Geotechnics of

WASTE FILLS

Theory and Practice

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Geotechnics of Waste Fills— Theory and Practice

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Foreword

This publication, *Geotechnics of Waste Fills—Theory and Practice,* contains papers presented at the symposium of the same name held in Pittsburgh, PA on 10–13 Sept. 1989. The symposium was sponsored by ASTM Committee D-18 on Soil and Rock. Dr. Arvid Landva, Professor of Civil Engineering, The University of New Brunswick at New Brunswick, presided as symposium chairman. He was also editor of this publication, along with G. David Knowles, Malcolm Pirnie Inc., Albany, NY.

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INTRODUCTION

The purpose of this symposium was to explore the geotechnical properties and behavior of waste fill materials and to compile them into one volume that could serve as a reference text on a subject that is not widely addressed in accessible literature.

The symposium was sponsored by ASTM Committee D18, Subcommittee D18.14, Geotechnics of Waste Management. STP 1070 will serve as a guide to Committee D18 members in their future efforts to address the problems of landfill geotechnics, such as stability of slopes, settlement of fills and groundwater (leachate) flow.

The term "waste fill" covers a wide range of materials, from mineral fills contaminated with relatively small amounts of organic or vegetal debris through woodwastes and various types of tailings and slimes, to domestic and industrial refuse. Two categories of fill have purposely been excluded from this symposium: tailings and hazardous wastes. Also, we excluded liners, artificial or natural, from the list of topics. All these three topics have been widely covered in previous conferences, symposia and numerous papers.

Our involvement in the geotechnics of waste management has shown that more geotechnical attention should be paid to such aspects as placing methods, field and laboratory sampling and testing, classification and in-situ improvement methods. These are the topics that we sought to explore at this symposium, and the 23 papers presented here provide a valuable data base for the solution of problems pertaining to those topics.

The symposium was divided into four sections:

Section I - Landfill investigations, design, construction and closure (seven papers)

Section II - Stabilization, compaction and consolidation (six papers)

Section III - Stability and settlement analysis (six papers)

Section IV - Case histories (four papers)

LANDFILL INVESTIGATIONS, DESIGN, CONSTRUCTION

Morris and Woods emphasize the significant changes caused by large settlements after closure of landfills. These changes may negate contouring and drainage plans. Settlements can be predicted, but local regulations may not allow steeper slopes, even if temporary. Case records indicate necessity of perimeter ditches, proper compaction, daily covers, retaining structures for ash fills, and limited size of working areas. A computer program for primary and secondary settlements is given.

Orr and Finch report on case studies of the effects of earthquakes on landfills. Their studies pertain to the October 17, 1989, earthquake in the South Bay area east of Santa Cruz, California. They find that the two most important factors are acceleration and duration rather than the more commonly used magnitude. The properties of refuse may dampen or attenuate the effects of earthquakes.

Lawrence and Boutwell claim that electro-magnetic (EM) surveys have much to offer. They describe a statistical technique they have developed to interpret EM data: a multivariate regression prediction (MVRP). Three cases are described, and it is concluded that the correlation is satisfactory. The MVRP-EM method is most practical when there are time or budget restraints. It is extremely cost-effective for reconnaissance work.

Gifford et al. report on a geotechnical investigation of an Albany, New York, landfill to be used as a building site by the City. The investigation is laid out with due regard to architectural and structural requirements. The foundation layout is designed to minimize settlements or to allow for them. Settlements are predicted on the basis of the nature of the landfill materials and a comparison plot of case records of long-term settlement in landfill.

Sharma et al. discuss various methods of dynamic laboratory and field tests, including applicability. They describe the down-hole geophysical method as used at a landfill site in Richmond, California. The site is underlain by the San Pablo Bay Mud. The down-hole method was chosen because only one boring is required at each location, which makes this method cost-effective. Dynamic shear moduli and Poisson's ratios are reported for refuse and for the Bay Mud.

Huang and Lovell present a very thorough geochemical and geotechnical analysis of several sources of bottom ash (incinerated refuse). This paper constitutes an excellent data base for researchers and users.

Landva and Clark describe a comprehensive field and laboratory investigation of various waste fills in Canada. A classification system is proposed, and index tests and properties are discussed and presented. Also described is equipment developed for the testing of waste fill materials, and geotechnical properties are reported and discussed.

STABILIZATION, COMPACTION AND CONSOLIDATION

Briaud et al. describe a new test (the WAK test) they have introduced to check soil stiffness improvements after dynamic compaction. The WAK test appears to be at a preliminary stage, but it also appears to be a promising test that can be used as a very fast quality control test on dynamic compaction jobs. The authors also present their proposed curve fitting technique and stiffness determination.

Acar et al. present a comprehensive study of boiler slag. They discuss the results of laboratory studies and field compaction tests conducted to evaluate its engineering and field compaction characteristics. This paper represents another valuable data base for the geotechnical behavior of incinerated refuse. Recommendations are given for the optimum design and construction procedures for slag fill.

Davies discusses the reject resulting from the reworking of colliery waste tips and their use in landfill. The mixing of the coarser reject with tailings presents problems for compaction, but these may be alleviated by the addition of cement. The author discusses the properties of the cement-stabilized waste and conclude that the stabilizing effects diminish with increasing effective stress and water content.

Koutsoftas and Kiefer report on a dynamic compaction study of a mine waste spoil. They find significant improvements in geotechnical properties to depths of 9 to 12m after compaction with a 16 tonne weight from 20m height. Most of the improvement occurred during the later phase of treatment. The authors point out that the depth of improvement is limited and that another cost-effective and rapid method of improving waste fills is preloading.

Soliman presents the results of extensive tests on lime fixed flyash and FGD sludge. His conclusions are of considerable interest: the strength of the fixed material increases with time, with density, and with the salinity of the water. Hence the material could be compacted into blocks and dumped in the ocean to create a reef.

Martin et al. report on a study to stabilize acidic hydrocarbon sludge lagoons by microencapsulating it in a matrix of clay, which is neutralized and cemented with a lime-flyash pozzolanic mixture.

STABILITY AND SETTLEMENT ANALYSES

Mitchell et al. draw attention to the potential failure surfaces along lining system interfaces and their possible control of the overall stability of hazardous waste fills. Residual friction angles as low as 5° are reported. They carry out a 3-D stability analysis of a slope failure in a hazardous waste repository and conclude that, even though it is possible to plan filling operations on the basis of adequate factors of safety, this may presently be difficult because of a lack of a suitable 3-D analysis method and because of uncertainties about seismic effects.

Edil et al. outline an analysis approach for the settlements of refuse along the lines of previous analysis methods used for peats and organic soils. They compare their analytical results with actual field measurements and conclude that refuse settlement can be modeled satisfactorily. Another interesting conclusion is that primary compression is largely completed during the filling operation; secondary compression is more evident once filling has stopped.

Singh and Murphy evaluate studies of shear strength properties and settlement characteristics of refuse and discuss the inadequacy of the Mohr-Coulomb theory to account for the large yet non-catastrophic deformations in refuse. They conclude that a slope failure may not be the most critical aspect, but rather settlement of the refuse and bearing capacity of the foundation soil. They draw attention to the lack of knowledge of the dynamic strength characteristics of refuse.

Siegel et al. report on a comprehensive geotechnical investigation and slope stability study of an instrumented landfill in Monterey Park, California. They conclude, among other things, that CPT's are not useful in refuse, other than to identify weak zones, and that direct shear test results should be used with caution, depending on the size of the apparatus. Their tentative calculated factor of safety of 1.2 is subject to further studies in view of the uncertainties in determining refuse strength and the potential for refuse strength to change with time. One important conclusion from an interpretation of the 1987 Whittier Narrows and the 1988 Pasadena earthquakes is that landfill can withstand moderate earthquakes with only minor repairs.

Tieman et al. draw attention to the future needs for piggyback additions to landfills and illustrate some of the benefits of vertical piggybacking. But they also point out that such expansions can be complicated to design and construct. A case record is described where subgrade reinforcement and slope stability improvement were required. Each piggyback expansion will be unique with its own set of design and construction considerations.

Duplancic presents a geotechnical evaluation of deformation monitoring data on a hazardous waste landfill. The data indicate that the landfill is deforming similarly to earthfill dams. Deflections are larger in the fill zone, but almost negligible in rock and native clay zones. The analyses presented show that standard geotechnical techniques can be used to monitor the performance, and standard geotechnical computational methods can be used - with care - for landfill stability analyses and deformation assessment.

CASE HISTORIES

Belfiore et al. present a conventional soil mechanics approach to sludge fill investigations, emphasizing the necessity of adapting and integrating conventional geotechnical tools with the aid of a comprehensive performance monitoring program. The key objective was to study the effects of compaction methods on an improvement of the landfilling operations. On the basis of the results of the two case history studies, they conclude that the high drained strengths measured in the laboratory are confirmed by the long-term behaviour of sludges landfilled with slopes up to 35° without any stability problems. Also their tests and measurements show the beneficial effects of waste compaction, such as significant volume reduction and improvement in strength and deformation properties.

Hinkle describes the use of a 30m deep closed landfill as a marine container storage. He demonstrates that landfill property can be reclaimed and put to profitable use. One important aspect is a proper seal, and the design and construction of this is described in detail.

Oakley studies the use of the cone penetrometer (CPT) in a chemically stabilized waste fill. On the basis of field observations of settlements in two fills, he finds that settlements calculated from CPT data are reasonably close to those measured. Calculated rates of settlement are generally within about $\pm$ 50% of those measured.

Coduto and Huitric monitored settlement and horizontal movements at different depths within a sanitary landfill. They found, following two years of monitoring, that vertical strain rates are independent of depth while horizontal movements on slopes are greatest near the surface and diminish with depth. No permanent displacement occurred during a Richter magnitude 6.1 earthquake.

CLOSURE

A broad spectrum of topics have been addressed by the contributors to this volume. Settlement is analysed in five papers, stability of slopes in two, field and laboratory investigations in seven (demolition landfill, bottom ash, refuse, boiler slag, and lime-fixed flyash and FGD sludge). The effects of earthquakes are outlined in three papers, and field pilot tests (MVRP-EM survey, down-hole geophysical, CPT) in four papers. Stabilization by different methods (cement, dynamic compaction, lime-fixed flyash, clay and lime-flyash pozzolanic mixture, compaction) are described in five papers. Other topics addressed are the inapplicability of the Mohr-Coulomb criterion, the possible non-criticality of slope stability in regular landfills (compressibility of refuse and bearing capacity of the foundation soil are perhaps more important), the uncertainty of the strength characteristics of refuse, precautions required when designing and constructing piggyback additions to landfills, and the importance of designing and constructing a proper seal on a landfill to be used as a building site.

With all these topics addressed by experts in their respective fields, this volume should be a useful handbook for design and construction on and in the very large number of closed landfills in North America and elsewhere.

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Landfill Investigations, Design, Construction

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SETTLEMENT AND ENGINEERING CONSIDERATIONS IN LANDFILL AND FINAL COVER DESIGN

REFERENCE: Morris, D.V. and Woods, C.E., "Settlement and Engineering Considerations in Landfill and Final Cover Design," Geotechnics of Waste Fills - Theory and Practice, ASTM STP 1070, Arvid Landva and G. David Knowles, Editors, American Society for Testing and Materials, Philadelphia, 1990.

ABSTRACT: Design of municipal landfills for closure is complicated by the large settlement that normally takes place for long periods of time after abandonment. This means that landfill slopes can change significantly with time, negating careful contouring and drainage provisions. It is possible to try and forecast this, but regulatory considerations (for landfills of specific depths especially) may hinder adequate design for full expected post-closure settlement. Preferred management techniques are outlined, and specific recommendations made for maintenance and settlement.

KEYWORDS: landfills, municipal waste, fill closure, waste fills, fill settlement.

Municipal landfills are designed with many constraints, both technical and legal, which cover not only operation, but also impact significantly on final closure. Poorly designed or operated landfills are often more likely to show signs of distress after abandonment, when little emphasis is placed on control and monitoring, than during operation, when significant attention is paid to safe compliance.

One of the most awkward technical post-closure considerations is the large amount of fill settlement that can take place for many years after abandonment. Predicting so much settlement is difficult analytically, as municipal fill undergoes large amounts of secondary consolidation, not easily incorporated into traditional settlement calculations. Moreover the regulatory situation may make it difficult legally to develop a closure plan that will continue to perform satisfactorily for an indefinite period.

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Regulatory Considerations

Frequently the most intractable problem is administrative, in so far as final slopes are usually severely prescribed by regulation, and are in many cases not permitted to be formed at slopes that might be indicated by strict geotechnical design considerations. Regulatory practice in Texas (and many other states) is to classify municipal landfills according to whether storage is above or below ground. The operating plan of landfills licensed for below ground disposal will generally specify below-ground disposal only. As a result potential problems arise in the geotechnical design of the final cover, since this must be sloped to increase the runoff coefficient and minimize infiltration. However the slope of the final cover of below-ground landfills is normally limited by permit, in Texas to between 2% and 6% at the time of closure, irrespective of the recommendations of engineering analysis. In some states the maximum slope is 5%.

The situation is complicated further by the fact that many landfill operators choose to ignore the compression (or consolidation) of the municipal waste during operation, because they stand to benefit from doing so. Some state taxes are levied in theory on the basis of a unit rate per mass of deposited fill (e.g. 5¢ per ton). However rigorous weighing of every full and empty truckload is uneconomic, so in reality long-term measurements are made (usually by surveying) of deposited volume. These are then converted into an equivalent mass of fill, using an assumed density. In Texas this is currently in the range of 500 to 600 kg/m^3, which is generally a significant underestimate of actual municipal waste densities, particularly after some compression has taken place or under significant depths of overburden. This means that the deposited tonnage computed in this fashion is normally less than actually stored. More realistic values of density should undoubtedly be used by landfill operators, but since it would almost certainly result in a higher tax assessment, this represents a positive disincentive to support more accurate analysis. It would be preferable if taxes were levied on a strictly volumetric basis, thereby encouraging compaction.

Three case histories are discussed that demonstrate the consequences of improper design and operation, as follows:-

Case A. A municipally owned landfill that served approximately 70,000 people was closed approximately fifteen years ago. The location had an average rainfall of 1.25 m per year and a pan evaporation rate of 1.7 m per year. The landfilled area was about 150,000 m^2 and was a "below ground" landfill that utilized an area method of construction. The initial slopes were approximately one percent. Three years after closure 80,000 m^2 of the landfill cover would briefly hold ponded water after a rain. The water did not stay long because there were cracks or fissures open enough to expose the solid waste below the final cover. A portion of the final cover had settled below the original ground level. Leachate springs formed at the interface of the natural ground and the final cover and springs were almost continuous around the perimeter of the landfill. Leachate flow continued during dry periods; however, flow rates increased during wet weather.

The leachate flow rate was higher than could be accounted for assuming a zero runoff coefficient over the landfilled area. This caused a concern that there might be a groundwater spring under the landfill. Closer examination showed that the source of excess leachate was from an additional area of 150,000 m^2 that discharged runoff onto the landfilled area and into the solid waste through the portion of the final cover that had settled below the natural ground level. When this source of water was eliminated the leachate flow became intermittent. Fortunately, the city owned enough land adjacent to the landfill, that they were able to rebuild the final cover without too much difficulty to a two percent grade, at which point leachate flow ceased. Within another three years, however, the repaired cover had again settled enough to cause further ponding, open fissures and new leachate flow. The final cover remained a high maintenance item for nearly ten years.

The mistakes made during the operation of this landfill that contributed to the difficult closure included:

* no perimeter ditch to prevent runoff water from adjacent areas from reaching the landfilled area.

* below ground disposal only with no berm around the landfill area. The completed final cover had a slope of only about one percent which caused the final cover to be roughly parallel to the original ground. The general settlement caused the cover to sink below the natural grade in some places.

* the solid waste in the landfill was not compacted properly causing a great deal of differential settlement. The differential settlement caused the final cover to rupture in many locations.

* the final closure was not given appropriate priority during the operation of the landfill.

Case B. A privately owned municipal landfill that served approximately 30,000 people was closed approximately two years ago. It was in an area with 0.81 m of precipitation and 2.0 m of pan evaporation annually. The landfilled area was approximately 100,000 m^2, and had both "below ground" and "above ground" disposal.

Approximately three years before closure none of the landfill had received final cover, the slopes were less than two percent, and ponding water was extensive when it rained. Fortunately, no leachate was ever observed at this landfill. The solid waste was not being properly compacted. At this point a closure plan was developed for the landfill that included the purchase of compaction equipment, increasing the slope on the final grades to six percent, installing monitoring wells, and placing the final cover over completed areas as soon as they were finished.

In some areas that were being filled there was as much as 6 m of poorly compacted solid waste. Some of these areas settled as much as 1.5 m when solid waste and final cover were added. Several areas involving a total area of about 20,000 m^2 had to be refilled three times to hold a six percent slope until the landfill was closed.

Within two years after closure the six percent slopes have been reduced to about four percent due to settlement. No ponding has occurred. No leachate has been observed.

Case C. An industrial landfill is located in an area with 1.0 m of precipitation and 1.8 m of pan evaporation per year. It is an "above ground" landfill with a high plasticity clay liner and no berm, and is a "monofill" containing only ash and a final cover of a low plasticity clay.

The clay liner was constructed over the natural grade. The slopes of the natural ground ranged from two to four percent with several dry drainage channels. Only minor modification of the existing topography, including the channels, was undertaken when the liner was constructed. Perimeter ditches prevented surface water from entering the landfill area.

During construction immediately after a rain approximately 40,000 m^3 of ash washed out of the landfill. Fortunately it was captured in the surrounding sedimentation ponds.

The mistakes made in this operation included:

* No retaining structure was provided for this landfill.

* Did not use daily cover