VANE SHEAR TESTS IN
LAKE AGASSIZ CLAYS

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by
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ABSTRACT

A great deal of testing with vane shear equipment in homogeneous clay soils has been reported throughout the world. This thesis deals with the results of vane shear tests in the varved clay deposits of glacial Lake Agassiz in Manitoba.

The soil shearing resistance determined by a vane was compared, in most cases, to one-half of the unconfined compression test result for tube samples. The vane results from one test hole were compared to one-half the deviator stress as determined from triaxial tests.

In addition to the determination of the reliability of vane test results in varved clays, the suitability of the vane test equipment was also studied.

The test results indicate that the vane shear test will in general yield shear strengths in excess of those determined by unconfined compression tests on tube samples. On the basis of the test data presented in this thesis, the vane shear test appears to be a suitable means of determining the shear strength of varved clays although some refinements may be necessary in the testing equipment.

P R E F A C E

This thesis is an investigation of the suitability and reliability of the vane shear test in Lake Agassiz varved clays.

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CHAPTER I

INTRODUCTION

The main purpose of this thesis was to determine the reliability of shear strength values obtained by the use of vane shear apparatus in the varved clays deposited in Manitoba by glacial Lake Agassiz. This thesis presents the results of vane shear tests in Manitoba and a comparison with the results of unconfined compression and triaxial tests performed in the laboratory on samples obtained from the same location as the vane tests.

The determination of in-situ shearing strength of soil has been a subject of considerable interest for many years. Although several pieces of apparatus and methods of test have been used to determine this strength, there are probably only three basic types of tests presently in use. These are Penetration Tests, Pull Shear Tests and the Vane Shear Tests. The most popular of these has been the latter which, essentially, consists of driving a vane, usually having four blades, into the ground and measuring the torque required to rotate the vane and shear a cylinder of soil.

Since the shearing strength of a soil is so important to the Engineer in the design of dams, highway embankments, bridge and building foundations, etc., it is essential that this value be determined as accurately as possible. The accuracy and reliability of future testing methods may enable the designer to reduce safety factors which would reduce cost of many structures. Due to the complex nature of soil it is essential to investigate thoroughly any proposed foundation site. Depending upon the type and purpose of the foundation, dozens of test holes may be necessary. The vane tests provide a relatively quick method of strength determination and therefore can be used to supplement information obtained by sampling and laboratory testing of the soil, with little additional time consumption or expense.

Many papers have been published presenting data related to the vane-shear test, which is in limited use throughout the world. The data indicates that this method of strength determination may be more reliable for certain applications than those heretofore generally accepted.

Because the Lake Agassiz clay deposits are varved, a good correlation of the vane test results versus unconfined compression test results and the vane test results versus triaxial test results may not be possible. The varves consist of different soil types in varying thicknesses. Not only does the type of soil change distinctly from one layer to another but the moisture content can also vary considerably.

This investigation was carried out to determine whether a correlation similar to that obtained elsewhere on non-varved clays was evident in the glacial Lake Agassiz varved deposits.

It was also the purpose of this investigation to evaluate the suitability of the vane apparatus developed by the Manitoba Highways Branch.

CHAPTER II

A History of the Vane Shear Test

First recorded experiments with vane testing were performed by J. Olsson in Sweden in 1928 [1]. There is a German patent dated 1929 on this subject [1]. At the Third International Congress for Applied Mechanics, which was held in Stockholm in 1930, C. Forssel demonstrated a vane tester[1].

In Canada in 1941 a vane apparatus was used by A.W. McLoughlin on the investigations for the Welland Canal. It was used extensively in studies of slides on the Beauharnois Canal in 1942 and again in Sault Ste. Marie in 1943 [2].

In England the Army developed a vane in 1944 for testing the bearing capacity of soft ground in connection with tank mobility studies [3]. Work on the development of practical field equipment began in Sweden in 1947 under the Royal Swedish Geo-technical Society [1], and in England in 1948 under Bishop[3]. A paper describing tests and results of vane shear tests performed in Chicago glacial clays was published in 1949 [4].

Foundation Company of Canada, in 1950-51, developed a stress-strain device for use with a vane [2]. Information supplied by Geocon Limited, describing this latter device, was used in the construction of the equipment which was used to obtain the data for this thesis.

Tests with a vane in the foundation investigation for a fill across an arm of Lake Pend ' Oreille near Sand Point, Idaho, were undertaken in the early 1950's [5]. W. J. Eden and J. J. Hamilton used a field vane apparatus in determining shear strength in Leda clay deposits in Eastern Canada [6]. The results of these latter field tests were compared with those found by the laboratory testing of tube samples.

The work of Eden and Hamilton [6] was presented at the fifty-ninth annual meeting of the American Society for Testing Materials, at Atlantic City, N. J., on June 22nd, 1956. Work done by the Bureau of Reclamation, Denver, Colorado, was reported by Harold J. Gibbs [6] at the same meeting. A report by Carl W. Fenske on deep vane tests in the Gulf of Mexico and a description of a vane shear device developed by the Oregon State Highway Department, by William C. Hill also were presented at the 1956 meeting.

At the present time many provincial, federal, and state departments as well as consulting firms, are using vane shear information to supplement their regular soil test data.

CHAPTER III

GEOTECHNICAL PROPERTIES OF SOILS TESTED

The geology of the Lake Agassiz area in Manitoba is of special interest because dynamic geological processes have been responsible for marked textural variations in the parent material of the soil. As the result of glaciation during the Pleistocene period, a great deal of the area was covered by glacial drift or boulder till. The boulder till deposits ranged in thickness from less than 20 to over 200 feet [7].

From the beginning of the Pleistocene period when the ice began to melt, to the beginning of the formation of the existing soil, the glacial till was modified by geological agencies other than ice. In the Lake Agassiz basin, the original till was modified by the waters of the lake, and in addition, detritus from the higher lying regions was carried into the lowlands as a result of erosion and stream transportation.

When glacial Lake Agassiz was at its greatest height, the water in the vicinity of Winnipeg must have been between 550 to 600 feet in depth [8]. The waves of the lake caused the erosion of the drift and till along the shore lines and in the shallows. The finer materials removed by the water were transported and deposited to the deeper sections of the lake bottom. The accumulation of these sediments resulted in stratification of the lacustrine deposits in many sections of the basin, and varves of colloidal clay here occur with thin layers of coarse clay and silt or very fine sand. As the lake receded and its depth decreased the materials stirred and transported were the finer fractions consisting mainly of fine sand, silt and clay. When the lake had receded to the central lowlands, very fine materials were brought in by streams and tributary lagoons and deposited in the quiet waters of the lake basin.

As the lake reached its final stages, it began to receive alluvial sediments. These sediments are found spread over large areas of the lake bed. The thickness of these water-laid sediments differs greatly. The superficial deltaic and lacustrine materials in the central lowlands range up to 60 or more feet thick. The fine sand and silty layers outside of the central basin range in thickness from several inches to more than ten feet, and rest either on unassorted till or upon earlier lake deposits which are usually finer in texture than the surface deposits.

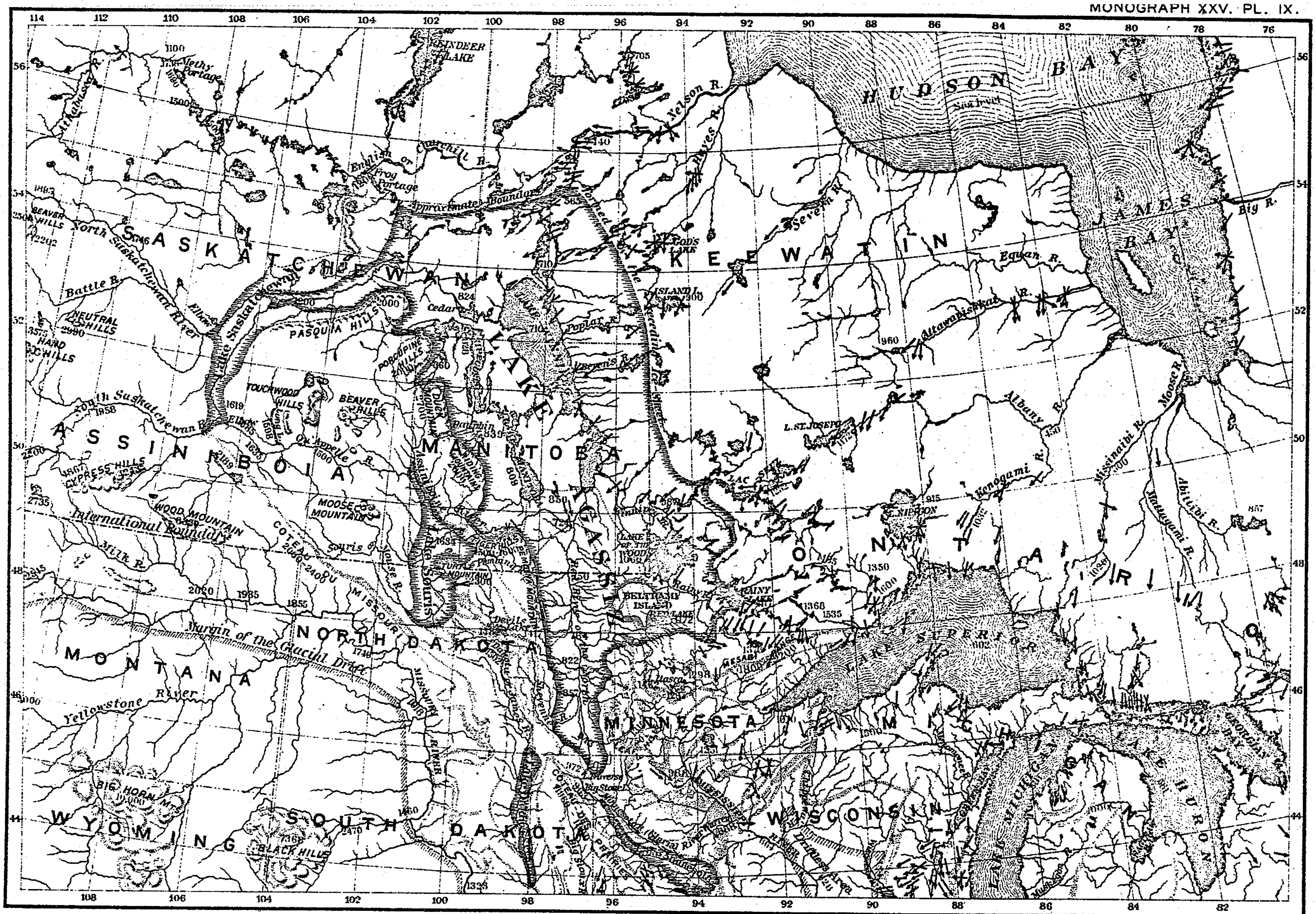
When the beaches were being formed along the western and southern shorelines of Lake Agassiz, glacial ice formed its eastern and northern boundaries. This ice sheet was not continuously retreating but rather oscillated backward and forward. In some cases as the ice advanced into Lake Agassiz the varved clays at the bottom of the lake were foliated and distorted [8]. This helps to explain why although the varves are generally found to be horizontal they are occasionally found in a vertical direction or at some angle between vertical and horizontal.

Figure 1 shows the approximate position and size of glacial Lake Agassiz. The area within which all the tests contained in this thesis were done is shown in Figure 2. This area is referred to as the Red River plain and represents only a small portion of the Lake Agassiz basin [9].

The Lake Agassiz clays generally fall into the classification of A-7-6 or A-7-5 clay soils and generally have a group index of 20. However, occasionally the soil encountered will have a group index slightly lower due to the presence of a higher percentage of silt than normally encountered.

With increasing depth the soil color generally varies from brown to olive or grey. The depth of the layers varies considerably. Because of the method of deposition of these various soil layers there is very little uniformity of layer thickness or soil type. The soil making up these different colored layers generally varies from silt or silty clay to clay with the silt fraction decreasing with increasing depth [10].

The varves themselves vary in thickness from 1/4 inch to as little as 1/64 of an inch. The varves generally consist of clay layers with intermediate silt or silty clay layers. It has been determined in other areas that considerable variations



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MAP WITH ALTITUDES OF LAKE AGASSIZ AND ADJOINING COUNTRY.

Scale, about 165 miles to an inch.

Lake Agassiz and associated Glacial Lakes [ ]

Altitudes in feet above the sea [710]

FIGURE 1. Map of Lake Agassiz.

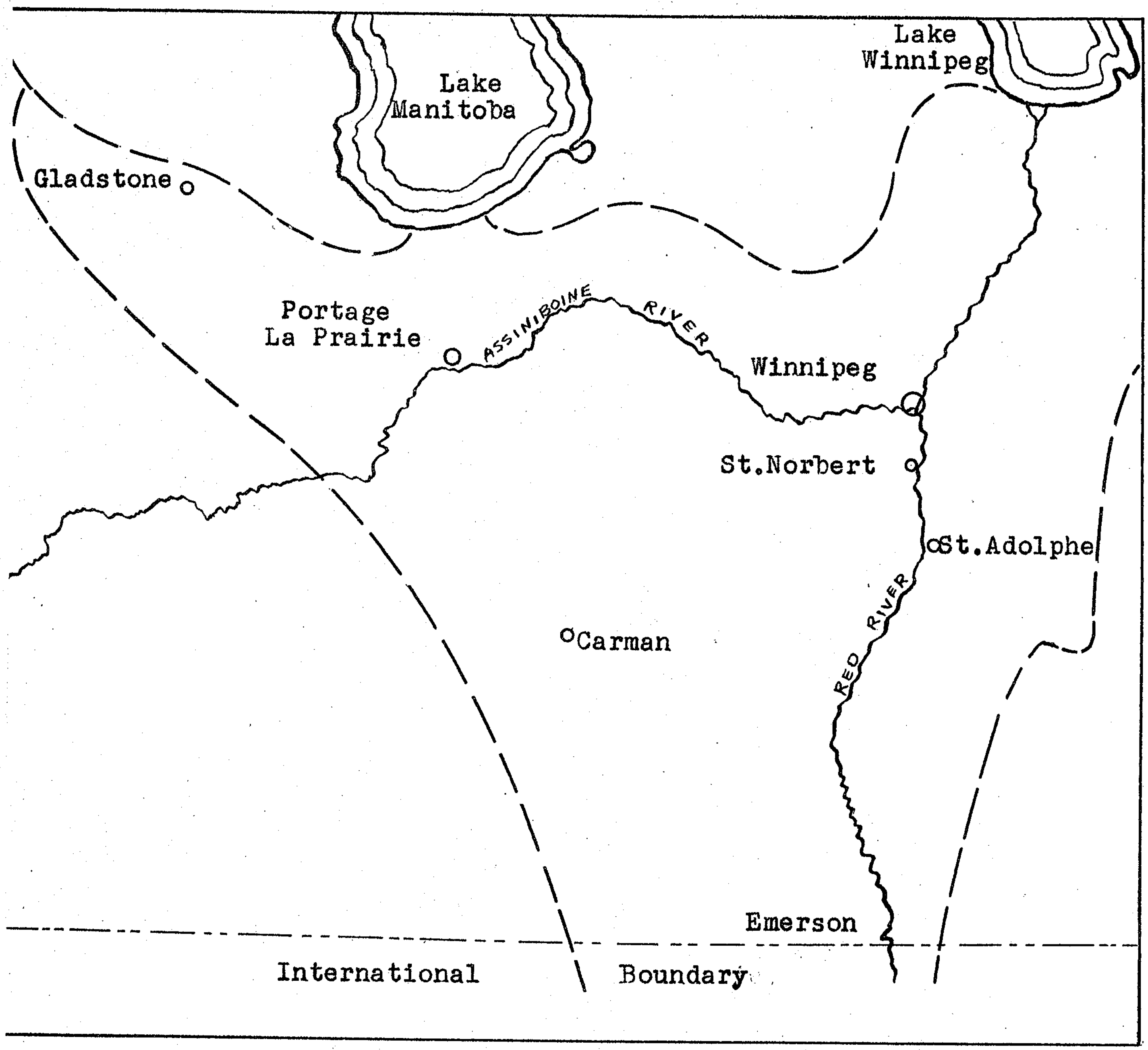

FIGURE 2. Approximate boundaries of the Red River Valley plain

in moisture content are possible within very small depth changes in varved clays. The dry density of the varved clays generally varies between 50 and 100 lbs. per cubic foot. The moisture content of the soil has been found to vary from 27% to 63% based on the dry weight of the soil sample. The degree of saturation of most of the Lake Agassiz varved clay ranges between 86 and 100%. Unconfined compression tests on a large number of varved clays in the vicinity of Winnipeg have yielded strengths averaging 2100 lbs. per square foot approximately [11].

The liquid limit of these clays generally varies between 37 and 117 with plasticity indexes ranging from 20 to 88. The clay is generally found to have low permeability, between 10^{-9} and 10^{-11} cm. per second. Because of the low permeability, ground water conditions have been very difficult to determine. However, the soil below a depth of 6 to 12 feet is generally found to be saturated [11].

The soil below this saturation level at the greater depths, is said to be normally consolidated or slightly over consolidated. That is, the soil has not been subject to greater over-burden pressures than those which presently exist. The upper layer of soil is generally considered to have been pre-compressed. This pre-compression of the soil is the effect of desiccation.