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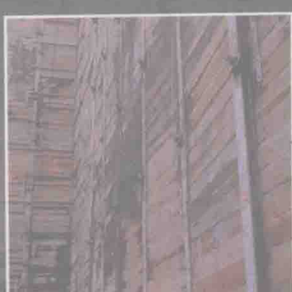
EARTH RETENTION SYSTEMS HANDBOOK



- Selection criteria for types of shoring
- Equipment requirements and options
- Safety and inspection methods
- Detailing for constructibility
- Design tables
- Code references

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EARTH RETENTION SYSTEMS

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PREFACE

When I was first approached to write this book, I asked Larry Hager of McGraw-Hill why he had focused on a topic which, to the general public, is not a high visibility issue. He replied that he had witnessed the death of a laborer, quite close to his house, who was killed in a cave-in while hooking up a new tank being installed at a nearby gas station. As a result of that accident, Larry felt that there should be a reference manual so that this type of event did not recur.

When I pointed out to Larry that the subject was covered to some extent by the OSHA regulations, he acknowledged that a lot of the information necessary was there. However, he felt that the information was not in a format which was readily accessible for the general public. Out of his concern was born this project.

For those of us involved in the shoring business, the dangers of excavations are known. But it is evident that those dangers are not apparent to the vast majority of the public today. We see improperly shored or un-shored excavations every day. I once had a Washington State Department of Labor and Industries Officer explain to me that over 50 percent of the citations he issued were a result of something he saw published in the newspaper which lead him to believe that something unsafe was occurring, prompting him to investigate further.

It is hoped that this text will be made available to every person who has authority over an excavation. The text is not intended to be a how to, nor a definitive treatise on design, but rather an introduction for persons of all technical skill levels to the basic shoring procedures which are available today.

Unlike other aspects of civil engineering, such as the design and construction of large commercial structures, the practice of shoring is almost without standards or codes. The methods of shoring have been developed largely by individuals functioning within small privately held contracting companies. These companies are run by individuals who are just that—individuals. They are intensely competitive and extremely entrepreneurial. Their companies survive and thrive because of their innovations. It should not surprise the reader that the practice of shoring is therefore very regional and quite without standardization.

This text will outline some of the methods used, and some of the more common techniques practiced. It is not intended to be, nor could it ever be, a defining document for the purposes of specifying shoring methods. It is hoped that the readers will gain a level of understanding such that they may be able to comprehend the basis for the design and construction of the shoring proposed for a particular project. The shoring of any given excavation should be entrusted to individuals and companies who are experienced in this work. Their diligence is the greatest safeguard of the public and those workers directly involved in the project.

It is my sincere hope that this book will raise the consciousness of those involved in excavations, be it through design, permitting, construction, or procurement, so that they will ensure that proper procedures are implemented and experienced personnel are engaged. In this day and age, when the knowledge and skill required to be safe is easily obtainable, it is simply inexcusable for us to continue to read news articles about cave-in accidents and deaths in underground construction.

ACKNOWLEDGMENTS

In writing this book, I had help from a lot of friends. This book involved a lot of support and input from people whom I have been close to in the business world for many years.

Those who helped me with job photos and drawing details include Bill Grady of KLB Construction, Brian Isherwood and Nadir Ansari of Brian Isherwood and Associates, Troy Adams of Skyline Steel, Scott McKellar of Hurlen Construction, Peter McDonald, and Bill Starke of Deep Foundations Contractors, Vince Jue of Champion Equipment, Ernie Brandl of Schnabel Foundation, Charlie Griffes of CT Engineering, Stan McAllister of City Transfer, Horst Aschenbroich of Con-Tech Systems, Bruce Jensen and Doug Banks of Williams Form Engineering, Robert Fisher of Dywidag Systems, Bill Warfield of Ingersoll Rand, Mike Weekes and Gary Berg of Stoneway Concrete, Don Morin of DMI Drilling, Jim Su of CivilTech, Alan Rasband and John Roe of Malcolm Drilling, John Monroe of Watson Inc, Matthias Heichel of ABI, Inc, Dan Fruhling of Fruhling Excavation, Ron Boscola of Murray Franklin, Tom Gurtowski of Shannon & Wilson, Ben Dutton of Equipment Corporation of America, Arne Carson of KPFF Consulting Engineers, Michael Leffer of Hans Leffer GmbH, Gary Schnee of Seaport Steel, Ed Sneffen of Golder Associates, Tony Barley of SBMA, Shannon Creson of Drill Tech Drilling and Shoring, and Bob Federighi and Matt Partain of Condon Johnson & Associates.

Colin Cox and Eric Lindquist of Golder Associates were tireless in their development of illustrations. I would also like to thank Pat Sievertsen and Leo Stapleton of Condon Johnson & Associates for their assistance with photo compilation. Skip Dickman of Dickman Hines Lumber provided insights on lumber grading and treatment, Joel Moskowitz of Mueser Rutledge Consulting Engineers gave me a view of the history of earth retention in New York City, and Bob Plum of Golder Associates was in invaluable resource for locating reference materials.

Scot Litke of the ADSC–The International Association of Foundation Drilling, and Roger Woodson of Lone Wolf Enterprises get high marks for encouraging me throughout the process.

A special thank you to David Cotton of Golder Associates for his assistance, not only with technical recommendations and arranging Golder's collaboration in providing illustrations, but also for taking the time to proofread chapters of the book and keep me going when times got tough.

The book would not have been possible had it not been for two people who have had a profound impact on my career and life. Dr. Hugh Peacock, my structures professor at the University of Western Ontario, rescued me from a life of civil service boredom and injected me into the world of construction. Once I was pressed into service in construction, Bill Lardner of Deep Foundation Contractors took the roll of mentor in my life, and showed me the joy of construction in the underground.

And last but certainly not least, to my wife Anne, my proofreader and supporter who never batted an eye when the book took over my life—because she knew it made me happy.

And to my golf partners, I assure you that in the future, I will not lose as much money to you on the golf course as I did this year because I will now be a little more focused on the game at hand.

ABOUT THE AUTHOR

Alan Macnab's entire career has been spent with earth retention construction companies involved in both design-build and hard bid construction. His roles in construction have included work in operations, supervision, estimating, marketing, and claims, including executive positions in both Canada and the United States. He has held positions in a number of industry associations, including the Presidency of the ADSC–The International Association of Foundation Drilling (1990-1991) where he continues to chair the Standards and Specifications Committee. He is currently Vice President, President-Elect of the Geo-Institute of the American Society of Civil Engineers. Macnab received his B.E. Sc. from the University of Western Ontario and continued there with graduate studies. He is licensed as a professional engineer in Canada.

Macnab has been involved in the construction of earth retention and deep foundation projects since 1973. These projects have been implemented throughout North America, including eastern and western Canada, the northeastern states, Rocky Mountain states, and West Coast. He has traveled extensively, reviewing construction techniques in North America, Europe, Asia, and the South Pacific. He is a frequent speaker on issues involved in these specialties to engineering, academic, and supervisory personnel and has written extensively on these topics.

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CHAPTER 1
INTRODUCTION

The body of work called variously Earth Retention, or Shoring, or Geo Support, or Sheeting has historical roots. Earth Retention, as we know it today, has been the amalgamation of construction technologies, equipment innovations and engineering analyses borrowed from many other disciplines. The real coalescing of these roots into a distinct discipline did not occur until well into the latter part of the 20th century, but now represents literally billions of dollars of work annually in the United States alone.

Earth Retention systems are created by a contractor drilling, driving and excavating, and an engineer investigating, analyzing, predicting, measuring and confirming. The innovations of the past have come together in the 20th century to form a critical mass which has evolved into the shoring industry as we know it today.

PILING AND PILE DRIVING

We may never know how those first timber piles, found in Swiss lakes, which supported stilt type houses from the period of 3000 BC were installed, but we assume that in some manner they were driven into the ground. Pile driving was born. We do know, however, that the Greeks were driving piles in 1000 BC and that later the Romans also performed pile driving. The driving of timber piles continued through the ages. Just when piles were first used for their lateral capacity as a retaining wall is open to conjecture. It may have been for fortifications where parallel lines of vertical timber piles were installed and fill was placed between them to create breastworks.

Advancements in shoring occurred when the timber piles used as retaining walls were replaced by squared timbers with tongue and groove joints for tighter fit. Later, several timbers were ganged together to form Wakefield sheeting. This form of tight sheeting survived until the early 20th century, when the patenting of steel sheet piling rendered timber sheeting obsolete. Steel sheet piling wasn't really put into extensive use until after World War I.

Piling was driven with drop hammers up until the introduction of air and steam hammers in 1845 in this country. The driving of steel sections appears to have begun around 1880, about the same time as the introduction of the shoring system called the "Berlin Method," named for the city of its origin. This was the origination of soldier pile and lagging. Soldier piles were primarily installed by impact driving in the U.S. until well into the 1950s. The first drilled soldier piles in Toronto were not installed until the early 1960s.

While the use of the vibro hammer was pioneered by the Russians in the 1920s, it really didn't reach the U.S. market until the 1950s. Originally, "vibros" were chain driven, electric devices. These were modified and redesigned in the U.S. in 1969 with the revolutionary introduction of the hydraulic vibratory hammers which are in use today. Most sheet piling is currently driven this way. In a parallel development, the sonic hammer or bodine hammer was introduced in the early 1960s. While showing great promise, the sonic hammer never gathered widespread support and so remains one of those good ideas which never fulfilled its advance billing.

The diesel piledriving hammer, invented in Germany in the late 1930s, came into use in the U.S. in the 1950s. It, together with the vibro hammer, largely replaced air and steam hammers for driving soldier piles.

DRILLING

A Chinese building code of 1103 AD records the use of excavated shafts as a form of foundation and it is generally accepted that all civilizations have excavated holes as a way of forming foundations. Hand excavated pneumatic caissons were first used in France in 1839, and in the U.S. in 1852 for the excavation of bridge piers. The first recorded use of the pneumatic caisson for a building in the U.S. was 1893 in New York City. In a parallel development, a formalized process of foundation production was instigated in the 1880s called the Gow Caisson or Chicago Caisson. This was a hand-dug hole, large enough for a man to enter, which was shored as excavation progressed. Instead of excavating to water and calling it a well as man had done since the dawn of time, pit miners sank shafts to a good bearing layer and called it a caisson.

Just when this hand excavation method was first used for underpinning is open to question, but there is recorded evidence of underpinning including temporary shoring of a retaining wall in France in the 1690s. With the onset of extensive building construction, which included significant substructures, in the urban cities of America in the 1880s, it can't have been long afterward that underpinning was required and the hand-dug underpinning pit was born.

The mechanical drilling of shafts began in Texas in the 1920s when horse-driven augered shafts were installed to overcome expansive soils which bedevilled the local builders. The early 1930s brought the first power-driven auger rigs and the drilled shaft industry took off. When the first soldier pile was installed by drilled methods in lieu of driving is open to argument, but by the late 1950s soldier piling, by the drilled and placed method, was becoming popular.

SOILS INVESTIGATION

The first recorded Standard Penetration Test (SPT), which of course was not standard at the time, was performed in a wash bored test shaft in 1902. By 1914, it had become standardized and is one of the many *in situ* tests which engineers now use to evaluate the soils in which excavations are made. A variety of cones, penetrometers, pressuremeters, and piezometers in use today all provide the input values for the analysis used for design of shoring.

ANALYSIS AND DESIGN

At the risk of leaving out significant parties, the shoring engineer can look back over a few seminal points in history to identify the basis of the design methods we use today. In 1770s Coulomb produced his theories on design for retaining walls and many are still in use. By 1857, Rankine had developed Earth Pressure Theory based on active and passive pressures. Some of his diagrams are still used to design cantilever and single level of bracing shoring.

It has been noted that by 1906 a Mr. J.C. Meems was writing about earth pressures in trenches and, although his work has largely been disregarded, it indicates that the profession was looking for ways to rationally design excavation support systems.

In 1943, Dr. Karl Terzaghi wrote papers on Wedge Theory and, as a result of work with strut loads on deep cuts in the Chicago Subway, he and Dr. Ralph Peck developed the diagrams that are used today for multi level bracing systems. With the advent of reinforced earth (1950s) and soil nailing (1970s), different methods of analysis were developed and engineers now often use Limit Equilibrium methods to solve their earth retention problems.

MEASUREMENT

The first recorded installation of steel struts in a shored excavation was 1926. Prior to that time, timber strutting had been used. It is a credit to the thoughtfulness of those early engineers, that those struts on the first job were instrumented with strain gauges.

Movement of excavations, which originally were measured against fixed baselines with levels and transits are, with the invention in the U.S. of the slope indicator casings in 1958, being monitored with much more accuracy. Global Positioning (GPS) methods, which really found their way into construction in the 1990s, have eased the problems involving measurement which used to require careful maintenance of fixed monitoring points.

SLURRY

The use of slurries to maintain stability in an otherwise unstable hole was born in the petroleum industry in 1914 when it was found that deep holes could be stabilized with slurries of natural material. The use of bentonite was originated by the oil well drilling industry 1929 and adapted for use in the drilled shaft industry in the 1950s. This technique, together with the driving of casing, made commonplace by the vibro hammer, has massively influenced the expansion of drilling in materials otherwise considered to be inappropriate for shaft excavation.

The first slurry trench cutoff walls for ground water control were installed in the U.S. in 1948 and the first structural slurry walls were constructed in Italy in 1950. Structural slurry walls did not appear in the U.S. until 1962. The hydrofraise excavation methods were derived in Europe in 1960 and the method arrived in U.S. in 1970.

TIEBACKS

While anchorages were recorded in Europe in 1874 and tiedowns made up of driven piles and screw piles are recorded in this country as early as 1902, the first drilled, post tensioned tiebacks were actually installed in Algeria in 1934. Drilled anchor technology for permanent anchors did not reach Europe until the 1950s and the U.S. until the 1960s, although there is some record of the use of driven beam tiebacks in the 1950s in the U.S.

Prior to this time, lateral earth pressures in deep cuts were restrained with either struts or rakers. In fact, until the end of World War II, most internal bracing utilized timber.

The first tensioned mechanical screw anchors were installed in U.S. in 1963, and drilled and belled anchors were installed in Toronto in 1965. In the early1960s, Europeans began investigating the development of frictional capacity in soil anchors and by the end of that decade regrouting techniques for anchors were being used in Europe.

Driven casing methods, for the purpose of installing anchors, were first introduced in 1970 in Europe and soon thereafter in the U.S. Today, the majority of anchors are installed with some form of what is now called duplex drilling which involves advancing a casing simultaneously with the drill bit.

With this onslaught of drilled anchors came specifications and consensus documents. The Post Tensioning Institute (PTI) issued its first recommendations for soil and rock anchors in 1976 and in 1991 the International Association of Foundation Drilling (ADSC) recognized the work of anchored earth retention as being within the scope of its responsibilities.

DEWATERING

During the 1890s, the work of installing deep foundations for major buildings in waterbearing sands in New York was being performed by Pneumatic Caisson methods. In this method, hand excavation was carried out under air pressure within an enclosed box. This is not to say that these were the first sunken caissons. Sunken masonry caissons are recorded as early as 1204 AD in Egypt. The first evidence of an excavation where an attempt was made at keeping the excavation dry, which we would now call the cofferdam method, was recorded in 1753 in France. In 1768 an unwatering project was attempted utilizing an undershot waterwheel to develop pumping power. The first real attempts at deep dewatering were not made in the U.S. until 1927, and the technique really didn't become commonplace until after World War II when a tremendous building boom enveloped the country.

SECANT WALLS

The first use of secant walls is recorded in the 1920s in Europe but it was not until 1950 in the U.S. when continuous pile walls, as they were called, were installed. The 1970s brought forth the introduction, in Japan, of soil/cement mixing technology. Methods were devised to perform mixing to considerable depths. This method, now referred to as the Deep Mixed Method (DMM), was first introduced into the U.S. in the early 1980s, but it wasn't until 1986 that a large commercial application was performed. DMM is now commonly used to create deep secant pile walls for earth retention purposes. This technology has a number of uses as a ground improvement tool which bodes well for its continued use. Soil mixing relies on a knowledge of rheology gained from the grouting industry to assist in its many applications.

SOIL NAILING

Although the Romans appeared to be exercising a form of soil nailing when they drove timber piles for slope stability improvement, soil nailing as we know it was first introduced in France in 1972 and in U.S. the in 1976.

MICROPILES

Micropiling was first developed in Italy in the early 1950s where it was used as a method to repair war damage. The first North American application of micropiling came in Canada in 1971 and micropiles were installed followed soon thereafter in the U.S. in 1973.

COMPUTERS

Not only has the proliferation of computers in the 1980s and 1990s changed the face of data logging when measuring earth retention performance, every engineer and contractor has one on his/her desk. The tool to deal quickly with the tiresome iterative solutions so inherent in moment calculations, or to optimize strut configurations, or to solve limit equilibrium problems is at the engineer's finger tips today. Engineering calculations are far less burdensome than even 25 years ago.

THE INDUSTRY

With the onset of the building boom in the 1880s in the U.S. came the formation of specialized foundation companies which performed subgrade works. Because the solutions of the time involved a more integrated relationship between temporary works and the completed structure, these companies performed all the foundation work. It would have been impossible to separate the work of excavating a pneumatic caisson from the subsequent construction of the footing or wall within the caisson. With this specialization came the creation in the early 1900s of specialty engineering firms who performed soils investigations and foundation designs.

As the shoring industry developed, the shoring schemes became less integrated with permanent construction. In North America, the work of soldier pile and lagging was initially performed by general contractors who utilized the services of structural engineers for design and piling contractors as subcontractors for the installation of the driven soldier piles. However, by 1960 the practice of shoring had advanced to the point where engineers with specialized skills in earth retention design could support themselves on a steady diet of this type of work. At the same time, specialty contractors staffed with civil engineers had taken over the construction of complete shoring systems and were offering those systems on a design-build basis.

As one can readily see, the pieces of the puzzle that go together to form the knowledge and skill base of the shoring engineer and contractor come from many roots. Some are home grown, while many have been taken from foreign lands and different industries. The 21st century is bringing added technological change in the form of methods designed to reduce the amount of open cut necessary to construct today's infrastructure. These methods include microtunnelling, New Austrian Tunnelling Methods (NATM), trenchless technology and directional drilling. In spite of this, there can be no question that the amount of earth retention work will continue to expand. Newer innovations and additions will continue to change and refine the part of earth retention in underground construction, but the earth retention industry will remain a dynamic industry peopled by innovators.