影印版

Third Edition

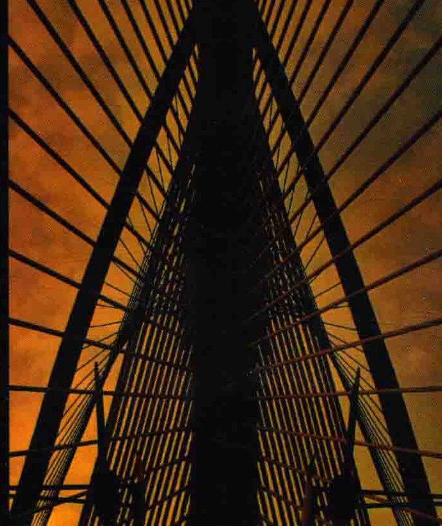
HANDBOOK OF CIVIL ENGINEERING CALCULATIONS

土木工程计算手册

木结构 · 土力学

Timber Engineering·Soil Mechanics

TYLER G. HICKS, P.E.



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HANDBOOK OF CIVIL ENGINEERING CALCULATIONS

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PREFACE

This third edition of this handbook has been thoroughly updated to reflect the new developments in civil engineering since the publication of the second edition.

Thus, Section 1 contains 35 new LRFD (load resistance factor design) calculation procedures. The new procedures show the civil engineer how to use LRFD in his or her daily design work, and since LRFD is a preferred design method among recent civil engineering graduates, the handbook is right in line with current design methods.

However, since an alternative design method is still used by some engineers around the world, namely ASD—Allowable Stress Design—it, too, is covered in this handbook. Thus the civil engineer will find both methods available to him or her so a suitable design method can be chosen using the third edition of this handbook.

Section 2, on reinforced and prestressed concrete, has been updated with new calculation procedures. The calculation procedures given in this handbook provide a wide-ranging coverage of this important specialty in civil engineering.

Section 3, timber engineering, has new methods and procedures for making calculations in this popular branch of civil engineering.

Section 4, soil mechanics, provides new ways to make soil calculations. Since nearly all structures require soil calculations, the new method given is an important addition to this handbook.

Section 5, surveying, route design, and highway bridges, has important new calculation procedures. Highways and roads, in much of the civilized world, are in poor condition. Potholes, cracks, and edge deterioration are rampant. Drivers often suffer blown tires, broken axles, and damaged wheels on such highways and roads.

When complaints are filed, the most frequent answer heard is "Roadway budgets have been cut; we don't have the money for repairs." In the United States, Congress is considering a major highway repair bill, but it seems to be moving very slowly—much slower than it should—considering the poor conditions of highways and local roads.

If the bill passes and money is appropriated for highway and road repairs, an enormous amount of work will be required. Civil engineers will have at least 10 years of highway and road work ahead of them. And, as part of the bill, new highways will be built. This will open opportunities for creative designs that make for safer driving in all types of weather. Truly, an exciting future is open to civil engineers in highway and road work.

As part of highway and road repairs, bridges will also need lots of work, plus—in some cases—complete replacement. Bridges have suffered numerous failures in recent years, with unfortunate loss of life. Many highway bridges need extensive repairs to steel elements, along with reinforced concrete rehabilitation.

Again, money is needed for this important work. And, like highways, the excuse is lack of funding. Hopefully, money assigned to highway repairs will include funds for bridge repair and replacement.

With bridge design constantly improving and new repair methods being developed, highway spans will be upgraded to reduce the loss of life from structural failures. The third edition of this handbook includes much valuable material on safe and effective bridge design. Civil engineers are urged to become familiar with codes covering safe bridge design. Knowing, and using, such codes will enhance almost every design, while making it safer for drivers and pedestrians.

With the highway, road, and bridge work ahead in next one or two decades, civil engineers have a very bright future. These engineers will seldom want for an important position. The demand for their skills will be ongoing for a very long time.

Section 6, fluid mechanics, pumps, piping, and hydro power, has new calculation procedures in it. A new method of generating hydro power in drinking water, irrigation, and wastewater lines is presented in this section. Also, a proven way for preliminary hydro power generating unit selection is given.

Section 7, water supply and storm-water system design, presents new ideas on water supply and usage. Water shortages are plaguing many parts of the world today. And these water shortages go far beyond the drinking water supply. In some countries the water shortage extends to farms. Owners of farms do not have enough natural water to irrigate their crops. So, some farmers move from nearly barren lands to more copiously supplied areas where they can safely grow their crops.

Drinking water supplies, covered in this section of this handbook, are also in short supply in some countries. Such shortages are critical to people's health. Finding sufficient potable water and delivering it to people's homes and work places is a critical task for civil engineers. The design of safe drinking water systems is also presented in this section. Thus, the civil engineer has the tools to provide safe drinking water, regardless of its source.

And since storm waters may be a source of drinking water, and a scourge to roads and buildings, its control is also provided. Full coverage of storm-water runoff rates, rainfall intensity, and the sizing of sewer pipes is also given in this section. Thus, the civil engineer is fully prepared to both supply and control water in all its uses and sources.

Section 8 covers sanitary wastewater treatment and control—an important topic in today's environmentally conscious world. The newest treatment methods are discussed in a number of important calculation procedures.

Section 9 covers engineering economics. This section has been fully revised so it focuses on the key calculations the civil engineer must make during his or her career. The result is a laser-like focus on the important calculation procedures used in daily civil engineering practice.

Since the second edition of this book was published, there have been major changes in civil engineering. These changes include following:

- **Antiterrorism construction** to protect large and small buildings structurally against terror attacks such as those that have occurred in New York, Paris, Mali, etc.
- **Increased building security features** are now included in almost every major—and many minor—structures to which the public has access. The increased security is to prevent internal and external sabotage and terrorism that could endanger the occupants and the structure.
- **Building Codes have been changed** to provide better protection for occupants and structures. These Code changes affect the daily design procedures of many civil engineers. Such changes are reflected in a number of the calculation procedures in this handbook.
- **"Green" building design is more popular than ever.** Buildings now win awards for their "green" efficiency that reduces energy consumption in new, existing, and rehabilitated buildings. Such "green" awards are important leasing sales features.
- **Major steps to improve indoor air quality (IAQ)** for all buildings have been taken in building design. These steps include much more than prohibiting occupants from smoking in buildings. New rules prohibit smoking within stated distances of the exterior of buildings. IAQ is a major concern in office buildings, schools, hotels, motels, factories, and other buildings throughout the world.
- **Better hurricane, tornado, flood, and wave resistance design of buildings** and other public structures after several disasters including Hurricanes Katrina and Sandy, the

superstorms in the Pacific and Indian Ocean. The loss of more than 250,000 lives in such storms has civil engineers searching for better ways to design, and build, structure—buildings, bridges, dams, etc.—to withstand the enormous forces of nature while protecting occupants. Also under study are (a) early-warning systems to alert people to the onset of dangerous conditions and (b) better escape routes for people fleeing affected areas. New approaches to levee and flood wall design, especially in cities like New Orleans, are being used to prevent recurrence of Hurricane Katrina losses. All these changes will be the work of civil engineers, with the assistance of other specialized professionals.

Taller buildings are being constructed in major cities around the world. Thus, 1,000-foot+ (305 m) mixed-use buildings (residences, stores, offices) are being constructed worldwide. Some even have wind turbines to generate the electric power needed to run the building. Civil engineers will be busy designing the foundations, structural members, and reinforced and prestressed concrete elements of these extra-tall buildings for years to come.

And with the emphasis on "clean energy," hydro power sites are being developed at a faster pace than in many previous decades. New, and updated, generating facilities offer more than just electricity. Some serve as water-supply sources for fresh water used in both agricultural and domestic systems. Sites being developed are in areas throughout the world because electricity is needed almost everywhere on the globe. Civil engineers have, and will continue to have, a major role in the design and construction of these new, and updated, hydro power facilities.

With so many changes "on the drawing board" and computer screen, civil engineers and designers are seeking ways to include the advancements in their current and future design of buildings, bridges, dams, and other structures. This third edition includes many of the proposed changes so designers can include them in their thinking and calculations.

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 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 2000 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 that is the topic of the procedure.

And because 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 30 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 needs to 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 that belong in the book but have been left out, the editor 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, P.E.

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 at the beginning 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
inch	millimeter	mm	25.4
feet	millimeter	mm	304.8
	meter	m	0.3048
square inch	square millimeter	mm^2	0.0006452
cubic inch	cubic millimeter	mm^3	0.00001638
$inch^4$	$millimeter^4$	mm^4	0.000000416
pound per cubic foot	kilogram per cubic meter	kg/m^3	16.0
pound per foot	kilogram per meter	kg/m	1.49
pound per foot force	Newton per meter	N/m	14.59
pound per inch force	Newton per meter	N/m	175.1
pound per foot density	kilogram per meter	kg/m	1.488
pound per inch density	kilogram per meter	kg/m	17.86
pound per square inch load concentration	kilogram per square meter	kg/m^2	703.0
pound per square foot load concentration	kilogram per square meter	kg/m^2	4.88
pound per square foot pressure	Pascal	Pa	47.88
inch-pound torque	Newton-meter	N-m	0.1129
chain	meter	m	20.117
fathom	meter	m	1.8288
cubic foot per second	cubic meter per second	m^3/s	0.02831
$foot^4$ (area moment of inertia)	$meter^4$	m^4	0.0086309
mile	meter	m	0.0000254
square mile	square meter	m^2	2589998.0
pound per gallon (UK liquid)	kilogram per cubic meter	kg/m^3	99.77
pound per gallon (U.S. liquid)	kilogram per cubic meter	kg/m^3	119.83
poundal	Newton	N	0.11382
square (100 square feet)	square meter	m^2	9.29
ton (long 2,240 lb)	kilogram	kg	1016.04
ton (short 2,000 lb)	kilogram	kg	907.18
ton, short, per cubic yard	kilogram per cubic meter	kg/m^3	1186.55
ton, long, per cubic yard	kilogram per cubic meter	kg/m^3	1328.93
ton force (2,000 lbf)	Newton	N	8896.44
yard, length	meter	m	0.0914

(*continued*)

TABLE 1. Commonly Used USCS and SI Units* (*Continued*)

USCS unit	SI unit	SI symbol	Conversion factor—multiply USCS unit by this factor to obtain the SI unit
square yard	square meter	m^2	0.08361
cubic yard	cubic meter	m^3	0.076455
acre feet	cubic meter	m^3	1233.49
acre	square meter	m^2	4046.87
cubic foot per minute	cubic meter per second	m^3/s	0.0004719

*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, $9.290304 \times 1/100 = 0.09290304$, 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 $4.046873 \times 1000 = 4046.8$.

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 $2.768 \times E + 4$.

*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 allows 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 a 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.

CONTENTS

SECTION 3
TIMBER ENGINEERING

In designing timber members, the following references are often used: *Wood Handbook*, Forest Products Laboratory, U.S. Department of Agriculture, and *National Design Specification for Stress-Grade Lumber and Its Fastenings*, National Forest Products Association. The members are assumed to be continuously dry and subject to normal loading conditions.

For most species of lumber, the true or *dressed* dimensions are less than the nominal dimensions by the following amounts: ⅜ in. (9.53 mm) for dimensions less than 6 in. (152.4 mm); ½ in. (12.7 mm) for dimensions of 6 in. (152.4 mm) or more. The average weight of timber is 40 lb/ft^3 (6.28 kN/m^3). The width and depth of the transverse section are denoted by b and d, respectively.

BENDING STRESS AND DEFLECTION OF WOOD JOISTS

A floor is supported by 3 × 8 in. (76.2 × 203.2 mm) wood joists spaced 16 in. (406.4 mm) on centers with an effective span of 10 ft (3.0 m). The total floor load transmitted to the joists is 107 lb/sq.in. (5.123 kN/m^2). Compute the maximum bending stress and initial deflection, using $E = 1{,}760{,}000$ lb/sq.in. (12,135 kPa).

Calculation Procedure:

1. *Calculate the beam properties or extract them from a table*

Thus, $A = 2⅝(7½) = 19.7$ sq.in. (127.10 cm^2); beam weight = $(A/144)$ (lumber density, lb/ft^3) = (19.7/144)(40) = 5 lb/lin ft (73.0 N/m); $I = (1/12)(2⅝)(7½)^3 = 92.3$ in^4 (3841.81 cm^4); $S = 92.3/3.75 = 24.6$ in^3 (403.19 cm^3).

2. *Compute the unit load carried by the joists*

Thus, the unit load $w = 107(1.33) + 5 = 148$ lb/lin ft (2159.9 N/m), where the factor 1.33 is the width, ft, of the floor load carried by each joist and 5 = the beam weight, lb/lin ft.

3. *Compute the maximum bending stress in the joist*

Thus, the bending moment in the joist is $M = (⅛)wL^2 12$, where M = bending moment, in.·lb (N·m); L = joist length, ft (m). Substituting gives $M = (⅛)(148)(10)^2(12) = 22{,}200$ in.·lb (2508.2 N·m). Then for the stress in the beam, $f = M/S$, where f = stress, lb/sq.in. (kPa), and S = beam section modulus, in^3 (cm^3); or $f = 22{,}200/24.6 = 902$ lb/sq.in. (6219.3 kPa).

4. *Compute the initial deflection at midspan*

Using the AISC *Manual* deflection equation, we see that the deflection Δ in. (mm) = $(5/384)wL^4/(EI)$, where I = section moment of inertia, in^4 (cm^4) and other symbols are as before. Substituting yields $\Delta = 5(148)(10)^4(1728)/[384(1{,}760{,}000)(92.3)] = 0.205$ in. (5.2070 mm). In this relation, the factor 1728 converts cubic feet to cubic inches.

SHEARING STRESS CAUSED BY STATIONARY CONCENTRATED LOAD

A 3 × 10 in. (76.2 × 254.0 mm) beam on a span of 12 ft (3.7 m) carries a concentrated load of 2730 lb (12,143.0 N) located 2 ft (0.6 m) from the support. If the allowable shearing stress is 120 lb/sq.in. (827.4 kPa), determine whether this load is excessive. Neglect the beam weight.

Calculation Procedure:

1. *Calculate the reaction at the adjacent support*

In a rectangular section, the shearing stress varies parabolically with the depth and has the maximum value of $v = 1.5V/A$, where V = shear, lb (N).

The *Wood Handbook* notes that checks are sometimes present near the neutral axis of timber beams. The vitiating effect of these checks is recognized in establishing the allowable shearing stresses. However, these checks also have a beneficial effect, for they modify the shear distribution and thereby reduce the maximum stress. The amount of this reduction depends on the position of the load. The maximum shearing stress to be applied in design is given by $v = 10(a/d)^2 v'/\{9[2 + (a/d)^2]\}$, where v = true maximum shearing stress, lb/sq.in. (kPa); v' = nominal maximum stress computed from $1.5V/A$; a = distance from load to adjacent support, in. (mm).

Computing the reaction R at the adjacent support gives $R = V_{max} = 2730(12 - 2)712 =$ 2275 lb (10,119.2 N). Then $v' = 1.5V/A = 1.5(2275)/24.9 = 137$ lb/sq.in. (944.6 kPa).

2. *Find the design stress*
Using the equation given in step 1, we get $(a/d)^2 = (24/9.5)^2 = 6.38$; $v = 10(6.38)(137)/[9(8.38)] = 116$ lb/sq.in. (799.8 kPa) < 120 lb/sq.in. (827.4 kPa). The load is therefore not excessive.

SHEARING STRESS CAUSED BY MOVING CONCENTRATED LOAD

A 4 × 12 in. (101.6 × 304.8 mm) beam on a span of 10 ft (3.0 m) carries a total uniform load of 150 lb/lin ft (2189.1 N/m) and a moving concentrated load. If the allowable shearing stress is 130 lb/sq.in. (896.4 kPa), what is the allowable value of the moving load as governed by shear?

Calculation Procedure:

1. *Calculate the reaction at the support*
The transient load induces the absolute maximum shearing stress when it lies at a certain critical distance from the support rather than directly above it. This condition results from the fact that as the load recedes from the support, the reaction decreases, but the shear-redistribution effect becomes less pronounced. The approximate method of analysis recommended in the *Wood Handbook* affords an expedient means of finding the moving-load capacity.

Place the moving load P at a distance of $3d$ or $\frac{1}{4}L$ from the support, whichever is less. Calculate the reaction at the support, disregarding the load within a distance of d therefrom.

Thus, $3d = 2.9$ ft (0.884 m) and $\frac{1}{4}L = 2.5$ ft (0.762 m); then $R = V_{max} = 150(5 - 0.96) + \frac{3}{4}P = 610 + \frac{3}{4}P$.

2. *Calculate the allowable shear*
Thus, $V_{allow} = \frac{2}{3}vA = \frac{2}{3}(130)(41.7) = 3610$ lb (16,057.3 N). Then $610 + \frac{3}{4}P = 3610$; $P = 4000$ lb (17,792.0 N).

STRENGTH OF DEEP WOODEN BEAMS

If the allowable bending stress in a shallow beam is 1500 lb/sq.in. (10,342.5 kPa), what is the allowable bending moment in a 12 × 20 in. (304.8 × 508.0 mm) beam?

Calculation Procedure:

1. *Calculate the depth factor F*
An increase in depth of a rectangular beam is accompanied by a decrease in the modulus of rupture. For beams more than 16 in. (406.4 mm) deep, it is necessary to allow for this reduction in strength by introducing a *depth factor F*.