Geotechnical aspects of road design in Libya

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SINCE 1973 Scott Wilson Kirkpatrick & Partners have been designing roads for the Ministry of Communications, Libya. At present a total length of some 2 300km of road has been, or is being, designed (see Fig. 1) and of this, more than 900km is out to contract. The roads generally have a 110km.p.h. design speed with a pavement width of 7.5m.

For a design programme of this magnitude, the geotechnical aspects have covered a wide range of problems typically associated with arid environments. This article describes some of them.

Geology and topography

Libya covers an area of about 1 600 000 square kilometres bordering the northern coast of Africa. It is crossed by three climatic zones; a mediterranean, a semi-desert, and a desert zone. The mediterranean zone has an annual rainfall as high as 600mm and a climate comparable to that of parts of southern Europe; southwards this rapidly gives way to intense desert conditions.

In western Libya, the alignments mostly cross a succession of horizontal or near horizontal bedded carbonate rocks ranging in age from Tertiary to Upper Cretaceous. In the north, the comparatively high annual rainfall (about 300mm) has produced a subdued landscape comprising rounded hills, undulating plateaux, and well developed residual soils. Progressing southwards, the harsher landscape (Fig. 2) is indicative of the rapid decrease in annual rainfall; hills and stepped plateaux become flat topped, capped by more resistant limestone strata; soils are poorly developed and contain increasing proportions of granular or wind blown material. Further south still, older Devonian and Cambrian sandstone formations outcrop and form a dissected stony desert (yardang), making movement by vehicle extremely difficult. Throughout most of the area, volcanic activity during the Tertiary has resulted in a number of isolated dyke swarms, basalt flows and volcanic necks.

By way of contrast, in eastern Libya, as shown in Fig. 3, much of the topography in the area of the alignments is characterised by a monotonous, flat, predominantly stony or sandy desert (serir). The underlying formations range from unconsolidated sands, shales and carbonate rocks of Tertiary age in the North, to Cretaceous sandstones in the area around Kufra. Intermediate outcrops of sandstone and shale of Devonian & Silurian age are found close to the route. Further south, large outcrops of Precambrian age occur near Uweinat. The greater part of the alignments are covered with superficial deposits of Quaternary sands and gravels.

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Terrain classification

A requirement of the client was the production of soil classification mapping at 1: 50 000 scale along the line of the proposed routes with trial pits at 5km (later 1km) intervals or at "every change in soil type". Whilst this was a satisfactory method of determining subgrade characteristics in the predominantly uniform landscape in eastern Libya, it was clearly unsatisfactory where the proposed alignment crossed widely differing terrain. Under these circumstances (such as along the Gharian-Brak road) the method of terrain classification was adopted.

Along the line of the proposed route, the terrain was classified into two basic categories, i.e. Land Systems and Land Facets (see Brink *et al*, 1966; Beavan & Lawrence, 1973). Briefly, a Land System is a pattern of land forms which have evolved under fairly uniform geological and climatic conditions, and are composed of similar topographical units. These units, known as Land Facets, are units of landscape which are reasonably homogeneous and fairly distinct from the surrounding terrain. Soils and materials developed on them are usually reasonably uniform. The units are an extension of the geomorphological divisions proposed by Fookes & Knill (1969).

Classification was carried out initially by aerial photographic interpretation using 1: 25 000 and 1: 40 000 scale stereo pairs. Land System and Land Facet boundaries were identified on a 4km band width along the proposed alignments and marked on transparent overlays. This information was then transferred and rationalised on overlays to 1: 50 000 scale controlled mosaics. Preliminary maps were produced, compared with the published geological data, checked in the field for accuracy, and revised as necessary.

For the route alignments in western Libya, a total of nine Land Systems and 18 Land Facets was identified. Table I shows the Land Facet designations and types. Experience gained on the first route in western Libya (Gharian-Brak) permitted accurate terrain classification mapping to be produced very rapidly for the remainder of the spur routes in that area once the aerial photography had been obtained. Fig. 4 shows an example of the mapping and Table II shows an example of the Land Facet descriptions.

In general, trial pitting along the alignment was carried out after the preliminary mapping was complete. In this way, the alignment could be reviewed, and pit positions could be located to give a more representative picture of the extent of the subgrade soils.

Pavement design

Trial pits were excavated by hand tools to 1m depth where possible and samples brought back to our laboratory in Tripoli for testing. As a minimum requirement, each sample was classified according to AASHTO Test M145. These test results were then carefully scrutinised and compared with their respective trial pit Land Facet designations. Bulk samples were then selected which were considered to give a realistic range of the predominant subgrade soils. These were tested for density (AASHTO T. 180 Method D) and California Bearing Ratio (AASHTO T. 193).

Investigations beneath two existing paved desert roads in Libya indicated that in general the in situ moisture contents were considerably less than optimum (Fig. 5). A limited CBR testing programme was undertaken to examine the effects of these low moisture contents. The results usually showed an increase in CBR value when either the sample was compacted 1 or 2% dry of optimum or when the sample was compacted at optimum and allowed to dry out to an "equilibrium" moisture content prior to testing. The results, however, were erratic, and it was decided to base the pavement design on CBR values obtained from samples compacted at optimum moisture content as representing the maximum subgrade moisture content condition that was likely to exist under the final pavement.

Design subgrade CBR values were evaluated in accordance with the Asphalt Institute method (1970) whereby the design subgrade strength is defined as the subgrade value that 90% of all CBR test values are equal to or greater than. However, in applying this method, the CBR

TABLE I. LAND FACET DESIGNATIONS AND TYPES

Land Facet Designation	Type
a.	Mesa/Garet
b.	Stepped plateau
c.	Rolling plateau/plain
d.	Undulating plateau
e.	Dissected plateau
f.	Weathered dissected plateau
g.	Wadi channel
h.	Desert plain (Serir)
j.	Desert plain (Yardang/ Dissected rock)
k.	Sand dunes
l.	Coarse piedmont
m.	Foot slope piedmont
n.	Alluvial fan
p.	High hills and ridges (Alps)
q.	Low ridges, cols, saddles and foothills
r.	Playa
s.	Salt Playa
t.	Alluvial plain

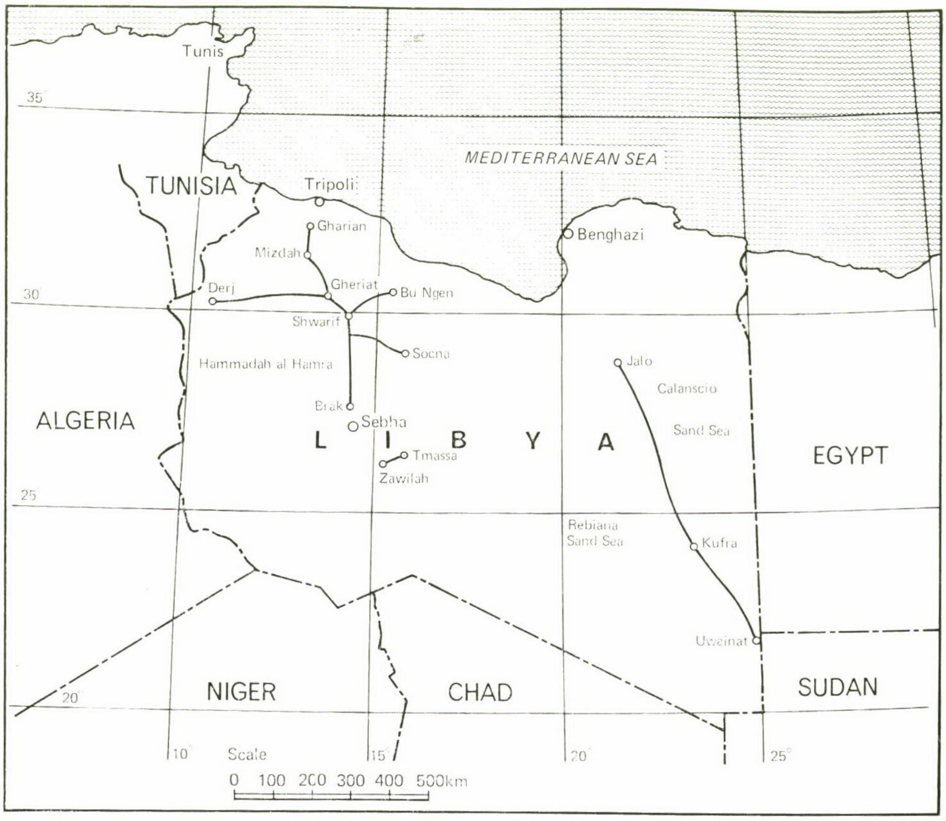

Fig. 1. Location of road alignments

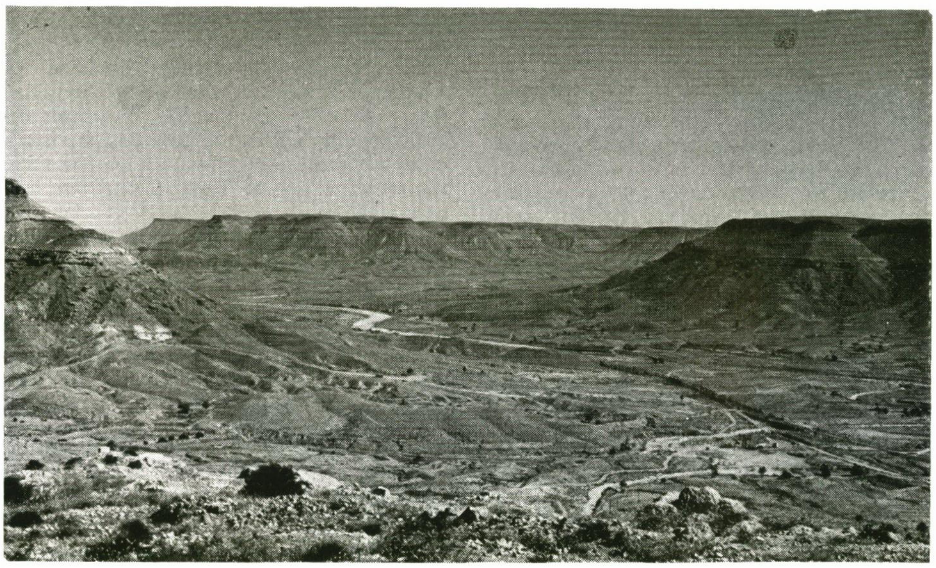

Fig. 2. Typical terrain for the alignments in Western Libya

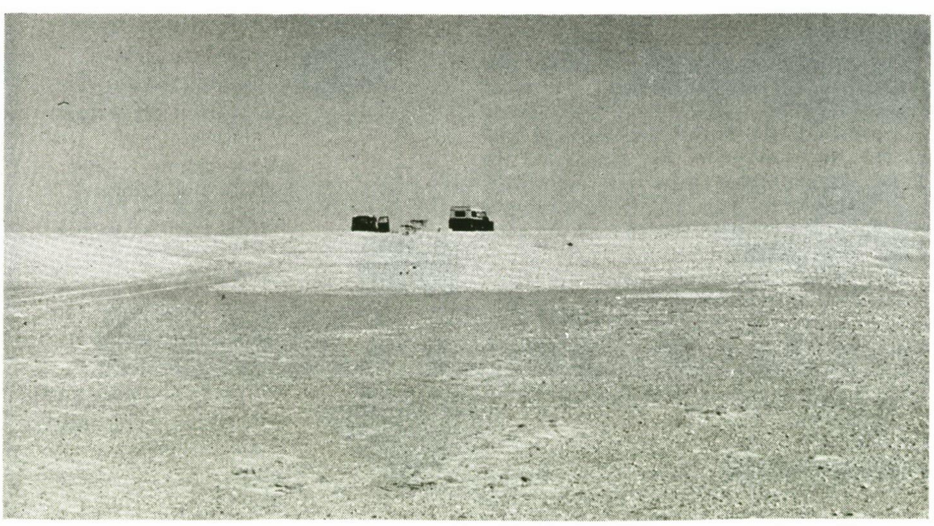

Fig. 3. Typical terrain for the alignments in Eastern Libya

test results were compared with the terrain classification mapping and, if necessary, "weighted" so that the design subgrade strength accurately represented the actual conditions along the alignment. In addition, chosen lengths of each route could be assigned a particular subgrade strength value.

It would be quite false to claim that each land facet has a unique soil type or a unique CBR value. The benefit of carrying out terrain classification from the road designer's view point is that it gives him a means of comparing alternative alignments and a rational basis for choosing subgrade CBR values. From a contractor's view point, there is the opportunity of rapidly assessing a wide range of problems such as access, mobility, potential borrow areas, and materials sources. The mapping is also useful for pin-pointing areas where selected fill for subgrade (or sub-base) is likely to be required and from where it may be obtained.

Pavement design was based on the AASHTO Interim Guide for the Design of Pavement Structures (1974). Pavement construction layers are usually a selected fill sub base (where necessary), a 150mm crushed stone base, and a 100mm asphaltic concrete binder and wearing course, the latter being a client requirement.

Construction materials

Naturally occurring construction materials were required for the various pavement layers and for concrete in bridges and culverts. Contractors in Libya prefer to use wadi deposits or residual surface boulders or cobbles rather than to quarry bedrock. For the roads in western Libya, locating materials for construction purposes was relatively simple. Where possible, specific rock sources were located and recommended at approximately 50km intervals along the alignments. These were supplemented by a list of other sources investigated along the route. Quantities for recommended alluvial deposits and residual surface boulders were estimated by trial pitting and aerial photographic interpretation. Quality was checked by visual examination of typical samples, together with Los Angeles Abrasion Tests (AASHTO T. 96), Sodium Sulphate Soundness Tests (AASHTO T. 104), Bitumen Stripping Tests (AASHTO T. 182) and Bulk Specific Gravity and Absorption Tests (AASHTO T. 85).

The dangers of sampling surface or near-surface rock exposures arising from the formation of duricrusts (hardened surfaces often underlain by porous or friable zones) have been highlighted by Fookes (1976). Consequently, where quarrying bedrock was recommended, quantities were estimated by examining rock cores obtained with a lightweight portable drilling rig (coring up to AX size), using geological mapping and aerial photographic interpretation only as aids.

Fookes (1977), Fookes & Collis (1975, 1976), French & Poole (1976), and Harrison (1971) have described at length the problems of internal and external chemical attack on concrete and bitumen in arid climates. In general, because of the comparatively low incidence of evaporites, the low humidity, and a deep water table, the problems of attack are likely to be considerably less than those experienced in the Arabian Gulf. Nonetheless, because of the intended use of dolomitic limestones (which occasionally contain chert inter-

TABLE II. AN EXAMPLE OF LAND FACET DESCRIPTIONS

LAND SYSTEM No. 3

Land Facet	*Form*	*Soils and materials*	*Engineering properties and comments*
3a	Mesas/Garets. Isolated flat topped turrets of rock rising sharply from the level of the surrounding ground, generally 20-50m high. Usually capped by horizontally bedded limestone up to 4m thick.	Residual soils usually less than 1m thick comprising a coarse silty sandy gravel with frequent subangular cobbles and boulders. Horizontally bedded limestone up to 4m thick is exposed as capping to this facet with intermediate marl, marlstone and shale beds exposed on the scarp faces. The limestone is very variable in quality.	The massive horizontally bedded limestone often presents the best exposures for quarrying operations but access is usually extremely difficult. However, these same beds are frequently present in adjoining plateaux and plains where the problems of access are lessened.
3b	Stepped Plateau. These are upland facets which are areas of tableland having little relief apart from occasional sharp steps controlled by rock outcrops. These outcrops themselves form the intervening flat area. The facets may be large or very limited in extent, and each step is a small scarp usually a few metres in height.	Residual soils usually less than 1m thick overlying horizontally bedded limestone. Soils generally silty sandy gravels with frequent subangular to angular cobbles and boulders. Limestone beds often exposed at plateau steps although frequently masked by colluvium which can contain a higher proportion of fine grained material derived from the marl interbeds.	AASHTO soil classification group A-1-b to A-2-4 although this will often change to A-4 in the vicinity of plateau steps. The horizontally bedded limestone may be suitable for quarry development although careful preselection will be necessary.
3c	Rolling Plateau/Plain. This may be either an upland or lowland facet where the ground surface is generally smooth but broadly rolling with an amplitude of less than 4m. Extensive areas can have virtually no relief.	Residual soils usually less than 1m thick. Soils generally sandy gravels with frequent subangular to angular cobbles and boulders when underlain by the Had limestone but more fine grained with boulder sizes usually absent when underlain by the Surfa formation.	AASHTO soil classification group A-1-b to A-2-4. The underlying limestone beds are usually exposed at the perimeter of this facet and, therefore, have good access for quarry development although careful preselection will be necessary.
3l	Coarse Piedmont (talus). This comprises localised areas bordering high upland facets and consists of steeply sloping surfaces which usually merge into facet *3m*.	Coarse colluvial and landslip debris up to large boulder size of very variable depth lying immediately below scarp faces.	Materials generally too coarse for incorporation into subgrade without processing and too variable in strength for pavement construction.
3m	Foot Slope Piedmont. This facet consists of gently sloping surfaces which link an upland to a lowland facet.	Colluvial soils of variable thickness usually overlying a gently stepped rock surface. The soil profile generally comprises coarser grained gap graded cobbles gravels and sands at the upper levels and finer grained materials at the lower levels. However, extensive intermediate levels can contain appreciable quantities of clayey material where the parent rocks were fine grained or marls.	AASHTO soil classification group very variable depending on whether the material has been predominantly derived from the stronger limestone beds or the more extensive weaker marls. Generally A-1-b to A-2-4 for the soils derived substantially from stronger materials; A-4 to A-6 for the soils derived from weaker materials. Although soils usually good for subgrade, imported fill material or sub-base will be required where the alignment crosses the weaker areas. This facet is often large in area and, since it frequently merges imperceptibly into other lower lying facets, is difficult to map with accuracy. It often forms a localised subfacet within larger facets and has only been mapped where it is of appreciable extent.
3q	Ridges, Cols, Saddles, Foothills. These are localised upland features frequently located within larger facets or at the margins of plateaux and watersheds.	Shallow coarse grained residual and colluvial soils often up to boulder size ranging from zero to rarely more than 1m in depth. Frequent horizontal or gently dipping rock outcrops.	Difficult terrain for route alignment which may require shallow rock cuts or fills. Access for quarry development is usually fair to good although hard limestone beds in this facet rarely exceed 1m thickness with extensive interbeds of marl, marlstone and calcareous shale.
3t	Alluvial Plain. Lowland facet with a planar or near planar sloping surface usually dominated by a single major drainage channel. This facet often includes minor wadi channels.	Typically fine grained or gap graded stratified alluvial soils. Rock is rarely exposed in the larger wadi plains and may be at a depth in excess of 5m. Smaller wadi plains and channels frequently expose limestone bedrock and the alluvial cover rarely exceeds 1m or 2m. Upper reaches often contain significant subangular to rounded wadi gravel deposits. Lower reaches often contain fine clayey silty sands with varying amounts of evaporites (gypsum, calcite or salt).	AASHTO soil classification group for the alluvium in the upper wadi reaches (i.e. smaller wadi plains and channels) generally A-1-b to A-2-4; in the lower reaches (i.e. broad flat wadi plains) generally A-4. Selected fill material may be required as a final subgrade layer for embankments on the lower reaches to ensure a satisfactory subgrade strength.

Fig. 4. The drawing shows an example of terrain classification mapping — part of the Gharian-Brak road — while the overlay (reproduced in brown) is an aerial photograph of the same area

beds), alkali aggregate reactivity and the presence of sulphates are both being examined.

Soil samples from a few localised areas set hard in the CBR moulds after compaction. These samples contained gypsiferous or calcareous binders and were usually associated with playa (lake flat) or peripheral wadi deposits. Although these types of soils have been used for road bases elsewhere (see Ellis & Russell, 1974 for a comprehensive list of references; Tomlinson, 1978), their use in pavement construction was not seriously considered because of the ready availability of more traditional materials.

For the roads in eastern Libya, the location of suitable rock sources in some areas was extremely difficult. This was due either to the material being of poor quality or to there being apparently only limited quantities available. For this reason, the first 350km of the Jalo-Kufra Road will include a 100mm sand-bitumen base, this being substituted by a 150mm crushed stone base for the remaining 275km. The limited quantity of rock available for the first 350km will be utilised in the asphaltic concrete binder and wearing courses.

Wind blown sands

In order to avoid sand drifting it is necessary to ensure a streamline flow for sand-bearing winds blowing across the road. For this reason the slopes of all shallow embankments and cuttings (i.e. up to 1m) were restricted to 1 in 4 or less. For embankments in non-dune areas higher than 1m, a side slope of 1 in $1\frac{1}{2}$ was specified but flattened near the top. In general, cuttings were avoided except in areas where the occurrence of wind blown sand was considered most unlikely.

In sandy areas, embankment slopes and shoulders will be protected by a layer of natural gravel or crushed rock. Baxter (1974) has found that a gravel blanket with a mean size of at least six times the mean size of the sand particles is an effective method for protection against wind erosion. The gravel breaks up the air flow and a skin of relatively still air is formed between the larger particles, so that the wind velocity is insufficient to move the same grains.

Sand dune areas were avoided wherever possible. When this was not possible, the embankment height was raised to the crest level of the highest dune in the vicinity. Dune stabilisation measures have been reported by numerous authors (e.g. Bagnold, 1941; Edwards, 1968; Fookes, 1976). However, dune stabilisation would be uneconomical for the dune sizes under consideration and raising the embankment height was the only practical alternative.

In the case of the Kufra-Uweinat Road, seif dunes of up to 18m in height were unavoidable. Examination of aerial photography taken at widely separated time intervals, and a limited dune movement monitoring programme, both indicated very little dune mobility in a direction perpendicular to the dune chains. In these cases, the road traverses each dune chain at right angles, with the top of the embankment rising at a grade of 2-4% to the top of the dune. Although it is anticipated that deposition will occur on the leeward side of the embankment, the road should remain clear. In the case of these high embankments the upper 3m has been flattened to 1 in 4, the remainder being 1 in 2.

Water

Water is required in large quantities for construction purposes and this can pose severe problems. Even for site investigation work this raises difficulties and for rock coring we used air flush. Generally, shallow groundwater sources such as wadi alluvia are very poor in quality and wells have unproven yields. The characteristics of water-bearing strata at depth (usually in excess of 300m) are better known as a result of the relatively large number of wildcat wells put down by oil companies. Nonetheless, the cost of constructing additional wells at, say, 25km intervals along the alignments will be considerable, although the costs could be mitigated by their later use for other purposes.

Attention has been given to the possibility of 'dry' compaction of predominantly sandy subgrades in an effort to reduce the amount of water required for construction. Earlier researchers such as Cochrane (1964), Naterajan & Paint (1966), Townsend (1973) have shown that the dry density/moisture content relationship for some, but by no means all, naturally occurring sands gives a higher dry density at, or near, zero moisture content than the dry density at optimum moisture content (see Fig. 6). However, it appears that there is no simple explanation for this difference in behaviour of different sands, which, at least superficially, are very similar. From a limited laboratory study and literature review, Grace & Cocksedge (1978) consider that aggregation of particles caused by the presence of plastic fines and/or the presence of significant quantities of soluble salt is probably a significant factor in preventing some sands from achieving high densities when compacted dry. In addition, the influence of dissolved salt on the surface tension of pore water may play a part. Attempts to formulate a simple test which would predict the shape of the compaction curve have only had limited success. For the present, material for dry compaction can only be positively identified by carrying out laboratory compaction tests to produce the full dry density/moisture content curve.

Other aspects of dry compaction which still need resolving are the practical considerations such as choice of compaction plant, method of containment, erosion protection, specification of density, and method of control testing.

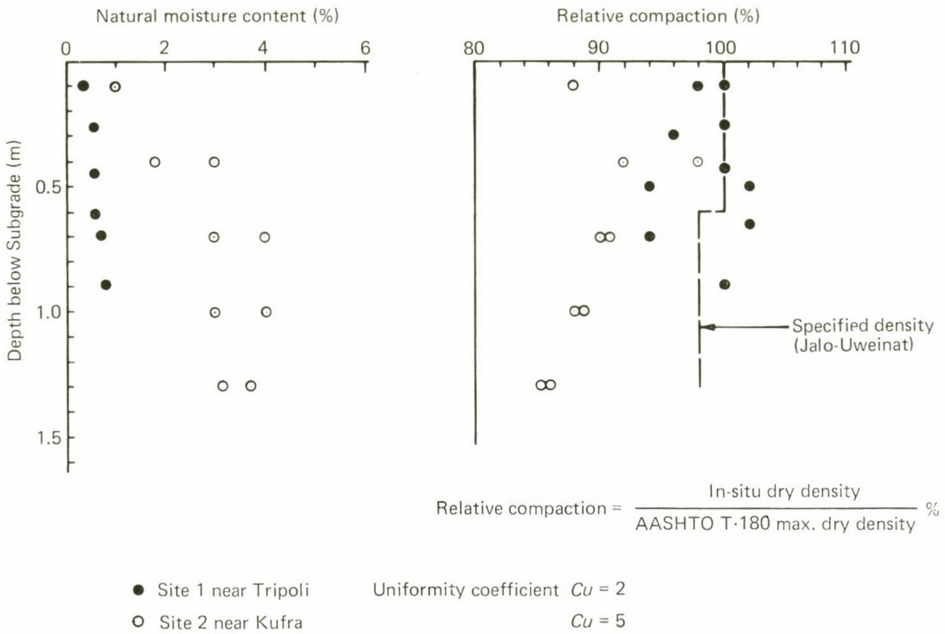

Fig. 5. Moisture content and in situ density profiles beneath two heavily trafficked desert roads in Libya

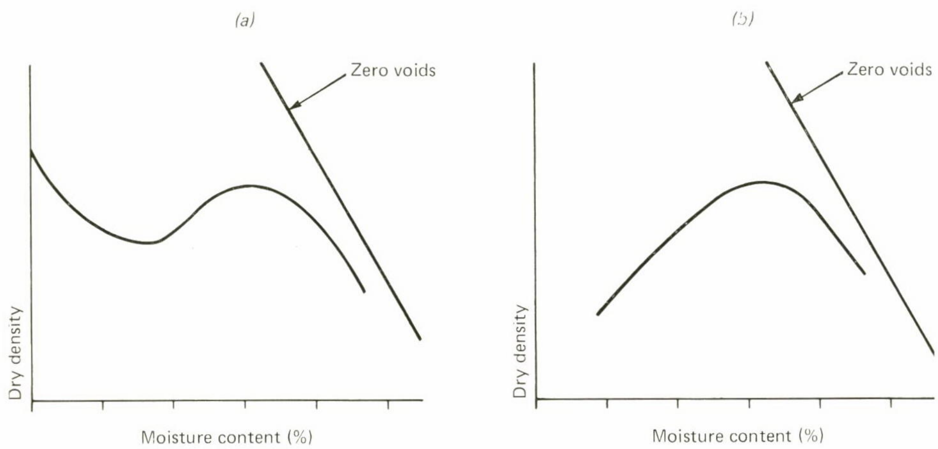

Fig. 6. Compaction curves: (a) particular shape for certain cohesionless soils; (b) typical shape for most soils

Subgrade compaction

Previous experience has shown that where subgrades are composed of predominantly single size cohesionless materials, densification can occur to considerable depths due to traffic loads e.g. Grace (1974). Investigations carried out beneath existing heavily trafficked desert roads in Jordan (Baxter, 1974) and Libya (Fig. 5) indicate that relative compaction caused by traffic vibration can be in the region of 100% Mod AASHTO (Test T. 180) to a depth in excess of 0.5m. Consequently, for sand subgrades in eastern Libya, it was specified that the earthworks shall be compacted to 100% Mod AASHTO for the upper 0.6m, and 98% Mod AASHTO below this level. In western Libya, the subgrade soils tend to be less uniformly graded and usually contain plastic fines; as a result the compaction specification below 0.6m was relaxed to 95% or 90% Mod AASHTO, depending on soil type.

Foundations for drainage structures

Due to the predominantly flat terrain and extremely low annual rainfall along much of the alignments in eastern Libya, drainage structures are few in number. Between Jalo and Kufra, a total distance of 625km, culverts have been considered unnecessary. On the other hand in western Libya, because of the varied terrain and the comparatively high rainfall (particularly in the north), bridges and numerous culverts are required.

Subsoils in the wadis are rarely finer grained than sand sizes and frequently contain gravels, cobbles, or boulders. For the culverts, since even the large culverts are monolithic reinforced concrete box structures with comparatively low bearing pressure, no special site investigations were required. For the bridges, the initial investigation consisted of trial pitting and rock coring in an attempt to locate and prove bedrock at each abutment and pier position. Where bedrock was not located, usually at deeply incised or wide wadis, a supplementary investigation was carried out using a shell and auger rig to obtain an SPT 'N' value profile with depth. In all cases, however, the limitation on founding depth was the result of considerations of erosion rather than of settlement.

In spite of the occurrence of dolomitic limestones and marls with gypsum interbeds, tests for sulphates (BS 1377: 1975 Test 10 but using a 2:1 water : soil extract) have indicated very few areas where protective measures against external sulphate attack will be necessary.

Field logistics

Desert travel for the ill prepared can be exceedingly dangerous. In many cases, staff engaged on geotechnical works have to examine features several kilometres off the proposed or pegged alignment and perhaps up to 200km from any permanent human habitation. The implications of a major vehicle breakdown or personal injury without adequate emergency resources are obvious but cannot be over emphasised.

Comprehensive supplies are clearly necessary, including tenting, bedding and provisions for locally recruited labour.

Although topographic maps have often proved to be totally inadequate, to date we have usually been fortunate in obtaining aerial photographic coverage at an early stage in each project. This minimises the risk of becoming lost, if at least only temporarily. Quote: "I was never really *lost;* but there was a time when I was certainly puzzled for a week or two!"

Acknowledgements

The author wishes to thank his colleagues for reviewing this article and for their helpful comments.

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