Summary of Treatments for Highway Embankments on Soft Foundations

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This paper summarizes the procedures that have been developed in the New York State Department of Public Works for the evaluation and solutions of foundation problems involving highway embankments.

Early in the line selection stage of design, the critical soils areas are located and sufficient data obtained to determine the soil properties. By establishing close coordination between the location engineers and soils engineers, it is often possible to avoid critical soils problems having expensive solutions by minor shifts in alignment. The most economical and satisfactory solution to an embankment foundation problem is determined not only by the soil properties, but also by consideration of construction time, right-of-way, location of project, cost and availability of construction materials, and highway geometrics. Experience with various methods of treatment is described.

•THE BASIC function of a highway engineer is to design, construct and maintain a satisfactory and adequate highway system utilizing the most economical methods available. In the New York State Department of Public Works organization the Bureau of Soil Mechanics is responsible for providing the location, design, and construction engineers with complete information on the location of critical foundation areas, the type of treatment required to provide a stable embankment foundation, and the necessary treatment details to be incorporated into the contract documents.

New York State has a great variety of soil deposits that present embankment foundation problems. Tidal marsh deposits containing organic silts and clays are found in the lower Hudson Valley and in western Long Island. Many of the major river valleys in upstate New York were at one time large postglacial lakes. Varved silts and clays up to 200 ft in thickness now fill these former lake locations. In central New York, near Syracuse, these silt and clay deposits are often found under a surface cover of peat and soft marl. In western New York, the former shore lines of Lake Ontario and Lake Erie reached inland beyond their present boundaries leaving extensive lacustrine deposits of silts and clays. The St. Lawrence Valley and Champlain Valley on the northern boundary of the state contain deposits of sensitive marine clays. All over the state, including the upland areas, small postglacial lakes or ponds existed and have been subsequently filled with highly compressible peat and muck.

A combination of a large highway construction program and extensive areas of soft soil deposits presents a great number of embankment foundation problems. Each year the Bureau of Soil Mechanics investigates 30 to 50 major foundation problems. This paper outlines the procedures that have been developed over the past 20 years to provide, in the highway design, the most economical and satisfactory solution to these problems. The proper time to solve all the details of foundation problems is during the design phase. If this work is left until construction, the cost of treatment will be higher and the results most likely will not be as successful.

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The fundamental requirements of any treatment are (a) to provide a method of constructing an embankment that will be stable against lateral movement or shear failures of the foundation soil during and after construction, and (b) to eliminate all post-construction differential settlement of the foundation soil that would be detrimental to pavement performance and that would make the riding characteristics of the roadway dangerous.

Every embankment foundation problem usually has more than one solution. However, the most economical and satisfactory solution depends upon a careful evaluation of the following five factors:

1. Characteristics of the foundation soil—Sufficient subsurface investigations and laboratory testing must be conducted to determine the extent, depth, and the strength and consolidation properties of the critical layers.

2. Highway alignment and grade requirements—Often expensive foundation treatments may be avoided by a slight line shift to avoid a limited area of poor foundation conditions. Similarly, a decrease in grade line, when possible, may diminish the stability and settlement problems and the cost of any necessary foundation treatment.

3. Available construction time—The most economical method of treatment often is the use of time to allow the foundation soils to consolidate and gain shear strength. Combinations of controlled rate of construction, surcharge treatment, and waiting periods are used for this method of treatment. The usual construction contract runs for about two years. Stabilization periods of from six to nine months may be used on portions of a project with little inconvenience or delay to the contractor.

For projects where embankment foundation problems exist over a major part of the area, consideration may be given to stage construction by letting a separate grading contract followed by a paving and structures contract after sufficient stabilization time has elapsed.

4. Construction materials—The selected method of treatment will often depend upon the availability and cost of construction materials. For example, a project involving unsuitable material excavation of swamp deposits requires a suitable granular material to provide a stable underwater backfill. When a highway location is in mountainous country there usually will be excess rock excavation available for underwater backfill at a reasonable cost. However, in an urban area the cost of granular underwater backfill may be considerably more expensive. On urban highway projects, excess excavation often is not available, since the required fills usually exceed the material available from cuts. Also, many urban areas are adopting regulations restricting development of gravel pits and excavations making it necessary to import material from distant sources for the backfill material at a considerable cost.

One solution for embankment foundation stability problems is to construct the fills with a lightweight material, such as slag, cinders, or lightweight aggregate obtained from expanded shale. The use of this material depends upon its availability and cost, including transportation.

5. Location of project—The cost of right-of-way often influences the type of treatment selected. The use of stabilizing berms may be impractical due to the high cost of right-of-way in an urban or industrial area. The effect of the highway construction upon adjacent structures, utilities, highways and railroads must be considered. Embankment settlements may also cause detrimental settlement to adjacent facilities unless protective measures are incorporated into the highway design.

SOILS INVESTIGATION PROGRAM

The soils investigation program is planned so that the major foundation problem areas may be investigated and evaluated early in design in order to assess the magnitude of the problems involved. This policy not only applies to highway embankment foundation problems, but also to structure foundations and highway cuts. For critical foundation problems, the cost of treatment may become so large that the designer may desire to compromise on other design requirements in order to reduce or eliminate the foundation treatment costs.

For example, the preliminary alignment considered for a typical Interstate highway crosses a swamp area approximately 1000 ft long. An exploration program is made to determine the subsurface soil profile and to evaluate the soil properties. The results show that the treatment will require excavation of the unsuitable material and replacement with granular borrow to an average depth of 20 ft. Preliminary estimates indicate that the cost of providing a stable foundation to original ground surface will be in the order of $350,000. With this information, the designer determines if the proposed line can be moved to areas of more favorable soil conditions. Concurrently, additional explorations are conducted on possible alternative alignments to determine the foundation conditions and the economics of treatment. Frequently hundreds of thousands of highway construction dollars can be saved by using this exploration procedure and by working closely with the designer in the preliminary stages of a project. This coordination also eliminates the costly and frustrating situation of scrapping completed designs because of critical foundation conditions which are "discovered" after the design is nearly complete.

In order to provide the designer with the necessary information at the proper time, the following procedures have been adopted for major highway projects:

1. Terrain reconnaissance survey—During the initial line selection study, the boundaries of the major soil deposits are determined by field inspection and by a study of aerial photographs and agricultural soil maps. A summary of highway design considerations is made based upon a general knowledge of the engineering properties of each particular soil type and the past experiences in highway construction and pavement performance on each soil type. Reports on the detailed procedures of terrain reconnaissance surveys used by the New York State Department of Public Works have been published previously (1, 2, 3).

2. Preliminary soils investigations and design—This phase of the exploration program is usually confined to the soil deposits where major embankment foundation problems are expected. Sufficient subsurface explorations and testing are required to develop the soil profile, and the strength and compressibility characteristics of each soil stratum. This allows the soils engineer to determine the general type of treatment required and to prepare a preliminary cost analysis. A conference is arranged with the designer to determine the most practical solution. The selected solution may be influenced by non-soil factors such as highway alignment, grade requirements, anticipated time for construction, right-of-way costs and limitations, land usage, available construction materials, and design class of highway. Often, the result of comparing all the factors involved is a shift of the line to an area with better soil conditions or a decrease in the grade line to improve embankment foundation stability and settlement problems. This type of approach insures the most economical solution to a foundation problem while assuring that all other requirements of the highway design are satisfied.

3. Final foundation design—Additional explorations, testing and analyses are made to determine the details and limits of the foundation treatment. Sufficient drawings, special notes and specifications are required for the contract documents, so that the desired end result of the selected treatment may be achieved. A description of the foundation conditions and the general treatment has been found to be effective in giving the contractor and supervising engineer an understanding of the purpose, desired results, and methods of payment for the treatment.

METHODS OF TREATMENT

This section discusses the various methods of treatment that may be used to provide a stable foundation for the highway embankment. The selected method, or combination of methods, not only depends on the soil properties, but upon an evaluation of all the other design factors discussed previously.

Removal of Soil by Excavation

This treatment is used for swamp deposits that are predominantly organic. A typical peat or muck may contain, by volume, nine parts water and one part organic and inert soil. This material has a very low shear strength and is highly compressible under embankment loads. It is very difficult to stabilize this soil in place satisfactorily so as to obtain a smooth pavement for high-speed traffic. Explorations through old country and town roads constructed across peat deposits indicate that extensive maintenance has been required in order to keep the roadways above high water. As much as 10 ft of asphaltic concrete has been found on several old roads crossing swamps. This type of settlement and maintenance cannot be tolerated on modern highways.

Sufficient explorations should be taken to indicate the depth of excavation on the contract cross sections and to predetermine quantities. A contour plan of the depth of unsuitable material is made available to the project engineer for large projects where the swamp bottom is irregular.

The width of excavation should be such that the embankment slopes will not be unstable resulting in settlements or lateral movement of the roadway shoulder. Typical sections for various cases of excavation are shown in Figure 1. Some designers become concerned that the stability of the backfill against the adjacent peat or muck may be critical and that the backfill will spread and crack. A circular arc stability analysis

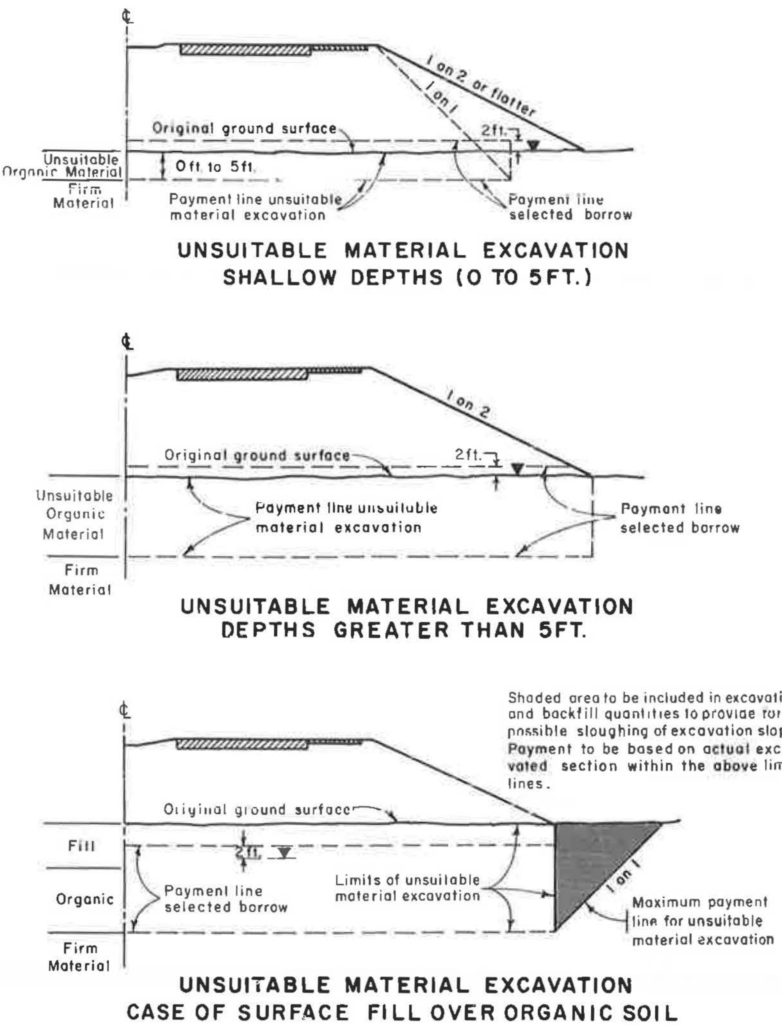


Figure 1. Typical sections for excavation of unsuitable material.

or sliding wedge analysis often shows that this condition should be critical. However, experience on many projects has indicated backfill with vertical side slopes underground will be stable against this type of movement. A possible explanation is that the organic soils supply more passive resistance against lateral movement than the available methods of analyses indicate. Also, explorations on several completed projects show that the backfill below ground surface remained in a vertical plane and practically no bulging of the backfill occurred.

On one project where the depth of underwater backfill was large as compared with the fill height above ground, cracks appeared in the embankment. The area over the crack was surcharged in order to force displacement. However, no displacement occurred and the surcharge apparently served to increase the intergranular strength of the backfill and increase the stability of the area since no post-construction distress appeared.

On large excavation projects, disposing of unsuitable material may be a problem. The specifications should indicate that the material is to be placed in spoil banks outside the right-of-way or used in construction to flatten slopes. Soils with high organic contents will shrink over 50 percent on drying.

During construction, the vertical excavation slope in peat or muck will be stable for several days before backfilling, provided that the excavation is kept full of water. When the water has been pumped out of excavations, the sides have caved in, resulting in needless additional excavation. This is a basic slope stability problem. When the organic material is under water, it has a submerged unit weight of 5 to 10 pcf. When the excavation is drained, the saturated unit weight of the adjacent soil increases by approximately 62.4 pcf from the submerged weight. The increase in effective weight greatly decreases the stable height of excavation. This fact is often overlooked by engineers in the field. Frequently, engineers require the contractor to lower the water level so that the excavation may be inspected. When this is done, sloughing problems will develop on the sides of the excavation.

For fills with widths of the order of 200 ft, it is not practical to carry the entire width of backfill across the swamp at one time. The usual procedure is to progress the backfill in strips 50 to 70 ft wide. Advancing fill fronts are skewed away from the completed portions to help eliminate the possibility of unsuitable material being entrapped between the fills. This method has been used successfully on several projects with no adverse post-construction settlements at the boundary between adjoining backfill strips.

Frequently, the unsuitable organic soils are underlain by very loose silt or soft clayey silt that appear to be unsuitable material for an embankment foundation when uncovered by excavation equipment. However, when backfill is placed on this material, it will consolidate rapidly and provide an adequate foundation. A very difficult problem to control in the field is the problem of over-excavation when the underlying soil is loose or soft. In order to control this practice, which has resulted in very costly overruns of excavation and backfill quantities, the following item is included in the New York State Department of Public Works Construction Specifications for excavation. "The Contractor shall remove all muck, peat and other organic swamp deposits to the payment limits as established by the Engineer prior to such excavation. No reimbursement will be made for any excavation in excess of such payment limits." The purpose of this clause is to determine the properties of the questionable material before large quantity overruns develop. A fast method is to obtain samples from test pits or auger holes ahead of the excavation and determine the moisture content of the questionable soils. The moisture content and soil description can be correlated with strength and consolidation properties from testing on similar swamp soils.

Figure 2 shows a moisture content correlation chart based on the laboratory test results from many types of swamp soils. This chart is often used to obtain the necessary information for a field decision on excavation depths that have not been determined by previous explorations. An important limitation of this chart is that it only applies to swamp soils where the precompression loads are low and the soils are soft or loose. For soils outside of swamp areas, the strength and consolidation characteristics may have been modified by precompression or soil structure and the correlation will not apply.

CHART FOR ESTIMATING SUITABILITY OF SOILS IN SWAMP DEPOSITS FOR HIGHWAY EMBANKMENT FOUNDATIONS BASED ON SOIL IDENTIFICATION AND MOISTURE CONTENT

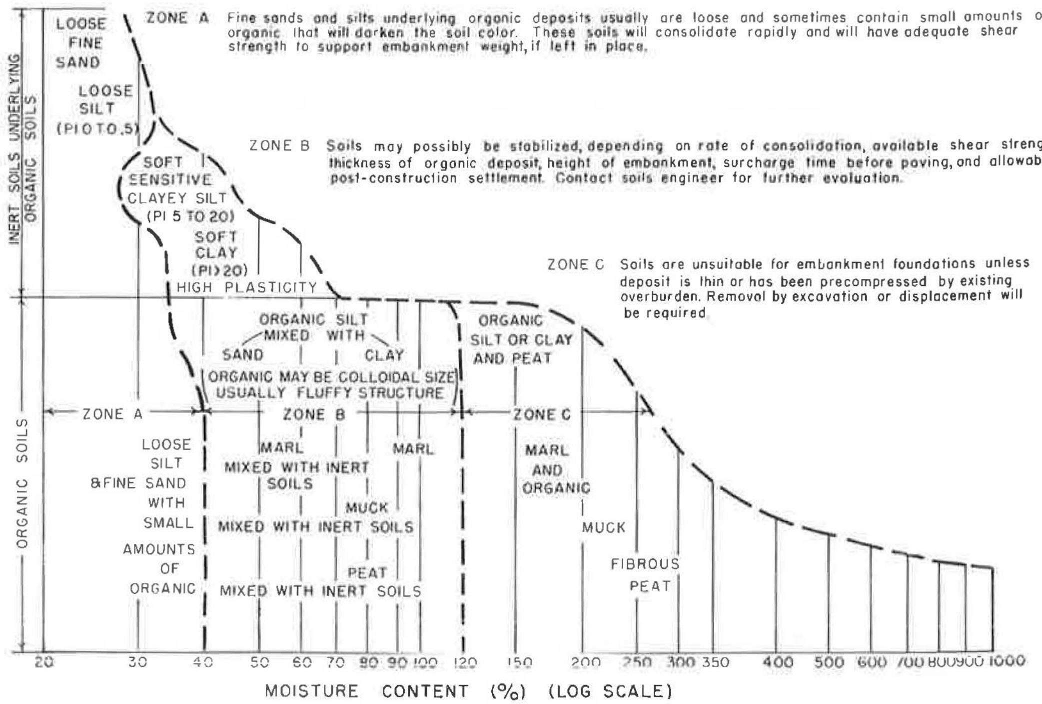


Figure 2. Moisture content correlation chart.

The following case history illustrates the economics of overruns on unsuitable material excavation and replacement. The north approach roadways to the Throgs Neck Bridge in the Borough of Bronx, New York City, were located in a shallow tidal swamp about 1½ mi long. Soil conditions consisted of 5 ft of peat mixed with organic clay underlain by 4 ft of soft clayey silt over firm sand. Excavation and replacement of the surface organic deposit was required. However, in the initial excavation work, the underlying clayey silt was also removed because it appeared to be very wet, soft, and unsuitable material for a foundation. Previous laboratory testing, and analyses, had indicated that this material would consolidate rapidly and provide a satisfactory foundation. It was decided not to excavate the soft clayey silt. If this over-excavation had been allowed to continue, the overrun in cost for excavation and backfill for the project would have been over $800,000.

Another application of the problem of unsuitable material removal involves the stripping of sod and topsoil under embankments outside of swamp areas. This material, which usually contains a small amount of organic, will compress rapidly during construction under the embankment loads and will provide an adequate foundation for the roadway. New York State Specifications require stripping of sod and topsoil only when the embankment height is less than 6 ft or when topsoil is required as an item on the project. The savings in construction costs with the elimination of sod and topsoil stripping is significant. The cost for 6 in. of stripping and 6 in. of backfill under a 15-ft high embankment on the Interstate System is of the order of $30,000 per mile.

A special problem of embankment stabilization by excavation is encountered for widening projects on secondary roads crossing swamps. These old roads are usually floating on fills that have penetrated by displacement and settlement to a considerable depth below the swamp surface. The existing roadway is reasonably stable, since the underlying soil is well compressed after 30 years or more of loading. Any new embankment material placed on the ad-

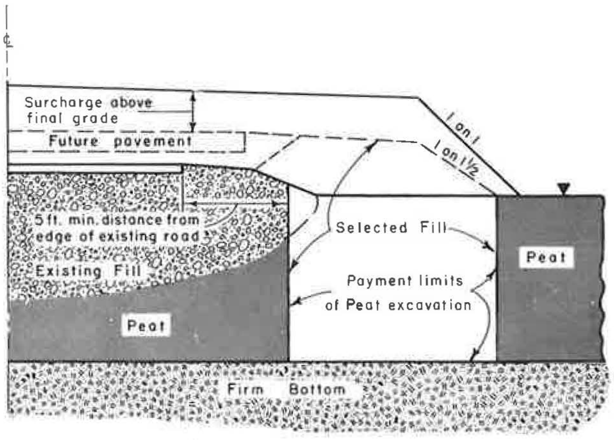


Figure 3. Typical section for widening highway on swamp soils. (Note: Length of open excavation must be carefully controlled to preserve stability of existing embankment.)

jacent swamp surface will undergo settlement of perhaps several feet, thus creating a differential settlement problem across the highway section. Figure 3 shows the typical section for the successful method of treatment used in New York State. The organic material under the widened section is excavated and backfilled with suitable granular soil. This method has been used successfully to depths of 20 ft. Failure of the existing roadway into the open excavation is prevented by keeping a minimum length of open excavation parallel to roadway centerline. Specifications require that the distance from the toe of excavation to the toe of backfill shall be less than 15 ft at all times during each day's operation and less than 3 ft at the conclusion of a day's operations. Also, no traffic should be allowed within 10 ft of the open excavation. After completion of excavation and backfill, a surcharge may be used, if necessary, to decrease differential settlements across the roadway. The excavated material may be used to flatten slopes.

Removal of Soil by Displacement

The displacement procedure is accomplished by placing sufficient embankment material on the foundation soil to cause the underlying soil to displace by shear failure in the direction of least resistance. The essential design features for a successful displacement operation are to have sufficient embankment weight to force out the underlying soil and to have a sufficient depth of mudwave excavation before the advancing fill front so that the direction of displacement can be controlled and the fill will continue to sink to the desired depth. Also, the advancing fill front should have a steep front face. The displacement method is used for peat and muck deposits greater than 30 ft in depth where complete excavation may become difficult, and to remove very soft clays or organic silts that would not stand on a steep excavation slope under water.

In a swamp with an irregular to firm bottom difficulty is encountered obtaining complete displacement when the displaced soil is directed against a rising firm bottom surface. The front of the fill should be skewed as necessary to direct the displacement toward the deeper portion of the swamp. Frequently, a drawing is included in the plans indicating the direction of successive fill fronts as the embankment is constructed across a swamp area.

In deep swamps, culverts should be located where the organic material is shallow, usually near the edge of the swamp. The possibility of culvert settlement due to consolidation of deep backfill and possible pockets of entrapped organic material is elimiated.

Occasionally the organic material is underlain by very soft clays that increase in strength with depth. For this case a detailed laboratory testing and stability analysis is required to predict accurately the depth of displacement for design.

The method of payment for removal of unsuitable material by displacement methods presents a problem, since it is not practical to measure quantities in the field. The method used in New York State is to predetermine the quantities of removal by detailed explorations and by laboratory testing and analyses in order to predict as accurately as possible the volume of displaced material. A special payment item is used in contracts for a predetermined quantity of excavation between designated station limits. The above method of measurement and payment has been successful and satisfactory on numerous projects. Use of this payment method is not recommended if there is any uncertainty on the behavior of the soil material under displacement action since the predicted quantities could be erroneous. A typical section for this treatment is shown in Figure 4. A waiting period before paving is desirable to allow the backfill and any entrapped organic soil to consolidate. Sometimes a surcharge is used to eliminate any expected post-construction settlement.

The rate of backfill placement should not exceed the rate of removal of a mudwave material. If this rule is not enforced, the backfill can trap pockets of unsuitable material resulting in undesirable settlements after paving.

The surface root mat is removed at least 30 to 40 ft ahead of the backfill to promote displacement. All mudwave material is excavated that rises above a designated elevation for a 30 to 40-ft distance in front of the backfill in order to insure continuing displacement to the desired depth. The critical elevation for excavation may be determined from stability analyses. However, the water elevation in the excavation at the time of construction is very important and often cannot be predicted. Any mudwave material rising above water will have a much greater counterweight effect than submerged material and should be removed. All excavated material should be cast behind the advancing fill front or removed from the site.

Controlled Rate of Construction

The two previous methods involved removal of the foundation soil. The following methods involve treating the soil in place to provide a stable foundation. Controlled rate of construction is the most economical method when it can be used, since it involves no additional construction materials. The only requirement is adequate time.

Controlled rate of construction is used where the foundation soil would undergo shear failures if the embankment is built rapidly. However, as a soil consolidates, an accompanying increase in shear strength occurs. The consolidation-strength relationships may be determined by laboratory testing. Stability analyses are conducted to determine the factors of safety for various heights of embankment and various degrees of consolidation throughout the subsurface soil profile. The maximum safe height of embankment

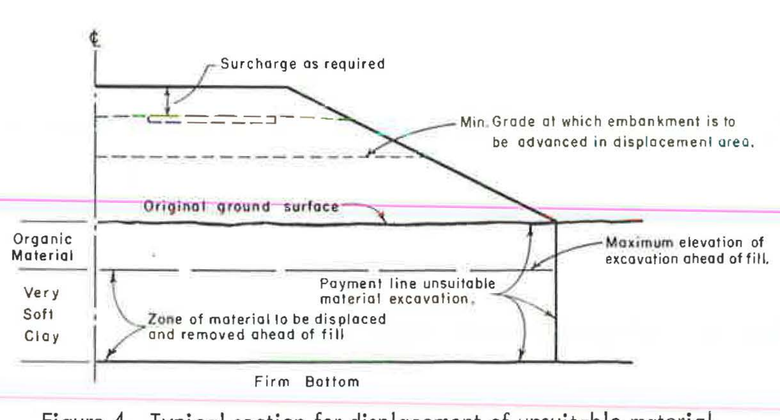


Figure 4. Typical section for displacement of unsuitable material.

that can be placed with no rate restrictions is first determined in order that the maximum consolidation may be obtained during the waiting period. The time interval between fill increments and the height of increments is next established by analysis. As each increment is placed, the factor of safety should not decrease below an established minimum value.

The minimum factor of safety for design is influenced by the completeness of the explorations, the quality of the undisturbed samples, the consistency of the test results, and the sensitivity of the soil structure. Where the information is dependable, a minimum factor of safety of 1.25 is used for embankments. Where structures such as bridge abutments are involved, the minimum factor of safety is set at 1.50 at the time structure work is scheduled to begin.

Occasionally, situations arise that justify a "calculated risk" and lower factors of safety are used. This is usually in areas where an embankment foundation failure would not damage any structures or drainage pipes, the shear failure would not cause future differential pavement settlement, and there is sufficient right-of-way available to place a counterweight berm if required. The consequences of a failure in terms of economics and future highway performance should be thoroughly considered before using this philosophy of design.

Field instrumentation such as settlement platforms and piezometers should be installed to check the field settlement with the design estimates. The waiting periods between fill increments may be decreased if the consolidation occurs faster than predicted. Also, collection of field performance data is valuable for use in designing future projects.

Stabilizing Berms

When the weight of an embankment causes shear stresses greater than the shearing strength available in the foundation soil, a possibility exists that the embankment will cause the underlying soil to displace laterally. The zone along which this movement takes place approximates a circular arc with the center of arc over the side slope of the embankment.

The factor of safety against failure is the ratio of the resisting moment to the driving moment along the arc. The driving moment is determined from the weight of the embankment material and the resisting moment determined from the available soil shear strength along the failure arc. The purpose of a berm placed against the outer embankment slope is to provide a counterweight that will reduce the overturning moment on the failure arc and increase the factor of safety.

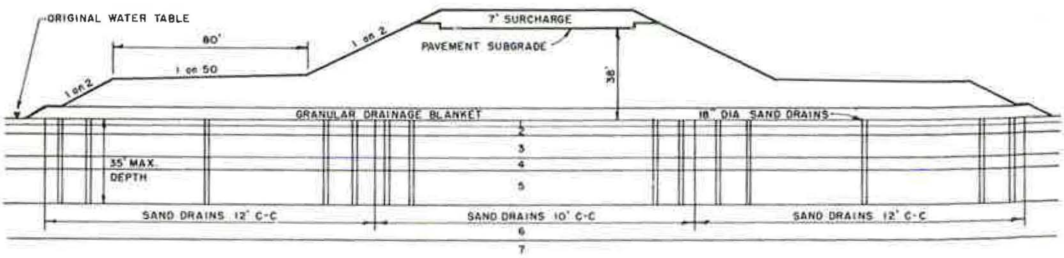
An exception to this analysis occurs if the weak foundation soil is relatively thin and the circular arc type failure does not occur. The failure condition consists of a lateral squeeze movement of the soft material resulting in sinking and sometimes spreading of the embankment.

The stability of various combinations of berm widths and heights are found to determine the most economical and satisfactory solution. The toe of the berm should extend beyond the arc of the most critical circle. Also, the berm should be checked for stability to ascertain that the berm itself will not fail. A series of step berms have been used to achieve stability of the berm embankment.

The stability analysis by graphical methods to determine the most critical factor of safety can be very time consuming. New York State has developed a stability analysis program for the electronic computer (4) to reduce the time required for this analysis. The program has been designed with sufficient flexibility to determine the factors of safety at any stage of construction for various degrees of consolidation of the foundation soil. Also, the program can determine the most economical berm requirements and compute the stability of embankments placed on sloping ground surfaces.

Sand Drains

Another method used to consolidate and stabilize foundation soils is the use of sand drains. Sand drains are columns of pervious sand installed in the soft foundation soils on a grid pattern varying from 6 to 20 ft on centers. A blanket of pervious sand is



TYPICAL SECTION
SCALE 1" = 40'

LAYER	THICKNESS	SOIL	AVE. MOISTURE CONTENT %	LIMITS			AVE. SHEAR STRENGTH		AVE. CONSOLIDATION CHARACTERISTICS		
				LL	PL	PI	CONSOLIDATED UNDRAINED C-LBS/FT²	UNCONFINED STRENGTH LBS/FT²	COMPRESSION INDEX	COEFFICIENT OF CONSOLIDATION C_v - FT²/DAY	INITIAL VOID RATIO
1	3'	SOLVAY SLUDGE	280	150	128	22	Ø = 0° C = 350	300	4.00	3.0	7.50
2	2'	BLACK PEAT	200	-	-	-	Ø = 0° C = 350	300	1.50	0.1	4.00
3	10'	GRAY MARL	70	48	35	13	Ø = 20° C = 200	180	0.54	1.0	1.85
4	5'	SILT, SAND AND MARL	30	26	20	6	Ø = 15° C = 200	250	0.1 - 0.2	0.5-1.0	0.75-1.00
5	15'	SOFT CLAY	38	32	18	14	Ø = 10° C = 200	180	0.35	HORZ 0.12 VERT. 0.07	1.05
6	15'	FIRM SILT	25	NPL			Ø = 25° C = 300	400	0.02	2.0-3.0	0.69
7	-	FIRM SAND	20	NPL			-	-	-	-	0.58

Figure 5. Typical cross section and avenue soil properties, Oswego Blvd., Syracuse, N.Y.

placed on the top of the drains to allow the water moving out of the top of the drains to flow laterally from under the embankment. The superimposed embankment weight causes a pressure in the soil pore water in the underlying soil. The presence of the sand drains decreases the time for the consolidation to occur. As the soil consolidates, the shear strength increases. Therefore, the principal benefit of sand drains is to increase the rate of consolidation of the subsoil and the stability of the embankment.

Over the past 15 years, the New York State Department of Public Works has installed sand drains on eight highway projects. In general, the results indicated that the design procedures based on Terzaghi's theory of consolidation for compressible soils and developed by R. A. Barron (5) for application to sand drain design are reasonable, sufficiently accurate, and yield satisfactory results. Post-construction subsurface investigations and testing indicated that the change in moisture content due to consolidation and the increase in shear strength was close to the values predicted in design.

A typical sand drain treatment project was used for the construction of Oswego Boulevard on the outskirts of Syracuse, N.Y. Embankments up to 45 ft in height were constructed on surface organic materials underlain by soft clays extending to a depth of 35 ft. Figure 5 shows a typical cross section of the highway embankment, which also required stabilizing berms in addition to the sand drain treatment.

Post-construction explorations were made 21 months after construction to determine the characteristics of the foundation soils. Figure 6 shows a comparison of foundation settlements as determined by four different methods. Figure 7 shows the theoretical time-settlement plot compared with the field records. Figure 8 shows the theoretical pore pressure behavior compared against the actual records.

The one project with unsatisfactory results occurred in a tidal marsh organic clay deposit on Long Island. Long-term secondary settlements were detrimental to the performance of the roadway. It is our opinion that the cause of this settlement was due to the disturbance of the soil structure by the displacement method used to install the sand drains. A mandrel with a flap gate on the end was employed. Six years later, on another project several miles away, sand drains were installed in a very similar organic clay deposit, but this time using a non-displacement method. This procedure used the hollow shaft flight auger. The secondary settlement was much less and the pavement

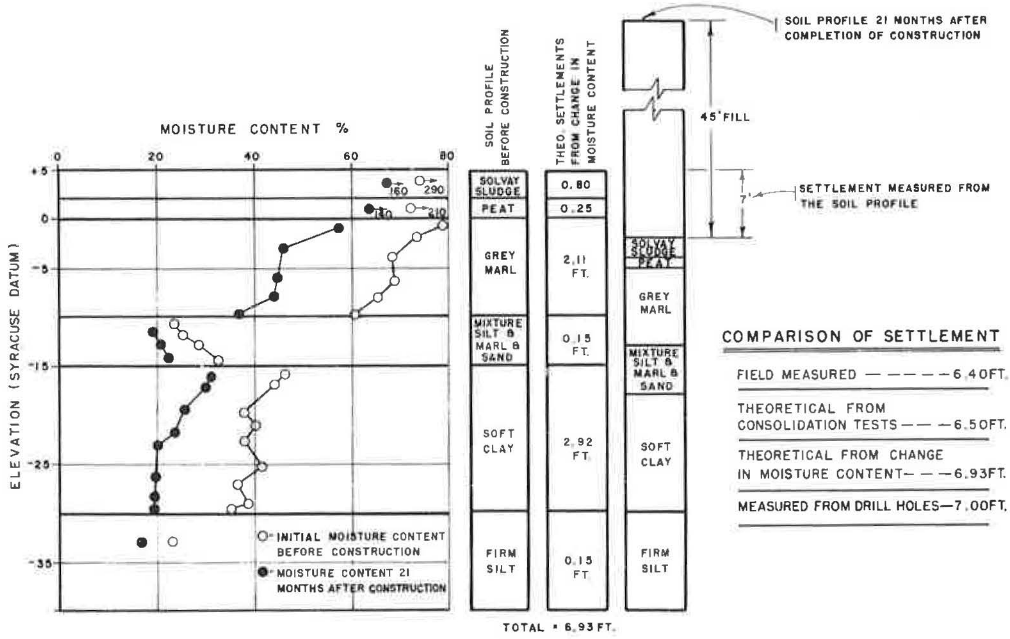


Figure 6. Moisture content—depth and settlement comparisons, Oswego Blvd., Syracuse, N.Y.

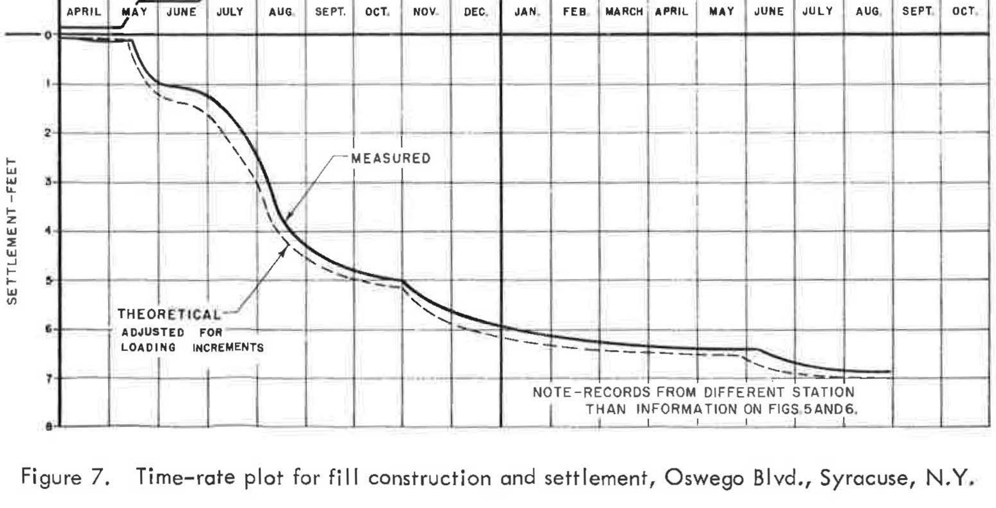


Figure 7. Time-rate plot for fill construction and settlement, Oswego Blvd., Syracuse, N.Y.

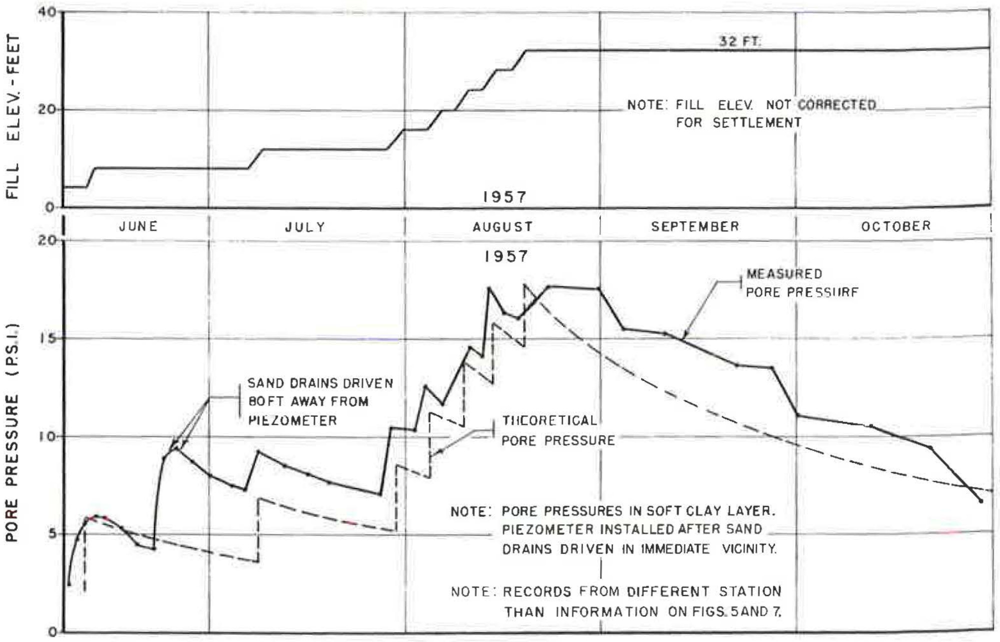


Figure 8. Time-rate plot for fill construction and pore pressures, Oswego Blvd., Syracuse, N.Y.

performance has been satisfactory to date except in one area where there was considerable peat mixed with the organic clay. Sand drains are not recommended for stabilization of deep deposits of high organic soils such as peat which are subject to long-term secondary consolidation.

The selection of sand drains for a solution to a foundation problem is also influenced by economics. The linear feet of drains required and the volume of free-draining sand can be large and this treatment can be quite expensive. For example, on six projects, the cost of sand drains per lineal foot varied from $0.72 on a large project to $1.65 on a smaller project. Because these projects were constructed over five years ago, a factor for increased labor costs would have to be added for present-day estimates.

Lightweight Fill

Another solution of stability problems is to decrease the weight of the embankment by using a material of a lighter density than ordinary earth embankment material. In steel-producing areas, quantities of water-cooled slag are often available. Water-cooled slag has a compacted wet density on the order of 70 to 80 pcf. Ordinary earth embankment density will vary from 125 to 135 pcf. The use of the lighter material will reduce the embankment weight approximately 40 percent, thus decreasing the stresses on the underlying soil. These lighter materials can be used if economically available.

Other materials that can be used are cinders and lightweight aggregate obtained from expanded shale. Cinders are becoming increasingly scarce and are difficult to obtain. In the northeastern U.S., there are 31 lightweight aggregate plants, but the quantity that can be obtained is often limited in terms of the volumes needed for highway embankments. The in-place weight of lightweight aggregate is 55 to 70 pcf, and in New York State the cost per cubic yard in-place is approximately $4.00 to $5.00 plus transportation charges.

Because of the limited quantities available, the principal use of lightweight fill has been in the vicinity of structure abutments where an alternate end berm treatment would involve lengthening the structure.

Surcharge

Embankments are often built to heights above future pavement grade to decrease the post-construction settlement. The effectiveness of the surcharge is dependent upon several factors which should be analyzed, such as the time-settlement characteristics of the foundation soil, and the ratio between surcharge height and final fill height. As the surcharge height-fill height ratio decreases, the effectiveness of the surcharge also decreases. The loading intensity of the surcharge increment on the compressible layers should be checked by usual pressure distribution methods. If the fill is high and the compressible layer is deep, then the surcharge will be relatively ineffective.

Also, the effect of a surcharge loading on the stability of the embankment for a foundation shear failure should be checked. Often a surcharge would have been desirable from the standpoint of settlement problems, but would have made the stability critical.

Surcharges have been used effectively in the areas of bridge abutments located on soils such as loose silts, fine sand, and clayey silts that consolidate rapidly. By preloading the abutment area, the structure settlement may be reduced to a magnitude that allows the use of a spread footing foundation instead of piles. The economics of a surcharge treatment should also be studied, since, in New York, payment is required for placing the material and also for removal to subgrade elevation.

CONCLUSION

The most satisfactory and economical solution to highway embankment foundation problems may often be obtained in the early design stages when alignment or grade changes may be made to eliminate or reduce the cost of foundation treatment. This requires a preliminary exploration program to provide the information for an early evaluation of the foundation problem.

The final selected treatment and detailed design is based upon a more extensive investigation program with emphasis placed upon careful undisturbed sampling and testing to obtain the most reliable design information possible. The selected solution to each problem is often influenced by factors other than the soil properties such as available construction time, availability and cost of construction materials, right-of-way and location of project.

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Discussion

PHILIP KEENE and ROBERT J. ISABELLE, Respectively, Engineer of Soils and Foundations and Assistant Highway Engineer (Foundations), Connecticut Highway Department—The author has given a clear presentation of the various methods of treatment which are used by his Department. His paper should be of considerable value to the practicing highway engineer and to the soils specialist.

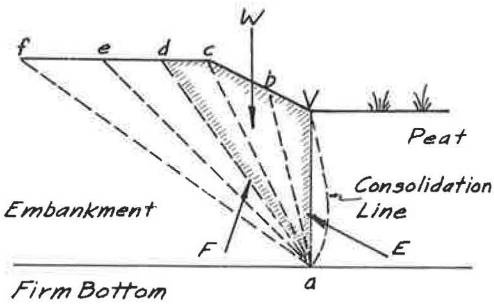

Figure 9.

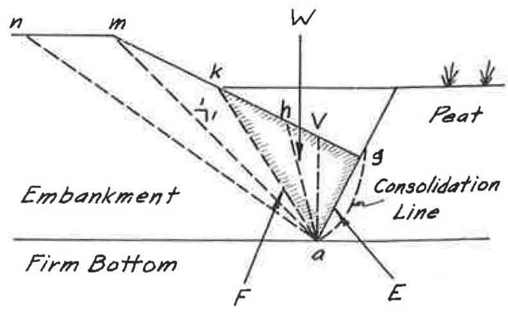

Figure 10.

The writers wish to discuss the desirability of the lateral limit of muck excavation for depths greater than 5 ft, described under "Removal of Soil by Excavation" and shown in Figure 1 of the paper. It is true that after excavating the muck and backfilling with select material, there will be no failure by shear through the muck which would result in large displacements and a "mud wave." However, there will be continuous small lateral and downward movement of the muck, due to consolidation, since the pressure from the backfill greatly exceeds the pressure which existed before construction. This movement, at first, would be a type of primary consolidation; in later months or years it would be secondary consolidation. The latter might be a few inches per year in magnitude and is similar to long-term settlements mentioned by the author. This movement is shown by the dotted line in Figures 9 and 10.

When the depth of muck is much greater than the height of embankment above swamp elevation, and the excavation limit is vertically below toe of slope, as line av in Figure 9, a crack in the shoulder area at d will result. This is because the wedge avd would gradually move to the right and cause a rupture along ad. If the muck experiences appreciable lateral consolidation after the shoulder is paved, lateral movement of the wedge avd would occur, the crack at d would open up and the shoulder would require resurfacing.

A safer practice, used by the Connecticut Highway Department, is to excavate out to point a in Figure 10, where a is on a 1 to 1 "directional" line through the top of slope, point m. Using this method, cracking due to lateral movement of a wedge of embankment would occur at point k, where it would cause no trouble. Field observations have verified this.

It can be added that the critical wedges, mentioned above, are determined by analysis of various trial wedges, such as avb, avc, avd, ave, etc., in Figure 9. For each trial wedge, the forces W (weight of wedge), F (frictional resistance in the embankment) and E (resistance of muck) are plotted. The wedge resulting in the maximum value of E is the critical one. The direction of F is assumed as 35 deg from the normal to the rupture plane of the wedge. Different assumptions can be made for the direction of F and E and the slope of the excavation limit, but the same conclusion would be arrived at, so long as point a is unchanged.

LYNDON H. MOORE, Closure—The author welcomes the comments presented by Messrs. Keene and Isabelle. The suggested wedge analysis method for analyzing the stability of the backfill against lateral movement is probably the best available at the present time. The author mentions in his paper that this type of analysis does indicate a critical stability condition, but experience with many swamp crossings has indicated that this does not prove to be a serious problem in the field. Although there have been a few instances where cracks appeared near the sides of the backfill during construction, there never have been any cases observed in New York where post-construction distress of the shoulder or pavement has occurred due to the lateral movement of the backfill. Also, drill holes have indicated that the lateral boundaries of the backfill against the muck material have remained nearly vertical.

The author is not prepared to present a theoretical analysis of why the spreading does not occur. There is no doubt that on deep swamps there must be a pressure transmitted to the peat soil.

The additional width of excavation and backfill proposed by the discussors to satisfy the wedge analysis could amount to considerable additional cost on a long swamp crossing. It may prove to be more economical if a surcharge were substituted prior to paving to preload the sliding wedge and achieve a certain degree of equilibrium before paving.

Also, when the muck is excavated on a slope flatter than vertical, then the weight of the backfill will have a vertical component acting upon the compressible organic material. The backfill weight will cause considerable consolidation of the peat and certainly would result in cracking along the proposed failure plane outside of the shoulder limits. If this consolidation and movement of failure wedges is considerable, then a series of successive failure wedges could progress up the side slope of the shoulder of the embankment.

In conclusion, the writer agrees with the discussors that theoretically this is a problem that should be considered in design. However, from experience in New York State, it has been found that additional widening of the excavation beyond the toe of the embankment is not necessary to construct a stable backfill and embankment for a swamp crossing.