

Coral as an aircraft pavement material—case histories

C. Stevens and B. G. Verrall

Mr D. Newill, *Transport and Road Research Laboratory*

Few papers have been published on the use of coral as a construction material, either for roads or airfield pavements. This Paper, therefore, which deals with the formation and properties of coral as well as its performance in an airfield pavement, is a valuable addition to available information. It is also relevant to many other coral islands in the region.

71. As a member of the team involved in the field work it was clear that considerable thought had to be given to the equipment that could be taken to such a remote location. A simple dynamic cone penetrometer which was initially correlated with the California bearing ratio proved to be extremely useful in obtaining information about the strength and thickness of the layers of the airfield pavement.

72. When dealing with coral, especially the detrital material described as lagoon mud, problems arise in carrying out laboratory tests because of the weakness of coarser particles. Their breakdown makes it difficult to determine the particle size distribution. This also affects the density during compaction. In practice this means that the use of heavy rollers or grid rollers are important to achieve high densities and high strengths. It is notable that during the field work described in the Paper the compaction trials were carried out with a relatively light roller weighing 7.5 tonnes.

73. Coralline materials are often referred to as self-cementing which results in an increase in strength with time. This has often been referred to in papers describing the behaviour of coral used in airfield construction in the Pacific region during the Second World War. There was no evidence to support self-cementation during this investigation, as samples taken from parts of the runway which were believed to have been constructed more than 40 years ago completely disintegrated when immersed in water.

74. A final point to consider in constructing airfields of this type is the suitability of using surface dressing as a seal for the pavement. A coarse surface texture is likely to be prone to damage by heavy aircraft especially in turning areas where stone loss may be high. A smoother surface with a final sand seal layer may be desirable.

Mr G. Austin, *Consultant, formerly British Airports Services*

Generally surface dressings using 3 mm clippings do not cause problems with jet aircraft, and the simple application of a deflector plate to the nosewheel may solve any problems that there might be with larger stone sizes. I have been involved with laterite airstrips in Africa where Boeing 737s with deflector plates are the usual type of aircraft operating off those strips.

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76. Surface dressing was a standard method of sealing aircraft pavements in the 1950s. This was cheap and easy to prepare, apply and maintain. It went out of favour when reverse thrust propeller aircraft came into existence. The reversing of the thrust on the propeller sucked into the propeller the loose stone arisings which could be thrown up by the aircraft wheels, greatly damaging aircraft propellers.

77. Recently I have successfully re-introduced runway surface dressing at Kirkwall using a 3 mm pre-coated chip. One must not continue to write off surface dressing as a surfacing for runways: it is very good, it is very cheap and very suitable in many cases.

78. British Airports have recently used the dynamic cone penetrometer extensively on evaluation of the south runway at Heathrow which is to be resurfaced in 1989. Fifty or sixty boreholes have been tested with the dynamic probe tester at the same time as carrying out some 900 FWD tests.

79. Concerning rutting of the Tarawa pavement, I would suggest possible densification of the materials under the wheel tracks, and I would be interested to know whether or not the Authors took core samples from the rutted areas and the non-trafficked areas to compare densities.

80. In 1984 I went to Barbados and spent almost five weeks there doing an investigation on the runway at Grantley Adams International Airport. As part of that investigation I carried out a thorough investigation of the materials and resources on the island itself. It is a most interesting geological structure as a coral island, not formed in the way of Tarawa coral atoll. The main core of Barbados is very old and very hard limestone which came up with the plates from the ooze at the bottom of the Atlantic Ocean, around the core of which various terraces of corals have formed. There are three main terraces: the lower reef terrace, the middle reef terrace and the upper reef terrace. These terraces are formed in an eggshell-type structure. These shells can be either 50 to 60 or 100 feet thick or in other places thin with very soft corals beneath.

81. One of the problems in Barbados was that the existing asphalt surfacing on the runway was deforming very badly and there were serious slippage cracks. After analysing cores and taking samples, we concluded that these problems were primarily related to the use of soft coral aggregates. The hard eggshell of the coral was too hard and attritious for the island's contractors to process through their crushing plants. The harder shell was ripped and discarded, the soft coral only being crushed for aggregates, both for concrete and for so-called marshall asphalt. Binder contents varied from about 7% to 11½%, although the laboratory maintained that it was MPBW Specification 201 marshall asphalt. Also, there was an extremely high filler content, i.e. passing 75 microns, from 6% to 18%. This was partially in the as-supplied aggregates, but also a tremendous amount came from attrition in the drier of the mixer drum.

82. A pavement is not complete without properly designed and laid impervious and textured surfacing on it, i.e. grooved or frictioned marshall asphalt or brushed concrete. In my experience in Barbados, the grading of the marshall asphalt being used was too fine, and there was an excess of filler. Add poor compaction with inadequate surface preparation and a smooth surface with low durability results.

83. The role of filler material in a marshall asphalt is complex but critical: it reduces the quantity of voids and increases the stability of the mix. Nevertheless there is a limit to the filler content before adverse effects result. This is usually not more than 5%. If one is going to use coral aggregates in marshall asphalts or any

bituminous surfacing, one must reduce the filler size material inherent in the aggregates when it is won, by sieving. Furthermore, one must reduce or allow for filler increase due to attrition in the heating drum of the mixing machine. Possibly there is a role here for cold asphalt mixes where there can be little or no attrition in the drying only mixer drum.

84. Another possibility, if one needs to use hot mixes, is to introduce some silicious or cementitious material mixture into the aggregate to seal and reduce its porosity, and also give it some coating strength before it goes through the drum.

85. Certainly grading and filler quantities are particular problems with soft corals when talking about asphaltic materials and producing a stable surfacing. As it is difficult to take large mixing and laying machinery to remote island locations, cold asphalt mixes do lend themselves very readily to that situation. Thin asphalt surfaces with some element of man-made fibrous reinforcement could form a very useful capping to the materials the Authors have described, from strengthening, waterproofing and operational surface points of view.

Mr R. D. Nutt, *Brian Colquhoun and Partners*

I was asked to look at a land-based air system for the Ellice Islands, Tuvalu, which comprise eight small islands. The capital of Tuvalu, the island of Funafuti, has a runway of about 1600 feet, which was built by the Americans in 1943. The runway dominates the island which is flanked by the Pacific Ocean and a lagoon.

87. Possible locations for runways on other islands like Vaitupu show that they could probably be 800 meters long. There is not much room on any of the islands to put an airstrip, which was one of the issues we were to look at. The lengths of coral shore are short, and so material is limited. Moreover, if too much sand or coral is taken away the 12 foot high waves cannot be broken down.

88. A cross-section shows that the islands are flat, going to the edge where there are palm trees with a little bit of coral or sand, before rapidly going down to the ocean bed. But there is only 15 meters, so there is not very much material. Where the lagoons have been blasted the coral is about 6 feet deep, much of it fairly large boulders and extremely hard.

89. Where identification is possible, all the islands in Tuvalu appear to have a rising and falling water table, and in fact one of the problems at Funafuti is that in certain conditions there is a much higher water table. The runway is made out of crushed coral from what is now the mango swamp. I wonder what would have happened if any depth of mud had been used in Tuvalu—and the mud was looked at where there were lagoons—in relation to where mud had been dug out of the Gilbert Islands and had disintegrated. There are some fascinating things to be learnt there and I do not think much is really known about the property of these materials. The project on Tuvalu was not a total property exercise. Not only were materials being sought to build the strips, should the government decide to build them, but the economics of operating a land-based air system had to be looked at. In fact it would never have made any money and would have been a severe draw on their total wealth.

G. R. Woodman, *PSA Airfields Branch*

Although there has been plenty of evidence since the 1940s that coral behaves very well in pavements, there has been little hard data published on the subject, and this Paper provides far more than most previous ones.

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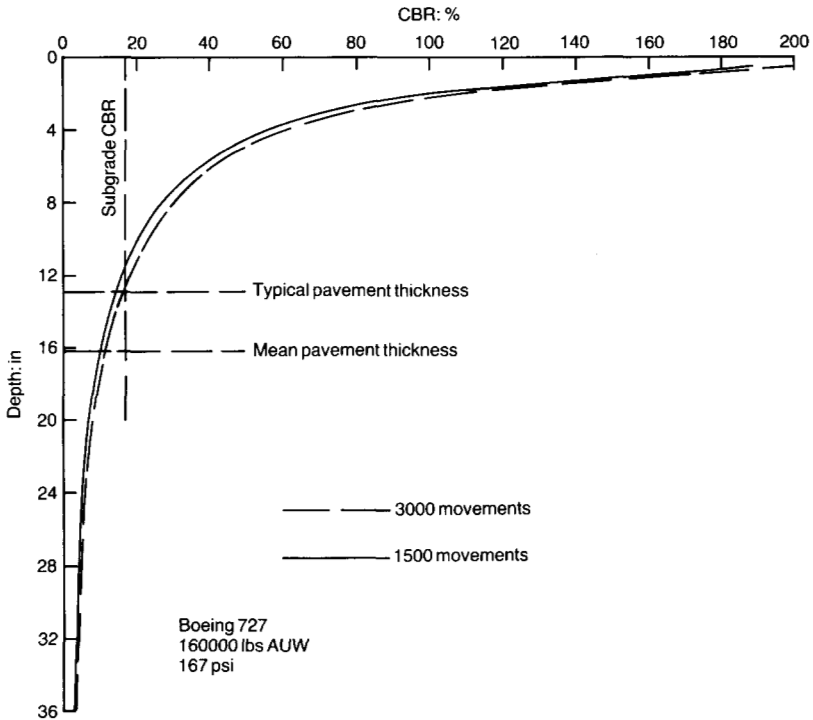


Fig. 9. CBR requirements: USACE CBR equation

91. PSA Airfields Branch has taken the analysis one stage further than the Authors and examined the effect of the overload aircraft, the Boeing 727. The US Army Corps of Engineers' CBR Equation¹⁶ has been used as it is the basis of flexible pavement design in the current FAA and PSA design guides.

92. In Fig. 9 curves of CBR requirement against depth are drawn for the Boeing 727. Two levels of trafficking are shown, 1500 and 3000 movements (within the life of the pavement), which should cover the range experienced at Bonriki. There is a reasonably close match between the CBR requirements and the typical pavement thickness (311 mm) and subgrade CBR (17%). This suggests that the pavement should have failed under the 727 movements, if the coral materials are equivalent to conventional unbound bases and sub-bases.

93. However, the typical thickness and subgrade CBR are the mean minus one standard deviation of the test results. If the two variables are independent (and they may not be) about 70% of the pavement area should be stronger than the strength calculated from the typical values. In practice significant rutting had occurred over 50% of the pavement length. In addition, the appropriate failure criterion in the CBR equation is one inch of heave, due to shear failure of the subgrade. The Authors report that no heave had occurred. The proportion of the pavement which had rutted and the lack of heave suggest that the rutting is not due to shear failure of the subgrade. The shape of the rut and the low subgrade

densities recorded (as low as 80% of the base course density) indicate that the rutting was probably caused by densification of the subgrade. The FAA design method requires a relative compaction of 95% modified AASHTO density to a depth of 600 mm below formation. Even if coral behaves differently to other unbound pavement materials and subgrades it is unlikely that the subgrade at Bonriki has an adequate relative compaction.

94. The FAA (or any other) design method does not take account of material density but relies on the achievement of adequate densities during construction. Even after overlaying, if the relative compactions of the existing pavement and subgrade are inadequate for the aircraft loading further deformation may take place for the same reason.

95. The Authors state that an equivalency factor between the coral base material and bituminous surfacing was derived from the test results. It would be interesting to know what the factor was, and how it was obtained.

Mr B. Dolton, Senior Engineering Adviser, ODA

Before ODA commissioned the Tarawa study, it was believed that the results would have application elsewhere. I would be interested in any evidence of this.

97. My second question is in relation to the material arising in Papua New Guinea, with which comparisons have been drawn. I wonder whether the material was a recent marine coral or whether it would have been ancient coral, which might have been buried and uplifted, and so would have changed substantially in property. Such coral-derived material is used in other Pacific islands, typically Vanuatu, which is of volcanic origin very much like Papua New Guinea. The coral material used there is quite different from that in Tarawa, most markedly in its plastic content.

98. The Authors described, and I have seen demonstrated at the airport itself, some particle breakdown during compaction. Were any tests done at the time, and does your Paper record tests which demonstrate the change in particle distribution before and after compaction?

99. Was the tyre wear experienced at Bonriki that which might be expected from a surface dressing using coral-derived aggregate, or was it simply due to the very high roughness of Bonriki?

100. I think that the Paper might have made more reference to the secondary benefit of this investigation, which was the establishment of the dynamic cone penetrometer as a very valuable testing tool amongst European consultants.

101. Unsealed coral pavements may take on a grey appearance which is very smooth and almost like concrete. Hence, the authors of wartime papers can be forgiven for attributing some cementitious property to the material. As far as they were concerned, within a short time of the trafficking, an unsealed pavement layer constructed with lagoon mud formed this tightly knit, concrete-like polished surface.

Mr Stevens and Mr Verrall

Referring to *Mr Newill's* first point concerning compaction plant, the Authors entirely agree with the point he has made. The use of the limiting 7.5 t steel roller and the 12.5 t rubber tyred roller were due to the fact that they were the available plant on the island. Much heavier rollers (about 20 or 30 t for the most part) were used in previous work during war time, in the 1973 pavement thickening at Bonriki, and also in the work at Christmas Island. The work also included experi-

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ments with vibrating rollers and sheep's foot rollers although generally they were smooth steel rollers. The Authors' objective was to demonstrate, using the existing rollers, that adequate CBRs could be achieved. That was as far as it was possible to go, but the Authors would entirely agree that the use of heavier rollers would be essential during construction and that there would have to be a period of trials with those rollers to determine the number of passes, to ascertain the appropriate moisture contents for those levels of compaction, and to demonstrate that the resulting material had adequate properties.

103. Concerning *Mr Newill's* point about surface dressings, in the final report to the client the Authors put forward various options for pavement development in reaction to certain scenarios for the development of air traffic in the region. The traffic forecast showed only limited potential for traffic development, and the air traffic scenarios which were considered most likely were not very different from the existing traffic pattern of one or two 737 movements a week. Options with larger aircraft were considered and the Authors have since been asked to look into the implications of use of the airport as an alternative for the 767 operations across the Pacific, but again it would be quite infrequent aircraft movements.

104. For these traffic scenarios, the surface dressing appears to provide an appropriate seal coat for the surface of the runway. The Authors' tests showed that it protected the lagoon mud from penetration by rainwater, and provides an excellent surfacing in terms of coefficient of friction.

105. In terms of alternatives to the surface dressings, one option which does exist and which was included as a maintenance activity for the surface dressing, particularly with the larger aircraft which were considered, was the application on top of the surfacing dressing from time to time of a mixture of crusher-run and bitumen emulsion. This had been done at the airport previously by the local public works department and had been very successful.

106. *Mr Austin* referred to the attachment of deflector plates to the nosewheel of B737 aircraft and it can be confirmed that the B737s that have been operating in and out of Bonriki have been specially equipped with nosewheel deflector plates and special thick paint coatings on the fuselage to minimize the damage occurring to the aircraft from stone chips.

107. *Mr Austin* queries whether core samples were taken from rutted and non-rutted areas to compare densities. The Authors did not take core samples, and believe that the lagoon mud probably could not be satisfactorily cored, but use was made of some density tests recorded in trial pits taken by a previous study by consultants Sir William Halcrow & Partners a few years earlier, about 1978-80. There were a number of trial pits put down both in the wheel track and on the edge of the pavement there. Photographs at that time and also some site levelling that was done and given in their report indicates that rutting was in evidence and the densities show no difference between the wheel track and the edge of the pavement, neither for the upper layer of lagoon mud constructed by the New Zealanders in 1973-74 nor the lower layer of lagoon mud, nor the subgrade.

108. *Mr Austin's* description of the geological structure of Barbados and the different structure at Tarawa Atoll helps to emphasize the point made in the conclusions to the Paper that a fuller description of the location and nature of deposits reported in case histories is needed in order to advance understanding of the engineering properties of coral materials.

109. *Mr Austin* has suggested that a pavement is not complete without a marshall asphalt or brushed concrete surfacing. At Tarawa the choice of surface

dressings is very largely controlled by availability of materials for concrete aggregate, and it is not thought possible to exaggerate the difficulties of winning good quality aggregates on the island. Blasting of the reefs has been carried out on Tarawa and on several of the other islands and the consequences have been quite dire. Not immediately but over a period of years, large areas of island have been washed away in storms.

110. There are also land ownership difficulties such that when this study was carried out the cost of acquiring the lengths of coral reef, which are used for fishery and also are passed down from family to family, meant that the cost of the aggregate was comparable with the cost of importing it 2000 miles after winning it as a hard aggregate from the mainland. That controlled, and it is thought always will control, thinking on aggregate availability at least in Tarawa and in the Gilberts Group.

111. One point that should also be recalled when considering the serviceability of the runway at Bonriki Airport is that the island has been well served by this airport in its existing situation since 1973-74 when it was overlaid and surface dressed. Since the Authors' study in 1984, the B737 operations have continued and there have been verbal reports from regular visitors to the island that there has been no further visible deterioration in the condition of the runway. The surface dressed lagoon mud is providing the nation of Kiribati with a very serviceable pavement indeed. If the runway were overlaid with marshall asphalt or concrete it would be a severe drain on their resources for aggregate on the island to provide that layer.

112. *Mr Nutt* outlined the nature of the coral materials available on the Ellice Islands. The situation on Tarawa Atoll was probably the same as at the Ellice Islands, except that in the case described by *Mr Nutt* the material had been thrown up by a recent storm. That had not happened recently on Tarawa so the material was the eroded products of such events in the past. These consist of a mixture of dense coral, which was mainly derived from the outer reef, and individual pieces of very porous coral, which make poor aggregate, and which were derived from broken off branches of individual branched corals. The latter are in the minority on the reef. The majority of the corals are massive brain-type corals.

113. During the discussion the *Chairman* noted that if the lagoon mud material cannot be re-compacted then patch repair must be rather difficult, the edges of the new and the old material being very difficult to merge. In response the Authors would comment that there is not in practice a difficulty providing that one does not attempt to re-use existing material. One would cut out for the repair patches, to give a stepped profile through the existing pavement and then re-compact with fresh material, taken straight from the lagoon into the compacted area. All of the excavated material would be discarded so that there was no recompaction of any material which had previously been compacted. It would appear from the existing repairs that a very good bond is formed between the old and the new lagoon muds. In this situation recompaction means scarification, loosening, reducing to a granular material and re-compacting back into an interlocking material. It does not mean re-passage of the compaction plant over an already compacted material. That does not have any adverse effect.

114. *Mr Woodman* considered that densification of the subgrade is a probable cause of the rutting. It is acknowledged that, in a situation such as at Bonriki where the subgrade compaction as constructed may not have been up to modern standards, the subgrade may densify further each time that regular services are

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introduced by aircraft which are heavier than those which have previously used the airport. However, this is not considered to be necessarily the case at Bonriki Airport. The following comments are made on Mr G. R. Woodman's points and some further points are made which support this contention.

115. The reference by Mr Woodman to significant rutting having occurred over 50% of the pavement length is reasonably correct. However, a comparison with the statistically derived implication that about 70% of the pavement should be stronger than the strength calculated from the typical values, should not be made without incorporating the significant effect of the traffic history of each section of the runway. The eastern third of the runway length is relatively infrequently trafficked since most movements are on Runway 09 and landing aircraft turn at about chainage 1 + 400 and backtrack. The most significant rutting is in the most frequently trafficked length of runway.

116. Use of the mean less one standard deviation when assessing subgrade CBR values for design purposes is recommended by the FAA pavement design advisory circular as being common paving engineering practice. The Authors' evaluation is thus on the same basis as the design method and it is not surprising to see significant rutting over a large proportion of the trafficked runway length, given that the pavement has been shown to have been significantly overloaded according to back analysis by the same design method.

117. The comparison made by Mr Woodman between the subgrade and base-course densities, should be tempered by an awareness that the two materials have very different gradings. Also, despite the apparently low densities, in situ density tests conducted during previous studies,¹¹ at which time significant rutting was already evident, did not show any significant difference between the in situ density of the subgrade under the wheeltrack and that under the untrafficked outer third of the runway.

118. The pavement bearing capacity, evaluated by the Authors as PCN 20/F/A/Y/T is adequate for the usage (current in 1984) by B737 aircraft. Regular services by B737 aircraft have continued, and it is reported by visitors to the island that there has been no further noticeable deformation or other deterioration. It is a reasonable conclusion that, whether or not densification of the subgrade had occurred in the past, the current state of compaction of the subgrade is sufficient to bear the stresses and strains imposed on it by B737 movements without significant further densification.

119. A simplified analysis has been carried out using the method of equivalent thicknesses to calculate the vertical compressive stress on the subgrade formation underneath a B737 undercarriage. For the existing runway pavement the maximum stress is calculated to be 222 kN/m².

120. Not included in the Paper, but forming part of the 1985 report to the client, was the calculated typical pavement thickness which would be required to enable operations by B727 aircraft at the appropriate maximum take-off weight for the existing runway length. The pavement thickness required is 457 mm.

121. Analysis of this thicker pavement using the same method of equivalent thicknesses gives the maximum vertical compressive stress on the subgrade formation under the B727 undercarriage as 180 kN/m². This is less than that under the B737 on the existing runway, and it is concluded that there should not be significant further densification of the subgrade if operations are carried out by aircraft heavier than B737s such as B727s provided that the runway is overlaid in accordance with the recommendations.

122. In response to *Mr Bolton*, an attempt was made to carry out a very limited number of determinations of the particle size before and after compaction, but they were completely unsuccessful because of the enormous degree of variability of the material before compaction, which gave a very wide envelope. Hence it was very difficult to compare the envelope after compaction with that before. Furthermore, a great difficulty was the wet sieving of material which itself resulted in particle breakdown. There was difficulty in establishing a consistent test method.

123. It is believed that this illustrates the need for a more fundamental study of the engineering and other properties of the lagoon mud, and this was the reason that a direct route was taken from borrowing to compaction trials to pavement tests. Within the scope of the study there were neither the resources nor the time to carry out a large scale fundamental research of this sort (which would involve study of the properties of lagoon mud) and so it was necessary to go straight to field performance.

124. Clearly, with lagoon mud, if a good engineering knowledge of the material is to be obtained, the intermediate step of laboratory testing must be developed, and northern European and northern American soils criteria fail for lagoon mud in exactly the same way as they fail for many of the tropical red soils and other unusual materials round the world. Correlations, such as have been very successfully established for tropical red clays between in situ moisture content and field performance, need to be established afresh.

125. As an illustration of some of the odd properties of lagoon mud, take the observation that if lagoon mud is stored in a closed container it grows a mould, it becomes covered in fungus, and it also degrades giving a very foul smell. It is quite obvious that it has a very high organic content, and this may well play a part in the difficulties of compacting and wetting up a material which has over-dried.

126. On the point concerning surface dressing and tyre wear, it is the Authors' opinion that high levels of tyre wear would be found on any similar use of coral gravel in surface dressing. The very nature of the material is such that it will not polish off. It will never become a smooth stone. After a certain amount of wear there will still be the sharp coral edges as part of the texture of that stone.

127. Concerning the use of the dynamic cone penetrometer (DCP), the Authors were pleased to incorporate this test into the methodology. It allowed rapid extension of knowledge about the pavement. After the first few days it was found that a trained-up work gang of the local workers from the public works department had been created who were able to carry out DCP tests largely unsupervised. The data that the DCP gave were very informative.

Reference

16. TABOZA CEREIRA A. *Procedures for development of CBR design curves*. Soils and Pavements Laboratory, US Army Engineers' Waterways Experiment Station, Pittsburg, 1977, Instruction Report S-77-1.