Construction of the Maiduguri-Bama road, Northern Nigeria

by

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and

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Mr Henry Grace (Messrs Scott & Wilson, Kirkpatrick & Partners) wished to add a few remarks concerning the pavement design to supplement the information given in the Paper.

49. As would have been noticed, the road was constructed along a sand ridge, and that sand was in an extremely loose state. A number of tests was carried out in order to determine its density, and it was found that the sand in its natural state was at approximately 80 to 85% of the density which would be obtained in the British Standard compaction test. It was known at the time of design that loose sand of that type would be very susceptible to additional compaction by vibration of traffic. However, it was not known what degree of compaction would be required for light traffic roads and to what depth the subgrade would be affected by compaction of traffic. There was no information on this whatever, although a certain amount of information had been collected by the Germans in respect of highly trafficked autobahns and also by the Americans for the pavement design of airfields.

50. In order to obtain information on the problems, a study was made of an unpaved track which existed between Maiduguri and Bama and which had for years carried the traffic between those two centres. The traffic had run in very marked wheel tracks, and holes were dug in the wheel tracks to obtain densities at various depths. From that, a density profile was obtained as shown in Fig. 13. It was found that at ground surface under the wheel tracks the density was slightly more than 100% of the B.S. compaction test, and it dropped off with depth until at approximately 20 in. it was down to just over 80%. That was what was found in general from the initial investigations. It was considered that if the subgrade were compacted to not less than those densities, and then 5 in. of bitumen sand pavement were added, there would be no further deformations when the road was open to traffic. However, when the road was opened up to traffic the Authors were rather disconcerted to find that deformations very soon appeared in the nearside wheel tracks. The deformations were formed by the construction traffic which was fairly intense, but nothing more than one would expect the road to carry. The deformation was normally about 1 in. deep, and the maximum deformation amounted to something like 2 in. In view of the careful study which had been made and the careful control which had been exercised, the Authors were somewhat nonplussed and decided to carry out a thorough investigation. That was done by excavating trenches through the deformed areas, and it was found that the pavement had not compacted at all, but that the subgrade had been deformed in exactly the same way as the surface. Further density tests were carried out to see what had happened after the road had been open to traffic.

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FIG. 13: DENSITY PROFILE

51. A pavement composed of 5 in. of sand/bitumen had been put in, but before it was put in the densities in the subgrade were tested. They were slightly in excess of the densities which had been found below the wheel tracks (see Fig. 13). After the bitumen pavement had been constructed and the failures or deformations had taken place, it was found that the densities had increased slightly immediately underneath the pavement, but that there was a considerable increase in density at depth. The density had gone up from about 80% to something like 90% at a depth of 20 in. The conclusion was eventually reached that it was due primarily to the effect of the vibrating plate which had been used for compacting the bottom of the trench on which the haunch had been placed. The plate was an effective machine and it shook up the foundation and seemed to affect the subgrade to a considerable depth. Also the effect of the vibration spread out from the plate in a bulb shape formation, and it was believed that it actually compacted to a certain extent the loose sand beneath the sand bitumen pavement at some considerable depth. That was confirmed by the fact that there was no deformation in the other wheel tracks.

52. After that, the road was raised so that an additional thickness of sand at a greater density was obtained. At the same time the use of the vibrating plate was discontinued. There was no further trouble. The problem of densities building up by traffic vibration was very important, and similar problems had been experienced in Great Britain. In connexion with a recent motorway in Britain, a similar investigation was carried out on one of the old trunk roads which of course had been heavily trafficked for the last 30 or 40 years. It was found in that case that there were 2 ft of base, under that there were 2 ft of sand which had a density of approximately 103% of the B.S. compaction test, and underneath there was a further depth of 2 ft which had a density of 100%. Therefore, it could be said with some certainty that the effects of vibration had gone at least 6 ft into the subgrade in the case of that very busy road. That might be of interest, because there were sand areas in Britain where new roads had to be constructed, and it was doubtful whether a great deal of work had been done in regard to that problem to date.

53. The only direct comment he had on the Paper concerned the titles of §§ 41 and 44 which were 'Failures of the subgrade' and 'Failures of the base course'. To any road engineer the term 'failure' conjured up a vision of badly cracked and damaged pavements and something that would require replacement. On visiting the Maiduguri-Bama Road he never saw anything like that, although he did see deformations. In his view the term 'failure' would have been better replaced by 'deformation'.

54. Mr Grace said he had travelled over the road at an average speed of 70 miles/h, and the finished surface was comparable with the surface on the motorways. To have produced a two-lane road of such a standard for a cost of something under £13 000 per mile was a very creditable performance.

Mr F. H. P. Williams (Tropical Section, Road Research Laboratory) said that Mr Gandy had put up with him for three months while he conducted an experiment on the road.

56. In § 3 it was stated that the bituminous-stabilized base proved to be the cheaper in every case. That was rather surprising, and it would be interesting to hear from the Authors what it was being compared with. If they were comparing the specification shown of the 5-in. bitumen base between fairly heavy sand/cement kerbs with a similar 5 in. of soil/cement between similar kerbs, then it was not really comparing like with like, because the soil/cement would not require kerbs, which were only necessary to contain the sand/bitumen mix. At the time when the road was being designed, there was an idea that the bitumen mix was equivalent to a greater thickness of soil/cement mix. Since then, this had proved not to be the case, because with the higher temperature in the tropics the bitumen mix did not give any greater stiffness. Had the same thickness of soil/cement and soil/bitumen been compared?

57. It was rather surprising that with bitumen costing twice as much as cement, bitumen/sand mix could normally prove to be cheaper.

58. In §§ 6-8, dealing with the design of the bitumen mix, the Authors pointed out that the Road Research Laboratory had conducted the original experiments. Mr Williams asked how they interpreted the figures in Table 1 in order to arrive at the final mix. Mr Williams had always found it very difficult, and his own feeling was that one made up a mix, looked at it, and if it looked right then one used it. If that were so, the issue should not be confused by introducing a number of figures which people could not follow, because the mix used was not one which gave the highest stability nor the highest density.

59. In § 10 reference was made to the sand/cement kerb, and it would be interesting to know its cost. If it had been omitted and a soil/cement base used, how much extra width could have been put in for the same price?

60. All too little reference was made to the difficulties of measuring binder content in hot climates. The hot extraction test which was usually used could be very difficult. It was slow and the filtering which was necessary could take a long time, which meant that one did not obtain a result in time to be useful. Another factor which led to difficulty was that very often there was moisture present, possibly due to condensation overnight, and moisture present in the extractor could give the wrong result. Fig. 14 showed some apparatus which one of his colleagues rigged up in order to try and get over the question of filtering the sample to obtain binder content. The filter thimble in a glass bottle was available, but it did not work and the apparatus shown was contrived, using a discharged oil filter with the thimble inside it. Air pressure was exerted on the outside, forcing the bitumen solution through the thimble into the glass jar for final recovery.

61. The apparatus was not without its difficulties, and occasionally the tube would blow off and someone would get an eye full of solvent. For that reason a small prototype apparatus had been developed using a manually operated centrifuge.

62. Before leaving the question of bitumen recoveries, Mr Williams emphasized the fact that most binder solvents were toxic, and on going into field laboratories,

FIG. 14: FILTER APPARATUS

especially overseas, one often found that ventilation was bad. When dealing with binder recoveries it was necessary to keep draughts out, therefore windows had to be kept shut, and there were generally no fume cupboards. In dealing with binder recoveries it was necessary to provide a fume cupboard and a well-ventilated place in which to work.

63. With regard to § 36, it would be interesting to know why 80/100 bitumen was specified for the surface dressing instead of heavy cut-back, which would have made spraying easier.

64. In § 37 reference was made to the improvement in stability of a sand mix with the addition of surface dressing. That was certainly a fact, and it was doubtful whether it could be explained purely by the difference in temperature. In the experimental sections the temperature—both without surface dressing and with surface dressing—was measured, and the increase in stability was more than could be accounted for purely by a change in temperature. One of the main causes of increase in stability, in his opinion, was the rough underside of the surface dressing. When the mix was squeezed between this rough surface and the base, there would be a greater edge effect which would resist flow and so prevent deformation.

65. With reference to § 41, he agreed with Mr Grace that the failures were not sufficient to cause alarm. However, he had no objection to the term 'failure'.

66. So far as the subgrade was concerned, Mr Grace's explanation might well be the correct one, but Mr Williams said he wanted to suggest another explanation.

67. In the rainy season the water flowed over the edge of the road; some went inside the concrete kerb and most of it went into the sand immediately at the edge. That meant there was a concentration of water in the soil immediately at the edge of the road. If one considered the compaction curve of the sand down below in the subgrade, it started off at a point well on the dry side of, and above, the compaction curve. When it was flooded with water, its moisture content increased so that it was below the curve and the effort of the traffic could compact it. That might well be the explanation of the failure rather than the effect of the vibrating plate and the soil falling down.

68. In § 44 the Authors referred to the ravages of ants. On the experimental section an effort was made to get a long length prepared so that experimental bases could be constructed. To prevent the surface of the section drying out, polythene sheet was placed over the formation once it had been prepared, to keep it in this state until it was wanted. Unfortunately white ants decided otherwise. They had taken a large chunk out of the polythene sheet, and their runs underneath the polythene sheet spoil the good surface that was wanted. However, once the road was constructed there did not seem to be any trouble from white ants.

69. The other type of ant was the black harvester ant, and they had made a hole right through 5 in. of the bitumen/sand mix, and had brought up the sand from underneath. Similar trouble also occurred on sections which had been surface dressed. On the two short soil/cement stabilized sections there appeared to be no trouble from ants.

70. In § 46 the Authors referred to the experimental sections. They were different from the main experiment in that they were cold mixes, whereas the main contract was hot mix. In the experimental sections an endeavour was made to see how low a bitumen content could be used with the idea of making the bitumen/sand mix competitive with soil/cement. It was also desired to see whether the sand could be used at ambient air temperatures. Initially laboratory tests had suggested that one might go down as low as $1\frac{1}{2}\%$ of binder, but the mixing was done with a spatula in a saucepan. Actually on the job it was possible to go down to $1\frac{1}{2}\%$ on one section, but Mr Williams became so frightened at the look of it that he took up two-thirds of the section. However, it was interesting when considering the inspection reports $2\frac{1}{2}$ years after laying to see from Fig. 15 that section 1A which was $1\frac{1}{2}\%$ was very good; Section 2, 2% , was very good; Section 3, $2\frac{1}{2}\%$, was good; Section 4, 3% was fairly good, and Section 5, 4% was fairly good.

2½ in. thickness—200/300 sec at 25°C cutback						
Section No.	1A	2	3	4	1	
Binder content (per cent)	1½	2	2½	3	4	(d) indicates slight deformation
Condition	Very good	Very good	Good (d)	Fairly good (d)	Fair (d)	

4 in. thickness—200/300 sec at 25°C cutback							
Section No.	5	6	7	8	9	10	11
Binder content (per cent)	2	2½	3	3½	4½	4½	4½
	2	2½	3	3½	1½	2	2½
Condition	Very good	Very good	Very good	Good (d)	Good	Good (d)	Good (d)

4 in. thickness—100/150 sec at 40°C cutback				
Section No.	16	17	18	19
Binder content (per cent)	3	4	5	3½
	3	4	5	3½
Condition	Very good	Very good	Very good	Very good

Upper 2 in.
Lower 2 in.

Condition of sections three years after laying in 1960
FIG. 15: FULL SCALE EXPERIMENT WITH BITUMEN/SAND MIXES

71. That was in keeping with the results obtained from the Hubbard Field Test. Assuming the same density, stability tended to decrease as binder content increased. The experiments showed that for light traffic, provided the mixes were compacted, a low binder content could be used, because they gave the stability required in the base; wear on the surface was taken by the surface dressing. Much the same picture was given by the sections made with 200 to 300 second cutback, the higher binder contents showing more deformation. With heavier cutback still, all the sections were very good. The experiment was interesting because it showed that one could go down to low binder contents provided a surface dressing was applied to take the wear.

Mr H. H. Campbell (Bitumen Engineer, Shell International Petroleum Co.) said that unfortunately his colleague, Mr Edwards, who helped in the supervision of this particular road work was unable to be present, because he was in another developing country supervising a similar type of work.

73. Probably the greatest value of the Paper was its highlighting of road work in developing countries, which was refreshing in present times when motorways were receiving such prominence. After all, a far larger proportion of the world's roads remaining to be constructed was in developing countries and the methods evolved merited equally wide professional publicity. The Paper showed that professional advice was still greatly valued abroad, and there was great scope for the engineering profession to help in the development of what one might call low-cost road surfacing.

74. The use of an 80/100 penetration bitumen for surface dressing was questioned. One would imagine that the reason was one of costing; on that particular road 80/100 penetration bitumen was available from bulk sources, and therefore in order to keep costs down as well as maintain only one grade on site, it was probably preferred to use it for surfacing as well.

75. On the question of failures, the value of publicizing them was well-known. The Institution often invited papers on failures, so it should not be felt that reference to failures in one paragraph of a particular paper need give a wrong impression.

76. The problem of weeds and ants had always to be reckoned with in asphalt surfacing. The ants were probably deep down in the subgrade and it was impossible to remove them; but when dealing with asphalt surfacing, weeds could not be overlooked and it was important always to remove them first.

77. With regard to the question of stability, there was probably more to it than just stability when one was dealing with a sand mix. Although in a bitumen/sand mix one tended to have a low binder content in order to get stability, it was also necessary to have sufficient bitumen to coat the grains of sand. It might therefore be necessary to use more bitumen than that required for maximum mix stability. However, if the binder content was increased unduly, there would be a tendency to get lubrication and therefore a reduction in stability. Provided one had sufficient to coat the grains of sand then the job was done.

The Chairman (Sir James Farquharson) said he had spent some years in the Sudan where the phenomenon of sand ridges on a clay plain was common. On reading the Paper he was amazed to find that the sand ridge on which the carpet could be laid ran from Maiduguri to Bama directly. It would be interesting to know what would have happened if the ridge had run the other way, and the Authors had found it necessary to build a road across the clay plain. What would have been the difference in cost?

The following contributions were received in writing:

Dr C. C. Agbim (Lecturer in Engineering, University of Lagos, Nigeria) wrote that Nigeria's network of roads consisted of about 6500 miles of Federal highways, 7000 miles of Regional highways, and over 17 000 miles of minor highways maintained by various local authorities.

80. Over a large part of the country, the traditional medium of base-course construction was rock laterite—a brownish to red metamorphosed material composed of sands, gravels, and clay in addition to the oxides of titanium, silicon, aluminium, and iron in varying proportions. This material, which appeared to be distributed in the tropical belt of the world, showed large variations, due to composition and varying degrees of laterization. In a typical construction in Nigeria, the prepared subgrade was pitched with rock laterite of 9 in. size and blinded with gravel laterite. Bituminous seal was applied on most major roads.

81. Other forms of construction had been attempted, but to a very limited extent. These included stabilization in soil/cement (Port-Harcourt and Western Avenue Lagos) and the construction of rigid pavement in concrete (Central Lagos and University of Lagos approach road). The construction of the 42-mile Maiduguri to Bama road in bitumen-stabilized sands added a new dimension to the country's road construction methods.

82. This project showed a number of interesting features. Apparently, the stabilization with lime might have been ruled out on account of the high price of imported lime and the rather low hydroxide content of the local manufacture. However, was the alternative of stabilization with cement considered? If so, was the availability of water for mixing and curing a deciding factor?

83. With relatively cheap local labour, haunches were usually cast against shutters. It would be useful to know the relative economy of an automatic curb-laying machine such as was used in this project. In addition, was it possible that the rather low standards reported in obtaining the correct road finished levels could be attributable, at least in part, to a variable *in situ* slump of the extruded haunch?

84. Long delays were usually associated with machinery requisitions. It did appear however that in this project a wide range of equipment was available, and in some cases various pieces of machinery were tried until best results were achieved. Was the contract time sufficiently flexible to accommodate these delays, or was it prearranged to have these alternatives available on the site during construction?

85. A number of failures due to the undermining of the subgrade by surface water had been reported in the interval between the construction of a highway and the provision of adequate drains. Where such problems from surface water were likely to be serious, and this was nearly always so with each tropical downpour, the road construction should be followed up, if not preceded by the provision of some form of suitable drainage.

86. A high standard of supervision appeared to have been maintained. It was also interesting to note that the road-laying machine was adaptable to the construction of rigid pavements. No doubt, the performance of this road would influence the road construction policy in this part of the country.

87. The execution of the contract at a price of £12 700 per mile was impressive, considering the rather difficult site conditions, and the relative novelty of this form of construction in Nigeria.

Mr H. S. Bhatia (Senior Materials Engineer, Ghana) said that the Authors had done well in putting forward some very interesting data on the construction of a road using sand/bitumen, under tropical conditions. The work on soil/bitumen mixes for road construction was still in a stage of infancy and the Authors would do well in bringing forward another paper later, dealing with the general behaviour of this pavement under traffic.

89. Firstly, he would like to ask the Authors why 25/75 sand mix was preferred over 50/50 mix, though the latter gave rather higher densities and better stability values. In his opinion 50/50 mix might have had a better grading which could be responsible for higher density as well as the stability of the mix. It would have been helpful if the final gradings of all the three mixes were given. Further it was considered that if a mix could have a low plasticity such as a Plasticity Index of 4–6, the stability values

would have increased considerably for the sand/bitumen content. It was, however, not known whether there was any possibility of getting a clayey material on the site.

90. On p. 3, the Authors showed that moisture played an important role in the compaction of the mixes. Would the Authors suggest what moistures were used in the field mixes and was it possible to maintain those moistures at the time of compaction, due to the fact that hot process was used for laying the pavement?

91. Could the Authors also suggest what minimum Hubbard's Field Stability Values were considered satisfactory for sand/bitumen mixes used under tropical conditions? It would have been helpful if C.B.R. values of a few of the sand/bitumen mixes had also been determined for purposes of comparison. The C.B.R. values were better understood by the field engineers for making an assessment of the quality of pavement materials.

The Authors, in reply, thanked Mr Grace for his remarks and referred to his comment on the deformations or failures. They were inclined to the view that something could be referred to as a failure if it deformed beyond one's own specification. There were very few failures in which material had to be removed, but there were in fact two which were traced to shortage of bitumen. Neither was more than a few yards square, but in each case it had to be taken out and replaced. This would definitely fall within the definition of 'failure'.

93. It was kind of Mr Grace to comment on the riding surface. Five years after the construction of the first stretches of the road, it was probably still the best riding surface in Northern Nigeria. It was a matter of interest that the resident engineer had made an inaugural run of 42 miles in just over 33 minutes!

94. With regard to Mr Williams' comments, it would certainly seem that soil/cement should be cheaper. The ruling price of bitumen in Maiduguri at the time of the contract was £40 per ton. The price of cement was £20 per ton. The percentage was the same. The answer lay in the make-up of the tenders. Three alternative specifications were included in the tender document. These were:

- (i) cement-stabilized base and double surface dressing of bitumen and gravel;
- (ii) cold mix bituminous stabilized base and single surface dressing;
- (iii) hot mix bituminous stabilized base and single surface dressing.

In every case tenderers offered the hot mix base at the lowest price.

95. It was interesting that the proposed road from Maiduguri to Lake Chad was to be constructed of soil/cement. It was doubtful whether bitumen would have been used in the case under discussion, but for the fact that it was cheaper, and the Government required economy. However, having used it, there was no doubt that it had made a very satisfactory road. There were difficulties with soil/cement in arid hot areas, and getting a good surface finish was one of them. Probably one of the worst areas of surface finish on the road was the soil/cement experimental section!

96. The sand/cement kerb was in fact a deep haunch extending well into the sub-grade and its prime purpose was to contain the subgrade. The Authors would in fact have retained it in the event of a cement-stabilized pavement having been built. The haunch was probably up to twice the cost of a cubic yard of cement-stabilized base and an extra 6 inches of width on either side might have been provided by doing away with the top 6 inches of haunch and substituting the cement-stabilized base. There are arguments for and against the adoption of this procedure depending on the circumstances.

97. A debt of gratitude was certainly owed to the Road Research Laboratory for their modifications to the cold extractor. An improvised piece of apparatus was used until the end of the job and it was found to be very successful. No doubt it contributed greatly to the sanity of the Soils Engineer who failed to make conventional apparatus work at all.

98. Concerning the use of 80/100 bitumen for surface dressing, the use of only

one grade on site meant that the Contractor need have only one bitumen heater and the distributor could be filled from this as required. The Authors felt, however, that the use of a bitumen of this grade for surface dressing in tropical countries had very great advantages and the quality of the surface five years after laying would seem to support this view. Using 80/100 bitumen, operations had to be organized so that there was a minimum delay in placing the stone after spraying. If this rule was observed a high quality dressing was obtained. The use of a cutback might conceivably have had an adverse effect on the stability of the base.

99. The Authors admitted the indefinite nature of the Hubbard Field results. They had stated that the test was indicative only and carried out under difficult circumstances. The mix chosen showed acceptable values of stability at the Hubbard Field density.

100. The Authors thanked Mr. Campbell for his comments and stressed the need for adequate binder content in the base. A road had to survive for many years.

101. The Chairman's comment was appreciated. Perhaps it was the luck of the Irish. The cost of a mile or road across the clay plain could be three to four times that of a mile of the Maiduguri-Bama Road.

102. In reply to Dr Agbin the Authors emphasized that the original intention had been to construct the road with a soil/cement base. Lime was ruled out on account of its high price and because the materials available along the road were non-plastic. However, there was at the time a large quantity of bitumen available and the alternative specification had been included. A possible shortage of water for construction purposes had been in mind when so doing.

103. It was the Authors' view that the production of a haunch by the kerb-laying machine was more economical and faster than the conventional methods. The difficulty in getting the correct levels was due more to the lack of compaction and levelling in the trench.

104. The compaction equipment on site at the beginning of the contract was standard contractor plant. There were rubber-tyred rollers of 8-10 tons weight, steel-tyred rollers, a vibrating roller and tractor. Experiments were made with all of these. The 25-ton pneumatic roller was ordered by the Contractor when he realized that his compaction plant was not sufficiently heavy. During the period of waiting for this to arrive, surface dressing was suspended as the base course could not be brought to full density with the available equipment. The arrears were soon made up and the surface dressing was completed in good time. The Authors thanked Mr Agbin for his general comments and sound advice on drainage.

105. Mr Bhatia raised several questions of a technical nature to which the Authors would reply as far as they were able. They agreed that information on the future performance of the road should be obtained and published. Mr Williams had this in hand on the experimental sections.

106. The Authors agreed that the Hubbard Field Test results were somewhat inconclusive but the 25/75 mix gave acceptable stability values at or near the likely field density. Mr Melville had some doubts about the other mixes at similar densities. Clayey materials were not readily available.

107. On the question of moisture, the Authors would like to look into the records of the job and see what information was available.

108. The Authors suggest a minimum Hubbard Field Stability Value of 1000 lb for a sand/bitumen base under circumstances similar to those relating to the Maiduguri-Bama Road.

109. C.B.R. values were obtained on the original laboratory mixes at various densities. The C.B.R. values at a density corresponding to the average base course density of 120.2 lb/cu. ft varied between 83 and 140 for curing periods of 1 day and 4 days respectively.