl	Santa Cruz Marl
Section	1	2	3	4 & 5
%[1]				
SiO_2	0.6	2.7	2.2	2.3
Al_2O_3	0.2	0.7	0.4	0.5
Fe_2O_3	0.05	0.15	0.1	0.2
CaO	35.4	52.3	53.6	53.0
MgO	17.4	1.2	0.5	0.7
Mn_2O_3	0.01	0.02	0.01	0.01
P_2O_5	0.01	0.01	0.01	0.01
TiO_2	0.01	0.02	0.02	0.02
K_2O	0.02	0.03	0.02	0.04
LOI[2]	45.9	42.3	42.9	42.7
Total	99.6	99.4	99.8	99.5
$CaCO_3$ equiv[3]	63.2	93.4	95.7	94.6
$MgCO_3$ equiv[3]	36.5	2.5	1.0	1.5

Notes:

[1] Components determined by X Ray fluorescence on a fused bead sample, undertaken in duplicate

[2] Loss on Ignition at 1000°C

[3] $CaCO_3$ equiv is CaO x 1.785
$MgCO_3$ equiv is MgO x 2.09

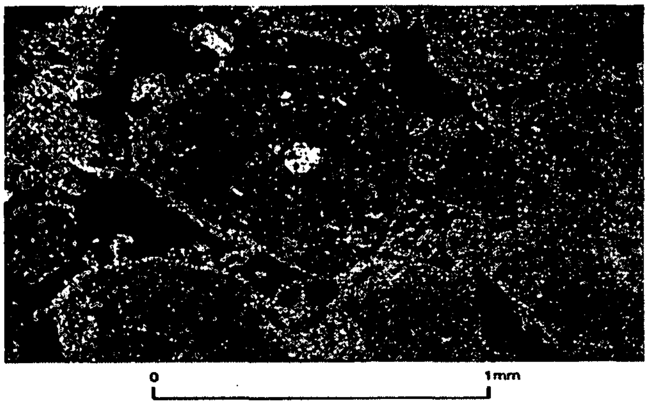


FIGURE 4 San Victor marl under crossed polar light, showing nucleation growth of one particle but nonnucleation in others; dark areas are voids.

On the other sections, the surface dressing was applied within 2 days of priming. A layer of 13-mm chippings was applied on MC 3000 (0.95 L/m²). A second layer of 20-mm chippings was applied during the main construction period 3 months later.

After construction of the field trial, two boreholes were sunk and lined with perforated plastic tube in order to determine the fluctuation of the water table at the site. Observations carried out during 1978 and 1979 showed that the water table was about 1.5 m below ground level in the dry season. In the wet season, however, water overflowed the top of one borehole and was near the top in the other. Standing water was also present in the side drains.

MONITORING OF EXPERIMENTAL SECTIONS

Traffic Surveys

It was established that 850 vehicles per day used the road in 1992 compared with about 600 per day in 1978, which represents an annual growth rate of 2.5 percent over this period. The traffic generated by the sugar cane harvest is very significant because it accounts for a large proportion of the commercial traffic on the road. Traffic volumes are increased by approximately 200 vehicles per day during the cane-harvesting season, although this figure has obviously fluctuated from year to year according to economic and climatic factors. Almost all sugar grown in Belize is cultivated between Orange Walk and Corozal and, since 1986, most has been transported southward to the Tower Hill factory near Orange Walk town.

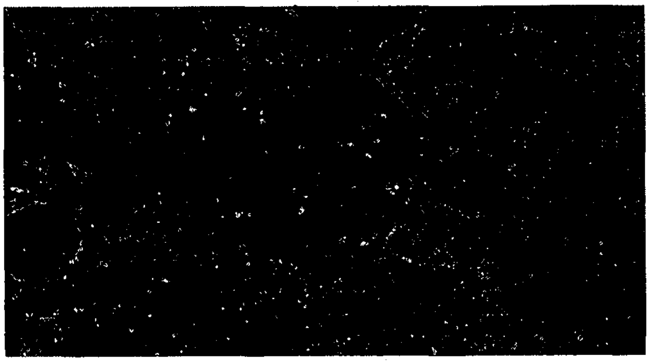


FIGURE 5 Same as Figure 4 but with ultraviolet light (lighter areas are voids), showing microporosity of the particles.

The annual esa, presented in Table 4, have been calculated from data supplied by BSI and are verified by the TRL surveys in 1980, 1984, and 1992 (boldface type). A loaded sugar cane truck typically weighs 12 Mg (12 tonnes), 8.5 Mg (8.5 tonnes) of which is sugar cane. Approximately three-quarters of the load is carried by the rear axle; therefore, each loaded truck carries about 1 esa. From BSI records, the annual esa contribution for both sides of the road trial caused by sugar cane movements to the Tower Hill and Libertad sugar refineries has been calculated. In 1986 sugar production was centralized at the Orange Walk refinery and the Libertad refinery was taken out of service, with obvious effects on the axle loads. The values presented in Table 3 for the intervening years between the surveys were interpolated by using the 2.5 percent average growth rate given previously.

Performance of Marl Road Bases

Field Monitoring

The density attained at construction and changes in moisture content are the main factors influencing the strength of pavement materials. Water infiltration through the surface or from below can result in a progressive loss of strength of the pavement materials and consequent deterioration of the road. Therefore, one of the principal aims of road materials design is to minimize the ingress of water.

At construction, the dry density varied ±3.5 percent from the average value. The variation in moisture content was ±30 percent from the average value. During each monitoring visit, a number of test holes were dug in each trial section to determine the variation in moisture content and strength across the width of the road. There were five sampling positions: both road shoulders, verge side wheel tracks, and the center line. At each position a dynamic cone penetrometer profile or a Clegg impact test or both were carried out. Then a sand replacement density and moisture content were determined on the road base. The hole was continued down through the subbase and embankment fill by using a screw or post-hole auger and was terminated in or just above the natural ground. Samples were removed at intervals and their moisture content was determined.

The main trends in the moisture content, dry density, and strength of the marl road bases are summarized below:

1. There has been a slight increase in moisture content in the road bases with time but average strengths are still high. The crushed stone section is the strongest, and the marl is less strong (CBR, 60 to 100 percent), especially the unsealed road shoulders.
2. The moisture content of the marl subbase has increased slightly compared with the construction moisture, but the strength is still high (CBR, 80 to >100 percent).
3. The thickness of marl fill laid under the road trial varied from about 600 to 700 mm. The construction moisture content of the fill was approximately 13 percent and it has wetted up only slightly since construction, more in Sections 1 and 2 than in Sections 3 and 4.
4. In all sections, but particularly Sections 3 and 4, the very high CBR values of the fill between 300 and 450 mm occur because of

TABLE 4 Annual Axle Loads for Trial Sections

Year	Orange Walk lane, esa		Corozal lane, esa	
	cane traffic	non-cane traffic	cane traffic	non-cane traffic
1979	6,900	17,000	15,800	8,000
1980	**14,300**	**7,000?**	**14,600**	**8,000**
1981	12,700	19,000	14,000	8,000
1982	11,500	20,000	16,000	8,000
1983	13,000	21,000	15,600	8,000
1984	**12,700**	**22,000**	**14,000**	**8,500**
1985	11,300	23,000	13,900	9,000
1986	47,300	24,000	500	10,000
1987	42,900	25,000	500	11,000
1988	43,000	26,000	500	12,000
1989	47,100	27,000	2000	13,000
1990	51,400	28,000	4300	14,000
1991	51,200	29,000	4700	15,000
1992	**52,400**	**29,000**	**2600**	**15,500**
1993	51,300	30,000	4600	15,500
1994	54,500	31,000	3500	16,000
Totals	523,500	378,000	127,100	192,000
Grand Totals	**901,500**		**319,100**	

the presence of a stony layer. It appears that the stonier marl was fortuitously extracted from a local borrow pit during embankment construction. The presence of the stoney layer has significantly improved the overall strength of the pavement, measured in terms of the structural number, as discussed below.

Structural Number

The concept of structural number was developed as a result of the AASHO road test (*5*) to assign indices to road pavements derived from the strengths and thicknesses of their constituent layers.

Structural number = $a_i d_i$

where

a_i = strength coefficient of pavement layer i, and
d_i = thickness of pavement layer i (mm).

The strength coefficients of the road base and subbase were worked out for various types of unbound and bound materials and are summarized by Paterson (*6*). In the AASHO road test, the strength of the subgrade was CBR = 3 percent, so that the merits of combinations of different pavement materials could be assessed. However, to take account of subgrades with different strengths, the concept of modified structural number was developed by Hodges et al. (*7*). Further adjustment to allow for the decreasing influence of subgrade strength with depth was made by Rolt (*8*). From the results of this trial, the average CBR values of the pavement layers have been estimated and are presented in Table 5. Average modified structural numbers have been calculated from the visits with the corresponding strength coefficients derived from Paterson (*6*).

The fourth edition of TRL's *Road Note 31* (*3*) contains a structural catalogue where the subgrade strength for design is assigned to one of six classes. The subgrade (i.e., fill) CBR of all the sections is >30, which places them in category S6 (the strongest subgrade) of Chart 1—that is, the chart for granular road bases with surface dressings. The modified structural number for each section is then related to a prediction of the traffic that section should withstand (i.e., the design traffic). According to these predictions, all the sections have yet to reach their design traffic, mainly because of the very large contribution made by the subgrade marl.

Deformation

The repetition of cyclic stresses of varying intensity over a period of time results in the development of permanent strains whose magnitude depends on the original strength of the pavement and subgrade and the changes that have occurred in these materials with time, such as densification. The permanent strains are manifested by rutting in the parts of the road (i.e., the wheel tracks) subject to the cyclic load-

TABLE 5 Pavement Layer CBR and Structural Number

Section	Roadbase CBR, %	Sub-base CBR, %	Subgrade CBR, %	MSN[1] (of section)	MSN[4] (of cat)	Traffic Class[2]
1	>100	70	>30	3.15	>3.05	T5
2	70	70	>30	2.93	>2.92	T4
3	60	>100	>30	2.93	>2.92	T4
4	70	>100	>30	2.93	>2.92	T4
5	CB2[3]	>100	>30	3.32	>3.18	T6

Notes

1. Modified Structural Number is:
$MSN = 0.0395 (\text{sum } a_i.d_i) + SGC$
SGC is Subgrade Contribution is:
$SGC = 3.51.\log CBR - 0.85 (\log CBR)^2 - 1.43$

2.T4 = 1.5 to 3.0 million equivalent standard axles
T5 = 3.0 to 6.0 million equivalent standard axles
T6 = 6.0 to 10 million equivalent standard axles

3: CB2 is cement stabilised roadbase, UCS = 3 to 6 MN/m^2

4. Overseas Road Note 31 (1993), Chart 1

ings. The magnitude of the elastic deflection provides a measure of the performance and residual life of the pavement according to generally recognized limits.

Rut depth and deflection measurements were determined at approximately 8-m intervals in the wheel tracks of both traffic lanes during each monitoring visit: any changes in the measurements can thus be related to increasing traffic or to changes in the properties of the pavement or subgrade.

Rut depth measurements were carried out with a 2-m straightedge laid across the verge side and offside wheel paths in both lanes. Results for the last two visits are summarized in Table 6. Although there has been a recent slight increase in deformation, it is not appreciable and is typical of the kind of variation found in surface-dressed roads at the time of construction. Usually, rut depths ranging from 15 to 25 mm are required before the pavement is considered to be in a critical condition.

These small values of rut depth are all the more remarkable because the density levels achieved in the road base at construction were about 95 percent relative to BS (heavy) compaction, which normally is considered quite low. Clearly, however, there has been little secondary compaction under traffic.

Deflection was measured by a standard TRL method with the rear axle of a truck loaded to 62.3 kN. Measurements were made with a Benkelman beam, a device consisting of a slender metal beam that measures the flexing of the road pavement as a loaded truck passes. Deflection measurements are very small; values of 1 to 1.5 mm are high and can indicate a critical condition (*6*).

Deflection measurements are summarized in Table 7. They are all remarkably small. However, all sections have shown slight increases with time, with Section 1 (the control) showing the highest and Section 5 (the cement-stabilized marl) showing the lowest. The crushed-stone road-base deflection values are typical of this material. All the marl road-base values, however, are typical of cement-stabilized materials or even concrete.

The measurements of deflection and rut depth were accompanied by visual observation of the general condition of the trial road sections. In 1997 all the trial sections were in excellent condition. No maintenance of the pavement had been necessary other than the resurfacing, although on the shoulders marl has been replaced periodically to compensate for erosion losses.

TABLE 6 Rut Depth Data

Section	Date	Orange Walk lane		Corozal lane	
		Vergeside	Offside	Offside	Vergeside
1	Nov 1992	6 (3-8)	4 (3-8)	5 (4-8)	6 (3-10)
	Sep 1997	12 (5-15)	6 (5-8)	5 (4-8)	8 (5-10)
2	Nov 1992	7 (4-11)	5 (1-8)	4 (3-6)	1 (0-4)
	Sep 1997	12 (5-15)	7 (5-10)	5 (5-6)	5 (5-7)
3	Nov 1992	5 (3-8)	5 (4-7)	4 (3-5)	5 (3-7)
	Sep 1997	5 (3-7)	5 (2-7)	5 (3-6)	5 (3-7)
4	Nov 1992	6 (4-8)	5 (3-6)	5 (4-7)	6 (4-7)
	Sep 1997	7 (4-9)	5 (3-7)	6 (4-8)	6 (4-10)
5	Nov 1992	8 (6-9)	7 (6-8)	4 (3-6)	4 (3-5)
	Sep 1997	10 (5-15)	7 (4-7)	4 (3-8)	4 (3-5)

Notes1. Averages are single figures, ranges are in brackets.
2. Each average is calculated from nine measurements taken at the crosses in Figure 7.

TABLE 7 Deflection Measurements

SECTION	YEAR	ORANGE WALK LANE		COROZAL LANE	
		Vergeside Wheeltrack mm x 10^{-2}	Inside Wheeltrack mm x 10^{-2}	Inside Wheeltrack mm x 10^{-2}	Vergeside Wheeltrack mm x 10^{-2}
1 (Control)	MAR 79	39(29-48)	29(24-38)	27(23-36)	31(22-39)
	OCT 80	41(35-51)	36(30-46)	42(34-50)	41(30-49)
	MAR 84	44(39-55)	53(43-64)	34(28-38)	48(43-53)
	OCT 89	62(54-86)	51(47-59)	45(37-54)	48(43-53)
	NOV 92	64(54-75)	63(51-80)	43(39-50)	58(50-70)
2 (Texaco Pit Marl)	MAR 79	25(24-31)	21(18-25)	17(12-30)	17(11-21)
	OCT 80	22(13-38)	24(18-33)	17(11-27)	17(14-24)
	MAR 84	28(17-36)	35(24-40)	17(13-22)	28(17-39)
	OCT 89	31(20-45)	29(18-34)	24(16-34)	27(20-38)
	NOV 92	51(40-61)	49(36-61)	23(19-27)	35(20-50)
3 (San Victor Marl)	MAR 79	13(11-17)	13(12-15)	13(11-18)	11(9-15)
	OCT 80	12(9-18)	12(7-18)	7(4-10)	9(5-13)
	MAR 84	10(7-15)	21(18-25)	13(10-19)	16(9-22)
	OCT 89	16(12-19)	16(14-20)	16(14-21)	23(19-30)
	NOV 92	21(15-28)	27(17-53)	22(16-30)	18(15-20)
4 (Sta Cruz Marl	MAR 79	12(8-14)	12(7-14)	12(11-15)	9(5-13)
	OCT 80	11(9-13)	10(7-11)	9(7-12)	10(7-12)
	MAR 89	10(8-11)	15(9-19)	13(7-16)	8(8- 9)
	OCT 89	15(10-18)	12(8-15)	13(9-16)	18(15-24)
	NOV 92	19(11-24)	18(15-21)	19(9-23)	15(12-17)
5 (Cement stab. Sta Cruz marl)	MAR 79	7(6-11)	9(7-15)	9(6-19)	9(6-12)
	OCT 80	9(6-12)	11(8-14)	9(5-14)	9(3-13)
	MAR 84	9(6-12)	13(8-19)	9 (4-20)	14(6-30)
	OCT 89	13(10-20)	14(6-20)	17(12-25)	17(12-24)
	NOV 92	18(15-22)	16(10-23)	23(16-53)	15(10-21)

Note: Each single value (range in brackets) represents the average of nine duplicated readings. March is towards end of dry season, when the pavement is strongest: October is at end of wet season, when the pavement is weakest.

Performance of Cement-Stabilized Marl Road Base

The Santa Cruz marl was selected for stabilization with 5 percent cement. In the laboratory two levels of static compaction were used for the stabilized marl to give 92 and 97 percent of the maximum dry density obtained in BS (heavy) compaction. These two levels were chosen to embrace the specified density level of field compaction (95 percent). Unconfined compressive strength (UCS) values ranging from 2.5 to 5.5 MPa were obtained for the marl after 28 days of curing. According to *Road Note 31* (*9*) the stabilized material would be classified as CB1 [i.e., within a UCS range of 3.0 to 6.0 MPa (1 MN/m^2 = 1 MPa)].

The performance of the cement-stabilized marl road base has been excellent. A number of cracks developed in the early years but these have not increased. The low values of rut depth and deflection testify to the high strength of the road base. In 1992 samples were tested giving UCS values averaging 9 MPa for the fresh stabilized marl beneath the surface dressing and 5 MPa for the partially carbonated marl from the road shoulders. Strength increases with time are usual in uncarbonated stabilized materials and would obviously enhance the durability of the pavement because, apart from the gradual strength gain, the material becomes more water resistant. This result indicates that it is possible to use a much wider range of marls if they are stabilized.

Performance of Surface Dressing

The condition of the surface dressing has been crucial to the performance of the road bases. The original surface dressing was in very good condition during the 1989 visit (it was then 11 years old), with very little cracking, bleeding, and loss of stone. It was sampled and the bitumen was recovered by the Rotovapor method (*9*). Penetration tests were carried out, with the following averaged results [Pen units (mm × 10^{-1})]: Section 1, 32; Section 2, 31; Section 3, 25; Section 4, 26.

Although the bitumen recovered was a composite of the prime and two surface dressings it had clearly undergone some hardening but still retained considerable flexibility. MC 3000, the binder used for the surface dressing, has a Pen value of 80/100 when cut back with diesel fuel. Resurfacing with a single surface dressing using the same aggregate was carried out in late 1991.

COST SAVINGS

Potential savings in costs are considerable if marl is used instead of crushed stone for road base. The respective construction costs for the crushed limestone and marl road base in 1978 were about £17,500 and £6,000 per km. The cost of the stabilized section was not recorded but, assuming a cement price of £40 per tonne in 1978, a cost of £15,000 per km has been estimated. The all-in construction cost of the Northern Highway was £78,000 per km. Cost savings were thus £11,500 per km for the unstabilized marl, or 15 percent of the construction cost. The difference was mainly attributed to the quarrying and additional haulage costs of the limestone.

CONCLUSIONS

1. The selected marls do not conform to existing road-base specifications in terms of their particle size distribution, Atterberg limits, and strength in soaked CBR tests. The particles are weak and the material breaks down further under compaction, resulting in the particle size distribution becoming even finer. The fine material in the matrix is mostly silt sized, although the marl can contain clay lenses, which will increase the plasticity.
2. After trafficking for 19 years and cumulated axle loading of 1.3 million esa, deformation has been negligible. The good performance of the trial sections is attributed to the rigidity of the marl attained after compaction, as expressed by the compaction characteristics. However, the marl is sensitive to increases in moisture content, which in the trial have been controlled by construction of an embankment and by maintaining the surface dressing in good condition.
3. The performance of the cement-stabilized marl section has been even better with development of very high strength and only minor shrinkage cracking. The success of the stabilization means that it may be possible to upgrade more plastic marls to a standard acceptable for road base. Better performance can be expected from the stabilized section than from the unstabilized marls because it will retain its strength under wetter conditions.
4. There has been virtually no deformation of the trial marl sections so it is difficult to predict their remaining life. From the analysis of structural number an additional life of between 1 million and 2 million esa is indicated.
5. The potential cost savings of using marls instead of crushed stone are significant.

ACKNOWLEDGMENTS

Throughout the project the Belize Ministry of Works provided generous support and encouragement. BSI was kind enough to provide important data. Colleagues at TRL were involved in the earlier phases of the study and the engineers of the Crown Agents were instrumental in ensuring a high quality of construction.

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