A FOUNDATION PROBLEM IN BURMA[1]

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SYNOPSIS

This report describes an unusual phenomenon of swelling pressure of soils, its effect on structures, the methods used in studying the problem and recommendations to minimize its action. The type, formation and chemical analyses of the soil and the climatic conditions are given and their interrelationship discussed. The value of "in situ" permeability and shrinkage tests and observations is stressed. A minimum rather than a maximum safe loading is recommended for the soils in question and if the transmitted loading is less than the effective swelling pressure of the soil allowance should be made for the stresses induced by soil movements.

Until very recently Burma was hardly on the map. Few people knew of its existence and still less knew exactly where it was. Usually shown on the same map as India, with which it was formerly politically associated, its size faded into insignificance and its separation from India by the Bay of Bengal made it appear but a fringe of China or a side decoration to the map of India. But Burma is some fifteen hundred miles long, it is not a small and a not so insignificant country as might have been supposed.

Now that Burma is so much in the limelight and may in fact be one of the keys to the solution of the war in the East, it is perhaps not out of place to describe one of its minor problems, a foundation engineering problem.

THE PROBLEM

The problem confronting engineers working in the Central Plain of Burma was that so many buildings constructed there developed, soon after completion, a most elaborate and often very symmetrical pattern of cracks which simply refused to be obliterated. No matter how often they were repaired, they, as if out of cussedness, soon overcame this hindrance and reasserted themselves. There was no abatement throughout the years.

Though it was felt that the soil was in some way responsible for building failures, the conception of the possibilities of a building rising, instead of sinking was not then apparent. It was however clear that any investigation would have to be along lines very new to the engineer.

One of the condemned buildings, for example, was transmitting a pressure of only one quarter of a ton per square foot while much heavier buildings were crack free. An examination of building deflection curves showed they were mostly basically dome-shaped, with sinusoidal modifications, and not dish-shaped as they should have been for a structure founded in a horizontally homogeneous cohesive soil. (In those days the scope of soil mechanics was more limited than now and there seemed little hope of a solution through its aid.)

It was realized from past experience, however, that the characteristics of an undisturbed soil were not necessarily faithfully recorded by engineering tests on small samples estranged from their natural environment. Engineering tests did not sufficiently allow for the soil's yearly life cycle. It was in these 'in situ' characteristics that it was believed a solution to the problem could be found. As it happened, the problem developed into one of ascertaining a minimum safe bearing pressure, controlled by these 'in situ' characteristics, instead of the more usual problem of the maximum safe bearing pressure. There was no similarity between this minimum value and any known statically determined value. It depended on active phenomena, not inert mechanics.

The approach was therefore by applied pedology and the first step was to correlate

[1] Based on a detailed report to the Burma Government and published with the permission of the Government of Burma.

soil science with engineering knowledge and the principles of Soil Mechanics.[2]

THE SOIL

The hitherto unclassified soil was classified engineeringly as A6 (Public Roads Administration Classification) and agriculturally as a carbonate Ca-Mg-Na-Intrazonal Secondary Solonchatic-Solonetzic Complex of the Transitional Yellow Earth Group.

The surface soil is a "loam" beneath which lie the "clay" accumulation layer and the "clay" parent soil.

Average profile analyses gave for the clay fraction (Atterberg):

Depth 0-in. and 6-in.	20 per cent	(No pretreatment with H_2O_2)
Depth 30-in.	58 per cent	(Pretreatment with H_2O_2)
Depth 42-in.	61 per cent	" " "
Depth 90-in.	54 per cent	" " "
Depth 150-in.	48 per cent	" " "

The profile is generally consistent and, where weathering has been more active, is made up of an approximate 3½-ft., deep zone of blackish soil—locally known as 'Black Cotton'—resulting from the downward weathering of the parent loess-like material. Under this horizon A lies an approximate 4-ft. deep accumulation zone, or horizon B, arising out of mixed upward and downward weathering, which includes in its upper half the 2-ft. transition stage of black to yellow or mottled black-yellow soil (soil circulation effect). The accumulation zone, containing alkaline salts, is locally known as 'Kyatti', or sticky soil, although 'Kyatti', or sticky, characteristics may be found elsewhere in the profile.

Where the downward weathering is ostensibly less active, as on the tops and slopes of microrelief and in higher undisturbed, e.g., uncultivated, etc. ground, horizon A is formed by the horizon B, in the above, and the surface soil may be yellowish.

Both the accumulation zone and the yellowish parent soil contain horizons of lime and manganese concretions particularly between 4 and 7 ft. Lower horizons of lime concretions were also noticed.

The soil is mildly siliceous ($S/R = 2.3$ at surface to 2.6 at 3½ ft.; $S/A = 2.9$ at surface to 3.5 at 3½ ft.) and the predominant replaceable base varies and may be Ca, Mg or Na ($V = 35$ per cent with $T = 41$ to $V = 64$ per cent with $T = 44$ are surface variations with a maximum $T = 68$ when $V = 44$ per cent).

The clay minerals, for one set of samples taken from a depth of 21 in., and examined by X-ray methods in the United States of America, were montmorillonite in small quantities and, apparently, considerable illite.

The average yearly rainfall (tropical) is 34-in. occurring between May and October, and the average temperature is 28°C. (82.4°F).

Weathering is considered to be mixed mild tropical podsolic in the non-disturbed surface soils and where surface drainage is better; and mild allitic in the disturbed irrigated and like areas. In the podsolic areas there is a downward translocation and accumulation of Fe_2O_3 at a depth of about 2 ft. and of Al_2O_3 between 3 and 7 ft. Soluble silica increases slightly with depth to 4 ft. In the allitic areas there is no downward sesquioxide translocation though the sesquioxide and Al_2O_3 content are somewhat higher than for the podsolic areas. There is a small surface accumulation of manganese and potassium. The soluble silica also increases down to 4 ft. and is higher than in the podsolic areas. Sodium carbonate is more generally distributed and below 4 ft. sulphate and carbonates apparently coexist.

STEPS TO THE SOLUTION

1. Monthly moisture determinations for four sites, over a period of 13 months, to a depth of 12 ft. indicated no horizon of constant moisture content. Since foundations in Mandalay do not extend to this depth, but generally lie at a depth of about 4 to 7 ft., the effects of soil volume changes under foundations must be considered. Values—ranges are given in Table 1—were very low and only likely to be approached in England during or after, a drought.

2. An examination of soil chemistry and mechanical analyses data indicated 'in situ' permeability though the soil, previously considered a Na-clay, had been assumed impermeable. This permeability[3] could be due, under such a weathering system, to the presence of free and replaceable calcium and magnesium. The relatively high replaceable magnesium and sodium pointed, with such

[2] "Fundamentals of Soil Mechanics," 1939; Published for Indian Roads Congress Meeting, 1943.

[3] Permeability would, of course, decrease in the more solonetzic depression areas of non-irrigated ground.

a soil and weathering system, to detrimental volume changes.

'In situ' permeability, though not supported by the engineering permeability test performed under conditions differing from site conditions, was nevertheless supported by observations and moisture content analyses; while high 'in situ' shrinkage was confirmed by site observations and measurements.

'Bad sites', from the point of view of damaged structures, were not marked by higher clay fractions or higher shrinkage coefficients but, if anything, by higher permeability.

3. 1 and 2, conjointly, suggested relatively rapid volume changes under foundations and there was evidence in support.

4. The yearly moisture content fluctuation ranges, to the depth examined, are considered —and for the data available were found— to lie approximately within the residual shrinkage range of the 'in situ' shrinkage curve—where small voids changes correspond to high internal pressure changes—as contrasted with the believed more usual capillary range for British soils—where similar voids changes are accompanied by much smaller pressure changes. Such moisture content fluctuations in British soils, at foundation depths, are believed small, or non-existent, except perhaps during or after a severe drought.

With moisture changes within the residual shrinkage range—the approximate osmotic range—it is considered the swelling pressure of the clay is cyclically mobilized and made effective producing periodic vertical and horizontal loading on foundations leading to cyclical differential vertical and horizontal movements in structures transmitting loadings less than the effective swelling pressure.

The full and effective swelling pressure of the soil were both found, by laboratory and 'in situ' observations, to be about 1.6 tons per sq. ft.

5. Building deflection curves showed the basic building deflection curve to be the expected dish-shaped curve only when the pressure transmitted by the structure exceeded the swelling pressure and was otherwise dome-shaped. This indicated that the accepted conception of a dish-shaped deflection curve applying to structures sited on a horizontally homogeneous cohesive soil requires amplification to give a more general law introducing the moisture content factor. For the clay examined, the form depends on the ratio of loading to active swelling pressure; i.e., it is apparently a function of the moisture fluctuation range on the 'in situ' shrinkage curve.

6. For loadings less than the swelling pressure, the unexpected dome-curve is considered to result from soil volume changes occurring after construction. Originally, very dry—after exposure of excavation work during the dry weather—the soil of the central core, under a structure, takes up moisture—thereby releasing the effective swelling pressure—till, after a number of cycles of wetting and drying, it gradually attains some relatively constant equilibrium percentage, or volume, resulting in some accumulated upward movement in the centre of the building and the formation of a central support; whilst the exposed end walls, normally over contracted soil, accumulate small sinkages under percolation during the tropical rains by the higher than 'in situ' moisture intake—up to the F.M.E. and over—of the disturbed soil under the foundations.

TABLE 1

Depth., in.	Badly Cracked Building[a]			Uncracked but Distorted Building[a]			Undistorted Building[a]			Agricultural Irrigated Section		
	Max. %	Min. %	Range %	Max. %	Min. %	Range %	Max. %	Min. %	Range %	Max. %	Min. %	Range %
0	Min. from 4 to 6			F.M.E. about 18%								
48	19.43	14.75	4.68	17.10	11.38	5.72	17.75	15.35	2.40	19.90	16.35	3.55
78	17.86	13.99	3.87	14.30	12.05	2.25	16.15	13.23	2.92	20.55	14.70	5.85
138	16.05	7.93	8.12	15.85	9.48	6.37	15.44	10.80	4.64	24.85	18.44	6.41

[a] Samples taken in compound area well away from any building or drainage, etc. Notes: Percentages on dry weight.
Plastic Limits .... 18 to 24 per cent; Liquid Limits, 67 to 81 per cent
F.M.E.'s .. . . 18 to 20 per cent
Undisturbed density 1.61 to 1.71; entrapped air content 16 to 21 per cent (vol.); disturbed density 2.1 to 2.4.
Pedologically the soil was considered to be non-plastic when undisturbed and this was supported by site loading tests performed under very severe moisture conditions and by other observations.

For loadings greater than the swelling pressure and, presumably, for lesser loads should the moisture variations occur within the capillary range, the effective swelling pressure is suppressed, or inoperative, and the normal dish-shaped deflection curve develops.

Analysis of damaged buildings supported this theory in that the lighter the building pressure the worse the cracking. When the transmitted loading exceeded the effective swelling pressure, the structure was free from cracks or free from any but a few unimportant hair-cracks.

7. The interrelationships between transmitted loading and relative deflection for all-brick buildings in this area was given by:

$$\frac{d}{l} = 0.00265 - 0.00171\, p \ldots\ldots\ldots (1)$$

where d = relative deflection in feet,
l = length of structure in feet,
and p = transmitted pressure in tons per sq. foot.

The equation of the laboratory swelling pressure-swelling compression curve[4] was, for the plotted range of $p = 0.5$ to $p = 2.0$ tons per sq. foot,

$$S = 0.0063 - 0.0039\, p \ldots\ldots\ldots (2)$$

where S is the test swelling, or compression in feet, and p = the pressure release on swelling. Length of test specimen = 0.87 in.

These two equations give the interrelationship, for like loadings, of $S = 2.3\,\frac{d}{l}$; or, the (test) osmotic range strain is

$$f = 32\,\frac{d}{l}. \ldots\ldots\ldots (3)$$

Equation (1) can thus be expressed, for any load and proportional osmotic strain, as

$$\frac{d}{l} = f\,\frac{(1.55 - p)}{1.55}.\frac{1}{32}$$

where $f = 0.085$ against the average value of 0.087 for the agricultural shrinkage coefficient for five sites between the depths of 4 ft. and 12 ft.

Both curves (1) and (2) gave effective swelling pressure as about 1.6 tons per sq. ft. (1.55 and 1.65, respectively).

[4] Determined by the Building Research Station, Watford, England.

8. For loadings less than the swelling pressure secondary influences modify the basic dome shaped deflection curve, especially at ends, to give a sinusoidal dome-curve, the degree of modification depending on the flexibility and the type of design of the structure. This curve is subject to variations which were verified over periods of up to five years.

The factors responsible for changes in and the buckling of the basic dome curve are considered to be the differential movements caused by soil moisture changes and the time lag helped, possibly, by observed 'soil circulation', suspected thixotropic effects (said to be likely in an illite clay with high replaceable sodium) and the believed buckling of the more sodium clay areas consequent on the believed unequal ratio between horizontal and vertical shrinkage of sodium clays.[5]

CONCLUSIONS

Building damage occurs principally at periods of maximum soil moisture content (max. humidity and min. mean temperatures) and minimum soil moisture content (a period when the dry weather minimum moisture content is reached at higher levels accompanied by a rapid moisture increase between 12 ft. and 7 ft). At the same time the temperatures are a maximum and the humidity a minimum and for loadings less than the swelling pressure, damage arises from the high reverse deflections (which simple structures are not usually designed to withstand) whose effects are accentuated by increased curvature caused by sinusoidal modifications and by continued differential movement. Buildings transmitting loadings greater than the swelling pressure were not damaged.

For such soils, and pedological conditions, design should therefore concentrate on a minimum rather than a maximum safe loading, or should allow for the stresses induced by soil movements when the transmitted loading is less than the minimum safe loading which is equal to the effective swelling pressure of the soil.

[5] "The Vertical and Horizontal Shrinkage of Black Cotton Soil at Mandalay, Burma." A. T. Sen & F. L. D. Wooltorton, *Current Science*, 1942, Vol. II, No. 9, pp. 364–366; and "The Study of the Soil in the Field," G. R. Clarke, 1941.