SCHOOL OF
CIVIL ENGINEERING

INDIANA

DEPARTMENT OF HIGHWAYS

JOINT HIGHWAY RESEARCH PROJECT

IN/JHRP-83 /6

CONTROLLING MOVEMENT OF EMBANKMENTS
OVER PEATS AND MARLS

H. Allen Gruen, Jr.

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PURDUE UNIVERSITY

JOINT HIGHWAY RESEARCH PROJECT

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FINAL REPORT

TO: H. L. Michael, Director
Joint Highway Research Project

July 6, 1983

Project: C-36-5P

FROM: C. W. Lovell, Research Engineer
Joint Highway Research Project

File: 6-6-16

Attached is a final Report on the JHRP study titled "Controlling Movements of Embankments Over Peats and Marls." The research and report were performed by H. Allen Gruen, Jr. and C. W. Lovell of our staff.

The report investigates the properties and behavior of peat and a calcarious soil termed marl. The influence of calcium carbonate on soil is determined from tests on laboratory generated and field samples. The report further proposes classification, sampling, testing and analysis procedures which will produce reasonable predictions and control of embankment settlements where peat is the foundation.

The report was preceeded by an interim report entitled "Use of Peats As Embankment Foundations." Sections of this final report are found in the interim report where noted.

The report is submitted for review, comment and acceptance as fulfillment of the referenced JHRP study.

Respect fully submitted,

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1. Report No. IN/JHRP-83/6		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Controlling Movements of Embankments Over Peats and Marls				5. Report Date July 6, 1983	
				6. Performing Organization Code	
7. Author(s) H. Allen Gruen, Jr. and C. W. Lovell				8. Performing Organization Report No. JHRP-83-6	
9. Performing Organization Name and Address Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907				10. Work Unit No.	
				11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Indiana Department of Highways State Office Building 100 North Senate Avenue Indianapolis, Indiana 46204				13. Type of Report and Period Covered Final Report	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract <p>A deposit which frequently occurs in glaciated areas is peat underlain by a calcarious soil termed marl. This report investigates the properties and behavior of peat and marl. The influence of calcium carbonate on soil properties and behavior is reported.</p> <p>This report is presented as an aid to the engineer faced with the problem of building on peat and/or marl and should shed light on the unique properties and behavior of these materials. The report proposes a classification system for Indiana peats, which is in basic conformance with that developed in Committee D18 of the American Society for Testing and Materials. It further proposes sampling, testing, and analysis procedures which will produce reasonable predictions and control of embankment settlements where peat is the foundation.</p>					
17. Key Words Marl, peat, embankment, settlement, calssification, sampling, consolidation, strength				18. Distribution Statement No restrictions	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 180	
				22. Price	

Final Report

CONTROLLING MOVEMENTS OF EMBANKMENTS
OVER PEATS AND MARLS

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Project No.: C-36-5P
File No.: 6-6-16

Prepared for an Investigation
Conducted by the
Joint Highway Research Project
Purdue University
in Cooperation with the
Indiana Department of Highways

The contents of this report reflect the views of the
authors who are responsible for the facts and accuracy
of the material presented herein.

Purdue University
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July 6, 1983

ACKNOWLEDGEMENTS

The authors would like to thank Mrs. Janet Lovell for her help and advice during laboratory testing.

Special thanks are extended to Ms. Julie Babler for reveiw and typing of this report.

The authors would also like to thank the Indiana Department of Highways for their financial sponsorship of this study. The research was administered through the Joint Highway Research Project of Purdue University. Messrs. Bill Sisliano and Bob Rahn of the Indiana Department of Highways, Division of Materials and Research, were particularly cooperative in supplying relevant information and in the conduct of the research. The authors are grateful to them for their assistance.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACSSM	Association Committee on Soil and Snow Mechanics
ASCE	American Society of Civil Engineers
ASTM	American Society for Testing and Materials
NRC	National Research Council
SCPS	Swedish Committee on Piston Sampling
SMFE	Soil Mechanics and Foundation Engineering
USCS	Unified Soil Classification System
WHC	water holding capacity

LIST OF SYMBOLS

a	- rheological parameter
a_v	- coefficient of compressibility
A_c	- ash content
b	- rheological parameter
c'	- effective stress strength intercept
cc	- cubic centimeter
cm	- centimeter
C	- line intercept
CCE	- calcium carbonate equivalent
C_c	- compression index
c_v	- coefficient of consolidation
D	- slope of the line
e_o	- initial void ratio
ft	- feet
g	- gram
G	- density of solids
h_o	- initial thickness
H	- layer thickness after primary consolidation
HNO_3	- nitric acid
H_o	- initial thickness
i	- exponential parameter
in.	- inch

k	- coefficient of permeability
kg	- kilogram
kPa	- kilo-Pascal
LIR	- load increment ratio
LOI	- loss on ignition
m	- meter
max	- maximum
ml	- milliliter
mm	- millimeter
MPa	- mega-Pascal
N	- normality
NaOH	- sodium hydroxide
P_o'	- initial effective overburden pressure
r	- coefficient of correlation
sec	- second
sq	- square
S	- total settlement
S_o	- primary settlement
S_s	- secondary settlement
t	- time
t_a	- time at which secondary strain begins
t_k	- time at which tertiary strain begins
t_o	- time to complete primary strain
u	- excess of equilibrium pore water pressure
vs	- versus
W	- dry sample weight
w_n	- natural water content

$\dot{\gamma}$	- strain rate
z	- distance from the element to the drainage surface
α_p	- coefficient of primary consolidation
α_s	- coefficient of secondary compression
Δe	- change in void ratio
Δp	- applied stress change
$\Delta \sigma'$	- change in effective stress
$\Delta \sigma_I$	- stress level at which prediction is to be made
$\Delta \sigma_{II}$	- stress level for which rheological parameters were calculated
ϵ_i	- instantaneous strain
ϵ_p	- primary strain
ϵ_s	- secondary strain
ϵ_t	- tertiary strain
$\epsilon(t)$	- strain as a function of time
ϵ_v	- vertical strain
ρ_w	- density of water
λ	- rheological parameter
ϕ'	- effective angle of shear strength
ρ_d	- dry density
σ'	- effective normal stress
σ_1	- major principal stress
σ_3	- minor principal stress
τ	- shear stress
τ_f	- shear strength
$>$	- greater than
$<$	- less than

HIGHLIGHT SUMMARY

This report is presented as an aid to the engineer faced with the problem of dealing with peat and/or marl for use as an engineering material. Marl overlain by peat is a common deposit found in glaciated areas. Peat and marl are discussed separately in this report, however, it should be noted that both peat and marl are commonly found in the same deposit.

The report reviews the physical and mechanical properties of peat, methods of sampling and test procedures used to determine properties. The unique characteristics of peat are presented and classification systems which distinguish peat from other organic soils are outlined. A large portion of this report centers on the stress-deformation behavior of peat and methods used to estimate field settlements. Methods of building embankments over peat for use as highway foundations are briefly covered. In many cases preloading

the peat to improve its strength is a desirable way of utilizing peat as a foundation material. A rheological model first presented by Gibson and Lo (1961) is applied to peat for use as a control over preloading duration. The applicability of the model is tested on both laboratory and field data and is found to model actual peat behavior quite accurately.

Since calcium carbonate distinguishes marl from other soils, the effect of calcium carbonate on engineering behavior of marl was investigated. This was accomplished by testing samples which were produced in the laboratory. These tests showed that increasing the calcium carbonate content caused an increase in water content, initial void ratio, compressibility, and strength, all factors other than calcium carbonate content remaining constant. This was not the observed behavior for actual field samples. Calcium carbonate content had no discernible effect on any of the observed engineering properties. It was found that the behavior of marl is similar to other soft, highly compressible mineral soils, and should be treated as such for engineering purposes.

INTRODUCTION

Peat underlain by calcareous soils, termed marl, is a common depositional feature in glaciated areas. This combination of weak, highly compressible materials causes concern for highway engineers. Embankments are difficult to construct over peat and marl deposits due to the unique characteristics of these materials. This report investigates these characteristics and how they affect engineering design.

Marl is a soft earthy material, distinguished from other soils mainly by its high calcium carbonate content. Marl can be found underlying peat deposits in a very loose, saturated condition. Due to the low overburden pressure imposed by the peat, the marl is normally consolidated and highly compressible. This report investigates the effect of calcium carbonate on marl behavior and how to deal with this behavior in engineering design. To avoid confusion, peat will be dealt with first followed by a discussion of the behavior of marl.

The highly compressible nature of peat makes it one of the most undesirable foundation materials for

highway construction. Highway engineers try to avoid peat deposits whenever possible. Local peat pockets and shallow deposits are generally excavated and replaced by a more desirable material when encountered. However, there are situations when a peat deposit cannot be avoided. When a highway alignment must pass over a peat deposit, the load caused by the pavement and subgrade will cause some settlement to occur. For this reason, highway pavements must be elevated above the peat deposit by means of an embankment. This embankment causes an additional load on the peat resulting in more settlement. Predicting and dealing with these settlements has been a problem for highway designers and foundation engineers.

Even though peat is an abundant material in many parts of the world, most geotechnical engineers are not sufficiently familiar with the properties and behavior of peat to deal effectively with it. Peat materials present many unique problems which are not encountered with mineral soils. Due to this unusual behavior, specialized procedures and methods of analysis must be used when dealing with peat.

One of the major problems engineers have had with peat is relating its properties and behavior in a systematic way. This problem is caused mainly by the lack of a universal classification system which adequately

groups peat and highly organic soils. The Unified Soil Classification System (USCS), originally developed by Casagrande (1948), groups all highly organic soils into one category called peat, which is identified by "color, odor, spongy feel, and frequently by fibrous texture" (Holtz and Kovacs, 1981). The AASHTO (1970) classification system treats peat in a similar manner by placing all peats and highly organic soils into one group designated A-8, which is given a subgrade rating of "unsatisfactory." Trying to deal with peat, its properties, or behavior in a systematic way requires a more complete classification system. Considering all peats and highly organic soils in one group would be like treating all fine grained soils as one material with the same properties and behavior. Landva and LaRochelle (1982) stress that "it is important to distinguish between the very large variety of materials within the group of soils currently referred to as peat. The properties of these materials vary from that of textile-like fabric to that of a jelly-like substance. A case record of construction on peat land is of little value without such distinction and without a detailed description of the peat involved." Classification of peat and highly organic materials along with the properties and behavior of peat will be dealt with in later sections.

Note: Pages 4 through 113 are not included in this copy of the report. They are available in substantially the same form (only slight modifications) in the interim report IN/JHRP 83/3, entitled "Use of Peats as Embankment Foundations." They are also available in exact and final form, for the cost of duplication from:

Joint Highway Research Project
Civil Engineering Building
Purdue University
West Lafayette, Indiana 47907

MARL

The term marl has been used to represent a group of earthen materials ranging in consistency from a soft, water saturated muck to intact sedimentary rock. The common characteristic of these materials seems to be the presence of calcium carbonate. Much has been written about the Keuper Marls of England which consist of a series of mudstone type materials of Triassic age (Chandler 1969, Davis 1967a, Davis 1967b, Dumbleton 1967, Sherwood 1967, and Foley and Davis 1971). Hutchinson, et. al. (1973) report the characteristics of Etruria Marl which resembles mudstone and Menzies, et. al. (1974) discuss the properties and behavior of Antigua Marl which is a type of limestone with grading similar to that of gravel. On the other extreme, Raymond (1969) mentions a Muskeg composed of peat and the underlying soft lake marl with a consistency similar to soup.

The term marl as used in this report is confined to the soft, earthy material composed largely of calcium carbonate that is found as a deposit in lake basins, bogs, marshes or low areas that were once

covered with water. It may be defined as a mixture of calcium carbonate, detrital clay, silt, sand and organic matter which has been deposited in water.

Physical characteristics. In hardness and consistency fresh marl resembles softened butter, whereas in some of the marsh deposits that are partially drained it is firm enough to be cut in blocks and handled with a shovel. In many locations marl has consolidated to the consistency of a stiff clay.

Its color varies with the amount of impurities it contains. Marl is usually grayish-white, but darker colors may be seen where the marl is contaminated with peaty organic material. Pure marls are more white in color.

Marl as found in existing lakes may contain as high as 60% water by volume, while even the dry marl-beds occurring in swamps or marshes will carry 15 to 25% moisture by volume (Schwartz, 1959). This moisture, together with the fine granular character of the marl, gives it a sticky, putty-like character. Because of its fine texture, marl does not release much of its water by drainage. Even though marl may be as sticky as clay, it is markedly lighter in dry weight due to its large moisture content.

The particles or grains composing the marl are usually very fine and powdery. In some marls the shells of small snails and snail-like molluscs are very abundant, while in others no traces of shells are found. The most common form of shell is from the fresh water univalve *Helisoma Trivolvis* (Blatchley and Ashley, 1900). Marl usually contains very little sand or grit, though some of its shells and calcium carbonate particles may give it a gritty feeling when examined. Such shells and particles can usually be crushed between the fingers which will serve to distinguish them in the field from sand grains.

Marl formation. The source of calcium carbonate deposited as marl is from rock and soils containing calcium compounds, such as limestone. In the northern section of the United States this calcium source is thought to be glacial drift. Because of its origin, this glacial debris contains an appreciable amount of fresh or chemically unaltered rock fragments, containing calcium compounds. Soil waters percolating through these limy clays and gravels carry with them dissolved carbon dioxide, and the combined action of the dissolved gas and water leaches out the soluble lime compounds from the soils through which it filters. Marl is formed when these compounds are precipitated and deposited with the silts and clays which were suspended

in the flowing water. Marl is found, therefore, only in places that were once or are still covered with water. It is not necessarily confined to the immediate vicinity of present existing bodies of water, for the general water level has fallen, and many former shallow lake basins, covering thousands of acres, are now drained and dry land.

During the time of active deposition, a marl bed must have very little covering other than water. As soon as the upper surface of the deposit approaches the surface of the water, rushes, sedges and other marsh vegetation gain a foothold in the newly deposited marl and use it as a soil. The thickness to which the soil remains of such vegetation accumulate over the marl is governed by the relation of the surface of the marl to the ground water level. When the water level remains stationary for a great number of years, a thick bed of peat grows over the marl. If the water level is lowered while marl deposition is in progress, the marl dries fast and only a thin bed of peat is formed.

In most deposits there is a sharp contrast between marl and its underlying foundation. The marl appears as a distinct stratum and does not merge irregularly into the surrounding materials. The nature of the underlying material is determined to some extent by the character of the surrounding region. Sand or clay

usually forms the floor of the basins. Very rarely is there any muck or peat underlying the marl. In northern regions, such relations indicate that calcium carbonate deposition began after postglacial drainage channels were well established and when clay or sand deposition at some distances from shore was virtually at a standstill.

Location of marl deposits. Marl beds owe their origin to the precipitation of lime carbonate from solution. It follows that marl is always found in areas that were originally covered with water. Marl also underlies partially drained swamps, and in some places it is found in the banks of streams that have cut their channels into a bed of marl as the outlet of a former lake or bog was lowered. Not all lakes of the glaciated areas contain marl. The reason is that glacial lake basins are formed in a number of different ways, and some, therefore, are better fitted than others as reservoirs for the accumulation of marl.

Marl is most commonly found under the type of peat which develops around lakes and ponds (see Figure 26). It is either sedge-grass peat or pond peat composed of the remains of plants such as reed grass, cattails, bulrushes, and grasses.

FIGURE 26. DIAGRAM OF PART OF LAKE BASIN SHOWING THE RELATION OF MARL AND PEAT DEPOSITS IN A GROWING MARL BED.
FROM SCHWARTZ (1959).

Marl is commonly found in or around hard water lakes. It is the presence of calcium bicarbonate that gives water the property usually known as temporary hardness. If the lake water is soft, the calcium content is so low that no marl deposits are formed.

In the northern United States, more marl is found in basins of regions where the glacial drift is composed of open-textured gravels and sands than where impervious clayey tills cover the surface. This is true even if the lime carbonate content of the clay is higher than that of sands. This is because the water which leaches the calcium compounds flows more easily through the gravels and sands than the clayey tills.

Indiana Marl Deposits. Marl or "merl," as it is commonly called, is found in Indiana as a soft, earthy material, composed principally of an amorphous form of carbonate of lime. Large deposits of marl are found in the three northern tiers of Indiana counties. Smaller deposits are found scattered in other portions of the glacial drift-covered area of the state, but none has been reported south of this glacial area (Blatchley and Ashley, 1900).

Sand or gravel underlies most of the marl deposits in Indiana, though in a few instances a tough blue clay may be encountered.

In size the marl deposits of Indiana run from a few hundred square meters to several thousand square kilometers. Lake Wawasee, including the arm known as Syracuse Lake, in Kosciusko County, contains about 6900 square kilometers (Blatchley and Ashley, 1900). The thickness of the marl beds in Indiana varies from 0 to 15+ meters, a deposit of the latter thickness having been found in Turkey Lake, Lagrange County. Thickness may vary drastically over the deposit. Blatchley and Ashley (1900) report, "From our own experience it seems safe to say that a large majority of the deposits have a maximum depth of over 6 meters, even though the area of the deposit may be quite limited."

Blatchley and Ashley (1900) provide an excellent survey of Indiana's marl resources, including several county and lake maps with detailed descriptions and references provided. Maps are given for the following counties: Steuben, Lagrange, Noble, Whitley, Elkhart, Kosciusko, Fulton, Marshall, St. Joseph, Laporte and Lake.

According to Blatchley and Ashley (1900), the marls found in Indiana were used for the following purposes:

1. As an ingredient in the manufacture of Portland cement.

2. As a fertilizer of soils.
3. As a means of improving the mechanical condition of clayey, sandy or peaty soils.
4. As a mineral food for poultry.
5. As a polishing powder.
6. As a material for the manufacture of quicklime.
7. In the place of limestone in the manufacture of beet sugar.

A present day usage that Blatchley and Ashley failed to mention is marls' use as a highway foundation material. The remainder of this report will discuss the use of marl as an engineering material.

Effect of calcium carbonate. Since calcium carbonate differentiates marl from other soils, it was desirable to study its effect in more detail. In order to determine the effect of calcium carbonate on soil behavior, samples were constituted in the laboratory. The mixture initially consisted of 50% clay and 50% silt. These materials were disaggregated and thoroughly mixed. Six samples were made by adding varying amounts of powdered calcium carbonate to the silt-clay mixture. Water was added until the mixture had a soup-like consistency. The slurry was placed in plexiglass molds (12.7 cm diameter, 15.2 cm high) and

consolidated for 4 weeks under a pressure of 37 kPa. Several tests were run on the six samples, with results given in Table 7. Correlations of test results with calcium carbonate content are shown in Figures 27, 28, 29, 30, and 31.

Test procedures. The calcium carbonate content was determined by the following procedure which is currently used by the Indiana Department of Highways.

1. Weigh out 1 gram sample which has passed the #60 sieve.
2. Add 50 ml of 0.5N nitric acid.
3. Heat until effervescence stops.
4. Cool to room temperature.
5. Titrate with 0.25N sodium hydroxide to phenolphthalien end point. Note: In this case color change was difficult to detect until solid flocculated, which was about 1 ml from the end point. Flocculation varied depending on the amount of soil present.

Calculations.

$$\text{CCE} = \frac{(\text{ml HNO}_3 \times \text{N}) - (\text{ml NaOH} \times \text{N}) \times 0.05 \times 100}{\text{W}}$$

Where:

CCE = calcium carbonate equivalent or % calcium carbonate

(ml HNO₃ × N) = total milliequivalents HNO₃ added

(ml NaOH × N) = milliequivalents HNO₃ left, or milliequivalents base used

0.05 = titrimetric factor for CaCO₃

100 = %

W = dry sample weight

Table 7. Laboratory Test Summary.

Sample	Calcium Carbonate Content %	Loss On Ignition %	Water Content %	Initial Void Ratio	Compression Index	$(\sigma_1 - \sigma_3)$ 15% kPa
A	56.19	3.94	44.71	1.02	0.23	65.80
B	42.98	3.47	32.24	0.80	0.17	46.51
C	50.37	3.82	38.50	0.90	0.19	74.78
D	39.53	3.98	28.60	0.71	0.14	50.99
E	52.89	3.68	44.16	0.91	0.26	64.77
F	74.02	3.27	62.22	1.34	0.38	81.99

FIGURE 27.

CALCIUM CARBONATE CONTENT VERSUS LOSS ON IGNITION. SAMPLES CONSTRUCTED IN THE LABORATORY.

FIGURE 28. CALCIUM CARBONATE CONTENT VERSUS WATER CONTENT. SAMPLES CONSTRUCTED IN THE LABORATORY.

FIGURE 29. CALCIUM CARBONATE CONTENT VERSUS INITIAL VOID RATIO. SAMPLES CONSTRUCTED IN THE LABORATORY.

FIGURE 30. CALCIUM CARBONATE CONTENT VERSUS COMPRESSION INDEX .
SAMPLES CONSTRUCTED IN THE LABORATORY.

FIGURE 31.

CALCIUM CARBONATE CONTENT VERSUS PRINCIPAL STRESS DIFFERENCE DETERMINED AT 15% AXIAL STRAIN FROM UNCONFINED COMPRESSION TESTS. SAMPLES CONSTRUCTED IN THE LABORATORY.

Water content and loss on ignition were determined in accordance with ASTM standard D2974 (ASTM 1981). The initial void ratio and compression index were determined from standard oedometer tests, load increment ratio equal to 1. The unconfined compression test was used to determine the principal stress difference at 15% axial strain.

Test results. As shown in Figure 27, no obvious correlation exists between loss on ignition (organic content) and calcium carbonate content. This also seems to indicate that calcium carbonate and its byproducts are not burned off at 550 degrees celcius. Thus, igniting the sample does not directly alter the calcium compounds present.

Figure 28 shows a near linear correlation between water content and calcium carbonate content. These results show that increasing the calcium carbonate content increases the water content.

Figure 29 also shows a near linear relation between initial void ratio and calcium carbonate equivalent. This could be expected after observing Figure 28, since the samples were completely saturated. Thus, all other factors remaining constant, increasing the calcium carbonate content results in a higher water content and corresponding higher initial void ratio.

Figure 30 shows a positive correspondence between the compression index and calcium carbonate content. Once again, this is to be expected since higher calcium carbonate contents resulted in higher water contents and initial void ratios which are reflected by higher compressibilities.

Figure 31 shows an increasing strength (principal stress difference) with increasing calcium carbonate content. When the previous test results are considered, the opposite behavior might be expected; namely, as the calcium carbonate content increased, water content increases, the soils becomes looser, and the strength would be expected to go down. However as Figure 31 shows, this is not the case. The increasing strength with calcium carbonate content could be due to a "cementing" effect similar to that which takes place when lime is used to stabilize soils. In any case, calcium carbonate appears to have a positive effect on strength, as determined from these unconfined compression tests.

It should be noted that the six samples were the same except for differences in calcium carbonate content. This was done to isolate the effect of calcium carbonate content, eliminating other possible variations such as organic content, overburden pressure and clay mineralogy.

Field Samples. The effect of calcium carbonate on natural marl samples taken from the field was also investigated. Samples used in this testing program were obtained from seven sites throughout Indiana. These samples were taken from highway projects located in Whitley, Kosciusko, Miami, Noble, Steuben, Hamilton, and Laporte counties.

Figure 32 shows a large amount of scatter, and no apparent correlation between organic content and calcium carbonate content. This seems to discount any relationship between processes which form marl deposits and organic accumulation.

Figure 33 shows no clear correlation between carbonate equivalent and water content. The reason for this scatter is mainly due to variations in organic content. As shown in Figure 34, there exists a correspondence between organic content and water content. A regression analysis was performed to obtain the best fit line through the data, as shown in Figure 34. These two figures show that the effect of calcium carbonate on water content is minimal compared to other factors such as organic content.

Figures 35 and 36 show no correlation between initial void ratio or compression index and calcium carbonate content. This is to be expected when the

FIGURE 32. CALCIUM CARBONATE CONTENT VERSUS LOSS ON IGNITION.
SAMPLES FROM SEVEN SITES THROUGHOUT INDIANA.

FIGURE 33. CALCIUM CARBONATE CONTENT VERSUS WATER CONTENT. SAMPLES FROM SEVEN SITES THROUGHOUT INDIANA.

FIGURE 34. LOSS ON IGNITION (ORGANIC CONTENT) VERSUS WATER CONTENT.
SAMPLES FROM SEVEN SITES THROUGHOUT INDIANA.

FIGURE 35. CALCIUM CARBONATE CONTENT VERSUS INITIAL VOID RATIO.
SAMPLES FROM SEVEN SITES THROUGHOUT INDIANA.

FIGURE 36. CALCIUM CARBONATE CONTENT VERSUS COMPRESSION INDEX. SAMPLES FROM SEVEN SITES THROUGHOUT INDIANA.

results of Figures 33 and 34 are considered. Thus, there are factors other than calcium carbonate content which dictate initial void ratio and compression index for these marls.

Density of solids versus calcium carbonate content is shown in Figure 37. Density of solids is defined as the mass of solids divided by the volume of solids. These data show no clear relation between these two properties.

Figure 38 also shows no clear correlation between plasticity index and calcium carbonate equivalent. Once again, other factors such as clay mineralogy and clay content control the plasticity index of these soils.

Recommended design procedures. Considering the test results from the field samples, it can be seen that calcium carbonate content has no clear relationship with the engineering characteristics of marl. The marl found in Indiana deposits is influenced to a greater degree by other factors such as organic content, clay mineralogy, overburden pressure, etc. Since marl is currently distinguished only by calcium carbonate content, it is recommended that soils referred to as marl, be treated in the same way as other soft normally or slightly overconsolidated soil deposits.

FIGURE 37. CALCIUM CARBONATE CONTENT VERSUS DENSITY OF SOLIDS. SAMPLES FROM SEVEN SITES THROUGHOUT INDIANA.

FIGURE 38. CALCIUM CARBONATE CONTENT VERSUS PLASTICITY INDEX.
SAMPLES FROM SEVEN SITES THROUGHOUT INDIANA.

Therefore the analysis and design of structures over marl should be conducted in the same manner as for other soft, highly compressible mineral soils (Boutrup and Holtz, 1982; Chirapuntu and Duncan, 1976; Lukan and Teig, 1976; Tavenas, 1979; and Webster and Alford, 1978).

The engineer should note that in many cases, these marl deposits are overlain by saturated peat. Due to the low unit weight of the peat, and the depositional process, these normally consolidated deposits are typically very weak and compressible. Excavating the peat and replacing it with a much heavier fill may cause failure to occur in the underlying marl.

Preloading the peat and marl may be an effective method of improving the deposit for foundation use. Raymond (1969) has observed that the pore water pressure dissipates more quickly in marl than in most clays; however, not as quickly as in peat.

SUMMARY AND RECOMMENDATIONS

Peat. Peat is abundant in many countries around the world. A geotechnical engineer must be aware of the unique behavior of peat in order to deal effectively with this organic material.

Need for a uniform classification system. Peat and highly organic soils must be separated into categories which group materials with similar behavior together. Disagreements as to the behavior of "peat," as evident from a review of the literature, generally can be shown to arise from a lack of proper definition of the materials concerned. The proposed ASTM classification of peat and organic soil (Table 3) is recommended for use. The physical description of peat for geotechnical use should include the following:

1. Fiber content.
2. Ash content.
3. Acidity.

For example, a peat with a fiber content of 50%, ash content of 10%, and pH of 5, would be designated a

hemic, medium ash, moderately acidic peat.

Physical properties. The very loose structure of peat results in high water content, high void ratio, high compressibility and low shear strength. Peat in its natural state generally has a very high permeability; however, as the peat is compressed, the permeability is drastically reduced. This behavior accounts in part for the large deviation between peat and mineral soils. The effect of the organic fibers also has an important effect on the behavior and properties of peat. Typical values of physical properties for peat are shown in Table 8.

Mechanical properties. The fiber content of peat has an important effect on shear behavior. The fibers act as a reinforcement to triaxial shear. As the peat is compressed, the shear strength increases rapidly, being a function of the friction between fibers and tensile strength of the individual fibers. Peat, with its potential for large increases in shear strength with deformation, seems to be ideally suited to the preloading technique.

Peat has a high compressibility which continues for long periods of time. Settlement of peat is due to two separate mechanisms, 1) one dimensional consolidation, and 2) lateral displacement (shear strain).

Table 8. Typical ranges of physical properties for peat.

Fiber content	20% - 80%
Water content	500% - 1500%
Ash content	2% - 25%
Organic content	75% - 98%
Void ratio	5 - 20
Density of solids	1.4 - 2.0
Natural density	0.4 - 1.2 g/cc
Dry density	0.08 - 0.32 g/cc
pH	4 - 7
Natural permeability	1×10^{-3} - 1×10^{-5} cm/sec

Sampling and testing. The purpose of the site investigation should be to delineate the extent and depth of peat coverage and to obtain samples for classification and laboratory use. The coverage of the peat deposit may be obtained by soundings. Disturbed samples may be obtained from split spoon samples or continuous flight augers. Reasonably undisturbed samples may be taken with thin-walled samplers such as a Shelby tube near the surface, or a piston-type sampler at greater depths. Minimal sampling disturbance will occur if the sampling tubes are sharpened and lubricated. It is preferable to use a sampling tube which is the same size as the test specimen to avoid disturbance due to trimming.

The testing program should include procedures to determine the following index properties:

1. Moisture, ash and organic content (ASTM Standard D2974).
2. Density of solids (use correlation with ash content, Equation 1).
3. Fiber content (use method outlined in Testing section).
4. In-situ wet and dry density.

5. If metal or concrete is to be placed in contact with the peat, pH should be determined (ASTM Standard D2976, distilled water method only).

Embankment design. These writers recommend the following design approach for embankments over peat:

1. Preliminary surcharge design using settlement and time estimates from equations (14), (15) and (16). Stability analysis should be performed using strength from triaxial compression tests.
2. Compare preloading design to other possible solutions and choose most desirable alternative.
3. If preloading is chosen, install settlement plates and monitor settlements.
4. Use Gibson and Lo's model to control duration of surcharge.
5. After sufficient time, remove the surcharge and complete construction.

These writers suggest using single load tests, scaled to field dimensions using Equations (14), (15), and (16) to determine surcharge magnitude and time settlement behavior. The exponential parameter (i) can be assumed equal to 1.5 for preliminary design.

These writers recommend using consolidated undrained triaxial tests to model field behavior. The samples should be consolidated isotropically to the level of vertical effective stress anticipated in the field. Stability of the embankment need not be considered unless the height of embankment is 1m (3 feet)

or more, in which case the undrained strength parameters should be used in a stability analysis. Stability analyses involving peat soils are usually made by the conventional limit design methods of comparing required stresses with available strength on potential failure arcs, or alternatively on the basis of potential sliding blocks. Computerized stability analyses, such as those presented by Chen (1981) for three dimensional failures may be used to both refine and facilitate the computations.

If stability presents problems, loading berms should be utilized. The positive effects of loading berms have been analyzed by Hollingshead and Raymond (1972). Geotextiles also have a beneficial effect on embankment construction over peat. These fabrics placed between the embankment and peat deposit prevent local failures, inhibit pavement rutting, and prevent spreading of the embankment causing less fill to be used.

Preloading and control. If peat must be used as a foundation material, improving the properties of the deposit by use of preloading may be the most economical method. The technique presented in this report provides a tool for the designer to control the duration of the surcharge period.

During construction, settlement plates should be placed under the embankment. During and after construction of the surcharged embankment, the deformation behavior should be monitored. After the primary strain portion of the settlement has occurred (approximately three months), Gibson and Lo's model should be applied as a control over the duration of preload. After sufficient time has passed to accelerate the desired settlements, the surcharge is removed and highway construction is completed.

Concluding remarks. Many highways have been built over peat deposits using the preload method. This report improves on previous preloading analyses by presenting an accurate method of controlling the duration of the surcharge period. During the preliminary design, a conservative estimate of the required time for surcharge is made, based on laboratory compression tests. The settlement of the field embankment should be monitored by use of settlement plates. After settlement has progressed into the secondary strain portion, Gibson and Lo's model should be applied and the required duration of surcharge determined from this data (the contractor will not object if the surcharge time can be shortened). The laboratory and field data should be compared for several embankment sections and ultimately, correlations may be determined so that the

field measurements will not be routinely necessary.

The report also serves to familiarize the reader with: the relevant properties and behavior of peat, methods for building highway embankments over peat, and the latest efforts to classify peat.

Recommendations for future research. There is a need to correlate the rheological parameters from Gibson and Lo's model as determined in the laboratory to the parameters calculated under field loading situations. If this relation were determined, field settlements could be predicted from laboratory tests using this model.

The relationship between the shear strength of samples consolidated hydrostatically and those consolidated anisotropically is still not quantitatively understood. Qualitatively, the shear strength of peat is larger when consolidated by a hydrostatic pressure as compared to anisotropic, where the coefficient of lateral earth pressure at rest (K_0) is less than one. The magnitude of this difference has not been quantified. The actual consolidation which occurs in the field is anisotropic. To model this behavior in triaxial tests requires a knowledge of K_0 , which is difficult to determine for peats.

Research concerning peat will be made much easier when a standard classification of peat has been adopted. At that time, when a case study is presented, the researcher will know precisely what material is being referred to. Presently this condition does not exist and causes much confusion in the literature.

Marl. Marl, as is used in this report, refers to a soft, earthy material composed largely of calcium carbonate that is found as a deposit in areas that were at one time, or still are covered with water. In northern Indiana, marl is commonly overlain by peat.

Tests were conducted on specimens consolidated from a slurry, with varying calcium carbonate contents. These tests showed, all other factors being equal, that increasing the calcium carbonate content caused an increase in water content, initial void ratio, compressibility and strength. It was found, however, that the effect of calcium carbonate on the engineering properties of marl in field samples was minimal. Factors such as organic content had a much larger effect on marl behavior.

It is therefore recommended that marl be dealt with in the same manner as any other soft, highly compressible mineral soil deposit.

Recommendations for future research. The behavior of soft materials underlying peat deposits seem to be controlled by factors other than calcium carbonate content. It is likely that organic content is a major factor in determining the behavior of these soft soils. It would be desirable to know the effect of high organic contents (25 to 75 %) on strength and compressibility parameters of these soft deposits.

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Note: The Appendices, pages 164 through 180 are not included in this copy of the report. This section is contained in the interim report IN/JHRP-83/3, entitled "Use of Peats as Embankment Foundations." Copies of this report may be obtained at the cost of duplication from:

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