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Wayne R. Bergstrom
Engineering Geo Techniques, Inc., Midland, Michigan

Patrick Dugan
Standard Environmental Services, Inc., Warren, Michigan

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TEST FILL TO DETERMINE THE COMPRESSION BEHAVIOR OF A CLOSED INDUSTRIAL WASTE LANDFILL

Wayne R. Bergstrom, Ph.D., P.E.
Engineering Geo Techniques, Inc.
Midland, Michigan-USA-48640

Patrick Dugan
Standard Environmental Services, Inc.
Warren, Michigan-USA-48089

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ABSTRACT

A test fill was constructed over a closed, industrial waste landfill located in southeastern Michigan. The objective of this test fill was to evaluate the immediate and time-dependent response of the existing landfill to an increase in load. The closed landfill contains a widely varying mixture of non-hazardous industrial wastes such as foundry sand, ash, and wastewater treatment sludge. It also contains construction and demolition debris. The surface of the landfill is relatively flat and, at the site of the test fill, is underlain by approximately 30 feet (9.1 m) of waste, some 15 feet (4.6 m) of which is saturated. Native clay till underlies the closed landfill and is approximately 8 feet (2.4 m) thick. A fractured, relatively non-weathered limestone underlies the till. The test fill was comprised of approximately 5000 cubic yards (3,800 m^3) of clay and was 12 feet (3.7 m) thick at its peak. The size at the base was approximately 160 feet (48.8 m) by 140 feet (42.7 m). The settlement of the existing landfill surface beneath the test fill was monitored with three laterally-distributed settlement points. Settlement of up to 0.5 feet (0.15 m) occurred concurrent with imposition of the increased load. On completion of the test fill construction, the settlement pattern became linear with the logarithm of time. From this data, load-dependent and time-dependent compression characteristics were estimated for the in-place industrial waste.

KEYWORDS

compression index, landfills, secondary compression index, settlement, solid waste, test fill

INTRODUCTION

The design of a vertical expansion over a filled and covered landfill in southeast Michigan called for the construction of a new liner and leachate collection system over the existing landfill cover surface. One of the primary tasks for the landfill expansion design team was estimating and compensating for the anticipated settlement of the existing landfill surface to minimize the possibility of adversely affecting the integrity of the overlying design features.

However, very little published information is available regarding the likely compression behavior of the industrial and demolition wastes contained in the existing landfill. A test fill was therefore constructed and monitored to determine the compression behavior of the existing landfill. The test fill and data obtained therefrom are described below.

BACKGROUND

The existing landfill, some 160 acres (65 ha) in area, was constructed and filled in two phases beginning a little more than 20 years ago. The surface of the landfill is relatively flat and is generally covered by 2 feet (0.6 m) of clay cover supplemented by topsoil which supports a grass mixture. At the site of the test fill, the cover is underlain by approximately 30 feet (9.1 m) of waste, some 15 feet (4.6 m) of which is saturated. Native clay till underlies the closed landfill and is approximately 8 feet (2.4 m) thick. Fractured limestone underlies the till.

The existing landfill contains a widely varying mixture of non-hazardous industrial wastes such as foundry sand, ash, and wastewater treatment sludge. It also contains construction and demolition debris. According to available records and personnel recollections, the overall nature of the incoming waste stream has been consistent throughout the site life.

WASTE DENSITY DETERMINATION

An estimate of the in-place density of the existing waste was needed to fully evaluate the results of the test fill. It was also needed to estimate the load which the vertical expansion will apply to the existing fill, because the expanded landfill is expected to receive a similar waste stream in the future. Therefore, a test pit was excavated into the existing landfill and the waste therefrom was weighed.

The test pit was surveyed using standard techniques to determine the volume of waste removed. It was found to have contained approximately 13.93 cubic yards (10.65 m^3). The waste from the test pit was placed directly into a truck for weighing and was found to weigh approximately 21.1 tons (19.1 metric tonnes). The overall unit weight of the in-place waste was therefore estimated to be 112 lbs/ft^3 (1,793 kg/m^3). While this value may be expected to vary within the landfill, the wastes obtained from the test pit appeared to be representative of the typical waste stream. Therefore, the resulting unit weight is believed to be reasonably representative of the overall existing conditions.

TEST FILL

The test fill was constructed in July 1995 by the site owner/operator. Its construction and subsequent settlement were monitored by the owner's personnel.

Configuration and Placement

The test fill was constructed over an older portion of the existing landfill. It was comprised of nearly 5000 yd^3 (3,800 m^3) of clay and was 12 feet thick at its peak. The size at its base was approximately 160 feet (48.8 m) by 140 feet (42.7 m). See Fig. 1.

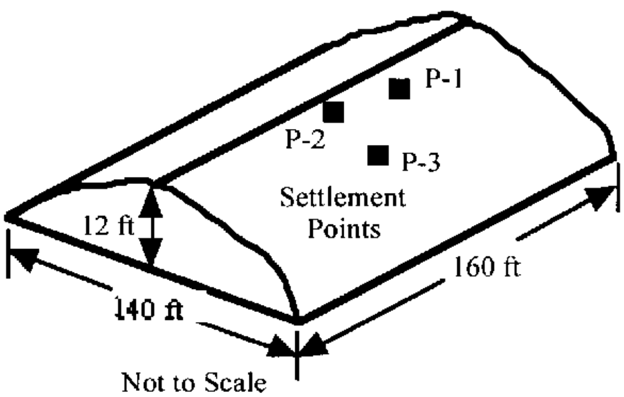

Fig. 1 Simplified schematic of the test fill showing the three settlement monitoring point locations

After stripping top soil from the area, the test fill was constructed over an 8-day period. The clay was placed in 3 lifts which were subject to truck and dozer traffic. No additional compaction was attempted.

Settlement Monitoring

Settlement of the existing landfill surface beneath the test fill was monitored with three laterally-distributed settlement points. Each point was comprised of a steel plate, placed at the landfill surface, on which was mounted a vertical steel rod. Each vertical rod was threaded so it could be extended upward in advance of the test fill construction. A pipe was placed around each rod to protect the rod and point from construction damage. The rods on each settlement point were periodically surveyed during test fill construction and for approximately one year thereafter.

Leachate levels in nearby open piezometers, set within the existing landfill waste, were also periodically monitored.

RESULTS AND EVALUATION

The results of the settlement monitoring were evaluated to estimate compression characteristics for the existing waste. The observed behavior and its evaluation are described below.

Settlement Behavior

The observed settlement at each settlement point is illustrated in Fig. 2. As can be seen, the initial movement observed at each settlement point was almost simultaneous with construction of the test fill. This initial, load-dependent settlement virtually ceased when the construction ceased. Thereafter, settlement was essentially linear on a log-time versus settlement graph. The resulting pattern of movement is very similar to that described in conventional soil mechanics for the compression behavior of natural clay deposits.

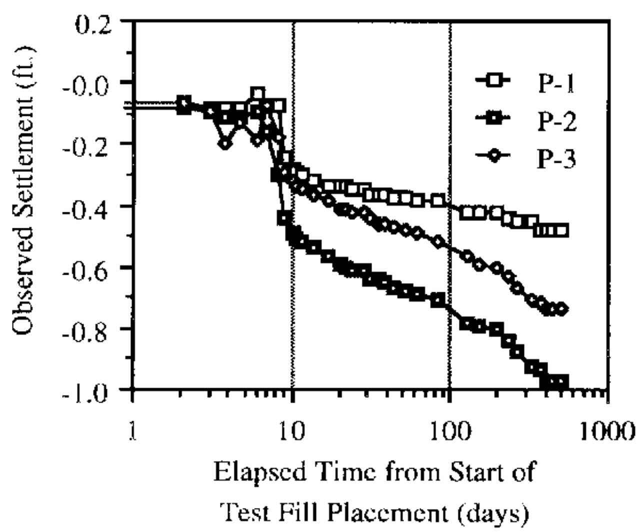

Fig. 2. Observed settlement pattern beneath test fill

Monitoring of leachate levels in open piezometers indicated that there was essentially no response to placement of the test fill. The closest well, located less than 80 feet (24 m) from the test fill, indicated a leachate level increase of approximately 0.1 feet (0.03 m) during test fill construction. However, the site received roughly 0.2 feet (0.06 m) of rainfall during the same period so even this small increase may not be directly attributable to the test fill construction.

Parameter Estimation

Various models for the compression behavior of solid waste have been proposed. For instance, Edil et al. (1990) suggest the use of the power creep law or a rheological model such as that originally proposed by Gibson and Lo (1961). However, the compression behavior of solid waste has most often been considered analogous to the compression behavior of native clay. Therefore, most field-derived compression characteristics of landfilled waste have been described in terms of primary and secondary compression pursuant to the conventional clay compression model. Fassett, et al. (1994) contains a compilation of published primary and secondary compression characteristics for solid waste..

Figure 3 illustrates the observed settlement pattern with the initial, rapid settlement identified separately from the much slower settlement component which is approximately linear on a log-time scale.

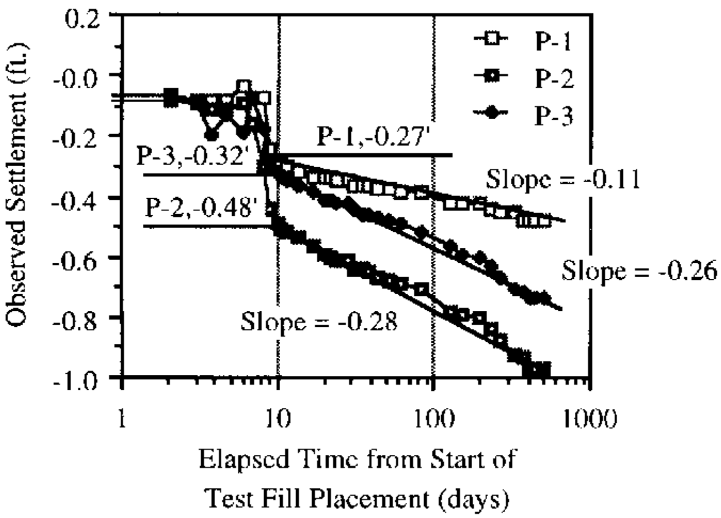

Fig. 3 Estimated values for evaluation of compression characteristics

Load-dependent Settlement. Because of the widely varying waste types received at this site, the initial compression of the existing waste likely includes an elastic, recoverable component as well as a consolidation component, leading to a permanent reduction in void ratio. It is also likely to be load dependent. Because the relative importance of these components to the behavior of different solid wastes is unknown, the usual approach is to combine all observed initial compression and term it primary settlement. This may be considered analogous to primary consolidation in natural clays and is typically modeled as

$$\Delta H = \frac{C_c}{1+e_o} H_o \log \frac{\sigma'_f}{\sigma'_o} \qquad (1)$$

where ΔH = layer compression, C_c = compression index, e_o = initial void ratio, H_o = initial layer thickness, σ'_f = final effective stress on the layer, and σ'_o = initial effective stress on the layer. Because the void ratio in a solid waste mass may be highly variable and is, in any event, unknown, it is more convenient to define the compression in terms of the primary compression ratio, CR_c, otherwise termed the modified compression index (Fassett, et al., 1994). It is defined as

$$CR_c = \frac{C_c}{1+e_o} \qquad (2)$$

The primary compression ratio was estimated by subdividing the existing landfill beneath the test fill into 15 individual layers. The calculation for layer "i" can be expressed as

$$\Delta H_i = CR_c \, H_{oi} \log \frac{\sigma'_{fi}}{\sigma'_{oi}} \qquad (3)$$

For the purpose of estimating the response of the landfill to future loading, an overall, global estimate of the primary compression ratio is desired. Therefore, the primary compression ratio is assumed constant with depth in this analysis.

The compression of the individual layers can also be summed to yield the total, measured primary settlement, $S_{measured}$. This is expressed as

$$S_{measured} = \Delta H_1 + \Delta H_2 + \ldots + \Delta H_i + \ldots + \Delta H_{15} \qquad (4)$$

Table 1 illustrates the values for estimating the primary compression ratio at settlement monitoring point P-2, located beneath the approximate center of the test fill. The initial load at the midpoint of each layer (σ'_{oi}) was based on an istimated cover soil unit weight of 135 lbs/ft^3 (2,161 kg/m^3) and the waste unit weight described above. The imposed test fill load was based on the same assumed soil unit weight and was distributed with depth using influence values taken from Fig A.6 of Perloff and Baron (1976). The final effective stress at the midpoint of each layer (σ'_{fi}) is the sum of these two components. No primary settlement was attributed to the 2-foot (0.6 m) final cover layer. This assumption conservatively results in a slightly higher estimate of the primary compression ratio in the waste.

The values in the rightmost column of Table 1 were substituted into equations 3 and 4 along with the measured value of total primary settlement from Fig 3, yielding an explicit solution for CR_c. The resulting estimate of the primary compression ratio at P-2 is 0.054. A similar analysis for points P-1 and P-3, using a slightly different distribution of the imposed load, yields primary compression ratio estimates of 0.031 and 0.037, respectively.

To summarize, the primary compression ratio for the existing industrial waste located beneath the test fill ranges from 0.031 to 0.054. This range is up to an order of magnitude less than the published results for municipal solid waste landfills, as compiled in Fassett, et al. (1994). However, primary compression ratios up to 0.46 were reported therein. Comparable data for industrial/construction waste landfills is not readily available. Two landfills for which primary compression ratios were reported in the referenced compilation received a mixture of municipal solid waste and industrial waste or construction debris. These two sites yielded primary compression ratios ranging from 0.08 to 0.21, much closer to the results derived herein.

Table 1 Valuess for Estimating the Compression Ratio at Settlement Point P-2.

Depth (ft)	σ'_{oi} lb/ft²	σ'_{fi} lb/ft²	$H_{oi} \log \frac{\sigma'_{fi}}{\sigma'_{oi}}$
2-4	382	2002	1.439
4-6	606	2161	1.104
6-8	830	2346	0.903
8-10	1054	2544	0.765
10-12	1278	2736	0.661
12-14	1502	2928	0.580
14-15	1670	3070	0.264
15-16	1751	3138	0.253
16-18	1825	3192	0.486
18-20	1924	3259	0.458
20-22	2024	3333	0.433
22-24	2123	3406	0.411
24-26	2222	3492	0.393
26-28	2321	3559	0.371
28-30	2420	3619	0.349

Time-dependent Settlement. Time dependent compression of solid waste has generally been considered analogous to secondary compression in peat. As such, it is typically modeled as

$$\Delta H = \frac{C_\alpha}{1+e_o} H_o \log \frac{t_2}{t_1} \tag{5}$$

where C_α = secondary compression index, t_2 = time at the end of a given interval, t_1 = time at the start of a given interval. All other symbols remain the same as previously defined. The secondary compression index can be combined with the unknown void ratio to describe the secondary compression ratio

$$CR_\alpha = \frac{C_\alpha}{1+e_o} \tag{6}$$

Rearranging these expressions yields

$$CR_\alpha H_o = \frac{\Delta H}{\log \frac{t_2}{t_1}} \tag{7}$$

The expression to the right of the equality is the slope shown on Fig. 3. For H_o = 28 ft. (8.5 m) of waste, the three slopes on Fig. 3 yield secondary compression ratios of 0.0039, 0.0093, and 0.010 for settlement points P-1, P-2, and P-3, respectively. These results are at the extreme lower end of the range of values reported for four different landfills containing municipal solid waste and industrial waste or construction debris, as compiled in Fassett, et al. (1994).

CONCLUSIONS

Settlement monitoring of the test fill reported herein yielded primary compression ratios for the existing industrial waste varying from 0.031 to 0.054. The resulting secondary compression ratios for the existing landfill were 0.0039 to 0.010.

It is recognized that the compression ratios estimated above will vary with location and probably with depth due to heterogeneity within the landfill. It is also recognized that these characteristics may vary with the magnitude of the imposed load. Furthermore, the applicability of the primary and secondary compression models to describe the behavior of various types of solid waste deserves further research. Other compression models, such as those described by Edil, et al. (1990), may ultimately prove to be more appropriate. Nevertheless, the results of this test fill can be used to help fill the void which currently exists in the literature regarding the compression behavior of industrial waste landfills.

ACKNOWLEDGMENTS

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