field by visual observations and by simple field tests. The order is identified by content of organic material; the suborder by the degree of decomposition of the organic materials; the great group by soil temperature; subgroups by intergrades to other great groups of organic soils; and the family by particle size, mineralogy, reaction, temperature, and soil depth.

The criteria used to classify peat soils identify soil properties that have significance for engineering purposes. Nomenclature used in the classification scheme is connotative and enables recognition of the properties.

The NCSS classifies and maps soils using Soil Taxonomy. Soil survey maps at scales of 1:15,840, 1:20,000, or 1:24,000 are available for about 1,660 counties in the United States. The maps and descriptions of peat soils can help engineers plan and conduct soil investigations for engineering purposes.

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Compression of Peat Under Embankment Loading

H. ALLEN GRUEN and C. W. LOVELL

ABSTRACT

Peat and organic soil are commonly avoided as sites for highway construction. There are situations when this is not possible or economical, and the peat must be dealt with. If the organic accumulation is relatively shallow, excavation and replacement are feasible. However, for deeper deposits other alternatives, including the preloading technique discussed here, need to be considered. Preloading both strengthens the peat, so that it can safely carry the intended load, and achieves long-term compression in an accelerated period. Prediction of the settlement of peat under both the service load and the preload is important. Rheological parameters can be derived from field testing to allow use of a method that predicts settlements and controls duration of preload. A case study involving a highway compares results predicted by the method with actual measurements.

Building highways over peat and other highly organic deposits has been avoided by engineers whenever possible. It has been customary to go around peat lands when planning a highway, and this is still the preferred solution. However, there are times when passing the highway alignment over the deposit may be an effective alternative.

When these deposits are relatively shallow (less than 5 m), excavation and replacement by granular materials are commonly used. However, when the deposits are deeper or of a large lateral extent, special foundation treatment is usually required.

One such treatment is preloading. As a result of expansion into areas with poor foundation soils, preloading techniques through surcharging have been developed with some success as a means of in situ improvement of soil properties. Preloading accelerates settlement and strengthens the deposit so that an embankment can be supported without failure or excessive settlement.

A major drawback to preloading peat has been the inability to predict the deformation characteristics of the organic deposit under loading. This lack of knowledge becomes apparent when attempting to determine the surcharge magnitude and duration required to accelerate settlement. The time rate and magnitude of settlement to be expected with peat are at best uncertain. Methods currently used to predict settlement give poor results when applied to large strain materials with significant secondary compression effects (i.e., peats). Thus, after a preload has been applied to peat, the rate and magnitude of settlement are often uncertain, and consequently the required duration of the surcharge period is unknown.

A technique to accurately control the duration of the surcharging period so that construction may be completed in the minimum amount of time is presented.

GIBSON AND LO MODEL

Gibson and Lo (1) proposed a rheological model that applies to large strain soils that exhibit secondary compression. This theory assumes that the structural viscosity of the soil is linear. For large values of time, the deformation behavior, $\varepsilon(t)$, may be written as

$$\varepsilon(t) = \Delta\sigma \left[a + b\left(1 - e^{-(\lambda/b)t}\right)\right] \qquad t > t_a \tag{1}$$

where a, b, and λ are empirical parameters that can be determined from deformation response data; $\Delta\sigma$ is the increase in vertical stress; and t_a is the time after which the stress has become fully effective. This model has been shown to closely model both laboratory and field behavior of peat (2,3).

Dhowian (4) derived the following method for determining the rheological parameters to be used in the Gibson and Lo model. If Equation 1 is differentiated with respect to time, the rate of strain obtained is

$$\partial\varepsilon(t)/\partial t = \Delta\sigma\lambda e^{-(\lambda/b)t} \tag{2}$$

Taking the logarithm of both sides in Equation 2, the following linear relation is obtained:

$$\log_{10}[\partial\varepsilon(t)/\partial t] = \log_{10}\Delta\sigma\lambda - 0.434(\lambda/b)t \tag{3}$$

which in a simplified form is the following straight line:

$$Y = C + D(t) \tag{4}$$

where

$Y = \log_{10}[\partial\varepsilon(t)/\partial t]$ = log of strain rate,
$C = \log_{10}\Delta\sigma\lambda$ = line intercept, and
$D = -0.434(\lambda/b)$ = slope of the line.

The parameters are determined by plotting the logarithm of strain rate against time from compression results for a particular soil. A straight line is then drawn through these points. The slope (D) and the intercept (C) of this line yield the values of b and λ. The primary compressibility parameter (a) is found by substituting the known quantities into Equation 5:

$$a = [\varepsilon(t)/\Delta\sigma] - b + be^{-(\lambda/b)t} \tag{5}$$

APPLICATION

The Gibson and Lo model may be used to extrapolate field settlement curves and predict field settlement under other than the applied stress level. This will be illustrated later by an example. The actual surcharged embankment is constructed in the field and settlement data are recorded. After a short period (normally less than 3 months), the load has become fully effective and sufficient data are available to determine the rheological parameters. This method has been computerized (3) so that data can be entered as they are collected, refining the rheological parameters to a greater accuracy as settlement progresses. When these parameters have been determined for a given deposit, the settlement behavior can be extrapolated to any time.

In a similar manner, using Equation 1, the stress change term ($\Delta\sigma$) can be chosen to predict the settlement behavior under other loads. Varying the stress change term in Equation 1, while using one set of rheological parameters (a, b, and λ), assumes that these parameters are constant with strain rate and that strain is a linear function of stress at any given time. This is not completely correct for peat. However, Gruen and Lovell (3) have shown that, for the stress change levels normally involved in the preloading of peat, the violation of these assumptions causes small and acceptable errors.

ILLUSTRATION

This method will be illustrated by a case history. A highway was to be built over an extensive deposit of peat and highly organic materials at Walt Disney World, Florida. Preliminary investigations and rough settlement calculations resulted in the selection of a surcharged embankment section to be placed on the deposit. Settlement plates were placed and the embankment was constructed. Settlement was monitored at regular intervals. In a short time excess pore pressures had dissipated (end of primary consolidation), and the rheological parameters for the model could be determined. Table 1 shows the observed settlement data and the calculated logarithm of strain rate. The movement of settlement plate 89 during the first 3 months and the embankment load are shown in Figure 1. Note that primary consolidation appears to end at approximately 40 days.

TABLE 1 Observed Settlement Data

Time (Days)	Settlement (cm)	Strain	Change In Time (Days)	Log $\frac{\text{Change In Strain}}{\text{Change In Time}}$	Midtime (Days)
0	0	0			
			5	-2.62	2.5
5	3.66	0.012			
			5	-2.13	7.5
10	14.9	0.049			
			5	-2.36	12.5
15	21.6	0.071			
			5	-2.32	17.5
20	29.0	0.095			
			10	-2.49	25.0
30	38.7	0.127			
			10	-2.74	35.0
40	44.2	0.145			
			10	-3.00	45.0
50	47.2	0.155			
			10	-3.30	55.0
60	48.8	0.160			
			10	-3.10	65.0
70	48.8	0.168			
			10	-3.30	75.0
80	52.7	0.173			

To determine the rheological parameters, the logarithm of strain rate was plotted against time as shown in Figure 2. Only the data for times after primary consolidation had occurred were used in determining the best fit line shown in Figure 2. In this example, the plotted points before 40 days are disregarded because the deformation behavior during this period is controlled by hydrodynamic effects. After the applied load has become fully effective (excess pore water pressure equals zero), the logarithm of strain rate plots approximately as a linear function of time. The rheological parameters b and λ are calculated from the slope and intercept of the line as shown in Figure 2. The rheological parameter a is determined from Equation 5.

Using these parameters in Equation 1, the settle-

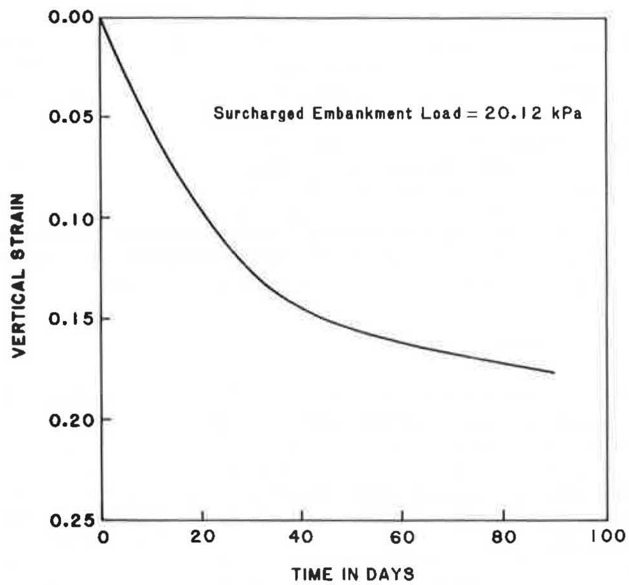

FIGURE 1 Settlement data from plate 89.

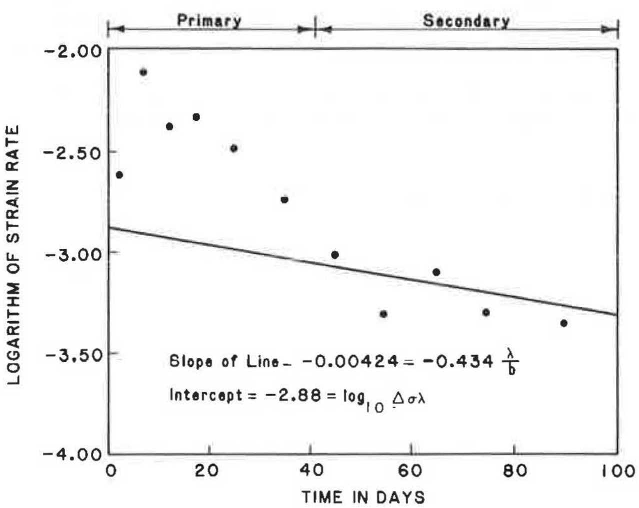

FIGURE 2 Logarithm of strain rate versus time.

ment record can be extrapolated as shown in Figure 3. This extrapolation agrees very well with actual settlements that subsequently occurred. At this point it is desired to estimate the settlement behavior of the deposit under only the service load (embankment with no surcharge). This is accomplished by using the calculated rheological parameters in Equation 1 along with a stress change ($\Delta\sigma$) corresponding to the anticipated service load. The estimated settlement behavior of the deposit under the service load is shown with the actual settlement curve due to the surcharge load in Figure 4. In this case it is assumed that the surcharge is intended to eliminate the settlements expected under the service load over a period of 30 years. As shown in Figure 4, the estimated strain in 30 years is 0.168.

The surcharge should remain in place until the desired settlements have occurred (roughly 70 days). During this time, settlement data should continue to be collected and used to refine the parameters used in the model. This approach can be considered somewhat of an observational method, in that the model becomes more and more accurate as settlement continues, providing more data for determination of the

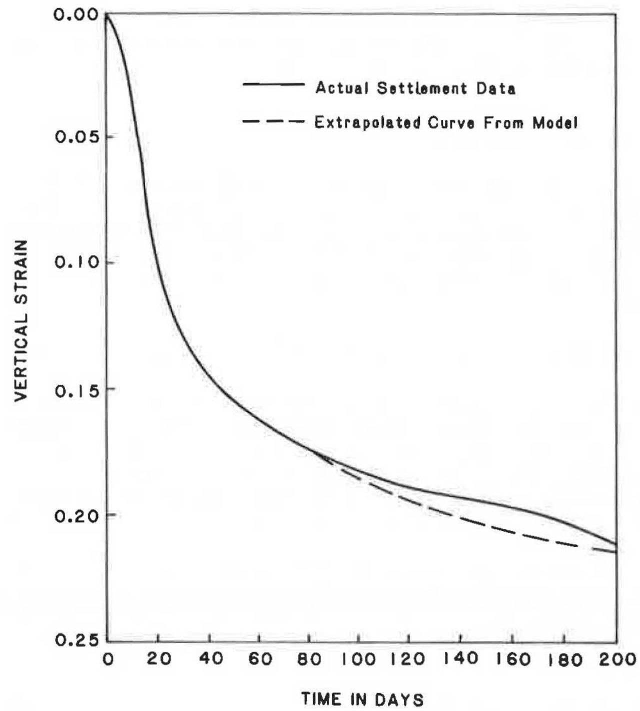

FIGURE 3 Actual and estimated settlement behavior.

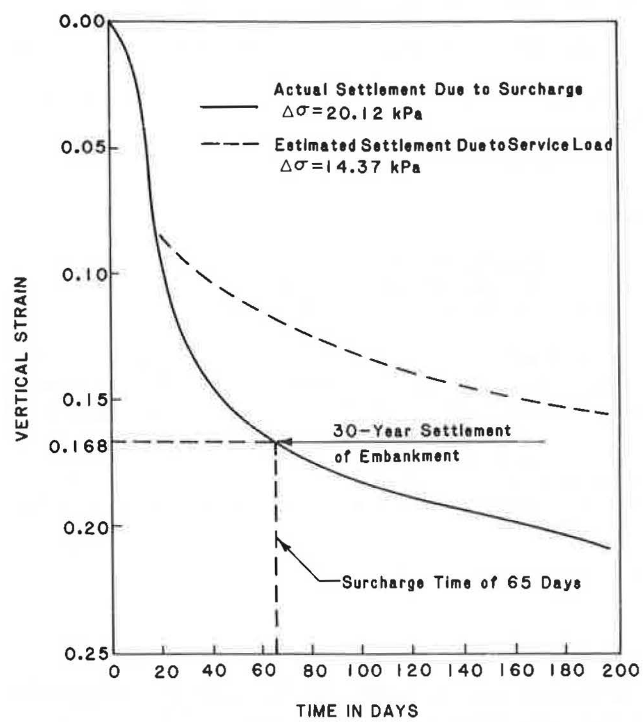

FIGURE 4 Actual field settlements and anticipated settlement due to service load only.

parameters. Determination of the rheological parameters and prediction of settlement have been simplified by use of the computer program given by Gruen and Lovell (3).

After sufficient settlements have occurred, the surcharge is removed and construction of the highway is completed. It should be noted that the settlement data used in this illustrative example were obtained from an embankment loading of peat at Walt Disney

World, Florida (see the paper by Swantko et al. in this Record). The actual design incorporated preloading; however, the rheological model approach was not used in the project. The use of the rheological model for other cases is reported by Gruen and Lovell (3).

CONCLUSION

If peat is to be used directly as a foundation material, its properties must be improved by preloading. Using preliminary settlement estimates, the magnitude and duration of preloading can be predicted and a surcharge applied. After the primary strain portion under the surcharge load has occurred, the Gibson and Lo theory can be applied to determine the rheological parameters used for the model. According to Landva (5) the field settlements under embankment loading have normally entered the secondary strain portion within 3 to 4 months. Using these rheological parameters, the surcharge settlement curve can be extrapolated and the settlement curve for the final design load can be estimated. These two curves can be compared so that the duration of preloading is sufficient to accelerate the anticipated settlements caused by the service load. Using the Gibson and Lo theory in this manner will give more accurate control over preloading than do other methods currently used. If the deposit is fairly uniform, a test section may be built to determine the rheological parameters for the deposit. These parameters can be used with the model for designing subsequent embankment sections and preloading programs.

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