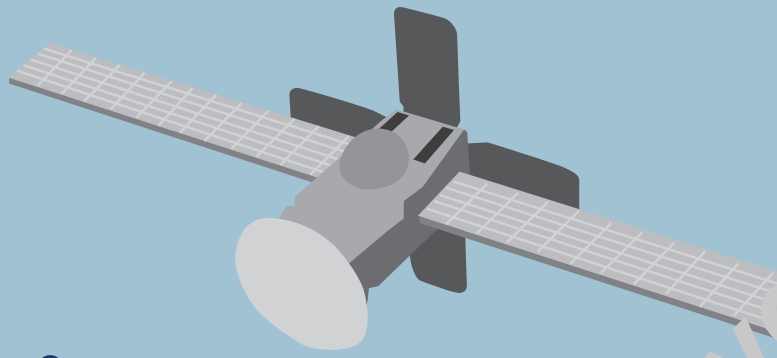


ASCE MANUALS AND
REPORTS ON
ENGINEERING PRACTICE
NO. 152



Surveying and Geomatics Engineering

Principles,
Technologies,
and Applications

Prepared by the Surveying Committee

EDITED BY

Daniel T. Gillins, Ph.D., P.L.S.

Michael L. Dennis, Ph.D., P.E., P.L.S.

Allan Y. Ng, P.L.S.



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CORS and OPUS for Engineers: Tools for Surveying and Mapping Applications, edited by Tomás Soler (ASCE/Geomatics Division 2011). This collection of 22 articles assembles the latest thinking on the use of two advanced services—CORS and OPUS—for obtaining accurate positional coordinates to use in high-accuracy surveying (ISBN 978-0-7844-1164-3).

NAVSTAR Global Positioning System Surveying, by the U.S. Army Corps of Engineers (ASCE Press 2000). The U.S. Army Corps of Engineers Technical Engineering and Design Guide No. 28 provides technical specifications and procedural guidance for surveying with the NAVSTAR GPS (ISBN 978-0-7844-0353-2).

Surveying and Geomatics Engineering

Principles, Technologies, and Applications

Sponsored by
The Surveying Committee of the
Surveying and Geomatics Division of the
Utility Engineering and Surveying Institute of the
American Society of Civil Engineers and the
National Geodetic Survey

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Library of Congress Cataloging-in-Publication Data

Names: Gillins, Daniel T., editor. | Dennis, Michael L., editor | Allan Y. Ng, editor.

Title: Surveying and geomatics engineering : principles, technologies, and applications / edited by Daniel T. Gillins, Michael L. Dennis, Allan Y. Ng.

Description: Reston, Virginia : American Society of Civil Engineers, [2022] | Series: ASCE manuals and reports on engineering practice ; no. 152 | "Sponsored by the Surveying Committee of the Surveying and Geomatics Division of the Utility Engineering and Surveying Institute of the American Society of Civil Engineers and the National Geodetic Survey." | Includes bibliographical references and index. | Summary: "MOE provides a comprehensive yet general overview to help support education and inform practicing engineers on the important role of the surveying engineer"-- Provided by publisher.

Identifiers: LCCN 2021059081 | ISBN 9780784416037 (paperback) | ISBN 9780784416044 (hardcover)

Subjects: LCSH: Surveying. | Geomatics.

Classification: LCC TA545 .S8535 2022 | DDC 526.9--dc23/eng/20220114

LC record available at <https://lccn.loc.gov/2021059081>

Published by American Society of Civil Engineers

1801 Alexander Bell Drive

Reston, Virginia 20191-4382

www.asce.org/bookstore | ascelibrary.org

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Errata: Errata, if any, can be found at <https://doi.org/10.1061/9780784416037>.

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ISBN 978-0-7844-1603-7 (print)

ISBN 978-0-7844-8400-5 (PDF)

ISBN 978-0-7844-8422-7 (ePub)

Manufactured in the United States of America.

27 26 25 24 23 22 1 2 3 4 5

MANUALS AND REPORTS ON ENGINEERING PRACTICE

(As developed by the ASCE Technical Procedures Committee, July 1930, and revised March 1935, February 1962, and April 1982)

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FOREWORD

Surveying engineering has been at the heart of the National Geodetic Survey (NGS) since our founding as the Survey of the Coast in 1807 by President Thomas Jefferson. The purpose, as stated by Congress, was “...for completing an accurate chart of every part of the coasts....” In 1878, under the name of the United States Coast and Geodetic Survey (USC&GS), our mission expanded to include the entire country. We continued under that name for nearly 100 years, until the creation of the National Oceanic and Atmospheric Administration (NOAA) in 1970. Today, the geodetic work of the USC&GS continues under the name NGS, as an office within NOAA’s National Ocean Service.

With this long and distinguished history, NGS is often touted as our nation’s first civilian *science* agency. Although our name has changed and the breadth of our work has grown, our core mission remains the same: to support surveying and mapping in the United States. We accomplish this mission through the creative application of scientific principles and mathematics to solve practical problems for the benefit of society—the very definition of *engineering*.

The NGS engineering ethos is an enduring connection not just to civil engineering in general but also to the American Society of Civil Engineers (ASCE) in particular. This connection is best exemplified by Major William Bowie, a geodetic engineer and Chief of the USC&GS Division of Geodesy from 1915 until his retirement in 1936. Bowie joined ASCE in 1917 and founded the ASCE Surveying and Mapping Division in 1926, serving as Chair until his death in 1940. The name was changed to Surveying Engineering Division in 1986, and then to Geomatics Division in 1997. It was renamed Surveying and Geomatics Division (SGD) in 2015, along with the creation of the ASCE Utility Engineering and Surveying Institute (UESI). As a UESI division, SGD carries forward the spirit of what Bowie started, by ensuring that surveying engineering remains an integral part of civil engineering.

This manual of practice is an extension of Major Bowie’s foresight and passion. Founded on science, rooted in mathematics, and focused on modern practical applications, it serves as a general but comprehensive reference for practicing engineers, surveyors, and other geospatial professionals. Within its pages, topics range from the fundamentals of geodesy, coordinate systems, least-squares adjustments, and error propagation through the latest innovations in satellite, terrestrial, mobile, and airborne technologies. It provides best practices for these technologies, as well as for other topics, such as establishing geodetic control, performing construction surveys, and employing geographic and building information systems in civil engineering. Two of the manual’s three editors are NGS employees who authored three of the 15 chapters herein. All other chapters are written by authors who are experts in their respective fields. This manual is a unique compilation of professional and practical material—all located in this one magnificent source.

A common thread running through the manual is the importance of the National Spatial Reference System (NSRS) to modern geospatial applications. The NSRS serves as the

foundation for civilian surveying and mapping in the United States and its territories. It forms an essential link between the geospatial professions and NGS, whose mission is to define, maintain, and provide access to the NSRS.

The NSRS has never been more important than it is today for ensuring that the work products of surveying engineering are correctly georeferenced and meet accuracy requirements. The vital role of the NSRS continues to grow as society seeks reliable integration and sharing of an ever-expanding array of geospatial data. NGS is currently in the process of modernizing the NSRS, and portions of this manual highlight these changes. As positioning technologies and methodologies evolve, the NSRS modernization will ensure that NGS remains a key partner in surveying and geomatics engineering. This is consistent with what Major Bowie started at ASCE in 1926; and there is no doubt that he would heartily endorse this manual were he alive today. Nearly a century later, this manual is a fitting legacy to Bowie's vision and the ongoing mission of NGS.

Juliana P. Blackwell
Director National Geodetic Survey

PREFACE

In 1985, ASCE published a manual of practice on engineering surveying. It has not been updated since, and the world we are living in today is a very different place when compared with that of 1985. This new reference manual provides a sorely needed and complete update on the modern practice of surveying and geomatics engineering.

In the early 1980s, the digital revolution had just begun with the introduction of the IBM PC. The internet was not widely available, nor was email. In the surveying world, the electronic total station was being introduced, and the US government was just starting to build the Global Positioning System (GPS) satellite constellation.

Today, as some predicted, the use of GPS and other Global Navigation Satellite Systems (GNSS) has become ubiquitous. High-resolution commercial satellites and mobile lidar systems are creating consumer map databases that support vehicle navigation systems in most countries around the world.

As this new Manual of Practice on surveying engineering was being written, mobile computing, autonomous vehicles, augmented and virtual reality, and—perhaps of the greatest potential impact—unmanned aircraft system (UAS) technology were all poised to create the next revolution in surveying and mapping.

None of this would be possible without the surveying engineer who performs work at the intersection of the two fields of surveying and engineering.

For those readers who might be familiar with the 1985 engineering surveying manual of practice, the prologue is an incredibly detailed history of surveying, complete with diagrams and references. I will not even attempt to duplicate that effort. Rather than looking back, it is hoped that this new manual will help establish a vision of the current and near-future role of the surveying engineer.

As stated in the prologue of the previous manual,

Lasers are being tested for acquisition of vertical control in photogrammetry and for providing line and grade in construction related surveying. Similar to radar-equipped Terrain Profile Recorder systems already in use, the laser beam achieves greater precision and resolution in air-to-ground measurement.

This was the early vision for what would become airborne lidar.

It continued,

As a result of the technological breakthrough in surveying and mapping, the survey engineer of the 1980's must be better trained in a much broader field of science than the surveyor of even a decade ago. A background in higher mathematics, computer technology, photogrammetry, geodetic science, and electronics is necessary for today's survey engineer to compete in this rapidly expanding discipline. But like his Nineteenth Century counterpart, the survey engineer should possess those admirable traits of early American character, energy, perseverance and close observation that led some young men who began as axemen and rodmen, to rise in their profession until they became distinguished engineers.

These admonitions in the 1980s are all the more true today. The modern surveying engineer is now faced with an all-encompassing digital suite of sensors and computer software that strain the limits of any practicing professional to keep pace with the changes that are taking place on the technology front. Surveying engineers should seek higher education opportunities and continue learning after graduation to stay abreast with all the latest advancements. With the multitude of changes, many have begun referring to the profession as “geomatics engineering” as it now encompasses a broader field.

Perhaps the greatest challenge facing today’s professionals, from a technical point of view, lies in the shift from 2D, paper-based documentation to 3D digital models that range in scale from an individual project to the entire globe. Satellite navigation systems such as GPS require that the surveying engineer understand the principles of geodesy to judge the accuracy of their 3D positions.

Despite the strong need for more education to keep up with the technology and to support engineering projects, it has been documented that civil engineering university programs are offering fewer courses in surveying and geomatics. Most states allow licensed professional engineers to perform activities associated with surveying engineering; however, many engineers do not necessarily receive the specialized skills, education, and training.

So, this manual is part of a call to action for the engineering community. There are exciting new opportunities for the surveying engineering profession to step up and assume a leadership role as the world struggles with profound changes, including urbanization, climate change, energy demand, decaying infrastructure, and the Internet of Things. These are just a few of the mega trends that require the knowledge and expertise of the surveying engineer.

This manual is intended to provide a foundation for the practice of surveying engineering, but it cannot replace the need for fundamental, continuous education and training because the technology and the profession are not going to stand still. The manual provides background information on the basics of geodesy, least-squares adjustments, error propagation, coordinate systems and transformations, surveying and remote sensing equipment, identification and establishment of control, construction surveying, best practices, and more. Because entire books could be devoted to each of these topics, this manual only provides a summary, and it points the readers to important references where they can find more details. The manual is meant to provide a comprehensive but general overview to help support education and inform practicing engineers on the important role of the surveying engineer. It is too important for this not to occur.

Gene V. Roe

Blue-Ribbon Review Panel

Kevin M. Kelly, Ron Singh, Dave Zilkoski

ACKNOWLEDGMENTS

This Manual of Practice was prepared over a period of several years under the direction of the Surveying Committee of the Surveying and Geomatics Division of the Utility Engineering and Surveying Institute (UESI) of ASCE. Numerous people contributed to the writing, review, and editing of the manual. Thanks to everyone for their service; without their help, this manual would not have come to fruition.

The manual was created following ASCE procedures for creating manuals of practice. First, authors with expertise and experience in a given subject area were invited to draft a chapter. Then, each chapter was sent to a minimum of two experts for peer review. After responding to the review comments and making revisions, the entire draft manual was submitted to three individuals on a Blue-Ribbon Panel to review its overall content. Afterward, the editors made revisions and edits in response to the Blue-Ribbon Panel's review comments. Finally, the manual was sent to the Executive Committee of the Surveying and Geomatics Division and approved for publication. I believe that the expertise of the many authors and the multiple rounds of review have greatly improved the overall quality of the manual.

I would like to thank the following individuals for serving as authors for chapters of the manual; many of these people also helped serve as peer reviewers of other chapters. Special thanks to Dimitrios Bolkas, Michael Bunn, Earl F. Burkholder, Erzhuo Che, Michael L. Dennis, Charles D. Ghilani, N. W. J. Hazelton, Lisa D. Herzog, Jaehoon Jung, Andrew C. Kellie, Matthew S. O'banion, Michael J. Olsen, Chris Parrish, Gene V. Roe, Michael J. Starek, Yelda Turkan, Jan Van Sickle, Marlee A. Walton, Benjamin E. Wilkinson, and David E. Woolley.

I also would like to thank the following people who served as peer reviewers: Steve Breidenbach, Jacky C. K. Chow, Georgia Fotopoulos, David Garber, Chris Glantz, Alec Grkovic, John Hamilton, Steve Hennessee, Brent Jones, Thomas Meyer, Norman Miller, Carol Morman, Jie Shan, Dru Smith, Tomas Soler, Tom Taylor, David Totman, Greg Wear, David Widmer, and Mark Woodson. I am also grateful for the excellent reviews by the three members of the Blue-Ribbon Review Panel: Kevin M. Kelly, Ron Singh, and Dave Zilkoski.

UESI staff provided valuable support and guidance throughout the entire process of creating the manual. Thanks to John Segna, who helped start the process, Diane Swecker, who continued and encouraged its completion, and Susan Reid, who was our primary and most helpful staff support.

Finally, I would like to thank my spirited coeditors who spent countless hours of service meeting, reviewing, revising, and responding to the many important needs required to edit and prepare the final draft of the manual. My most sincere gratitude to Michael L. Dennis and Allan Y. Ng. Your help was invaluable.

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CHAPTER 1

ENGINEERING SURVEYING WITHIN ASCE

Gene V. Roe

INTRODUCTION

ASCE defines engineering surveying as

those activities involved in the planning and execution of surveys for the location, design, construction, operation, and maintenance of civil and other engineered projects. Engineering surveying may be regarded as a specialty within the broader professional practice of engineering and includes all surveying and mapping activities required to support the sound conception, planning, design, construction, maintenance, and operation of engineered projects. Engineering surveying excludes the surveying of real property for the establishment of land boundaries, rights-of-way, easements, and the dependent or independent surveys or resurveys of the public land survey system. ASCE believes that this definition should be adopted by state engineering licensing boards.

These two paragraphs, taken from ASCE Policy Statement 333 (ASCE 2018), define the profession of engineering surveying on which this manual has been written and provided to the public. In addition, we believe that it is important to call the reader's attention to a subtle but critically important distinction in the use of the terms *engineering surveying* and *surveying engineer*. In the first case, we are referring to a type of surveying—an activity. In the second case, it is a type of engineer—an individual. The order in which the terms are used does matter within the profession and particularly when using these terms with the general public. Hence, in this manual, the terms *engineering surveying* and *surveying engineering* should be considered synonymously because they are used interchangeably in many publications. As noted in the following, there are other common phrases for describing this type of surveying activity.

GEOMATICS AND GEOSPATIAL ENGINEERING

The term surveying engineering represents the intersection of the two fields. Many other terms or labels are used to describe this combination of professions, both within and outside the United States. Some of them are discussed as follows.

Since 1926, the Surveying and Geomatics Division has been the lead group within ASCE concerning all topics related to surveying engineering and, more broadly, "mathematics of