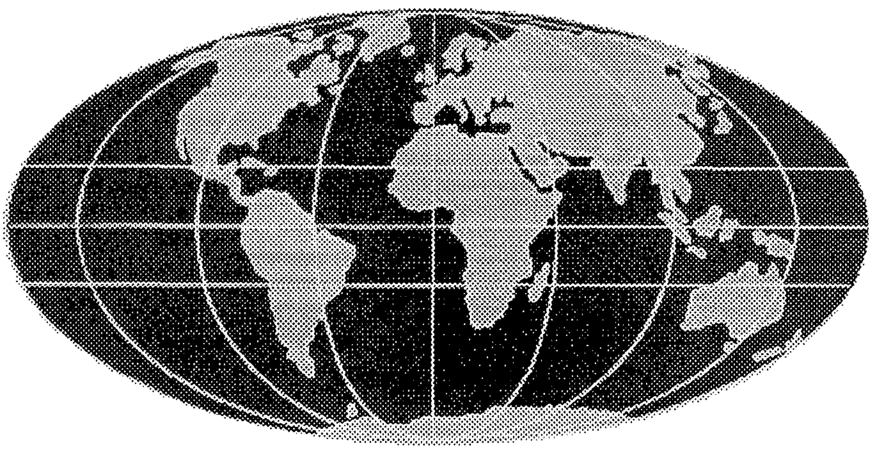
TRANSPORT RESEARCH LABORATORY

DFID Department For International Development

TITLE: Bituminous stabilisation of fine sands: construction of the Baiomori-Gashua road, Nigeria

by: V A P Harris, L S Hitch, J M Jowett



Overseas Centre
Transport Research Laboratory
Crowthorne
Berkshire RG45 6AU
United Kingdom

PA1130/1983

PA1130/83 HARRIS, V A P, L S HITCH and J M JOWETT (1983). **Bituminous stabilization of fine sands: construction of the Baiomori - Gashua road, Nigeria.** *Proc. Institution of Civil Engineers Part 1, 74 (May), 270-300.*

Proc. Instn Civ. Engrs, Part 1, 1983, **74**, May, 277–300

PAPER 8650

Bituminous stabilization of fine sands: construction of the Baiomori–Gashua road, Nigeria

V. A. P. HARRIS, MICE, MIHE*
L. S. HITCH†
J. M. JOWETT, BSc(Eng), FICE, FIHE*

Bitumen has been used to produce road base material in regions of cohesionless soil for many years. The engineer, however, invariably faces the problem of reconciling the properties of a given soil with available binders and processes to produce base material having the required properties. The Paper describes the investigational work leading to preproduction trials which was followed by successful road construction in an area of aeolian sand in northern Nigeria.

Introduction

Bituminous stabilization for the construction of road bases has become increasingly used in developing countries in the last 30 years, particularly in areas characterized by cohesionless soils and which are poor in aggregate sources. The Chad basin in northern Nigeria is a good example and in 1960 the road between Maiduguri and Bama (67 km) was constructed using the local Bama Ridge sand stabilized by a hot-mix process. Johnson & Gandy[1] of consulting engineers Scott Wilson and Kirkpatrick and Partners have described the design and construction of this project; Williams[2] of the Transport and Road Research Laboratory has described the construction of experimental sections on this road using cold-mixed cut-back stabilized material.

2. It might be reasonably argued that, notwithstanding the above experiences and many others, particularly in developing countries, there is still a general lack of information and understanding of bituminous stabilization: Katti, Davidson & Sheeler[3] when examining the role of water in cut-back bitumen stabilization have stressed this general problem. Three notable areas are:

(*a*) characteristics of local soils
(*b*) selection of binder and process
(*c*) test criteria.

Hitch & Russell[4] have compared several mix stability procedures when applied to the sand used for the Maiduguri Bama experimental sections; stability criteria

---

Written discussion closes 15 July 1983; for further details see p. (ii).
* Ove Arup and Partners.
† Transport and Road Research Laboratory.

Table 1. Examination of samples from experimental sections, Maiduguri–Bama road after 12 years

Section no.		2	4	5	9	16	18	Main contract, 9 m from section 21
Bitumen used		200–300 s at 25°C cutback*				S.125†		80/100 pen.
Bitumen content (nominal): pt/100 pt aggregate	Upper Lower	2·0	3·0	2 2	4·5 1·5	3 3	5 5	4 4
Bitumen content as laid: % weight	Upper Lower	1·8	2·8	1·8‡ 1·8‡	4·1‡ 1·7‡	3·0 3·0	4·7 4·7	—
Bitumen content after 12 years: % weight	Upper Lower	1·7	2·8	1·8	4·2 1·4	2·7 2·8	4·5 4·7	3·2 3·5
Recovery of bitumen (BS 598), pen. at 25°C (after 12 years)		15	14	15	13	17	15	14
Compacted density as laid: Mg/m^3		1·79	1·92	1·92	1·95	1·89	1·95	—
Compacted density after 12 years: Mg/m^3		1·88	1·93	1·92	2·07	1·92	1·97	1·87
Increase in compacted density: %		5·0	0·5	0	6	1·6	1·0	—
Marshall stability at 60°C (calc.) after 12 years		4·70 kN (mixes containing 3% and 4% bitumen) (CDM range 1·87–1·91)						
Marshall stability at 60°C (kN) remoulded material, after 12 years (75 blows)§		3·16(3)	7·98(3)	3·98(2)	9·74(3)	8·02(3)	8·19(3)	4·44(3)
Compacted density of remoulded blocks: Mg/m3		1·88	1·93	1·90	1·98	1·94	1·98	1·91

* MC4 (upper viscosity limits)
† MC5 (upper viscosity limits)
‡ Deduced from analyses of similar production
§ Bracketed figures show number of blocks prepared; equal quantities of upper and lower layer material were used where appropriate

for light traffic have been proposed. Further work by Russell[5] enabled stability criteria to be suggested for other traffic categories. However, these suggestions were not available at the time of the events now reported.

3. It is against this background that a road was built in an aeolian sand area of northern Nigeria. This Paper describes the construction of a sand–bitumen base with excellent load-bearing properties.

The Damaturu–Gashua–Geidam road, northern Nigeria

4. In 1970 Consulting Engineers Ove Arup and Partners were commissioned by the Government of North East State, Nigeria to survey and design the Damaturu–Gashua–Geidam (DGG) road (235 km). Based on existing economic haul distances the consultants proposed the following construction:

laterite base (61·5 km)
jigilin base (50 km)
bitumen-stabilized sand base (123·5 km)

Because of subsequent rapid increases in the price of the cut-back bitumen selected, only 55 km (the Baiomori–Gashua section) was constructed using bitumen-stabilized base.

Design standards

5. At the commencement of the DGG survey and design work the Maiduguri–Bama road had been in service 10 years. By 1976 it was known that the Maiduguri–Bama road carried 250–300 vehicles per day (vpd); observers report however that traffic had by 1980 increased to 1000 vpd or greater, since Maiduguri had become the State capital. The road has now been in service 20 years, without undue problems as far as is known. The performance of the experimental sections mentioned earlier was therefore of interest when designing the DGG road. Table 1 shows the properties of seven samples cut from the experimental sections after 12 years in service.

6. The Maiduguri–Bama road was constructed using Bama Ridge sands hot-mixed with 80/100 penetration grade (pen) bitumen: the contractor was required to achieve 95 % of the laboratory Hubbard-Field density of 1·986 Mg/m^3 124·0 lb/ft^3) which gave a Hubbard-Field stability of 5·34 kN (1200 lbf) at a test temperature of 49°C. It had, however, been estimated that the three DGG project roads would normally carry traffic volumes of 150–200 vpd during the early years after their construction with the exception of the crop evacuation period of August–October when the traffic might increase by 50 %. It was also estimated that a substantial proportion of commercial vehicles using these roads would have axle loads in the range 15–20 t. Consequently, in the absence of any other information, it was decided to adopt the Marshall test design criteria recommended by the Asphalt Institute of America[6] for heavy traffic as follows:

stability at 60°C	3·34 kN (750 lbf) (min)
flow	2·0–4·1 mm (8–16 × 0·01 in)

7. In addition, because of the anticipated heavy axle loads, the consulting engineers selected a tyre pressure of 689·4 kN/m^2 (100 lbf/in^2) for design purposes; using the recommendations of Jackson and Brien[7] the required stability condition is given by:

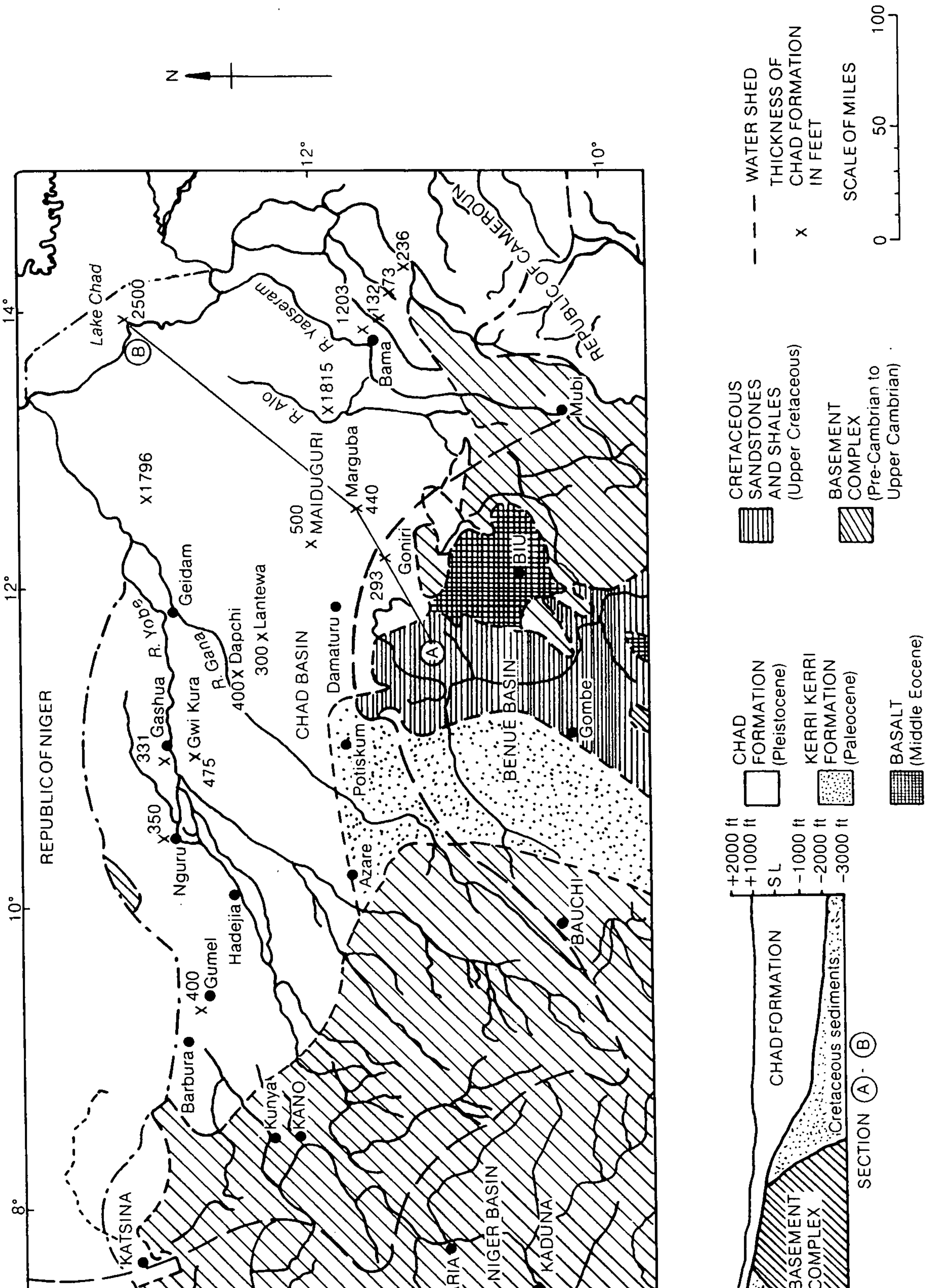


Fig. 1. Geology and extent of the Chad basin in Nigeria

$$\text{stiffness} = \frac{\text{Marshall stability (lbf)}}{\text{Marshall flow (0·01 in)}} > 1{\cdot}2 \times \text{tyre pressure (lbf/in}^2\text{)}$$

$$\text{or} \quad = \frac{\text{Marshall stability (kN)}}{\text{Marshall flow (mm)}} > 0{\cdot}003 \times \text{tyre pressure (kN/m}^2\text{)}$$

8. The annual rainfall in the project area ranges from 500 to 750 mm and occurs over a limited wet season of 3 to 4 months (June to September). It was decided therefore that the design requirements for water absorption should be strictly controlled in order to ensure that the stabilized base would not be unduly water sensitive. Accordingly a design specification for water absorption of 0–2% maximum was adopted.

Subgrade materials

9. The Chad basin is the largest basin of inland drainage in Africa occupying an area of approximately 1·68 million km^2 in west and central Africa; Fig. 1 shows the extent and the geology of the Chad basin in northern Nigeria.

10. The whole of the DGG road project area lies within the Chad basin where the principal soil type consists of the Chad formation sands. These are remarkably uniform fine sands, non-plastic and with 100% passing the 2·36 mm (no. 7) sieve. Typical grading curves are shown in Fig. 2.

11. Figure 3 is an electron-photomicrograph of the 600–210 μm fraction of a sample of aeolian sand from the Damaturu–Baiomori alignment while Fig. 4 shows the 210–75 μm fraction. Subgrade soils were found to be quite uniform over the project area and the sample examined can thus be considered as having properties similar to those nearer to Baiomori. The finer fraction is evidently more angular than the coarser one and Harris[8] has drawn attention to the

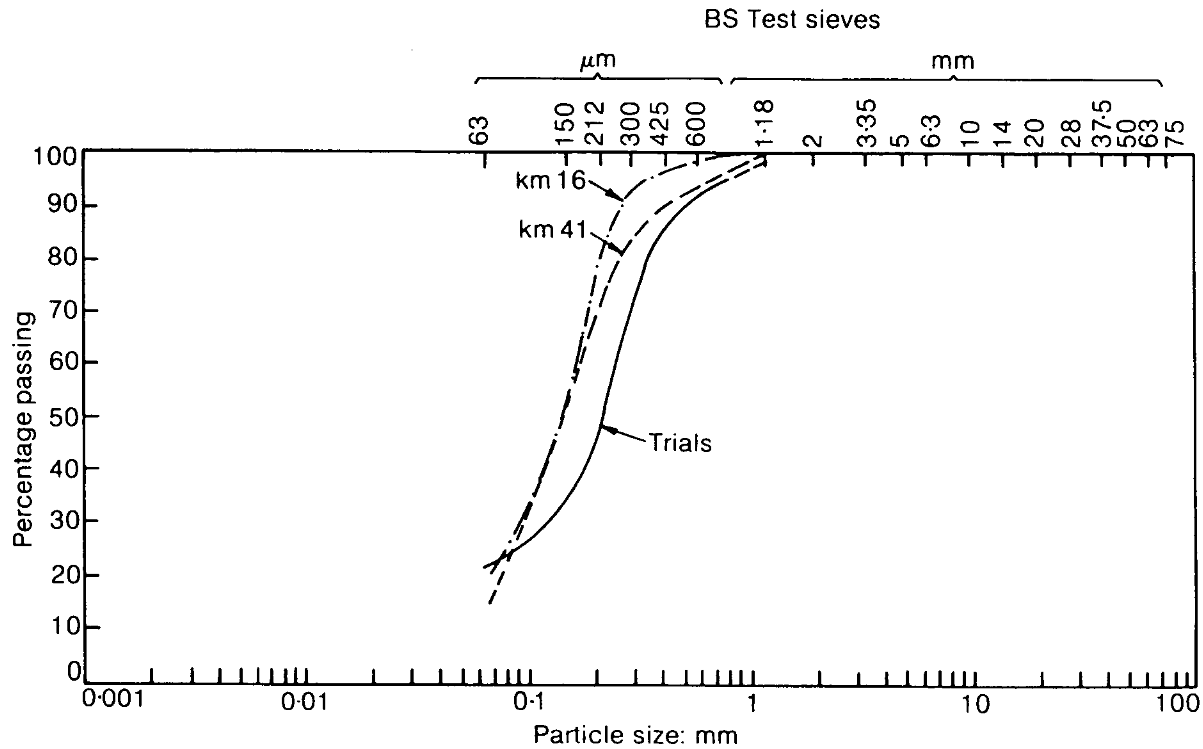


Fig. 2. Particle size distribution; 3 sands, Damaturu–Gashua–Geidam project

theory that the finer angular particles may, in fact, not be derived from the Chad formation but may be dust from the Sahara, transported by the Harmattan winds. This theory is supported by a study of Harmattan dust which was done by the US Bureau of Reclamation as part of their study of the Chad basin.[9] It has been suggested that these angular particles may be responsible for the excellent load-bearing properties of this soil: when compacted to a density of 100% BS standard compaction[10] at the optimum moisture content, these sands resemble soft sandstones. CBR values of 40% are common. Harris[8] notes that on drying out strengths improve even further and CBR values in excess of 200% have been recorded although the material reverts to the loose state under traffic, due to lack of cohesive materials.

Bitumens

12. Bitumen grades used variously at different stages of the laboratory and later full-scale work were:

penetration grade	80/100
cut-back grades	MC 1
	RC 2, 3 and 4

The cut-back grades, which may be unfamiliar, form a part of the older cut-back classification system of the Asphalt Institute of America.[11,12] In 1957 a system

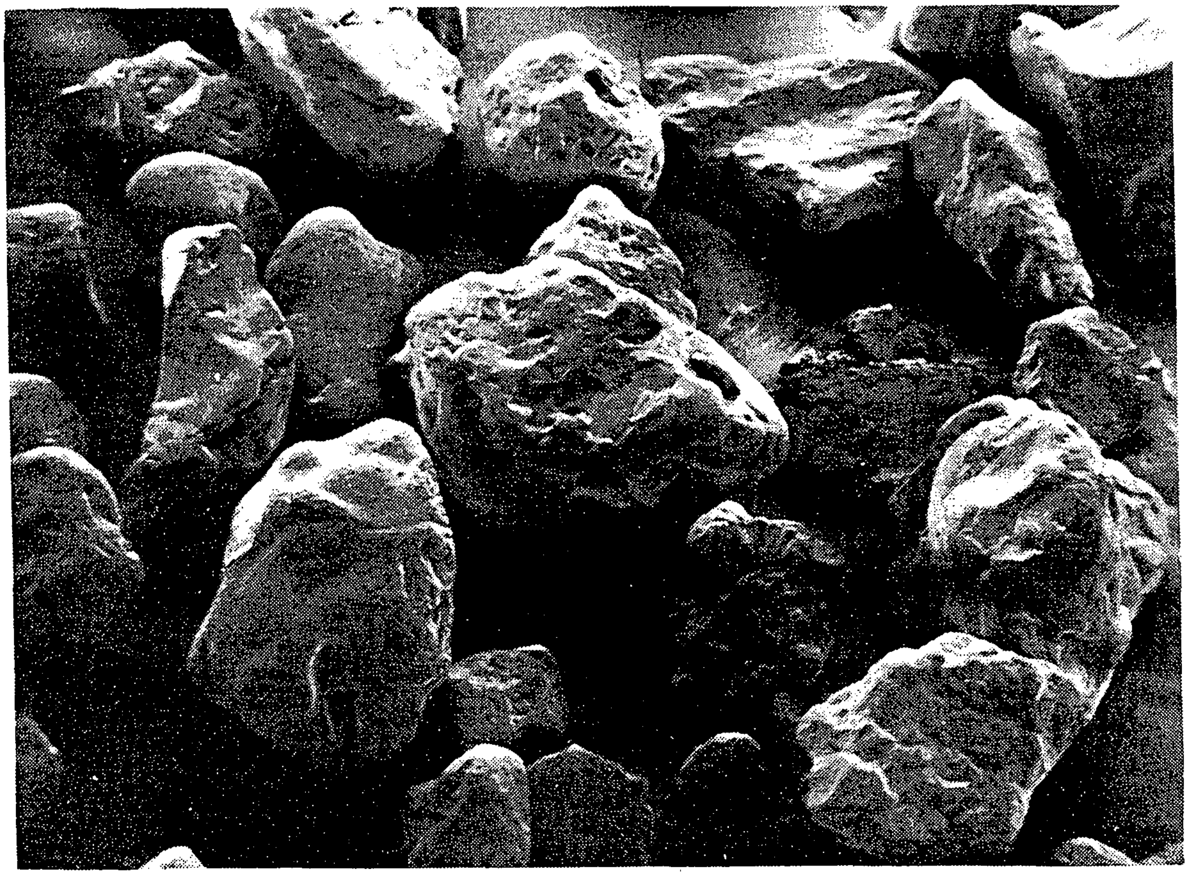


Fig. 3. Damaturu–Baiomori road; electron-photomicrograph of sand fraction 600–210 μm

based on kinematic viscosity (centistokes) at 60°C was introduced; the older system however is still retained in some areas.

Laboratory investigation

13. Preliminary materials testing was done at the Consultants' Central Testing Laboratory in Kano. In addition to the usual Marshall stability/flow determinations, further Marshall specimens were examined for water absorption by immersion in a water bath at ambient temperature for 24 h. Marshall specimens were cured as shown in Table 2.

14. The investigation occupied a period of 2 years and involved preparation of more than 50 000 samples of stabilized material. Harris has described the

Table 2. Curing of Marshall specimens

Binder	Curing condition
80/100 pen.	24 h in laboratory
Cut-back bitumen	3, 12 and 30 days under simulated field conditions

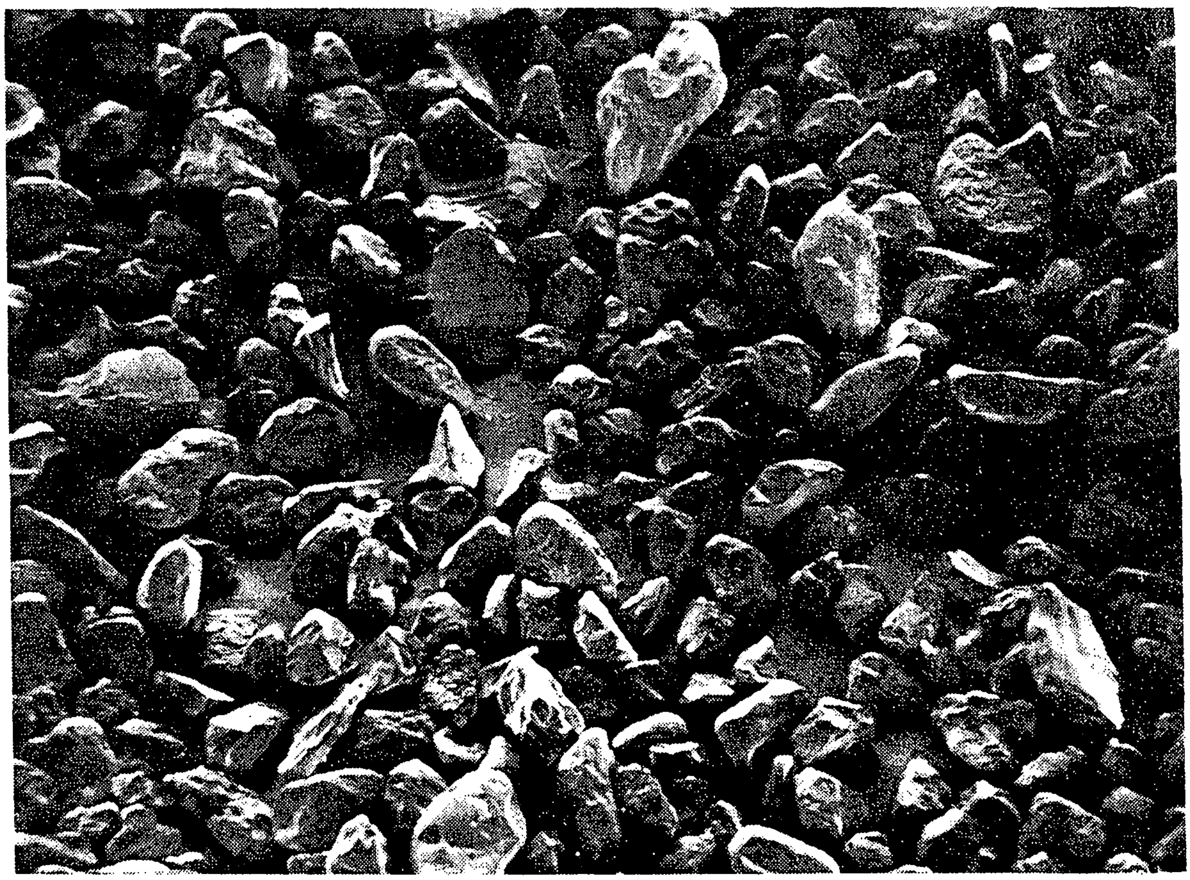


Fig. 4. Damaturu–Baiomori road; electron-photomicrograph of sand fraction 210–75 μm

Table 3. Summary of laboratory research programme

Programme	Objectives	Main conclusions
1	(*a*) To stabilize representative samples of subgrade sand with 80/100 pen. bitumen (*b*) To study the effect of adding coarse sand to mixtures prepared in (*a*) above	1. Only a small proportion of the samples achieved specified Marshall stability 2. Coarse sand improved density but not stability (coarse sand particles rounded)
2	(*a*) To examine the effect of jiglin and silt fillers in the dry/mix process* to standard subgrade sand† using 80/100 pen., RC2 and MC1 binders (*b*) To examine the effect of adding fillers as a slurry to the sand in the wet/dry mixing process‡ before adding binder	3. Fillers improved stability; jiglin more effective than silt 4. Stabilities greatly improved by adding fillers as a slurry
3	(*a*) To examine the effect of clay filler wet/dry mixed with 80/100 pen. and RC2 (*b*) To examine the effect of mixing fillers and sand in the wet/mix process§ using RC2 binder (*c*) To examine the effect of sand stabilized with RC2 in the wet/mix process	5. Clay filler gave higher stabilities than jiglin and silt fillers 6. Mixes gave stabilities substantially higher than the specification requirements 7. Mixes demonstrated that specified stability could be achieved and exceeded
4	(*a*) To examine the effect of different compactive efforts (Marshall test) (*b*) Comparison of CBR values on stabilized and unstabilized sand (*c*) Determination of optimum fluids content‖ for sand–water–bitumen mixes with RC2, RC3, and RC4 binders	8. Stability of stabilized material not very dependent on compactive effort 9. CBR test may be of some value, but more research is required 10. Optimum fluids content reflects optimum moisture content of a sand–water system

* In the dry/mix process both the sand and the filler were dried and, if necessary, the filler crushed to pass a 2·36 mm (no. 7) sieve before mixing with binder

† From test programme no. 2 a subgrade sand from Damaturu was used for all tests as typical of project

‡ The wet/dry process consisted of mixing a filler slurry with sand then drying before use. Where necessary the dried mixture was crushed to pass a 2·36 mm (no. 7) sieve before mixing with binder

§ The wet/mix process consisted of mixing binder with a wet sand/filler mixture or wet sand alone

‖ The optimum fluids content is the sum of the binder/water content at maximum dry density for a stabilized mixture

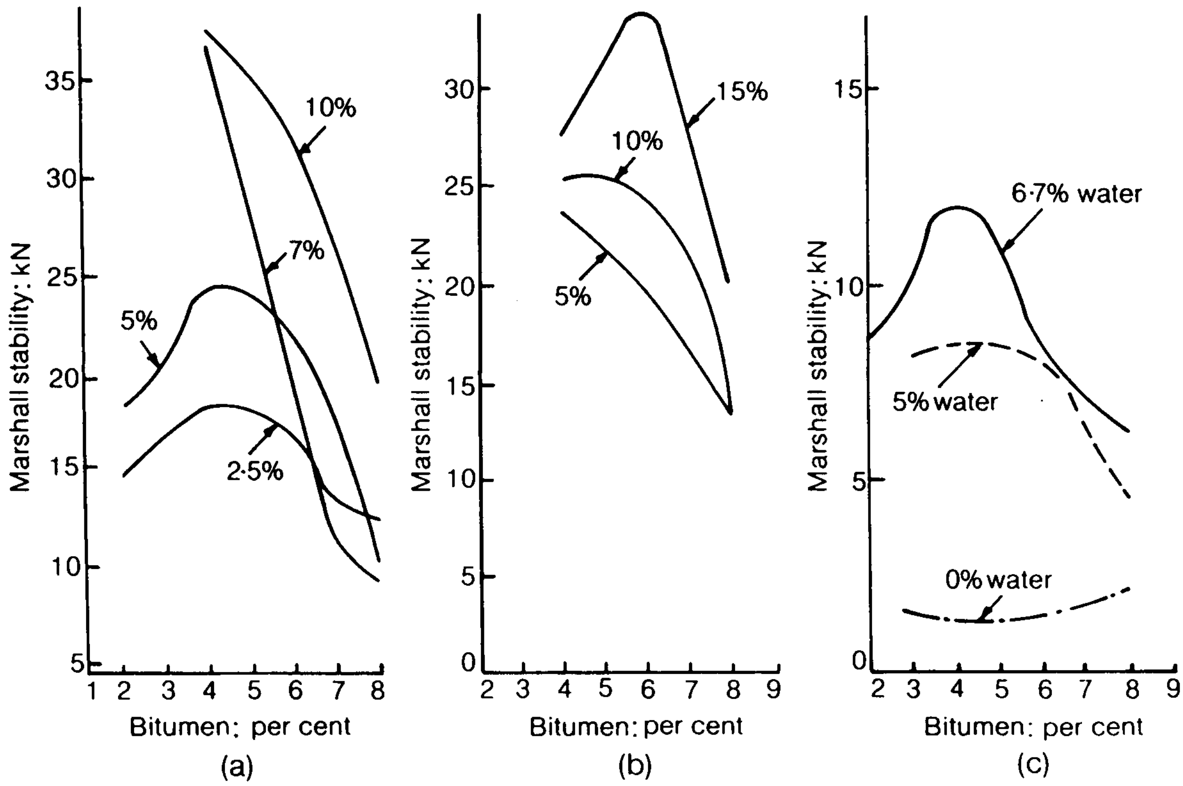


Fig. 5. Stabilization of subgrade sand with RC2 cutback bitumen: effect on Marshall stability of (a) clay filler, (b) silt filler and (c) water (percentage weights as shown)

investigation in detail;[8] Table 3 summarizes the course of the investigation and the main conclusions reached.

15. The most significant point in the research was undoubtedly reached in programme 3 where it was found that the required stability could be obtained using sand/RC2 binder in a wet mix process. Fig. 5 shows the effect on Marshall stability produced by different bitumen contents of a subgrade sand containing 0, 5 and 6·7% water compared with the addition of clay or silt.

16. The laboratory investigation showed that the required Marshall quotient would be satisfied by a mix containing, for example, 5% RC2 plus 5% water.

Preproduction trials

17. Based on the foregoing study, the specification shown in Table 4 was adopted for preproduction trials.

18. It was considered that, of the grading characteristics, only the percentage passing 75 μm (no. 200) sieve required monitoring; failure to meet the minimum percentage specified would have an adverse effect on stability, while materials exceeding the maximum value would require an increased working bitumen content which might result in slow curing. The voids in mix limits specified may appear to be unusually high. It was, in fact, found during the laboratory investigation that voids could not be reduced below 10% by volume because of the fine nature of the sands. The Asphalt Institute has suggested criteria[13] for hot-mix sand–asphalt base which demand a voids range of 3–18% but concede that values higher than 18% may be permitted provided that other criteria are met. Other suggested values are:

Marshall stability at 60°C	0·89 kN (200 lbf) (min)
flow	5·0 mm (20 × 0·01 in) (max)

These values would give a stiffness of 10 (lbf/0·01 in) minimum. In contrast, the consulting engineers' mix specification would give mixes with a minimum stiffness of 66.

Objectives

19. Preproduction trials were done in November 1973 and consisted of six sections of sand–bitumen base constructed at km 7 on the Damaturu–Baiomori road. Trials were done in order to confirm that wet/mix base materials, like those obtained in the laboratory, could also be mixed successfully in commercial

Table 4. Specifications for preproduction trials

Aggregate	
Percentage passing 75 μm (no. 200 sieve)	10–40% by weight
Liquid limit	0–10%
Plastic limit	0–5%
CBR value at maximum dry density (BS compaction) (soaked for 24 h)	10% (min)
Binders	RC2, RC3, RC4
Stabilized material (30 days curing)	
Marshall test properties (50 blows)	
Stability at 60°C	4·448 kN (1000 lbf) (min)
Flow	2·0–3·8 mm (8–15 × 0·01 in)
Voids in mix	10–20% vol.
Water absorption after 24 h soaking	0–2% (max)

Table 5. Subgrade sand used for trials

Grading: weight passing BS sieve: %	3·35 mm ($\frac{1}{8}$ in)	100
	2·36 mm (no. 7)	100
	1·18 mm (no. 14)	98
	600 μm (no. 25)	93
	425 μm (no. 36)	89
	300 μm (no. 52)	85
	150 μm (no. 100)	34
	75 μm (no. 200)	23
Liquid limit		Non-plastic
Plasticity index		Nil
Linear shrinkage		Nil
CBR at BS standard compaction (optimum moisture content)		45%
Maximum dry density		1·906 Mg/m^3 (119 lb/ft^3)

quantities using a conventional mixing plant and also to compare the performance of mixes made with RC3 and RC4 cutbacks with those made with RC2.

Subgrade sand

20. The properties of subgrade sand used for the trials are shown in Table 5.

Mixer

21. A Marini 1000 kg batch mixer was used; a water spray bar was mounted over the pugmill for the purpose of adding any additional water to the local subgrade sand which contained 2–3% moisture when fed to the plant. During the trials the spray-bar equipment was incapable of adding water in finely controlled increments, but for the later full-scale production the supply system was improved to permit increments of 0·5% by weight.

The mixing cycle

22. The pugmill was charged with sand, any additional water was sprayed in and then it was mixed for 15 s before the cut-back bitumen was sprayed in (10 s) after which mixing continued for a further 35 s. The total cycle time, including charging and discharge of the pugmill, was 70 s, but for subsequent full-scale production the reduced water content enabled this to be shortened to 45 s.

Total fluids content

23. Laboratory tests had indicated that the total fluids content (water plus bitumen) required would be 11–12% for a mix containing 6% by weight of bitumen. At this level the mixture was unstable when a 35 t Albaret pneumatic-tyred roller was used for compaction. The natural moisture content of 2–3% was eventually found to be sufficient for compaction purposes thus giving a total fluids content of 8–9% by weight under field conditions.

Spreading and compaction

24. A thickness of 215–230 mm (8·5–9 in) of loose bitumen-stabilized material was spread between sand–cement haunches by a Blaw Knox paver in 2 × 2·8 m (9 ft 3 in) strips and compacted to provide a base of 150 mm (6 in) thickness. A smooth-wheeled roller was found to be quite unable to compact this material at any stage. The lead roll displaced the material ahead of the roll in the form of a wave which broke at intervals and formed an unbonded layer over the rest of the base material. This roller also created tension cracks in the base at 50 mm centres for the full width of the roll. An Albaret 35 t pneumatic-tyred roller was successful, however, and after 4–6 passes the surface was reasonably smooth. An attempt to finish the surface with the smooth-wheeled roller was unsuccessful because tension cracks were formed once again. This machine was discarded in later work. Some 10–12 passes of the Albaret roller were needed to compact the base.

Surfacing

25. The finished trial strips were primed with MC70 at approximately 0·54 kg/m^2 (0·10 gal/yd^2) and later surface-dressed as follows.

first dressing (7 days after priming): 80–100 pen at 0·88 kg/m^2 (0·16 gal/yd^2) + 20 mm ($\frac{3}{4}$ in) basalt chippings at 17·5 kg/m^2 (70 yd^2/t) second dressing (2 days after first dressing): 80–100 pen at 0·97 kg/m^2 (0·18 gal/yd^2) + 10 mm ($\frac{3}{8}$ in) basalt chippings at 11 kg/m^2 (110 yd^2/t)

The prime coat, which had been applied in order to correct an apparent drying-out of the surface, was later considered to have been a mistake since it had softened the top 6 mm ($\frac{1}{4}$ in) of the base which was then marked by the wheels of the surfacing equipment.

Laboratory investigations during the trials

26. Marshall and CBR specimens were compacted during the trials using samples taken at the Marini mixer. Harris has reported the results of this investigation elsewhere.[8] Two aspects emerged.

(*a*) The material which were produced easily satisfied the design specifications.

(*b*) In general Marshall stability and compacted density increased with increasing total fluids content. However, because of the greater efficiency of site compaction equipment, resultant field densities and corresponding stabilities would, in fact, be higher still.

27. It was also found to be possible to trace the increase in strength as curing proceeded by the CBR test. Unsoaked CBR values were not lower than 25 after 5 days and were in the range 60–110 approximately after 30 days.

Conclusions

28. The field trials had shown that a satisfactory base material could be obtained with a mix containing 4·5–5% RC4 binder with 2–3% water. It had been the intention to specify RC4 bitumen for the main contract, but unfortunately the oil companies could not supply the bitumen in the required quantities and only RC2 was available. Accordingly the production mix was selected having a binder content of 5·5% RC2 bitumen to maintain the same residual bitumen content as the RC4 mix. Field laboratory tests on materials from a selected borrow pit established that the required stabilities could be achieved with 5·5% RC2 and 5% water and 30 days curing. In view of the results obtained in the field trials this laboratory optimum fluids content of 10·5% was reduced to 8·5% for the site compaction equipment, i.e. total water was to be 3% by weight.

29. Other conclusions were as follows.

(*a*) A 3 mm ($\frac{1}{8}$ in) screen would be introduced between the feed conveyor and the mixing drum in addition to the 6 mm screens in order to remove sand concretions.

(*b*) A water spray bar fitted with finer jets would be installed over the pugmill of the Marini mixer, and the speed adjustment of the water pump would be modified such that water would be added to the mix in increments of 0·5% by weight.

(*c*) The main drive motor to the Marini mixer would be replaced by a heavier duty motor because of the nature of the mix (the actual weight of each batch was 650 kg).

(*d*) The sand moisture content at the borrow pit would be checked frequently and the added water adjusted so as to maintain the optimum fluid content at the 8·5% level.

(*e*) A 19 t Albaret smooth-tyred roller would be provided in addition to the 35 t machine.

(*f*) The prime coat previously specified would be omitted in full-scale construction.

Sand–bitumen construction on Baiomori–Gashua road

30. Construction of sand–bitumen base started in October 1974 and was completed by July 1975. Fig. 6 shows a cross-section of the road. The specification provided for the following construction:

double surface dressing (80/100 pen. bitumen)	second dressing: 10 mm ($\frac{3}{8}$ in) first dressing: 20 mm ($\frac{3}{4}$ in)
base: RC2 stabilized sand	150 mm (6 in)
sub-base: selected local sand	100 mm (4 in)
subgrade: compacted local sand	

Sand–cement kerbs

31. Sand–cement was manufactured in a pan mixer to the following compositions:

subgrade sand	450 kg
cement	50 kg (11% by weight on sand)
water	35 kg (7% by weight on dry mix)

Because of the relatively dry nature of the mix the hydraulic kerb extruder, designed for working with concrete, was unable to produce kerb at the required output: the contractor therefore resorted to the use of steel forms and manual compaction using steel punners.

Mix design in field laboratory

32. The contractors' materials engineer had previously done a laboratory investigation using the sand intended for use, i.e. material at chainage 135 000. Mixes were prepared at RC2 contents between 4·5–6·5% at 0·5% increments and water contents between 2–7% (1% increments). Specimens compacted by the Marshall apparatus were cured for 3, 12 and 30 days in the laboratory at ambient temperature; they were then tested at 60°C for stability and flow. The 30 days stability values showed that mixes containing 5% water gave optimum

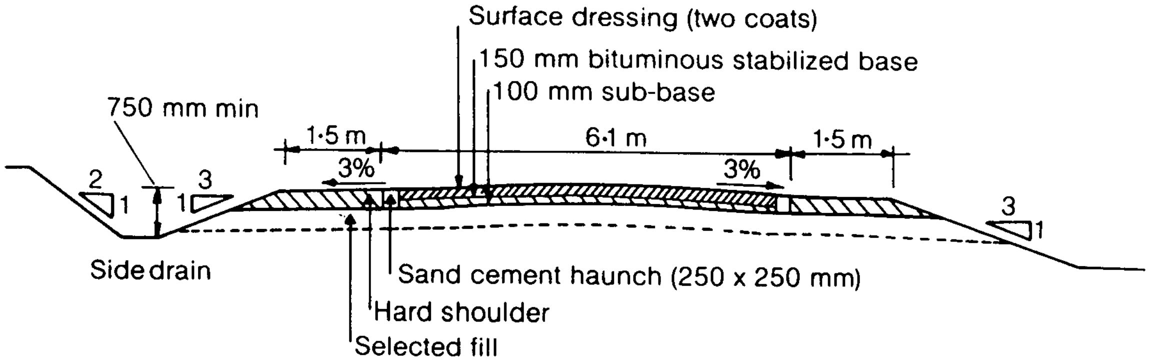


Fig. 6. Typical cross-section Baiomori–Gashua road

stability values at 5–5·5% RC2 level. The effect of water, which is discussed later in the Paper, is not entirely clear. However the field trials had demonstrated that the apparent optimum fluids content needed to be reduced to 8·5% for the site compaction equipment to be used. This had the effect of retaining the bitumen content at 5·5% RC2 but reducing the total water to 3% by weight.

Mix production and laying

33. The Marini mixing plant (Fig. 7) operated initially from a site at km 41 from Gashua (chainage 135 000) and was moved subsequently to km 16 (chainage 53 000). The borrow areas were immediately adjacent to these sites. Table 6 shows the gradings of the subgrade sands used.

34. The critical factor affecting stability appeared to be the percentage passing 75 μm sieve. Although the material at km 16 had only 5% more passing this sieve than that at km 41 the average Marshall stability (30 days curing) increased from 2·20 kN (494 lbf) to 5·72 kN (1286 lbf).

35. The first 300 m west from Baiomori junction was used as a second full-scale field trial to determine the effectiveness of the plant modifications found to be necessary during the preproduction trials. The Marini plant was operating satisfactorily but it was found that if the sand as dug contained more than 1% of moisture the screens clogged and the plant production was considerably reduced. The stockpiles were bulldozed and graded in an attempt to dry out the sand.

36. Production was slow initially and during the first month only 2·4 km (i.e. 100 m per working day) of base was laid. The contractor made an intensive effort to complete the contract on time and by operating the plant up to 18 h a day, 6 days a week, the production was increased to a maximum daily output of 1350 mixes (860 t). This was equivalent to 470 m of completed road base. The monthly production was increased to 12 750 t, or 7 km of base. A major factor in increasing mix production was the ability to reduce the mixing cycle from the 60 s per 650 kg batch to 45 seconds, without loss of mixing efficiency: an additional factor was the ability to stockpile the mixed material during Sundays (when worked) and also during the hours of darkness. Tests carried out on the stockpiled material showed that there had been no deterioration due to stockpiling. A thin crust which formed on the stockpile restricted the loss of mix

Table 6. Gradings of materials used in main contract

BS sieve	Percentage passing sieve	
	Borrow pit (chainage 53 000) km 16	Borrow pit (chainage 135 000) km 41
2·36 mm (no. 7)	100	100
1·18 mm (no. 14)	100	100
600 μm (no. 25)	98	94
425 μm (no. 36)	97	91
300 μm (no. 52)	94	87
150 μm (no. 100)	56	60
75 μm (no. 200)	20	15

volatiles and water prior to spreading: this crust dispersed readily in the bulk of the mix during loading and laying. This ability to stockpile mixed materials is a distinct advantage of the cold-mix process over the hot-mix process. A second very obvious advantage was that of being able to roll immediately after laying: in contrast, on contracts in that part of Nigeria which had used hot-mix techniques it had been found possible to roll only at night due to the high ambient day temperatures. During the construction of the work described from Gashua to Baiomori the daily maximum ambient temperature averaged between 43°C and 46°C for several months. The temperature of the base at 50 mm below the surface was recorded at 60°C for much of this period and at 25 mm below the surface temperatures of 69°C were recorded.

37. The Blaw Knox paver had been used to lay the stabilized base material during the preproduction trials. This machine, however, failed to operate satisfactorily when construction of the main contract began: the driven wheels of the paver dug into the sub-base, resulting in serious contamination of the base material. Various attempts were made to solve this problem, including priming the sub-base and laying base material in 2 × 100 mm layers but without success. It was decided therefore to abandon the use of the paver and to spread using a blade grader for the remainder of the contract (Fig. 8). The use of a grader proved to have several advantages.

(*a*) The rate of spread of the stabilized material was much faster using the grader and the material could be placed over the full construction

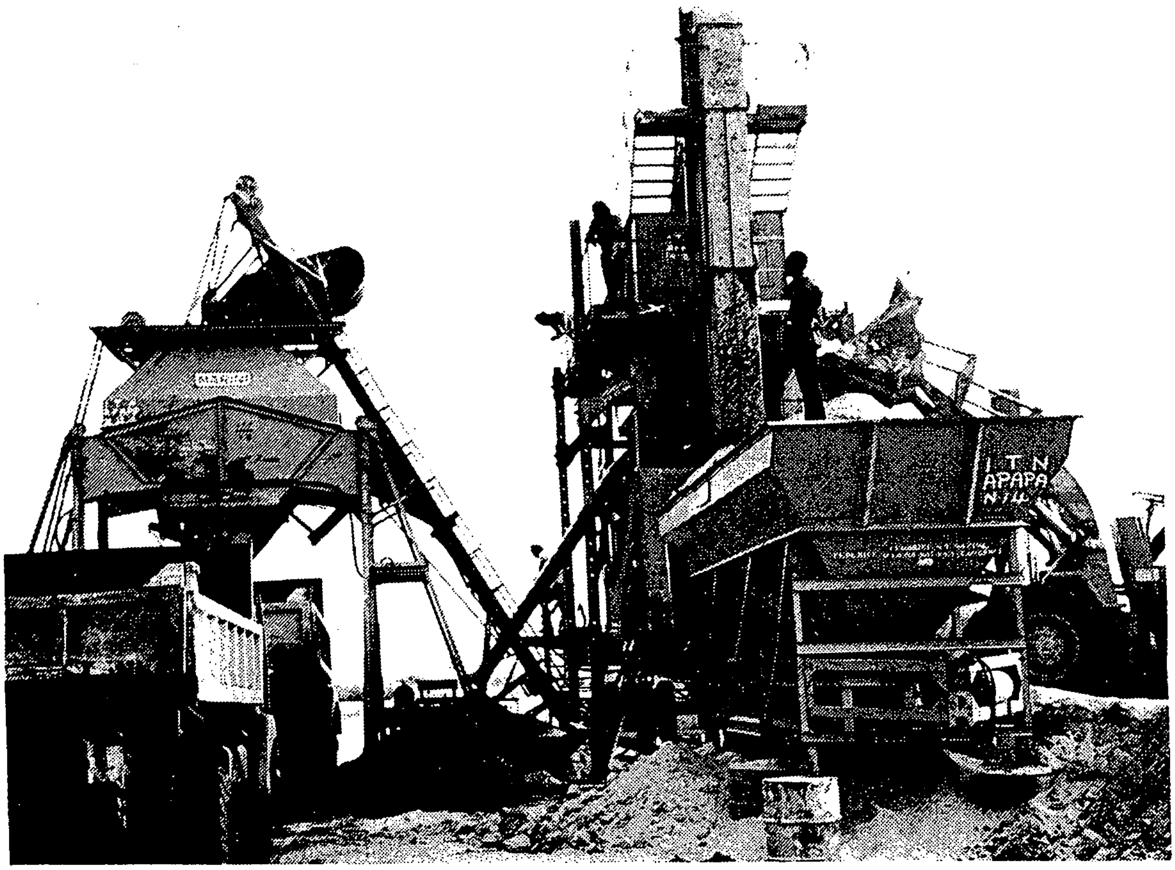


Fig. 7. Mixing plant, Baiomori–Gashua road

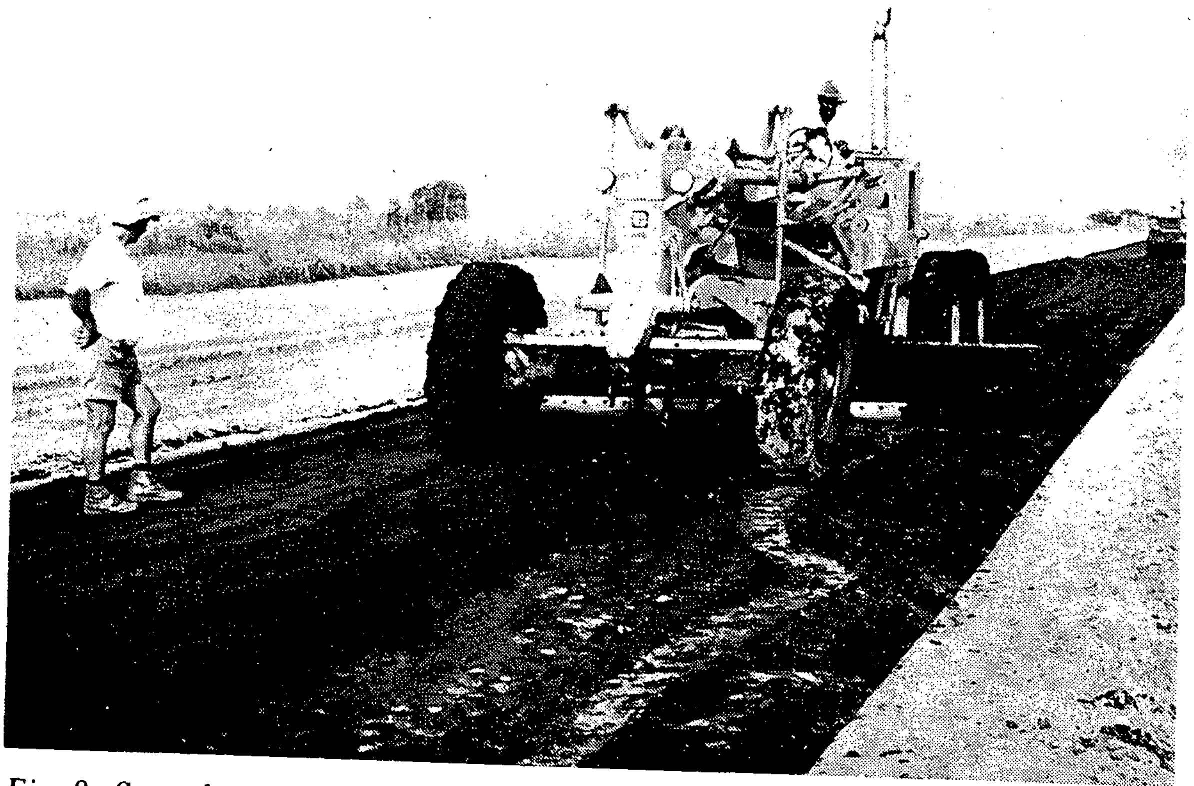


Fig. 8. Spreading sand–bitumen by grader

Fig. 9. 19 t pneumatic-tyred roller compacting sand–bitumen

Fig. 10. Finished surface of sand–bitumen base

width in one operation compared with the two half-widths required by the paver.

(*b*) Lorries reversing up to the paver had caused damage to the sand–cement kerbs. This damage could now be avoided using the grader since the stabilized material would be deposited in the centre of the road thus eliminating the problem.

(*c*) The grader wheels provided some initial compaction to the base material which had the effect that the main compaction of the base could proceed immediately after laying.

38. Use of the two pneumatic-tyred rollers proved to be a most effective method for compacting the stabilized base. The initial compaction was carried out with 5–6 passes of the 19 t Albaret (Figs 9 and 10) and final compaction was obtained with a further 4–5 passes of the 35 t machine. Some back-rolling with the 35 t machine was carried out during early work to establish whether or not the compacted density of the base was likely to increase to any great extent under traffic. However, the results of repeated sand replacement in situ density tests indicated that little improvement was likely to occur once the initial compaction had been achieved.

39. While there was, generally, little difficulty in compacting the base to the specified minimum density of 95% of the Marshall test density, there were some areas where this level was barely attained. In order to avoid crazing and cracking due to over-rolling, these sections were not overcompacted. It was considered that the reduced road density would be preferable to the risk of extensive crazing which had occurred on one section (km 21–22). Although it was not possible to

cut cores, laboratory samples were made up to the densities measured in the road and when tested these samples gave the specified minimum stability. The minimum acceptable density was therefore reduced to 95% BS heavy compaction.

40. There were some edge flow failures against the kerbs between km 36 and km 37. These were not continuous and were attributable to the intense heat; the failures were cut out and replaced with fresh material. There were a few small areas of heaving and two lengths of failure. One length was the extensive crazed and cracked section already described and this was repaired by scarifying, mixing in new material and recompacting. The second length was the first 300 m from Baiomori which exhibited rutting and heaving. This was also scarified, more material was added and then it was recompacted. All repairs were carried out satisfactorily during the construction period. Test cross-sections were established at various chainages and studied for any signs of rutting or deformation in the wheel tracks; no such rutting was observed.

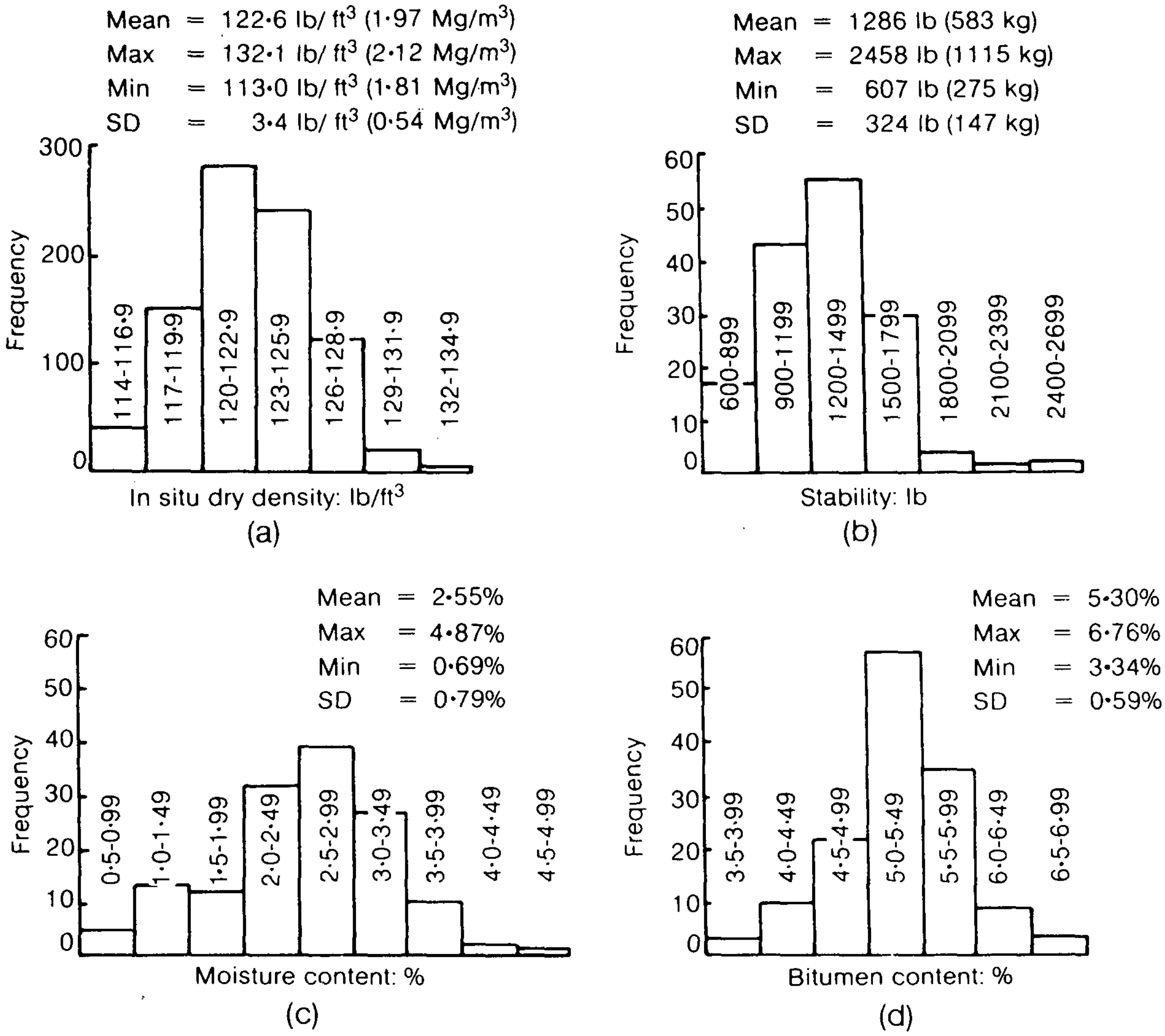


Fig. 11. Histograms of field laboratory control tests (km 0–km 27): (a) statistical analysis of in situ density tests; (b) statistical analysis of Marshall stability (30 days curing); (c) statistical analysis of moisture content of sand-bitumen mixes; (d) statistical analysis of bitumen content (including cutter) of sand-bitumen mixes

Surface dressing

41. In order to allow the curing of the base to proceed as fast as possible, the first coat surface dressing was deferred for 2 weeks after compaction of the base. After the first coat was applied it was trafficked for as long as possible so that any rutting that appeared could be filled with 10 mm chipping before application of a second coat. Very little rutting however occurred.

Laboratory control

42. Laboratory staff made regular measurements of moisture content on sand in the stockpile and in the borrow pit area generally, using the 'Speedy' instrument. Additional water was added at the pugmill as required so as to maintain a moisture content of 3% by weight; the working RC2 content of 5·5% plus the 3% water gave a total fluids content of some 8·5% by weight. The bitumen and water content of the mixed material was determined at least once a day; in addition, sufficient compacted Marshall specimens (2 × 50 blows) were prepared twice daily so that density, stability and flow could be determined after curing for 6, 12 and 30 days.

43. During the preliminary laboratory investigation Marshall specimens were cured by embedding them in sand outside the laboratory in order to simulate as far as possible curing conditions in the road after construction. This procedure was retained therefore during construction.

44. The total numbers of tests done during construction were:

sand grading	182
in situ density	2620
Marshall stability	5031
water absorption	320
moisture and bitumen content	733

Figure 11 shows histograms of some of the test data obtained.

The effect of water content on stability

45. In situ densities consistently averaged 2·0–2·02 Mg/m^3 (125–126 lb/ft^3) (groups of 10) compared with an average value for laboratory-compacted Marshall specimens of 1·92 Mg/m^3 (120 lb/ft^3). The moisture content used during production was 3% instead of the laboratory moisture content of 5%; production mixes made at this level were too wet for efficient compaction. However, since it was considered that water, other than that required to ensure good mixing and compaction, might affect stability, samples of mixed materials were taken on two different occasions and Marshall specimens were prepared both on material as sampled, and on material into which additional water had been mixed in the laboratory. Table 7 shows the results obtained on these specimens.

46. The effect of the additional water is illustrated in Fig. 12 which shows the results obtained from mixes produced in the preproduction trials. In the case of the RC2 mixes, the apparent benefit of increasing moisture content from 2 to 5% is particularly marked. The reasons for this improvement are not known although Alexander & Blott[14] observed the phenomenon during their investigations into factors affecting the structural stability of sand carpets. In an attempt to explain the effect of water they cited the behaviour of some dispersions of solid particles in a liquid medium which, on being allowed to rest after agitation,

Table 7. Effect of additional water in cutback-stabilized production mixes

Data sampled	15 October 1974						25 October 1974					
Bitumen content: per cent by weight*	4·6						4·7					
Water content: per cent by weight (as sampled)	1·6			1·6			2·4			2·4		
Water added: per cent by weight	0			3·3			0			1·5		
Total: per cent by weight	1·6			4·9			2·4			3·9		
Curing period: days	6	12	30	6	12	30	6	12	30	6	12	30
Marshal test at 60°C, stability: kN	0·94	1·23	1·42	2·39	3·11	3·01	1·69	1·80	2·12	2·87	2·92	3·52
Marshall test at 60°C, flow: mm	1·8	2·0	2·3	1·0	1·3	1·0	1·8	1·8	1·8	1·5	1·0	1·3
Bulk density, original: Mg/m³	1·986	1·986	1·986	2·002	2·003	2·002	2·003	2·002	2·002	2·002	2·002	2·002
Bulk density, cured:† Mg/m³	1·938	1·954	1·938	1·906	1·906	1·906	1·970	1·970	1·954	1·938	1·938	1·938
Percentage increase in stability	—	—	—	154	153	112	—	—	—	70	62	66

* Determined by hot extraction method
† Although the bulk densities of the cured 'water-added' specimens appear to have been lower than those of the corresponding 'as sampled' specimens by 16–32 kg/m³ (1–2 lb/ft³) there is a pronounced increase in stability

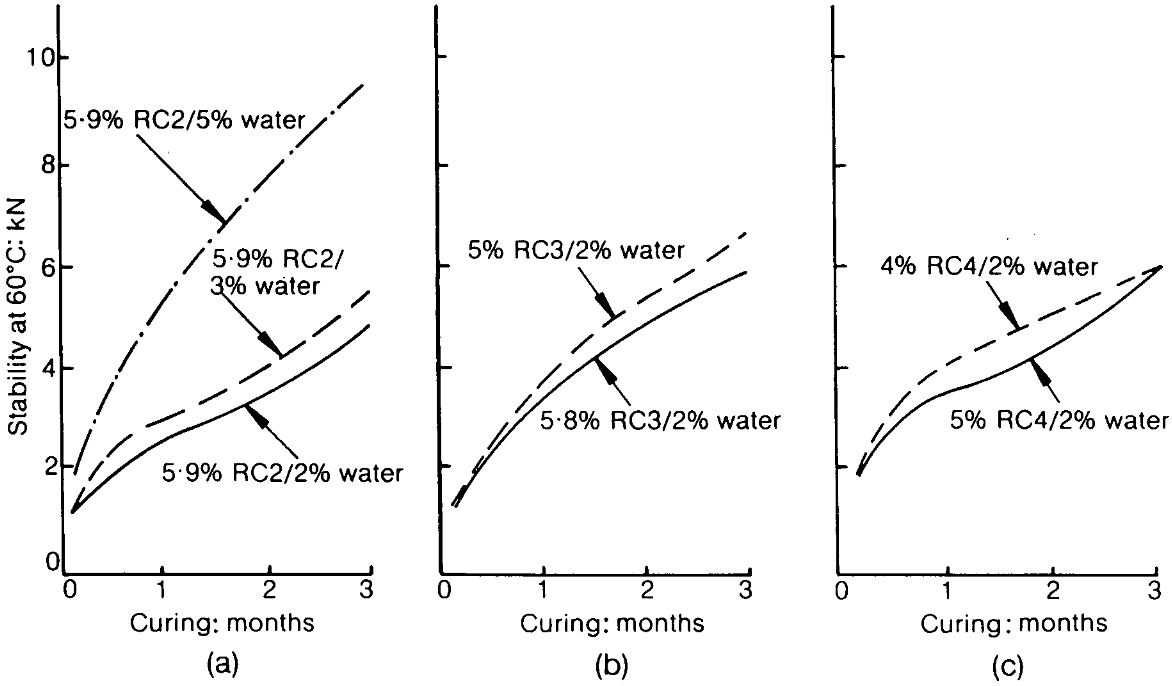


Fig. 12. Effect of moisture content on mix stability for 3 cutback binders: (a) RC2; (b) RC3; (c) RC4

Table 8. Examination of sand–bitumen base samples after 5 years in service

Origin	Binder, % weight	Properties of recovered binder		
		Pen at 25°C	Softening point, °C (ring and ball)	Penetration index
km 8	3·6	460 approx.	—	—
km 18	4·4	60	57	+1
km 45	5·1	72	49·5	0
km 50	3·7	27	65·5	+1
RC3 trial, km 42	3·7	43	63	+1
RC4 trial, km 42	3·5	28	72·5	+2

formed gels. They stressed the differences in the relative magnitudes of viscosity of water, cut-back bitumens and the harder penetration grades of bitumen, and suggested that a gel structure would form more quickly when filler particles are allowed to settle in a low viscosity medium than in one of higher viscosity. They further suggested that 'The effect of the initial water content in the wet mixes is maybe to bring the filler particles rapidly into a suitable state of aggregation in which they can more readily form a structure within the oil binder.' These suggestions were regarded by Alexander & Blott as highly speculative but the effect of water is undoubtedly useful irrespective of the mechanism.

Hardening of binder in service

47. In November 1980 samples of sand–bitumen base were taken from the road and sent to the Overseas Unit TRRL for testing as follows:

(*a*) binder content (BS 598[15] : Part 2 : Section 4.6)
(*b*) recovery of soluble bitumen (BS 598[15] : Part 2 : Section 6)

Dichloromethane was used as solvent. The results are given in Table 8.

48. Since the base construction occupied only a period of 10 months it would seem unreasonable to try to account for the differences in the apparent hardening of the binder recovered from materials which represent this time separation, particularly in the context of the first 5 years of service. The consistency of the binder recovered from km 8 must therefore remain unexplained; otherwise the RC2 binder can be said to have hardened to a penetration range of 30–70.

Performance of completed road

49. The 55 km of road were inspected in June 1979, 4 years after completion. The road base and surface dressing were in good condition and had required very little, if any, repair or maintenance; only one pothole was seen. The amount of rutting was negligible except for the westbound lane between km 37 and 40; the sand–cement kerbs appeared sound although in some instances the surface dressing had stripped from the top surface.

50. Although the testing during construction had shown that the km 0–27 base had a higher stability than the km 27–55 material there was no evidence of this strength difference on the road. During the construction of the main contract two additional test sections incorporating RC3 and RC4 binders were constructed at km 42: both of these were also in good condition at the time of inspection.

51. At the design it was considered that during the early years after construction the DGG roads would normally:

(*a*) carry traffic volumes of 15–200 vpd
(*b*) be subjected to some axle loads in the 15–20 t range.

52. The consulting engineers made a traffic and axle-load survey near to Gashua in April 1980 (after nearly 5 years in service). During the 7 day survey (12 h recording daily) the average daily traffic (one direction) was 340 vpd. The maximum multi-axle load recorded was 76 t; 7 other vehicles exceeded 50 t laden, the maximum axle load recorded being 18·8 t.

53. Axle load data were analysed using the procedure described in *Road Note 40*[16] and can be summarized as follows:

Daily traffic flow (1 direction) of 1 . 2 type vehicles* (or larger) = 100
Mean equivalence factors:† to Damaturu 2·54
to Gashua 1·74
Average equivalent standard axles (esa) (daily) = 100 × 2·54 = 254 esa
Annual axle loading (12 h day basis) = 254 × 365 = 92 715 esa

Traffic and axle-load predictions would thus appear to have been confirmed.

* 2 axles; single tyres front, twin tyres rear.
† Damaturu figure taken.

Conclusions

54. The Baiomori–Gashua road was one of the first roads to be designed for heavy axle loads which incorporated a bitumen-stabilized base made with the very fine aeolian sands of the Chad formation. The fact that it proved possible to achieve Marshall stabilities in excess of 4·448 kN (1000 lbf) with these sands, using RC2 binder and the wet/mix process demonstrates that it is possible to use this form of construction for trunk roads.

55. The wet/mix method of mixing stabilized base material in commercial quantities proved to be relatively simple provided that good quality control procedures were maintained at the mixing plant. The stabilized base material had very forgiving characteristics, demonstrated by the fact that it could be stock-piled for periods up to 7 days prior to spreading; this would not have been possible using a hot-mixed material.

56. The water–bitumen relationship in the wet/mix method is not fully understood and requires research. Clearly, however, there is an obvious practical advantage in establishing the optimum fluids content so as to achieve the required stability while using the minimum bitumen content.

57. The condition of the road has remained satisfactory after the first 5 years in service during which period it was used by vehicles in the number and axle-loading anticipated at the design stage.

58. After 5 years in service the residual bitumen content of the stabilized materials appears to be $4 \pm 0{\cdot}5\%$ of weight; the binder has hardened to a penetration range of 30–70.

Acknowledgements

59. The Authors wish to thank the Federal Ministry of Works, Lagos, Nigeria and Ove Arup and Partners for their kind permission to present this Paper. Thanks are due also to the Transport and Road Research Laboratory for advice and assistance throughout this study; TRRL also prepared electron photomicrographs of different sand samples. Finally, the co-operation of the contractors, Stirling Civil Engineering Nigeria Ltd, in making available their construction records is gratefully acknowledged.

References

1. JOHNSON C. M. and GANDY J. J. Construction of the Maiduguri–Bama road, Nigeria. *Proc. Instn Civ. Engrs*, 1964, **29**, 1–18.
2. WILLIAMS F. H. P. *Bitumen-sand mixes for road bases.* Road Research Laboratory, Crowthorne, 1968, Ministry of Transport, RRL Report LR 239.
3. KATTI R. K., DAVIDSON D. T. and SHEELER J. B. Water in cutback asphalt stabilisation of soil. *Highway Research Board Bulletin*, 1960, **241**, 14–48.
4. HITCH L. S. and RUSSELL R. B. C. *Sand-bitumen for road bases: an examination of five methods of measuring stability.* Transport and Road Research Laboratory, Crowthorne, 1976, Department of the Environment, TRRL Report LR 717.
5. RUSSELL R. B. C. *The design of sand-bitumen mixes for use in developing countries.* MPhil thesis, Department of Civil Engineering, University of Surrey, 1975.
6. THE ASPHALT INSTITUTE. *Mix design methods for asphalt concrete and other hot mix types.* The Asphalt Institute, Maryland, 1979, Manual Series no. 2.
7. JACKSON G. P. and BRIEN D. *Asphaltic concrete.* Shell International Petroleum Co. Ltd, London, 1962.
8. HARRIS V. A. P. Bituminous stabilisation of fine sands in Northern Nigeria. *Proc. Conf. on low cost roads, Kuwait*, 1974.

9. US Bureau of Reclamation. *Reconnaissance study, sand and water resources, Lake Chad basin, Nigeria.* US Bureau of Reclamation, Denver.
10. British Standards Institution. *Methods of test for soils for civil engineering purposes.* British Standards Institution, London, 1975, British Standard 1377:1975.
11. Griffith J. M. *Liquid asphalts: new specifications and recommended use.* The Asphalt Institute, Maryland, 1963, Information Series no. 124.
12. The Asphalt Institute. *Specifications for paving and industrial asphalts.* The Asphalt Institute, Maryland, 1980, Specification Series no. 2, 1980 edn.
13. The Asphalt Institute. *Construction specifications for asphalt concrete and other plant-mix types.* The Asphalt Institute, Maryland, 1975, Specification Series no. 1, Appendix B, 5th edn.
14. Alexander P. and Blott J. F. T. Factors affecting the structural stability of sand carpets. *J. Soc. Chem. Ind.*, 1945, **64**, 89–101.
15. British Standards Institution. *Sampling and examination of bituminous mixtures for roads and other paved areas.* British Standards Institution, London, 1974, British Standard 598.
16. Transport and Road Research Laboratory. *A guide to the measurement of axle loads in developing countries using a portable weighbridge.* HMSO, London, 1978, Department of the Environment, Department of Transport Road Note 40.