Technical Council on Cold Regions Engineering Monograph

Permafrost Foundations

State of the Practice

Edited by Edwin S. Clarke

ASCE

PERMAFROST FOUNDATIONS

STATE OF THE PRACTICE

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EDITED BY
Edwin S. Clarke, P.E.

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Cover Photo: Federal Aviation Flight Service Building at Fairbanks International Airport. The thermoprobes are used to keep the soils under the building in a frozen condition. Photo by Edwin S. Clarke.

Foreword

The ASCE Technical Council on Cold Regions Engineering (TCCRE) is publishing a series of Monographs on various cold regions engineering subjects. Each monograph reviews the state of the practice within a defined area through a set of papers written by invited experts in the field.

This monograph is the tenth in the series and the second of the 21st century. It focuses on the techniques used to construct foundations on permafrost, presenting the most current techniques used to design these foundations. As building expands in the northern latitudes, it is critical to get information about soil conditions and geotechnical and structural issues into the hands of the next generation of engineers and builders who will be dealing with the many challenges of building on frozen soils. Failure to understand the complexity of technical issues involved in building under these extreme conditions can result in a range of undesirable outcomes—starting with settlement or jacking of the soils—and resulting in conditions ranging from sloping buildings to swayback roofs to complete structural collapse.

This monograph includes eight chapters, which present the authors' experience in both the design and remedial actions required for the continued successful performance of these systems. Topics include an overview of frozen soils and geotechnical issues, the need for geotechnical investigation, structurally enhanced foundations, post and pad foundations, adjustable- design foundations, innovations in arctic engineering, building on marginal permafrost, case histories of pile foundations in permafrost, and refrigerated foundations.

Many people were involved in the preparation of this monograph. The topic of state-of- the-practice permafrost foundations came from Tom Krzewinski, who was the first chairman of the structures and foundation committee. The project would not have been possible without the assistance of John Segna our ASCE contact. All of the chapter authors are ASCE members, and they are to be given most of the credit. These articles reflect the experience of the individual authors, who have been expanding the knowledge and techniques used to build successful foundations in a demanding and challenging environment. See the table of authors for a complete listing. The early organization and coordination of the authors was handled by Edwin S. Clarke. He was assisted in these efforts by James Charlton. The final editing and conversion of the monograph chapters into a uniform format were performed by Janet Scheren of Scheren Communications.

Each paper had at least one technical review. All reviewers are listed in the table that follows; their assistance is greatly appreciated. Without them this publication would not be of the high quality that it is.

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Chapter 1

Introduction

By Edwin S. Clarke, P.E., F.ASCE

Permafrost is defined as soil that remains frozen for more than two years. At elevations less than 304.8 m (1000 ft.), it is frequently encountered north of latitude 60. It may also be found south of latitude 60 at higher elevations or in areas with colder climates. In general, permafrost is associated with polar regions and exists as a layer of continuously frozen soil underlying a thin, active layer of soils that undergo annual freeze/thaw cycles.

Any soil that maintains a frozen state is defined as permafrost. If the moisture content of soil is very low, the effects of temperature change will be minimal. However, all soil matrices contain water to some extent. While mineral soil properties are relatively temperature stable throughout the climatic temperature range, water is another story.

Freezing and thawing of the water in soil and the subsequent changes in physical properties of the soil matrix, such as density, hydraulic conductivity, thermal conductivity, shear strength, and compressive strength, are phenomena that concern engineers practicing in northern latitudes. When water freezes, its volume increases by about 9 percent. This dramatic expansion can generate significant stress. Pressures of 14.1 km/cm (200 psi) are possible under some conditions.

Permafrost is formed when conditions, such as climate, latitude, solar aspect, or vegetation patterns combine to keep the soil temperature lower than the freezing point of water. It is possible to artificially create permafrost using refrigeration systems. Naturally occurring permafrost is in a state of equilibrium. Heat flow into frozen soils during summer months is balanced by heat flow out of frozen soils during winter months. The equilibrium can be disrupted by human activities, such as clearing vegetation, building new facilities, or diverting existing drainage patterns, or by natural forces, such as global temperature cycles, forest fires, or erosion events. After disruption, the soil temperature profile adjusts until a new equilibrium is achieved. During the adjustment period, the depth of permafrost may increase or decrease, ice may form or thaw, and settlement or heaving of soils may occur. These events affect structures built on permafrost and are the prevalent challenge for engineers involved in development of northern regions.

Continuous permafrost primarily exists north of 60° latitude in Asia and North America. Figure 1.1 illustrates the extent of permafrost conditions in the Northern Hemisphere. Discontinuous permafrost is found at the boundary of continuous permafrost regions. Site-specific conditions such as vegetation, exposure, and soil types influence the ground temperature profile and existence of permafrost in these slightly warmer areas.