GEORGE F. SOWERS

BUILDING ON SINKHOLES

Design and Construction of Foundations in Karst Terrain

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ABSTRACT:

Based on over 50 years experience in geotechnical engineering, this book summarizes the mechanisms of sinkhole formation in limestone (or karst) terrain. The author also provides methods for overcoming sinkhole-related failures and for avoiding or minimizing future sinkhole collapses that impact on human activity. Professor Sowers also discusses site investigation, as well as the design and construction methods that are appropriate for building foundations in areas where sinkholes are likely to develop. It is written for engineers and geologists, in addition to other professionals who work together to solve sinkhole problems.

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PREFACE

This book reflects a half century of geotechnical engineering. A significant part of that time was involved with investigating damage caused by sinkholes to buildings, roads, dams, and other structures. This evolved into developing the most effective ways to prevent sinkhole problems during planning, designing, and constructing new projects in areas prone to sinkhole development.

The book summarizes my observations and research into the mechanisms of sinkhole formation and the natural and human forces that drive the mechanisms. Fifty years ago there were many misconceptions of the nature of sinkholes. This has changed. There are new and better ways to explore site conditions. Extensive and deep construction excavations have made it possible to examine the rock-soil interface directly. New data have helped to clarify the relation between groundwater changes, rock solution, and soil erosion. This has made it possible to correct most failures that have occurred and to avoid or minimize future sinkhole collapses that impact on human activity. The text reflects this progress. It describes, in some detail, for the non-geologists as well the non-engineers, the mechanisms of sinkhole development and their impact on humans. However, geologists can learn from the engineering observations based on construction experience and the engineers can learn form the geologists and hydrologists. The text includes site exploration, familiar to both engineers and geologists, but its emphasis on the particular techniques that are most useful in areas underlain by solutioned rock should be helpful to both. It also points out the similarities of sinkholes over solutioned limestone and those over openings in other rock formations, such as lava and even over sewers and mines. A third part of the text deals with design and construction measures appropriate for building structures in areas where sinkhole activity is liable to develop. It also describes where some measures that are sometimes employed not likely to succeed. The text does not include water-retaining structures. Although the present work reflects the author's experience with dam design, construction, and remediation work, material on that specialty would nearly double the size of the present work; therefore the preparation and design for dam foundations are not discussed.

Many people have contributed to this work by their insights when working with the author in solving foundation problems and failures. Others have reviewed drafts of this text and made many helpful suggestions. Most are or have been co-workers with Law Engineering and Law Environmental Services, particularly, Randy Knott, Clay Sams, Luther Boudra, and David Wheeless, who reviewed earlier versions of the text; their comments and suggestions improved it greatly. Dr. Janet Sowers Horn, the author's daughter, a consulting geologist and an expert in cave geology, made many helpful suggestions as well as provided insight into the geometry of the underside of sinkholes. Frances Sowers, a retired hydrologist with TVA and The U.S. Corps of Engineers, the author's wife, has shared the field examination of sinkholes and sinkhole damage with me for the past 53 years. She contributed her critique of the written text, improving the logic and the flow of the wording, as she has with my previous works. Finally, Robert Alexander, draftsman with Law Environmental Services turned sketches into finished drawings, and secretaries Betsy Reed, Peggy Farley, and Chris Shattuck helped smooth rough drafts into the completed manuscript. The author thanks all for their help in making this book a reality.

The two technical reviewers, Dr. Dan Brown Professor of the Department of Civil Engineering, Auburn University, and Dr. Allen Hathaway, Professor of Geological Engineering, The University of Missouri at Rolla, made significant contributions to the scope of the text and the flow of the words. The subject is so broad and at the same time technically so complex that some compromises were necessary to challenge the diverse persons that are involved with sink hole problems. It is my hope that the book will be a catalyst to bring this diverse expertise together to solve the problems instead of debating endlessly who is responsible and who should pay (although those problems also require answers).

CHAPTER 1

INTRODUCTION

1.1 HOUSE IN A SINKHOLE

After 2 years of unusually dry weather, a family was enjoying the sound of the latest of several intense thunderstorms at supper time. Their one-story house had been built in a new subdivision approximately 5 years previously on former farmland, just north of the town of Bartow, Florida. Bartow is in the central part of the state, approximately 35 mi (60 km) east of Tampa, in a part of a broad low ridge that forms the backbone of the Florida peninsula.

Suddenly, the house shuddered. The family members ran out the front door to find a 20-ft (6-m) diameter hole near one corner of the house. The hole enlarged during the night, but the house, although bent, remained intact. During the next day, the city dumped several truckloads of sand from a nearby pit into the hole, filling it to the original ground surface and temporarily stopping the subsidence. Subsidence continued erratically for several days, followed by refilling in an attempt to maintain the ground surface level. This only retarded the house settlement.

After several days of subsidence and filling, a second sudden dropout occurred accompanied by the loss of one end of the house in an open hole (Fig. 1.1). By this time the family's possessions had been removed and the family was housed elsewhere.

The uppermost soil in the subdivision consists of poorly consolidated silty sands and slightly clayey silty sands, 30 to 40 ft (9 to 12 m) thick, underlain by an irregular layer of highly plastic clay and clayey sand containing calcium phosphate nodules from 1 to 10 mm in diameter. Still deeper is a porous limestone with irregularly spaced, steep solution-enlarged fissures. During the dry years proceeding the failure, the local groundwater table had been further depressed by wells supplying domestic water to the city. In addition, large volumes of water had been utilized for processing the phosphate pebbles obtained by strip mining of the phosphate-bearing clay