11. D.P. Wagner, D.S. Fanning, and J.E. Foss. Identification of Source Materials for Acid Leachates in Maryland Coastal Plain. In Transportation Research Record 892, National Research Council, Washington, D.C., 1982, pp. 25-28.

The contents of this report reflect the views of the authors and do not necessarily reflect the official views of the Iowa Department of Transportation. This report does not constitute a standard, specification, or regulation.

Publication of this paper sponsored by Committee on Mineral Aggregates.

Construction of a Highway on a Sanitary Landfill and Its Long-Term Performance

MICHAEL J. BURLINGAME

ABSTRACT

The short- and long-term (4-5 yr) settlements of the Interstate 85 roadway in New Jersey, which was constructed on a sanitary landfill, are presented in this paper. Published, long-term settlement behavior of other structures constructed on refuse landfills are also presented for comparison. Stabilization of the landfill was accomplished by placing a pad of granular fill between the landfill and proposed pavement and then surcharging. Measured short- and long-term settlements are compared to those calculated from formulas developed on the basis of the behavior of sanitary landfill materials elsewhere. These equations were used to make conservative predictions of the measured settlements. Stabilization of the landfill with a heavier surcharge than is minimally required appeared to greatly reduce long-term settlements. A recent visual inspection of the roadway showed that it had no structural damage and little observable differential settlement.

In recent years, virgin soils have become increasingly difficult to find in the densely populated area between Philadelphia and New York City. The high cost of land and its scarcity forces development over old building sites or on reclaimed lands, such as sanitary landfills, once believed to be too costly or even impossible to build on. These subjects are discussed in this paper. Sanitary landfills are constructed of compacted refuse that is covered with a soil layer at the end of each day's operation (1). Compaction is usually accomplished by a bulldozer, which spreads the refuse; however, a heavy trash compactor resembling a sheepsfoot roller could also be used. Dump-type landfills, by comparison, also consist of refuse but this refuse is deposited in an uncontrolled manner. In this paper, the short- and long-term behavior of a highway constructed on a sanitary landfill is presented. The methods used to determine the height of surcharge, magnitude of settlement, and rate of settlement of the landfill are also discussed.

LITERATURE REVIEW

Methods of stabilization of sanitary landfills have been quite varied; however, heavy compaction and surcharging are the most popular ones. Table 1 contains a summary of information from several selected articles that deal with sanitary and dump-type refuse fills including the methods of stabilization, landfill ages and thicknesses, and the long-term performance of the structures constructed on them. Many case histories of attempts to stabilize refuse fills have been published, but only a few were selected for presentation in Table 1. These articles show the long-term success or failure of the stabilization method.

Sowers' article (1) about construction on sanitary landfills contains an excellent overview of their behavior and the construction difficulties that may occur. It is not the purpose of this paper to repeat Sowers' work here; however, anyone involved with this type of construction should study his work as a prerequisite.

The New York State Department of Transportation (NYSDOT) has constructed at least two highways on refuse fills (2). Heavy rolling was used to stabilize the fill. First, a 30-ton compactor was used which then allowed a 50-ton compactor to move across the landfill without rutting and becoming stuck. Densification was observed to occur to depths of up to 10 ft as determined by electrical resistivity surveys made before and after rolling. The first

TABLE 1 Literature Survey: Construction on Sanitary Landfills (*1-6*)

Reference	Sanitary Landfill Thickness	Landfill Age	Landfill Loading	Method of Stabilization	Total Settlements After Stabilization
G. Sowers	25 ft	Old?	1-story wall-bearing building on 10-ft thick embankment	None	0.5 ft in 7 yr; one-half to two-thirds of this occurred in the first year.
L. Moore and M. McGrath	5-25 ft (dump fill)	4-18 yr	0.9 mi of flexible roadway on 2-3-ft -ft thick embankment	8 passes with 30-ton roller and 38 passes with 50-ton roller	0.3-0.9 ft (on roadway surface) after 5 years; resurfaced due to large differential settlements 12 yr after construction.
	40 ft	20 yr	1.0 mi of flexible roadway pavement	8 passes with 30-ton roller and 20 passes with 50-ton roller; before rolling, the fill was undercut 4.5 ft and backfilled with granular soil.	Field inspection showed pavement still has very good serviceability 14 yr after construction.
J. Chang and J. Hannon	18-20 ft	7-10 yr	10-ft thick embankment	105 passes with 50-ton roller and numerous passes with loaded mechanical scraper before attaining full embankment height.	0.7 ft (average) after 400 days.
			10-ft thick embankment	Two layers of rebar steel placed near landfill surface. 30 passes with 50-ton roller and loaded mechanical scraper.	0.9 ft (average) after 400 days.
J. P. Welsh	20-38 ft	3-4 yr	18-ft thick, 40-ft diameter embankment	20-ton weight dropped from 88 ft, up to 20 times per location in grid pattern and 5-ft thick layer of coarse granular material spread over site.	0.05 ft after 6 days vs. 0.96 ft without stabilization.
R.G. Lukas	60 ft (dump fill of burned refuse and miscellaneous materials)	3 yr +	2, 2-story buildings	6-ton weight dropped from 35 ft, 9 times per location in grid pattern.	Up to 0.42 ft after 6 months. Buildings performed satisfactorily 2-3 yr after construction.

highway constructed on a relatively young dump fill that was stabilized in this way experienced large long-term differential settlements that required it to be resurfaced. In contrast, the second highway constructed in a similar manner on an older sanitary landfill was a success. This was attributed to the difference in age and placement of the refuse. The NYSDOT has begun earthwork on another highway over a refuse fill near Albany. Similar stabilization methods are being used there; however, because of the fill's high moisture content, it has been difficult to use the heavy compactor because of rutting. A substantial undercutting of the landfill and backfilling with granular material is anticipated to provide a stable working pad for the compactor (3).

A combination of heavy rolling and surcharging was used by the California Department of Transportation to stabilize two test areas along a highway right-of-way underlain by a sanitary landfill (4). In the first area, refuse was precompressed with a 50-ton roller before surcharging. In the second area, two steel reinforcing mats were placed near the landfill's surface to reduce differential settlements, and the area was rolled briefly with a 50-ton roller before surcharging. Heavy rolling was unsuccessful, however, when water was added to the refuse as it caused the roller to become stuck and it required 3 ft of granular fill to stabilize the area. The following observations were made as a result of these tests: (a) prerolling reduced settlements by 25 percent as a result of surcharging but did not reduce the time for settlement to occur under the surcharge, (b) eighty percent of the total surcharge settlement occurred within 30 days, and (c) steel reinforcing mats provided no significant reduction in differential settlements.

The Arkansas State Highway Department has used deep dynamic compaction (DDC) to stabilize a sanitary landfill along a new alignment for Route 71 (5). It has also been used to stabilize a refuse fill along Interstate 76 in Colorado (5). This relatively new technique involves dropping a multi-ton weight onto the ground in a grid-type pattern. Compaction is accomplished by collapsing voids, compressing, and crushing the refuse, which produces a somewhat different effect than can be obtained by comparatively lighter surcharges. After four passes in an overlapping grid pattern, the ground surface was depressed 6 ft along Route 71. The long-term behavior of refuse landfills stabilized by this method are not yet available. This information is expected to be published in the near future.

Lukas (6) reported the use of pounding to stabilize foundation subgrades of two 2-story buildings underlain by 60 ft of refuse dump fill. The pounding method appears to be similar to the more recent DDC method. A pressure meter test was made after pounding revealed that the upper 15 to 20 ft of the dump fill was densified. Both buildings performed satisfactorily for 2 to 3 yr following construction. This was partly attributed to the relatively old age of the fill and that burning of the refuse was performed when it was dumped. Groundwater location is very important for this method to be successful. Water causes more rapid attenuation of the impact energy and increases pore pressures which, in some cases, prevents densification.

CONSTRUCTION OF INTERSTATE 85--BACKGROUND

Interstate 85 in northeastern New Jersey is approximately 3,200 ft long and connects the eastern end of Interstate 280 to the Newark-Jersey City section of the New Jersey Turnpike. Surcharging of the landfill began in 1977 and the roadway was paved in 1980. The area consists of a 4-lane bituminous roadway with shoulders and is divided by a large, grassy median. Interstate 85 was constructed on a sanitary landfill 5 to 15 yr old with thicknesses varying from 6 to 30 ft. Composition of the landfill can best be described as residential and industrial waste. The landfill is underlain in areas by up to 8 ft of organic silt and peat, which is underlain by dense sands and gravels.

LANDFILL STABILIZATION BY SURCHARGING

Stabilization of the sanitary landfill was accomplished by surcharging with a 6-ft thick embankment for 1-2 yr after the surcharge height was attained. Before surcharging, a 6.8-ft thick pad of granular fill was placed on the landfill surface. Heavy compaction, surcharging, and removal and replacement were all considered as potential stabilization methods. DDC was relatively new at this time and was not considered. Heavy compaction was not selected because an embankment of up to 25 ft thick was proposed along the westbound roadway. Its subgrade could not be stabilized sufficiently by heavy rolling to eliminate large settlements. Removal and replacement of the refuse was not cost-effective and there was the problem of where to dispose of the excavated refuse. As a result, surcharging and a stage-type construction scheme were selected. The settlement-time behavior of the landfill during surcharging is presented elsewhere by Sheurs and Khera (7).

Profiles of soil conditions under the eastbound and westbound roadways and the surcharges are shown in Figures 1 and 2. Refuse excavated from the eastbound roadway was used as fill for the westbound roadway. Placement of this refuse fill was accomplished in thin lifts compacted with 3 to 5 passes of a 35-ton sheepsfoot roller (7). Large objects were removed from the fill before rolling.

Surcharges were designed by the firm of Howard, Needles, Tammen, and Bergendoff, the consultant for the state of New Jersey. To determine the necessary surcharge height, the sanitary landfill's load-compression response was assumed to be similar to that of a fine-grained soil, as indicated by Sowers (1), and equations were developed that were similar to those used for such soils. The equation developed to estimate primary settlements under the surcharge load was

$$\Delta H_p = 0.35H \log (1 + \Delta p/p) \quad (1)$$

where

ΔH_p = primary landfill settlement,
H = landfill thickness,
p = initial pressure at midpoint of landfill, and
Δp = added pressure as a result of surcharge, at midpoint of landfill.

To develop Equation 1, a primary compression index $[C_c/(1 + e_0)]$ of 0.35 was determined from laboratory compression tests made on sanitary landfill material by the Public Administration Service of Chicago. A representative total unit weight chosen for the landfill material was 70 lb/ft^3 (7). The U.S. Department of the Navy (8) recommends an equation similar to Equation 1 and gives primary compression indices from 0.1 to 0.4, which is also supported by field observations at other refuse fills (9,10).

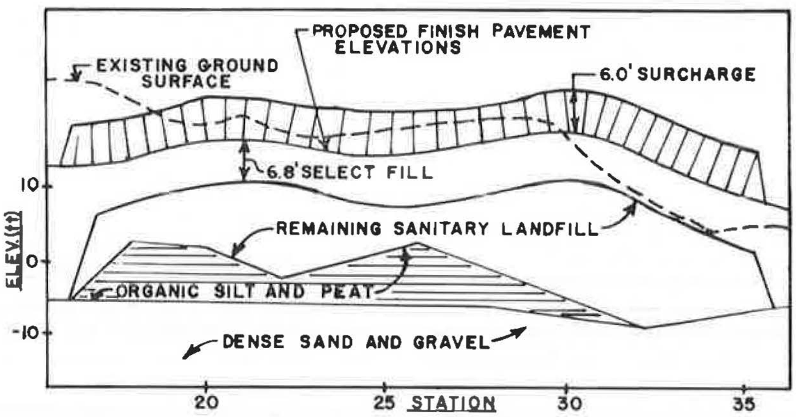

FIGURE 1 Interstate 85 eastbound profile.

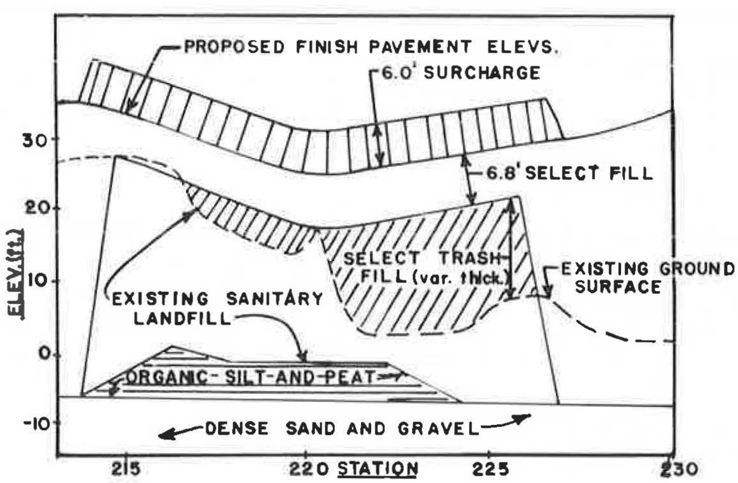

FIGURE 2 Interstate 85 westbound profile.

The equation developed to estimate secondary settlements under the surcharge load was

$$\Delta H_s = 0.10H \log (1 + \Delta p/p) \log (1 + \Delta t/t) \quad (2)$$

where

ΔH_s = secondary landfill settlement,
H = landfill thickness,
p = initial pressure of midpoint of landfill,
Δp = added pressure as a result of surcharge, at midpoint of landfill,
t = time for primary compression, and
Δt = time elapsed after primary compression has ended.

To develop Equation 2, a value of 0.10 was chosen for the secondary compression index. This was determined from the long-term field monitoring results in Sowers' article (1). In addition, this coefficient was assumed to vary semilogarithmically with pressure, in a manner similar to the behavior of organic soils. The Department of the Navy (8) recommends an equation similar to Equation 2 and gives secondary compression indices from 0.02 to 0.07, which is supported by field observations at other refuse fills (9-11).

To determine the proper surcharge height, the landfill settlement, which consisted of a 5-ft thick pad of granular fill under a 1.8-ft thick pavement section, was determined by Equation 1. A 30-ft thickness of sanitary fill was assumed. An additional height of surcharge was added to cause the secondary settlements predicted by Equation 2 for a 10-yr period to occur during surcharging. This was done to reduce secondary settlements in a manner similar to that in which organic soils are stabilized for secondary settlement. A shallow water table was indicated by the test borings, and calculations were made by using the effective unit weight of the landfill. During construction, however, groundwater was found to be deeper (7), which revealed that the total unit weight of the fill should have been used in the calculations of surcharge height. Because of this use of an effective unit weight and conservatism, the design surcharge height was twice that deemed necessary by calculations. A 2-ft surcharge would have eliminated primary settlements and an added 1 ft of surcharge would have reduced secondary settlements for 10 yr. This oversurcharging, however, should have reduced secondary settlements, which could have been larger if less surcharge was used. In the theoretical analyses of the landfill's settlements, none of the following were considered: (a) the rebound, which occurred when the surcharge was removed, (b) the recompression, which occurred when the highway was constructed, and (c) the fact that several portions of the landfill were cut or filled, which resulted in overcompressed or undercompressed landfill material.

FIELD MONITORING OF SETTLEMENTS

Settlements of the landfill were measured by 51 settlement platforms located every 200 ft along either roadway, at the centers of the proposed inner and outer shoulders and at the center of the main line roadway. Settlement platforms were founded on a 6- to 12-in. thick layer of granular fill over the landfill surface (7).

Settlements measured at the completion of surcharging versus landfill thickness are shown in Figure 3. Theoretical settlements of the organic soils underlying the landfill, from calculations by Sheurs and Khera (7), were subtracted from measured

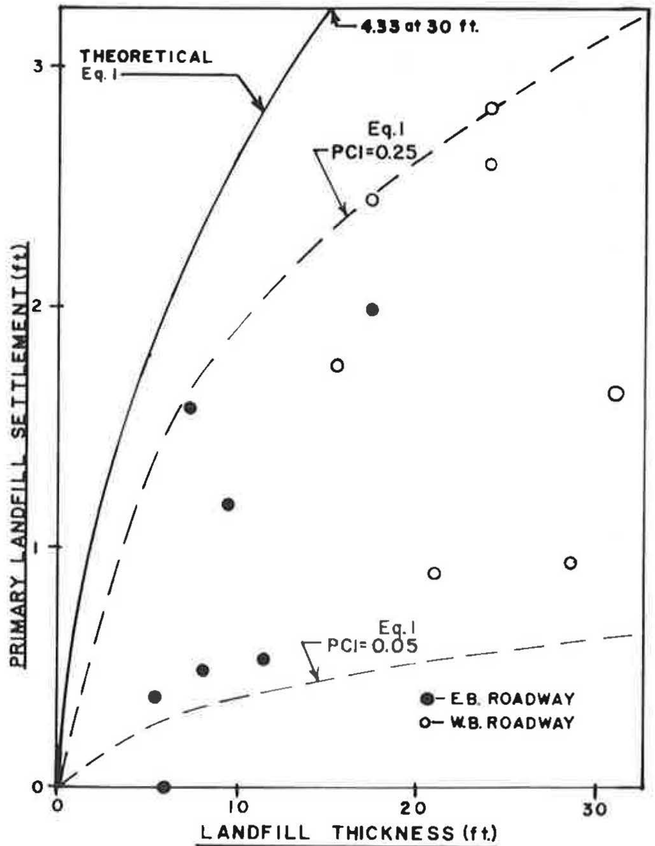

FIGURE 3 Primary landfill settlement.

total settlements to produce the points in Figure 3. The spread in the settlement data for similar landfill thicknesses is much greater along the westbound roadway. This is attributed to the landfill being thicker under the westbound roadway, which allows for greater variability in the landfill's composition and, therefore, greater variability in settlements. Figure 4, which shows the angular distortion settlements across the roadway after completion of surcharging, also indicates greater variability along the westbound roadway.

By comparing measured and computed settlements, it can be seen from Figure 3 that Equation 1 overpredicted all settlements. Engineering judgment would indicate that measured settlements should be less than computed by Equation 1, which was derived from laboratory tests on small pieces of refuse. The landfill contained large pieces of metal, timbers, and so forth, which were believed to reinforce the fill and reduce settlements.

Sheurs and Khera (7) showed that 92 percent of the primary settlements for this landfill could be bounded by Equation 1 by using primary compression indices of 0.20 and 0.16. Separate computations by the author, using the average of three settlement measurements at each roadway station, revealed that 93 percent of the settlement data could be bounded by primary compression indices of 0.25 and 0.05. The author cannot explain why Sheurs and Khera compute a lower value of 0.16. Figure 3 shows there was no settlement measured at one location. This is attributed to the use of this area as a haul road before installing settlement platforms (7).

At the completion of surcharging, maximum angular distortion values were measured in inches of differential settlement per inch of distance between two settlement platforms. These measurements are shown

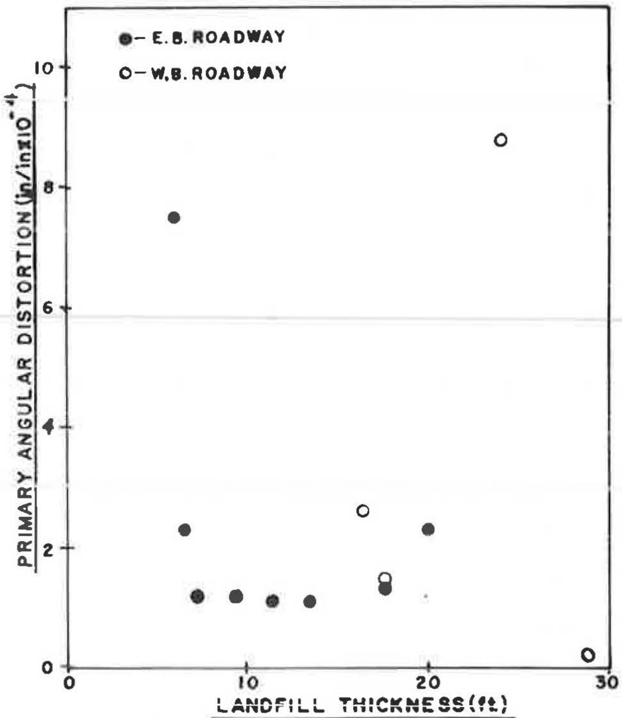

FIGURE 4 Primary differential settlement.

in Figure 4. The angular distortion values tend to remain below 0.003 in./in. and above 0.001 in./in., regardless of landfill thickness; however, several outliers are also shown.

The time for all primary settlements to occur was approximately 1 yr. This is shown in Figure 5, which presents the typical settlement time response of the landfill at two locations between 1977 (when surcharging began) and 1983 (when the most recent settlement readings were taken). This was anticipated from long-term monitoring results in Sowers' article (1).

Secondary settlements measured between 1980 (after the roadway was paved and opened to traffic) and 1983 are shown in Figure 6 versus landfill thickness. Secondary consolidation settlements of the organic materials underlying the landfill were not subtracted from measured field values. At three locations, no secondary settlements were measured. Heave measurements ranged from 0.02 ft to 0.04 ft and were measured by four scattered settlement platforms (two eastbound and two westbound). This is thought to have been caused by a rebound of the landfill that occurred when the surcharge was removed. The secondary settlements after 3 yr are still less than the rebound. The theoretical secondary settlement of the landfill versus landfill thickness, as determined by Equation 2, is also shown in Figure 6. The landfill was initially oversurcharged to try to eliminate all secondary settlements and Figure 6 shows that this was partially successful because the measured settlements were smaller. Oversurcharging was probably not fully effective because some secondary settlement is a result of decomposition and erosion in the landfill, which cannot be eliminated by surcharging. Computations show that the maximum secondary settlements could be closely bounded by Equation 2 by using a secondary compression index of 0.04. This value of secondary compression index is the average value recommended by the U.S. Department of the Navy (8). It seems reasonable to conclude from Figure 6 that it is desirable to induce large initial settlements by oversurcharging to reduce secondary settlements.

PRESENT ROADWAY CONDITION

The Interstate 85 pavement was designed for a 1-way average daily traffic (ADT) of 23,300 vehicles and a total truck percentage of 18. It was constructed with a 2-in.-thick bituminous surface course, a 4-in.-thick bituminous stabilized stone upper base course, an 8-in.-thick dense graded stone lower base course, and an 8-in.-thick sandy subbase.

Figures 7 and 8 show the roadway in late 1983, approximately 3 yr after it had opened to traffic. Visual inspections revealed that the pavement is structurally sound and shows no signs of distress. The roadway also shows no signs of differential settlement. Rideabilities on both eastbound and westbound roadways are good. Some localized depressions in the pavement occurred where settlement platforms were located in the center of the roadway. This was a result of inadequate compaction of the pavement section around the platforms during construction.

CONCLUSIONS

The following conclusions were drawn from this study:

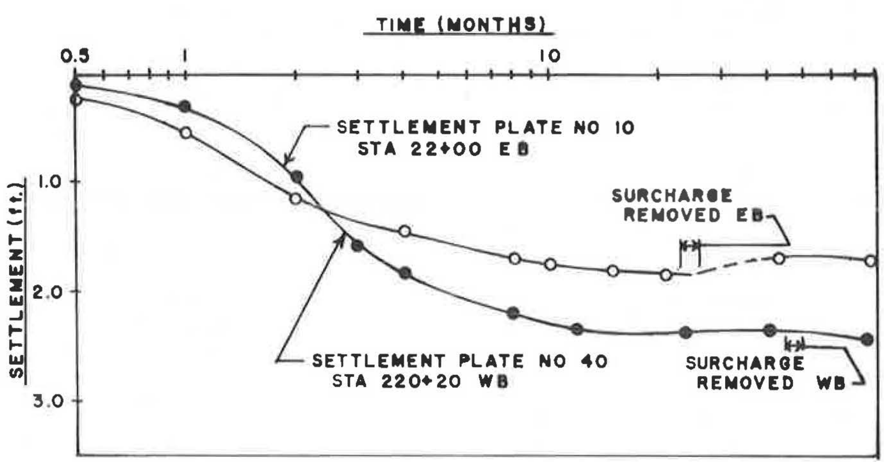

FIGURE 5 Measured settlements versus time.

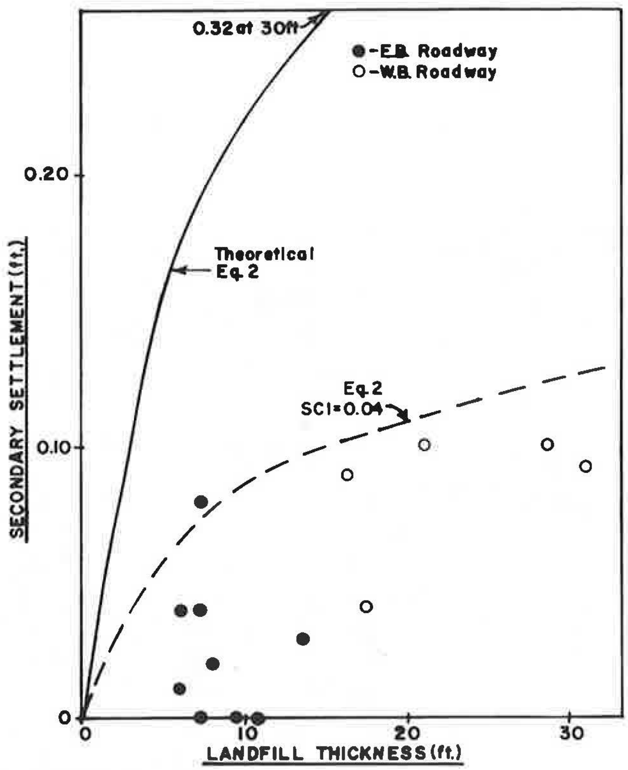

FIGURE 6 Secondary settlement in 3 years.

1. Equation 1 conservatively predicted the primary landfill settlements during surcharging.

2. The time for all large primary settlements to occur was approximately 12 months.

3. Maximum angular distortion of landfill surface measured during surcharging averaged approximately 0.0015 in./in. regardless of landfill thickness.

4. Large variations in all settlement magnitudes were measured at locations of equal landfill thickness. The thicker landfill along the westbound roadway exhibited noticeably greater variability in primary and secondary settlements than the thinner landfill along the eastbound roadway.

5. Secondary settlements were reduced or eliminated by oversurcharging, which was noted when settlements were observed to be much smaller in magnitude than predicted by Equation 2 under the roadway loading.

6. Conclusion 5 indicates the practicality of landfill stabilization methods such as super-heavy compactions (12) or DDC, which causes much larger settlements than would occur under the proposed structure, and which are effective to great depths. These methods, however, are sensitive to the location of the water table.

7. Further studies about how age, composition, and method of placement affect short- and long-term settlement behavior of refuse are needed so that different landfills can be compared. A recent study, for example, indicates a way of quantitatively determining the decomposition age of a refuse fill (13).

FIGURE 7 Interstate 85 eastbound, 3 years after construction.

FIGURE 8 Interstate 85 westbound, 3 years after construction.

ACKNOWLEDGMENTS

The author is grateful to: Ronald E. Sheurs of the Cavanaugh Construction Company of New Jersey, for much of the background information for this paper; Nicolai D. Nicu of the New Jersey Department of Transportation, for help in preparing this report; and Walter C. Waidelich of the Federal Highway Administration in Albany, New York, for initiating this study.

REFERENCES

1. G.F. Sowers. Foundation Problems in Sanitary Landfills. Journal of the Sanitary Engineering Division, ASCE, Vol. 94, No. SA1, Feb. 1968.
2. L.H. Moore and M.E. McGrath. Highway Construction on Refuse Landfills. Highway Focus, Vol. 2, No. 5, Dec. 1970.
3. M. McGrath. Verbal Communication. Soil Mechanics Bureau, New York Department of Transportation, Albany, Oct. 1984.
4. J.C. Chang and J.B. Hannon. Settlement Performance of Two Test Highway Embankments on Sanitary Landfill. New Horizons on Construction Materials, Envo Publishing Company, Inc., Lehigh Valley, Pa., Vol. 1, 1976.
5. J.P. Welsh. Dynamic Deep Compaction of Sanitary Landfill to Support Superhighway. Proc., 8th European Conference on Soil Mechanics and Foundation Engineering, Helsinki, Finland, 1983.
6. R.G. Lukas. Densification of Loose Deposits by Pounding. Journal of the Geotechnical Engineering Division, ASCE, Vol. 106, No. GT4, April 1980.
7. R.E. Sheurs and R.P. Khera. Stabilization of a Sanitary Landfill to Support a Highway. Emulsion Mix Design, Stabilization and Compaction. In Transportation Research Record 754, TRB, National Research Council, Washington, D.C., 1980, pp. 46-52.
8. U.S. Department of the Navy. Soil Dynamics, Deep Stabilization, and Special Geotechnical Construction. NAVFAC DM-7.3. April 1983, pp. 77-80.
9. S.K. Rao, L.K. Moulton, and R.K. Seals. Settlement of Refuse Landfills. Geotechnical Practice for Disposal of Solid Waste Materials, ASCE Specialty Conference, Ann Arbor, Mich. 1977.
10. A. Patel, et al. Terminal Development on a Refuse Fill Site. Geotechnical Practice for Disposal of Solid Waste Materials, ASCE Specialty Conference, Ann Arbor, Mich. 1977.
11. P. Keene. Sanitary Landfill Treatment, Interstate Highway 84. Geotechnical Practice for Disposal of Solid Waste Materials, ASCE Specialty Conference, Ann Arbor, Mich. 1977.
12. B. Clegg and A.R. Berrange. The Development and Testing of an Impact Roller. Civil Engineer, South Africa, Vol. 13, No. 3, March 1971.
13. T.J. Bookter and R.K. Ham. Stabilization of Solid Waste in Landfills. Journal of the Environmental Engineering Division, ASCE, Vol. 108, No. EE6, Dec. 1982.

Publication of this paper sponsored by Committee on Earthwork Construction.