building construction materials and types of construction

whitney clark huntington
(deceased)
robert e. mickadeit

fifth edition

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whitney clark huntington
(deceased)
robert e. mickadeit
architect and civil engineer
allan hancock college
chapter 10 written by
william cavanaugh, fasa
adjunct, rhode island school of design
consultant in acoustics

john wiley and sons
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preface

This text introduces building nomenclature and construction methods to students of architecture and building technology. It also may be used by those who are reviewing for state registration examinations. This edition provides a general updating with several significant additions such as tests covering soils, concrete, masonry, and mortar. All drawings have been redrawn and updated. Several new photographs have also been added. Among significant additions is the timely discussion of acoustics by William J. Cavanaugh, consulting engineer.

Chapters have been arranged in a sequence that follows the divisions of the Construction Specifications Institute (C.S.I.) format. However, some deviation was necessary to accommodate subjects that are not covered by the C.S.I. format. The discussion of the building elements and the acoustic chapter have been placed where pedagogical requirements seem best.

This text is intended as an introduction to construction materials and is by no means exhaustive. Sources for further study are listed in the references and recommended reading.

Several reviewers and a number of colleagues made valuable suggestions for this edition, and the consensus of their views has been incorporated. Unfortunately, it was not possible to accommodate all of their fine suggestions.

Professor William A. Baker, University of Wyoming, Professor Robert Peterson, University of Houston, and John Weavil, Daytona Beach Community College made exhaustive efforts to see that this text was properly updated. I especially appreciate the photography of Robert Alldredge, Gail Probert, and Denise Davis.

I thank them all for their work and effort.

robert e. mickadeit

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1.1 Organizations and Codes

BUILDING PROCESS

The need or desire of building may set in motion a number of steps and processes that will affect many people in order to fulfill the construction requirements. An overview of the construction process is outlined here.

Clients (individuals desiring a building) usually require the services of an architect or possibly an engineer. During the initial stage of the building process the architect is responsible for gathering and coordinating data that will be required for the construction process; often clients themselves supply this information. But the larger proportion of required information will be supplied by manufacturers, their technical organizations, professional organizations, and various codes.

Information of materials must be obtained from manufacturers or their representatives. Expert consultants may supply information that must be relevant, timely, and appropriate to the project.

Factual information about the building site should include contours, soils tests, weather, geologic evaluation, and availability of transportation and water.

The preliminary planning usually includes a report that lists likely solutions, alternative approaches, costs and may include economic feasibility studies.

Most states require an Environmental Impact Statement (EIS). Usually these apply only to major projects.

Concluding the preliminary planning are schematic plans of the project based on the data gathered. These drawings frequently include spatial concepts, delineated sketches that depict the project in plan, elevations, and perspective, as well as building models. These drawings may form part of a report required by other appropriate governing bodies such as a coastal commission, planning department, or a commission wielding architectural (design) control.

With the approval of schematics the preliminary phase is completed and the planning process enters into contract documents preparation. Data gathering usually continues in an effort to deal with problems that arise.

Various consulting engineers are engaged to solve specialty problems, such as mechanical, electric, structural, landscape, acoustics, and site gradings. These engineers and the architects prepare the working drawings that are used for the erection of the building or for contractor specialty drawings, known as *shop drawings*. These are used to make building components. For example, structural steel shop drawings are followed to cut, fabricate, and erect structural steel.

Working drawings require constant reference to and consultation of building codes and standards.

A number of legal approvals may be required, depending on the complexity and nature of the project. Usually local building officials have jurisdiction and should be consulted on code interpretations. State or federally controlled projects will require the appropriate stamps of approval, including state fire marshal approval or a seismic design check in some jurisdictions. Usually city or county building departments that exert control have a requirement that they must check plans for code conformity.

Written specifications are prepared along with the working drawings. Generally, specifications supplement the working drawings by stating quality, color, and other factors desired that cannot be stated conveniently on the working drawings.

Contracts are prepared that state the expectations required of the building contractor, owner, and architect. These include a number of bonds that must be furnished: the *bid bond,* which assures that the chosen bidder will accept the offered contract; *performance bond,* which assures that the contractor will perform functions faithfully according to the terms of the contract; and a *labor and material payment bond,* which assures that the contractor will pay for all labor and materials used on the project and will deliver a *lien-free* completed project.

Contract documents are sent to qualified contractors, usually for a printing and handling fee.

Contractors prepare their estimates usually based on a material survey called a *take off* that has been "extended" to include unit prices, labor, supervision, and transportation.

At a specified date, place, and time, the contractor's bid is opened and recorded. The successful bidder is then offered the bid and asked to provide the necessary bonds previously mentioned.

CONSTRUCTION STAGE

Mobilization of the contractor's work force proceeds by moving onto the site, ordering materials and equipment, and hiring, after which subcontracts are awarded. Building layout proceeds with the employment of a surveyor or civil engineer, and sitework commences, followed by the substructure of foundations and basements. The coordination of the project is handled by the general contractor's project manager. Success in this area requires a manager who can orchestrate several subcontractors and his or her own forces simultaneously with the least lost effort.

The architect usually inspects the project at appropriate times, such as prior to the pouring of the foundation, after framing is completed, after installation of finishes, and at the close of the contract.

Supervenient inspections are frequently made.

Engineers seldom inspect unless called in for a special problem. City, state, county, and federal inspectors may conduct supervenient inspections if the project is in their jurisdiction.

CODES

The purpose of building codes is to regulate the design and construction of buildings in a manner that safeguards the general public, although sometimes codes are viewed as inhibiting creativity.

Building codes usually include types of construction, function of the structure called *occupancy,* quality of materials, the imposed loads, allowable stresses, mechanical and electrical equipment, and other requirements related to buildings with special emphasis on fire safety.

Basically, the codes issued by various agencies are quite similar. There are, however, significant differences; therefore, the code adopted by a given municipality must be satisfied by buildings constructed within its jurisdiction. The requirements of various codes may be included in this text for instructional purposes, but for a specific application the governing code should be consulted.

MODEL BUILDING CODES

Most municipalities have building codes. Jurisdictions that do not originate their own building codes often adopt, by reference, all or parts of certain established model codes.

Today there is a tendency in model codes toward the *performance code.* This type of code requires a specified result. The advantage of this approach, as opposed to the rigid specification type code, is that newer materials and methods of construction may be permitted.

Many states have established building codes which may control all building construction within the state; however, individual communities may adopt their own codes. An example is the State Building Construction Code adopted by the State of New York. As stated therein: "The municipalities of the state have the option to accept or not to accept the applicability" of this code.

Several regional agencies have formulated *model building codes.* These have been prepared to assist municipalities in preparing codes, or a municipality may adopt such a code, by reference, if authorized by the statutes of the governing state. The following are examples of model codes.

The International Conference of Building Officials, Whittier, California, publishes the *Uniform Building Code*. This model code has been widely adopted by various communities—over 2,000 municipalities in 44 states. This code, known as the *UBC*, is kept current by constant review, with a new edition published every three years. Additionally, this organization publishes a volume of building standards that defines various building tests, a fire code, fire code standard, and material qualities.

The Basic Building Code is published by Building Officials and Code Administrators International, Chicago, Illinois. This model code, a performance code, is continually updated by annual supplements and revisions, as required. BOCA publishes several other model codes such as *The Basic Fire Prevention Code* and *The Basic Housing Code*.

The Standard Building Code is published by the Southern Building Code Congress, Birmingham, Alabama.

The National Building Code is recommended by the American Insurance Association, successor to the National Board of Fire Underwriters. This code contains appendices covering hurricanes and earthquakes. The American Insurance Association also recommends the *Fire Prevention Code* as a companion document.

OTHER CODES AND STANDARDS

There are a number of organizations that advance the knowledge of materials and methods of construction and promote codes and standards. Some of these organizations are concerned with several materials, while others are involved with only one material and its applications. These organizations produce literature that is of interest to a technical audience—architects, engineers, students, and inspectors. A partial description of the activities and contributions of some of these organizations follows.

Among authoritative organizations is the American Society for Testing and Materials of Philadelphia. The work of this society includes the development of standards, test procedures, criteria, and specifications and definitions for a vast number of materials. ASTM standards cover most building materials, including soils and rock. ASTM standards are frequently cited in building specifications as the basis upon which quality decisions will be judged. Their standards are reviewed (if necessary, revised) and published annually.

The Construction Specifications Institute (CSI), Washington, D.C., promotes the standardized specifications that cover the field of building construction. Their format for construction specifications and materials classifications has been widely adopted in the industry. Its literature covers not only specifications but includes commentary on the uses of materials.

The American Concrete Institute (ACI) of Detroit, Michigan, is an organization that disseminates information for the improvement of design, construction, manufacture, use, and maintenance of concrete products and structures. Its interests encompass all aspects of concrete production. The ACI *Building Code Requirements for Reinforced Concrete* (ACI 318), which is revised annually, serves as a building industry standard.

The American Institute of Steel Construction, Chicago, advances the use of fabricated steel framed structures. It performs research and development and serves to further the use of steel by technical publications, seminars, awards, scholarships, and the promotion of quality and safety in shop and field. Its *Manual of Steel Construction* is used as the industry standard for the design of structural steel. Also, the *AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings* is usually referenced by engineers in building specifications and is adopted by reference in building codes.

The American Iron and Steel Institute, New York, has established standards and produces technical information on steel and the industry. This includes information on uses, processes, and standard designations.

The Copper Development Association, Inc. New York, provides technical information regarding copper, bronze, and brass for building use.

The Aluminum Association, New York, provides standards and technical information that covers structural, mechanical, physical properties, uses, specifications, coatings, finishes, and building products of aluminum.

The National Fire Protection Association, Boston, Massachusetts, publishes the *Fire Protection Handbook*, which gives not only essential information on fire prevention and protection but details the reasons and with background information. Additionally, NFPA publishes the standards known as the *National Fire Codes* in seven volumes averaging 900 pages each. Most of these standards are published separately in pamphlets. Other publications of NFPA include an inspection manual and books covering particular occupancies.

The Asphalt Institute provides engineering, research, and educational programs for the asphalt industry and its users. The Institute produces extensive literature and audiovisual aids on the uses of asphalt in the building industry. Research engineers of the Institute are engaged in a number of programs such as thickness design of asphalt pavements, testing, and developing of paving mixes, soil

beneficiation and stabilization, aggregate studies, airfield pavements, linings for hydraulic structures, and energy conservation.

Several regional lumber associations encourage regeneration of the forests, establish standards and sizes for lumber, and supply technical data to specifiers, builders, and users.

Among these associations are:

- The Western Wood Products Association, Portland, Oregon, is the largest of these associations. It is an association of softwood lumber manufacturers of the 12 Western states grading pines, firs, spruces, and cedars.
- West Coast Lumber Inspection Bureau, Portland, Oregon, grades and inspects Douglas fir, hemlock, cedar, and other softwood lumber of California and the regions of Washington and Oregon west of the Cascade Summit.
- Redwood Inspection Service, San Francisco, California, grades and inspects products of *Sequoia sempervirens*.
- Southern Pine Inspection Bureau, Pensacola, Florida, covers longleaf pine, slash pine, shortleaf pine, and loblolly pine produced in the southeastern states from Maryland to Texas.
- Northeastern Lumber Manufacturers Association, Inc., Glens Falls, New York, grades northern and eastern pines, cedars, spruces, balsam fir, and other softwoods of New England, New York, New Jersey, and Pennsylvania.
- National Hardwood Lumber Association, Chicago, Illinois, performs services for the hardwood products industry parallel to those performed by the softwood associations. Among the myriad hardwoods that are its concern are walnut, maple, oak, birch, ash, hickory, and cypress, a softwood.
- The American Institute of Timber Construction (AITC), of Englewood, Colorado, tests and disseminates information on the structural aspects of timber construction, including laminated timber.
- The American Plywood Association of Tacoma, Washington, produces literature on plywood. This includes, but is not limited to, testing, grades, systems, specifications, physical qualities, and the structural and finished uses of plywood.

The widely adopted Uniform Construction Index provides three interrelated formats: the Specifications Format, the Data Filing Format, and the Cost Analysis Format. These formats follow a systematized classification of building materials and processes in 16 headings known as divisions. These divisions are arranged in a sequence that outlines in a most general way the order that would be followed in conducting a construction project.

Below is the complete Specifications Format.

MASTERFORMAT Broadscope Section Titles Reprinted from MASTERFORMAT, CSI Document MP-2-1, copyrighted June 1978, Construction Specifications Institute.

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Various agencies of the United States government, especially the Bureau of Standards, Washington, D.C., and the Forest Products Laboratory, Madison, Wisconsin, resemble the above associations.

Extensive lists of material and construction standards and their issuing agencies are included in reference [3]. (References are found at the back of the book.) Much information can be obtained, often at little or no cost, by writing these agencies. Publications by agencies of the federal government are obtained by writing the U.S. Government Printing Office, Washington, D. C.

FIRE-RESISTANCE RATINGS

Building codes commonly classify buildings according to type of construction and according to *use* or *occupancy*. The most important factor in the classification according to type of construction is the resistance to fire exposure. In classifying buildings according to fire endurance, it is necessary to measure the performance of the various structural parts of a building under exposure conditions. It is necessary that the fire-resistive properties of materials and members be measured and specified according to a common standard expressed in terms which are applicable to a wide variety of materials, situations, and conditions of exposure.

The *"Standard Fire Test,"* known also as the *fire endurance test,* accomplishes these objectives. This test is designated by the Underwriters' Laboratories as UL 263 and by the American Society for Testing and Materials as ASTM E119. It consists of exposing samples of the material, a building member, or an assembly to a fire of specified intensity and duration. In some cases, a 2½ in. fire hose stream is applied to a heated sample from a distance of 20 ft. Performance is defined as the period of resistance to standard exposure elapsing before the first critical point in behavior is observed, and it is expressed in hours. For example, a material is given a 2-hour rating if it withstands the test for a period of 2 hours.

Most of the common building materials and assemblies of materials have been tested, rated, and the results published by the Underwriters Laboratory. For this reason, it is not usual to make fire tests in connection with the design of individual buildings. An extensive report on such ratings is given in reference [4].

Fire endurance tests on a bearing wall assembly are required for a specified time in hours. Bearing walls are required to support their loads without penetration by flame or gases sufficient to ignite cotton wastes. The hose stream test (for assemblies that are to be rated for one hour or more) is conducted on the loaded assembly in a heated condition. The assembly, in a cooled state, must also support specified loads. in no event may heat that penetrates through the wall assembly produce a temperature rise of more than 250°F on the unexposed surface.

The fire endurance tests for nonbearing walls are similar to those conducted on bearing walls. Naturally, the nonbearing wall assembly is not required to carry imposed loads during the fire endurance test.

Floor and roof assemblies carry imposed loads during the fire endurance test. Acceptance as a fire rated assembly requires that the fire and temperature transmission requirements be similar to the forementioned bearing wall assembly. The hose test is not required.

The fire protective material that surrounds beams and columns may also be tested for endurance. The protective assembly must limit the rise in temperature in the steel member to not more than a specified amount.

Another fire test is the Test Method for Fire Hazard Classification of Building Materials, which is known as the Underwriters' Laboratories UL 723. This tests the *flame spread* ability of a material. The test determines "the comparative burning characteristics of the material under test by evaluating the flame spread over its surface, fuel contributed by its combustion, and the density of the smoke developed when exposed to a test fire." [22] The *flame spread classification* (FSC) of a material is graded on a scale from 0 to 100. As a basis, the classification of 0 is assigned to asbestos cement board and a classification of 100 is designated to select grade red oak flooring.

Flame spread ratings are usually specified for materials which are interior surface finishes, such as plastics, plywood, acoustic materials, and wall coverings.

BUILDING CONTENT AND FIRE SEVERITY

Burnout tests conducted in fire-resistive buildings indicate that the fire severity due to combustion of such materials as wood, paper, cotton, wool, silk, straw, grain, sugar, and similar organic materials may be considered to be as shown in Table 1.1. The values in this table enable fire severity to be visualized [11]. Fires in "fire-resistant" multifloor buildings have resulted in loss of life and property. These fires, in buildings that are intended to be fire resistant, nevertheless contained furnishings that supported fire and resulted in smoke damage and death due to inhalation.

FIRE LIMITS, ZONES, OR DISTRICTS

The New York State Code includes the following definition: *"Fire limits.* Boundary line establishing an area in which there exists, or is likely to exist, a fire hazard requiring special fire protection."

Two classes of fire limits are included in this code.

Fire limits A comprising the areas containing highly congested business, commercial and, or industrial occupan-

Table 1.1 **Relation of Amount of Combustibles and Fire Severity**

w	hr	w	hr	w	hr	w	hr	w	hr
5	½	10	1	20	2	40	4½	60	7½
7½	¾	15	1½	30	3	50	6		

Key: w is average weight in lb per square foot of floor area.
hr is fire severity in hours.

cies, wherein the fire hazard is severe; and or, Fire limits B comprising the areas containing residential, business and, or commercial occupancies or in which such uses are developing, wherein the fire hazard is moderate.

All of those areas not included in fire limits A or B are designated herein as outside the fire limits.

The areas within fire limits are often called *fire zones* or *fire districts*.

BUILDING CLASSIFICATION

Building code requirements are based primarily on building occupancy or use, type of construction, and location.

Classification According to Occupancy

The classification of buildings according to occupancy, as included in the National Building Code, is as follows.

Assembly occupancy means the occupancy or use of a building or structure or any portion thereof by a gathering of persons for civic, political, travel, religious, social, or recreational purposes.

Business occupancy means the occupancy or use of a building or structure or any portion thereof for the transaction of business, or the rendering or receiving of professional services.

Educational occupancy means the occupancy or use of a building or structure or any portion thereof by persons assembled for the purpose of learning or of receiving educational instruction.

High hazard occupancy means the occupancy or use of a building or structure or any portion thereof that involves highly combustible, highly flammable, or explosive material, or which has inherent characteristics that constitute a special fire hazard.

Industrial occupancy means the occupancy or use of a building or structure or any portion thereof for assembling, fabricating, finishing, manufacturing, packaging, or processing operations.

Institutional occupancy means the occupancy or use of a building or structure or any portion thereof by persons harbored or detained to receive medical, charitable, or other care or treatment, or by persons involuntarily detained.

Mercantile occupancy means the occupancy or use of a building or structure or any portion thereof for the display, selling or buying of goods, wares, or merchandise; except when classed as a high hazard occupancy.

Residential occupancy means the occupancy or use of a building or structure or any portion thereof by persons for whom sleeping accommodations are provided but who are not harbored or detained to receive medical, charitable, or other care or treatment, or are not involuntarily detained.

Storage occupancy means the occupancy or use of a building or structure or any portion thereof for the storage of goods, wares, merchandise, raw materials, agricultural or manufactured products, including parking garages, or the sheltering of livestock and other animals, except when classed as a high hazard.

Classification According to Type of Construction

Buildings are classified in building codes according to types of construction based on the fire resistance of their structural members or assemblies. Codes vary in the details of such classifications, but the objectives sought are similar. The *New York State Building Construction Code* will serve as an example.

According to this code, if the temperature required to ignite and support combustion of a material, or combination of materials, is below 1382°F., the material is designated as *combustible,* and if a higher temperature is required, it is designated as *noncombustible*.

The principal combustible materials used in buildings are wood, organic fiber boards, and plastics. The principal noncombustible materials are steel, aluminum, concrete, and masonry materials such as brick, stone, and structural clay tile, as well as plaster and glass.

According to the New York State Code, buildings are classified into five types as follows.

Type 1. Fire-Resistive Construction. That type of construction in which the walls, partitions, columns, floors, and roof are noncombustible with sufficient fire resistance to withstand the effects of a fire and prevent its spread from story to story.

Type 2. Noncombustible Construction. That type of construction in which walls, partitions, columns, floors, and roof are noncombustible and have less fire resistance than required for *fire-resistive construction.*

Type 3. Heavy Timber Construction. That type of construction in which the exterior walls are of masonry or other noncombustible materials having an equivalent structural stability under fire conditions and a fire resistance rating of not less than 2 hours; in which interior structural members including columns, beams, and girders are timber, in heavy solid or laminated masses, but with no sharp corners or projections or concealed or inaccessible spaces; in which floors and roofs are of heavy plank or laminated wood construction, or any other material providing equivalent fire-resistance and

structural properties. Noncombustible structural members may be used in lieu of heavy timber, provided the fire resistance rating of such members is not less than 3/4 hour.

Type 4. Ordinary Construction. That type of construction in which the exterior walls are of masonry or other noncombustible materials having equivalent structural stability under fire conditions and a fire resistance rating of not less than 2 hours, the interior structural members being wholly or partly of wood of smaller dimensions than those required for *Heavy Timber Construction.*

Type 5. Wood Frame Construction. That type of construction in which walls, partitions, floors, and roof are wholly or partly of wood or other combustible material.

Each of the five types of construction which have been described, except *Type 3,* is divided into two subtypes which vary according to the degree of fire resistance required. The requirements for subtypes *a* are more severe than those for subtypes *b*.

The fire-resistance ratings required for the various types and subtypes are shown in Table 1.2.

From Table 1.2, it will be noted that the highest required fire rating is 4 hours. This rating is required in the higher type of *Fire-Resistive Construction* for exterior bearing walls, for party walls, and for interior firewalls, bearing walls, and partitions. It is also required for columns, beams, girders, and trusses supporting more than one floor. These are the most important structural elements in a building. It is also required for the party walls and fire walls of *Heavy Timber Construction.*

The lowest fire rating required is 3/4 hour. It is required for panel and curtain walls in *Fire-Resistive Construction* and in the higher type of *Noncombustible Construction,* and interior partitions and nonbearing walls for all types of construction except *Fire-Resistive.* It is also required for bearing walls and nonbearing walls for the higher type of *Wood Frame Construction* and for various other members in *Ordinary and Wood Frame Construction. Noncombustible Construction* without a fire rating is required for various members in the lower type of *Noncombustible Construction. Combustible Construction* is permitted in some parts of *Heavy Timber Construction* and in several parts of *Ordinary and Wood Frame Construction.*

Table 1.2 Minimum Fire-Resistance Requirements of Structural Elements (By types of construction; fire-resistance ratings in hours)

	Construction Classification								
	Type 1 (fire resistive)		*Type 2 (non-combustible)*		*Type 3 (heavy timber)*	*Type 4 (ordinary)*		*Type 5 (wood frame)*	
Structural Element	1a	1b	2a	2b		4a	4b	5a	5b
Exterior									
Bearing walls	4	3	2	nc	2	2	2	3/4	c
Nonbearing walls	2	2	2	nc	2	2	2	3/4	c
Panel and curtain walls	3/4	3/4	3/4	nc					
Party walls	4	3	2	2	4	2	2	2	2
Interior									
Fire walls	4	3	2	2	4	2	2	2	2
Bearing walls or partitions	4	3	2	nc	2	3/4	c	3/4	c
Partitions enclosing stairways, hoistways, shafts, other vertical openings, and hallways									
On outside exposure	2	2	2	2	2	2	2	3/4	3/4
On inside exposure	1	1	3/4	3/4	3/4	3/4	3/4	3/4	3/4
Nonbearing walls and partitions separating spaces	1	1	3/4	3/4	3/4	3/4	3/4	3/4	3/4
Columns, beams, girders, and trusses (other than roof trusses)									
Supporting more than one floor	4	3	2	nc	c	3/4	c	3/4	c
Supporting one floor	3	2	3/4	nc	c	3/4	c	3/4	c
Floor construction, including beams	3	2	1	nc	c	3/4	c	3/4	c
Roof construction, including purlins, beams, and roof trusses	2	1	3/4	nc	c	3/4	c	3/4	c

Key: nc = noncombustible, c = combustible.

The code includes special requirements and exceptions that are not included in this table.

Example: This may vary with different codes.