HANDBOOK OF CIVIL ENGINEERING CALCULATIONS

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To civil engineers—everywhere: The results of your design and construction skills are with all civilized humanity every day of their lives. There is little anyone can do without enjoying the result of your labors. May this handbook help your work be more widely recognized and appreciated—worldwide.

About the Editor

Tyler E. Hicks, P.E., is editor of *Standard Handbook of Engineering Calculations, Standard Handbook of Mechanical Engineering Calculations, McGraw-Hill's Interactive Chemical Engineer's Solutions Suite, McGraw-Hill's Interactive Civil Engineer's Solutions Suite,* and other bestselling titles. He is also a consulting engineer with International Engineering Associates.

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PREFACE

This handbook presents a comprehensive collection of civil engineering calculation procedures useful to practicing civil engineers, surveyors, structural designers, drafters, candidates for professional engineering licenses, and students. Engineers in other disciplines—mechanical, electrical, chemical, environmental, etc.—will also find this handbook useful for making occasional calculations outside their normal field of specialty.

Each calculation procedure presented in this handbook gives numbered steps for performing the calculation, along with a numerical example illustrating the important concepts in the procedure. Many procedures include "Related Calculations" comments which expand the application of the computation method presented. All calculation procedures in this handbook use both the USCS (United States Customary System) and the SI (System International) for numerical units. Hence, the calculation procedures presented are useful to engineers throughout the world.

Major calculation procedures presented in this handbook include stress and strain, flexural analysis, deflection of beams, statically indeterminate structures, steel beams and columns, riveted and welded connections, composite members, plate girders, load and resistance factor design method (LRFD) for structural steel design, plastic design of steel structures, reinforced and prestressed concrete engineering and design, surveying, route design, highway bridges, timber engineering, soil mechanics, fluid mechanics, pumps, piping, water supply and water treatment, wastewater treatment and disposal, hydro power, and engineering economics.

Each section of this handbook is designed to furnish comprehensive coverage of the topics in it. Where there are major subtopics within a section, the section is divided into parts to permit in-depth coverage of each subtopic.

Civil engineers design buildings, bridges, highways, airports, water supply, sewage treatment, and a variety of other key structures and facilities throughout the world. Because of the importance of such structures and facilities to the civilized world, civil engineers have long needed a handbook which would simplify and speed their daily design calculations. This handbook provides an answer to that need.

While there are computer programs that help the civil engineer with a variety of engineering calculations, such programs are highly specialized and do not have the breadth of coverage this handbook provides. Further, such computer programs are usually expensive. Because of their high cost, these computer programs can be justified only when a civil engineer makes a number of repetitive calculations on almost a daily basis. In contrast, this handbook can be used in the office, field, drafting room, or laboratory. It provides industry-wide coverage in a convenient and affordable package. As such, this handbook fills a long-existing need felt by civil engineers worldwide.

In contrast, civil engineers using civil-engineering computer programs often find data-entry time requirements are excessive for quick one-off-type calculations. When one-off-type calculations are needed, most civil engineers today turn to their electronic calculator, desktop or laptop computer and perform the necessary steps to obtain the solution desired. But where repetitive calculations are required, a purchased computer program will save time and energy in the usual medium-size or large civil-engineering design office. Small civil-engineering offices generally resort to manual calculation for even repetitive procedures because the investment for one or more major calculation programs is difficult to justify in economic terms.

Even when purchased computer programs are extensively used, careful civil engineers still insist on manually checking results on a random basis to be certain the program is accurate. This checking can be speeded by any of the calculation procedures given in this handbook. Many civil engineers remark to the author that they feel safer, knowing they have manually verified the computer results on a spot-check basis. With liability for civil-engineering designs extending beyond the lifetime of the designer, every civil engineer seeks the "security blanket" provided by manual verification of the results furnished by a computer program run on a desktop, laptop, or workstation computer. This handbook gives the tools needed for manual verification of some 2,000 civil-engineering calculation procedures.

Each section in this handbook is written by one or more experienced professional engineers who is a specialist in the field covered. The contributors draw on their wide experience in their field to give each calculation procedure an in-depth coverage of its topic. So the person using the procedure gets step-by-step instructions for making the calculation plus background information on the subject which is the topic of the procedure.

And since the handbook is designed for worldwide use, both earlier, and more modern topics, are covered. For example, the handbook includes concise coverage of riveted girders, columns, and connections. While today's civil engineer may say that riveted construction is a method long past its prime, there are millions of existing structures worldwide that were built using rivets. So when a civil engineer is called on to expand, rehabilitate, or tear down such a structure, he or she must be able to analyze the riveted portions of the structure. This handbook provides that capability in a convenient and concise form.

In the realm of modern design techniques, the load and resistance factor method (LRFD) is covered with more than ten calculation procedures showing its use in various design situations. The LRFD method is ultimately expected to replace the well-known and widely used allowable stress design (ASD) method for structural steel building frameworks. In today's design world many civil engineers are learning the advantages of the LRFD method and growing to prefer it over the ASD method.

Also included in this handbook is a comprehensive section titled "How to Use This Handbook." It details the variety of ways a civil engineer can use this handbook in his or her daily engineering work. Included as part of this section are steps showing the civil engineer how to construct a private list of SI conversion factors for the specific work the engineer specializes in.

The step-by-step *practical* and *applied* calculation procedures in this handbook are arranged so they can be followed by anyone with an engineering or scientific background. Each worked-out procedure presents *fully explained and illustrated steps* for solving similar problems in civil-engineering design, research, field, academic, or license-examination situations. For any applied problem, all the civil engineer need do is place his or her calculation sheets alongside this handbook and follow the step-by-step procedure line for line to obtain the desired solution for the actual real-life problem. By following the calculation procedures in this handbook, the civil engineer, scientist, or technician will obtain accurate results in minimum time with least effort. And the approaches and solutions presented are modern throughout.

The editor hopes this handbook is helpful to civil engineers worldwide. If the handbook user finds procedures which belong in the book but have been left out, he urges the engineer to send the title of the procedure to him, in care of the publisher. If the procedure is useful, the editor will ask for the entire text. And if the text is publishable, the editor will include the calculation procedure in the next edition of the handbook. Full credit will be given to the person sending the procedure to the editor. And if users find any errors in the handbook, the editor will be grateful for having these called to his attention. Such errors will be corrected in the next printing of the handbook. In closing, the editor hopes that civil engineers worldwide find this handbook helpful in their daily work.

Tyler G. Hicks

HOW TO USE THIS HANDBOOK

There are two ways to enter this handbook to obtain the maximum benefit from the time invested. The first entry is through the index; the second is through the table of contents of the section covering the discipline, or related discipline, concerned. Each method is discussed in detail below.

Index. Great care and considerable time were expended on preparation of the index of this handbook so that it would be of maximum use to every reader. As a general guide, enter the index using the generic term for the type of calculation procedure being considered. Thus, for the design of a beam, enter at *beam(s)*. From here, progress to the specific type of beam being considered—such as *continuous, of steel.* Once the page number or numbers of the appropriate calculation procedure are determined, turn to them to find the step-by-step instructions and worked-out example that can be followed to solve the problem quickly and accurately.

Contents. The contents of each section lists the titles of the calculation procedures contained in that section. Where extensive use of any section is contemplated, the editor suggests that the reader might benefit from an occasional glance at the table of contents of that section. Such a glance will give the user of this handbook an understanding of the breadth and coverage of a given section, or a series of sections. Then, when he or she turns to this handbook for assistance, the reader will be able more rapidly to find the calculation procedure he or she seeks.

Calculation Procedures. Each calculation procedure is a unit in itself. However, any given calculation procedure will contain subprocedures that might be useful to the reader. Thus, a calculation procedure on pump selection will contain subprocedures on pipe friction loss, pump static and dynamic heads, etc. Should the reader of this handbook wish to make a computation using any of such subprocedures, he or she will find the worked-out steps that are presented both useful and precise. Hence, the handbook contains numerous valuable procedures that are useful in solving a variety of applied civil engineering problems.

One other important point that should be noted about the calculation procedures presented in this handbook is that many of the calculation procedures are equally applicable in a variety of disciplines. Thus, a beam-selection procedure can be used for civil-, chemical-, mechanical-, electrical-, and nuclear-engineering activities, as well as some others. Hence, the reader might consider a temporary neutrality for his or her particular specialty when using the handbook because the calculation procedures are designed for universal use.

Any of the calculation procedures presented can be programmed on a computer. Such programming permits rapid solution of a variety of design problems. With the growing use of low-cost time sharing, more engineering design problems are being solved using a remote terminal in the engineering office. The editor hopes that engineers throughout the world will make greater use of work stations and portable computers in solving applied engineering problems. This modern equipment promises greater speed and accuracy for nearly all the complex design problems that must be solved in today's world of engineering.

To make the calculation procedures more amenable to computer solution (while maintaining ease of solution with a handheld calculator), a number of the algorithms in the handbook have been revised to permit faster programming in a computer environment. This enhances ease of solution for any method used—work station, portable computer, or calculator.

SI Usage. The technical and scientific community throughout the world accepts the SI (System International) for use in both applied and theoretical calculations. With such widespread acceptance of SI, every engineer must become proficient in the use of this system of units if he or she is to remain up-to-date. For this reason, every calculation procedure in this handbook is given in both the United States Customary System (USCS) and SI. This will help all engineers become proficient in using both systems of units. In this handbook the USCS unit is generally given first, followed by the SI value in parentheses or brackets. Thus, if the USCS unit is 10 ft, it will be expressed as 10 ft (3 m).

Engineers accustomed to working in USCS are often timid about using SI. There really aren't any sound reasons for these fears. SI is a logical, easily understood, and readily manipulated group of units. Most engineers grow to prefer SI, once they become familiar with it and overcome their fears. This handbook should do much to "convert" USCS-user engineers to SI because it presents all calculation procedures in both the known and unknown units.

Overseas engineers who must work in USCS because they have a job requiring its usage will find the dual-unit presentation of calculation procedures most helpful. Knowing SI, they can easily convert to USCS because all procedures, tables, and illustrations are presented in dual units.

Learning SI. An efficient way for the USCS-conversant engineer to learn SI follows these steps:

1. List the units of measurement commonly used in your daily work.
2. Insert, opposite each USCS unit, the usual SI unit used; Table 1 shows a variety of commonly used quantities and the corresponding SI units.
3. Find, from a table of conversion factors, such as Table 2, the value to use to convert the USCS unit to SI, and insert it in your list. (Most engineers prefer a conversion factor that can be used as a multiplier of the USCS unit to give the SI unit.)
4. Apply the conversion factors whenever you have an opportunity. Think in terms of SI when you encounter a USCS unit.
5. Recognize—here and now—that the most difficult aspect of SI is becoming comfortable with the names and magnitude of the units. Numerical conversion is simple, once you've set up *your own* conversion table. So think pascal whenever you encounter pounds per square inch pressure, newton whenever you deal with a force in pounds, etc.

SI Table for a Civil Engineer. Let's say you're a civil engineer and you wish to construct a conversion table and SI literacy document for yourself. List the units you commonly meet in your daily work; Table 1 is the list compiled by one civil engineer. Next, list the SI unit equivalent for the USCS unit. Obtain the equivalent from Table 2. Then, using Table 2 again, insert the conversion multiplier in Table 1.

Keep Table 1 handy at your desk and add new units to it as you encounter them in your work. Over a period of time you will build a personal conversion table that will be valuable to you whenever you must use SI units. Further, since *you* compiled the table, it will have a familiar and nonfrightening look, which will give you greater confidence in using SI.

TABLE 1 Commonly Used USCS and SI Units*

USCS unit	SI unit	SI symbol	Conversion factor—multiply USCS unit by this factor to obtain the SI unit
square feet	square meters	m^2	0.0929
cubic feet	cubic meters	m^3	0.2831
pounds per square inch	kilopascal	kPa	6.894
pound force	newton	N	4.448
foot pound torque	newton-meter	Nm	1.356
kip-feet	kilo-newton	kNm	1.355
gallons per minute	liters per second	L/s	0.06309
kips per square inch	megaPascal	MPa	6.89

*Because of space limitations this table is abbreviated. For a typical engineering practice an actual table would be many times this length.

TABLE 2 Typical Conversion Table*

To convert from	To	Multiply by	
square feet	square meters	9.290304	E – 02
foot per second squared	meter per second squared	3.048	E – 01
cubic feet	cubic meters	2.831685	E – 02
pound per cubic inch	kilogram per cubic meter	2. 767990	E + 04
gallon per minute	liters per second	6.309	E – 02
pound per square inch	kilopascal	6.894757	
pound force	newton	4.448222	
kip per square foot	Pascal	4.788026	E + 04
acre-foot per day	cubic meter per second	1.427641	E – 02
acre	square meter	4.046873	E + 03
cubic foot per second	cubic meter per second	2.831685	E – 02

Note: The E indicates an exponent, as in scientific notation, followed by a positive or negative number, representing the power of 10 by which the given conversion factor is to be multiplied before use. Thus, for the square feet conversion factor, 9.290304 × 1/100 = 0.09290304, the factor to be used to convert square feet to square meters. For a positive exponent, as in converting acres to square meters, multiply by 4.046873 × 1000 = 4046.8.

Where a conversion factor cannot be found, simply use the dimensional substitution. Thus, to convert pounds per cubic inch to kilograms per cubic meter, find 1 lb = 0.4535924 kg, and 1 in^3 = 0.00001638706 m^3. Then, 1 lb/in^3 = 0.4535924 kg/0.00001638706 m^3 27,680.01, or 2.768 E + 4.

*This table contains only selected values. See the U.S. Department of the Interior *Metric Manual*, or National Bureau of Standards, *The International System of Units* (SI), both available from the U.S. Government Printing Office (GPO), for far more comprehensive listings of conversion factors.

Units Used. In preparing the calculation procedures in this handbook, the editors and contributors used standard SI units throughout. In a few cases, however, certain units are still in a state of development. For example, the unit *tonne* is used in certain industries, such as waste treatment. This unit is therefore used in the waste treatment section of this handbook because it represents current practice. However, only a few SI units are still under development. Hence, users of this handbook face little difficulty from this situation.

Computer-aided Calculations. Widespread availability of programmable pocket calculators and low-cost laptop computers allow engineers and designers to save thousands of hours of calculation time. Yet each calculation procedure must be programmed, unless the engineer is willing to use off-the-shelf software. The editor-observing thousands of engineers over the years-detects reluctance among technical personnel to use untested and unproven software programs in their daily calculations. Hence, the tested and proven procedures in this handbook form excellent programming input for programmable pocket calculators, laptop computers, minicomputers, and mainframes.

A variety of software application programs can be used to put the procedures in this handbook on computer. Typical of these are MathSoft, Algor, and similar programs.

There are a number of advantages for the engineer who programs his or her own calculation procedures, namely: (1) The engineer knows, understands, and approves *every* step in the procedure; (2) there are *no* questionable, unknown, or legally worrisome steps in the procedure; (3) the engineer has complete faith in the result because he or she knows every component of it; and (4) if a variation of the procedure is desired, it is relatively easy for the engineer to make the needed changes in the program, using this handbook as the source of the steps and equations to apply.

Modern computer equipment provides greater speed and accuracy for almost all complex design calculations. The editor hopes that engineers throughout the world will make greater use of available computing equipment in solving applied engineering problems. Becoming computer literate is a necessity for every engineer, no matter which field he or she chooses as a specialty. The procedures in this handbook simplify every engineer's task of becoming computer literate because the steps given comprise—to a great extent—the steps in the computer program that can be written.

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