An ACI Handbook

The Reinforced Concrete Design Handbook

A Companion to *ACI 318M-14*

SP-17M(14) Student Edition

American Concrete Institute
Always advancing

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THE REINFORCED CONCRETE DESIGN HANDBOOK

A Companion to *ACI 318M-14*

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DEDICATION

This edition of *The Reinforced Concrete Design Handbook, SP-17M(14),* is dedicated to the memory of Daniel W. Falconer and his many contributions to the concrete industry. He was Managing Director of Engineering for the American Concrete Institute from 1998 until his death in July 2015.

Dan was instrumental in the reorganization of *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)* as he served as ACI staff liaison to ACI Committee 318, Structural Concrete Building Code; and ACI Subcommittee 318-SC, Steering Committee. His vision was to simplify the use of the Code for practitioners and to illustrate the benefits of the reorganization with this major revision of *SP-17M.* His oversight and review comments were instrumental in the development of this Handbook.

An ACI member since 1982, Dan served on ACI Committees 344, Circular Prestressed Concrete Structures, and 373, Circular Concrete Structures Prestressed with Circumferential Tendons. He was also a member of the American Society of Civil Engineers. Prior to joining ACI, Dan held several engineering and marketing positions with VSL Corp. Before that, he was Project Engineer for Skidmore, Owings, and Merrill in Washington, DC. He received his BS in civil engineering from the University of Buffalo, Buffalo, NY and his MS in civil and structural engineering from Lehigh University, Bethlehem, PA. He was a licensed professional engineer in several states.

In his personal life, Dan was an avid golfer, enjoying outings with his three brothers whenever possible. He was also an active member of Our Savior Lutheran Church in Hartland, MI, and a dedicated supporter and follower of the Michigan State Spartans basketball and football programs. Above all, Dan was known as a devoted family man dedicated to his wife of 33 years, Barbara, his children Mark, Elizabeth, Kathryn, and Jonathan, and two grandsons Samuel and Jacob.

In his memory, the ACI Foundation has established an educational memorial. For more information visit http://www.scholarshipcouncil.org/Student-Awards. Dan will be sorely missed for many years to come.

FOREWORD

The Reinforced Concrete Design Handbook provides assistance to professionals engaged in the design of reinforced concrete buildings and related structures. This edition is a major revision that brings it up-to-date with the approach and provisions of *Building Code Requirements for Structural Concrete (ACI 318M-14).* The layout and look of the Handbook have also been updated.

The Reinforced Concrete Design Handbook now provides dozens of design examples of various reinforced concrete members, such as one- and two-way slabs, beams, columns, walls, diaphragms, footings, and retaining walls. For consistency, many of the numerical examples are based on a fictitious seven-story reinforced concrete building. There are also many additional design examples not related to the design of the members in the seven story building that illustrate various *ACI 318M-14* requirements.

Each example starts with a problem statement, then provides a design solution in a three column format—code provision reference, short discussion, and design calculations— followed by a drawing of reinforcing details, and finally a conclusion elaborating on a certain condition or comparing results of similar problem solutions.

In addition to examples, almost all chapters in the *Reinforced Concrete Design Handbook* contain a general discussion of the related *ACI 318M-14* chapter.

All chapters were developed by ACI staff engineers under the auspices of the ACI Technical Activities Committee (TAC). To provide immediate oversight and guidance for this project, TAC appointed three content editors: Andrew Taylor, Trey Hamilton III, and Antonio Nanni. Their reviews and suggestions improved this publication and are appreciated. TAC also appreciates the support of Dirk Bondy and Kenneth Bondy who provided free software to analyze and design the post-tensioned beam example, in addition to valuable comments and suggestions. Thanks also go to JoAnn Browning, David DeValve, Anindya Dutta, Charles Dolan, Matthew Huslig, Ronald Klemencic, James Lai, Steven McCabe, Mike Mota, Hani Nassif, Jose Pincheira, David Rogowski, and Siamak Sattar, who reviewed one or more of the chapters.

Special thanks go to StructurePoint and Computers and Structures, Inc. (SAP 2000 and Etabs) for providing a free copy of their software to perform analyses of structure and members.

Special thanks also go to Stuart Nielsen, who provided the cover art using SketchUp.

The Reinforced Concrete Design Handbook is published in two volumes: Chapters 1 through 11 are published in Volume 1 and Chapters 12 through 15 are published in Volume 2. Design aids and a moment interaction diagram Excel spreadsheet are available for free download from the following ACI webpage links:
https://www.concrete.org/store/productdetail.aspx?ItemID=SP1714DAE
https://www.concrete.org/store/productdetail.aspx?ItemID=SP1714DA

Keywords: anchoring to concrete; beams; columns; cracking; deflection; diaphragm; durability; flexural strength; footings; frames; piles; pile caps; post-tensioning; punching shear; retaining wall; shear strength; seismic; slabs; splicing; stiffness; structural analysis; structural systems; strut-and-tie; walls.

Khaled Nahlawi
Managing Editor

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*Chapters omitted from this Student Edition.
**Some examples omitted from this Student Editiion. See chapter for full descrption of example.

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CHAPTER 1—BUILDING EXAMPLE

1.1—Introduction

The building depicted in this chapter was developed to show how, by various examples in this Handbook, to design and detail a common concrete building according to ACI 318M-14. This example building is seven stories above ground and has a one story basement. The building has evenly spaced columns along the grid lines. One column has been removed along Grid C on the second level so that there is open space for the lobby. The building dimensions are:

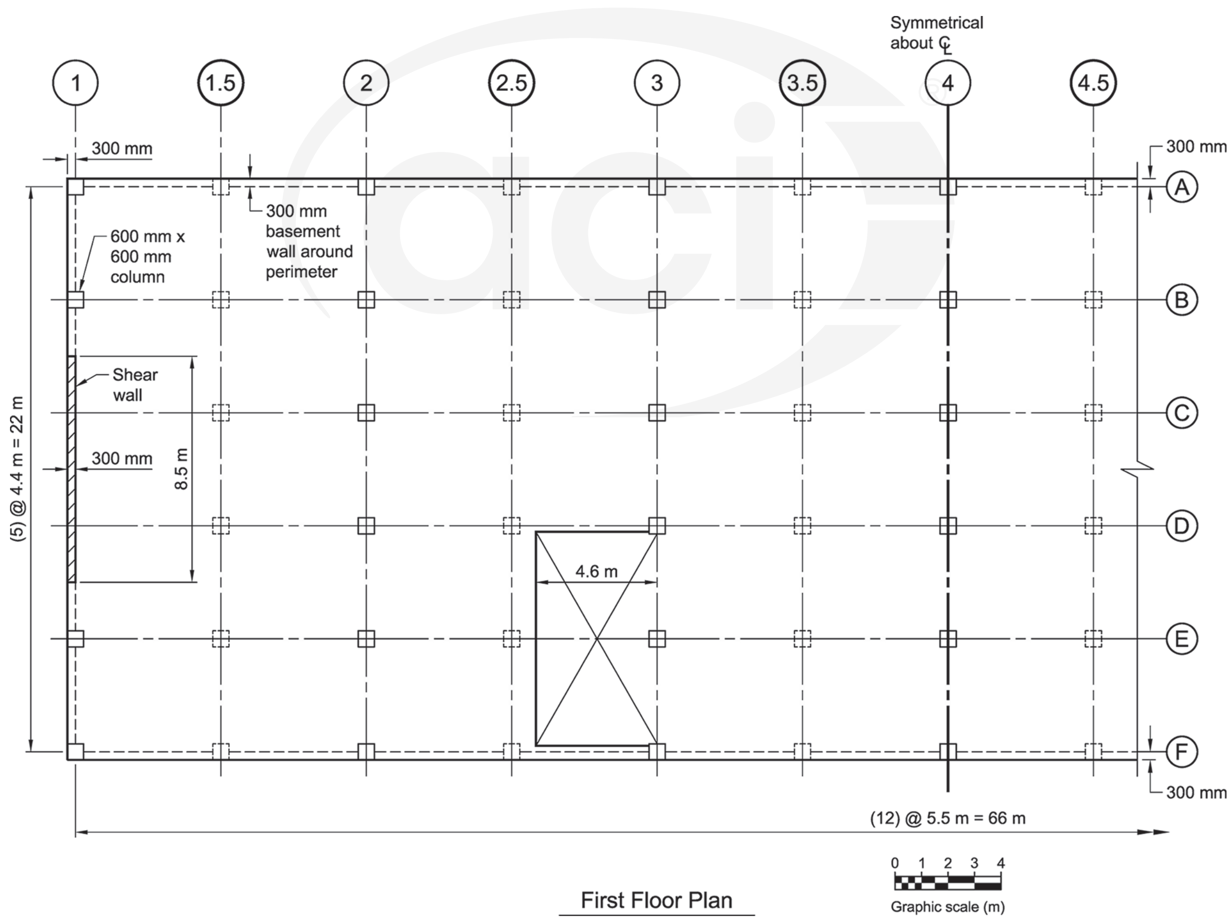
- Width (north/south) = 22 m (5 bays @ 4.4 m)
- Length (east/west) = 66 m (6 bays @ 11 m)
- Height (above ground) = 28 m
- Basement height = 3 m

The basement is used for storage, building services and mechanical equipment. It is ten feet high and has an extra column added in every bay along Grids A through F to support a two-way slab at the second level. There are basement walls at the perimeter.

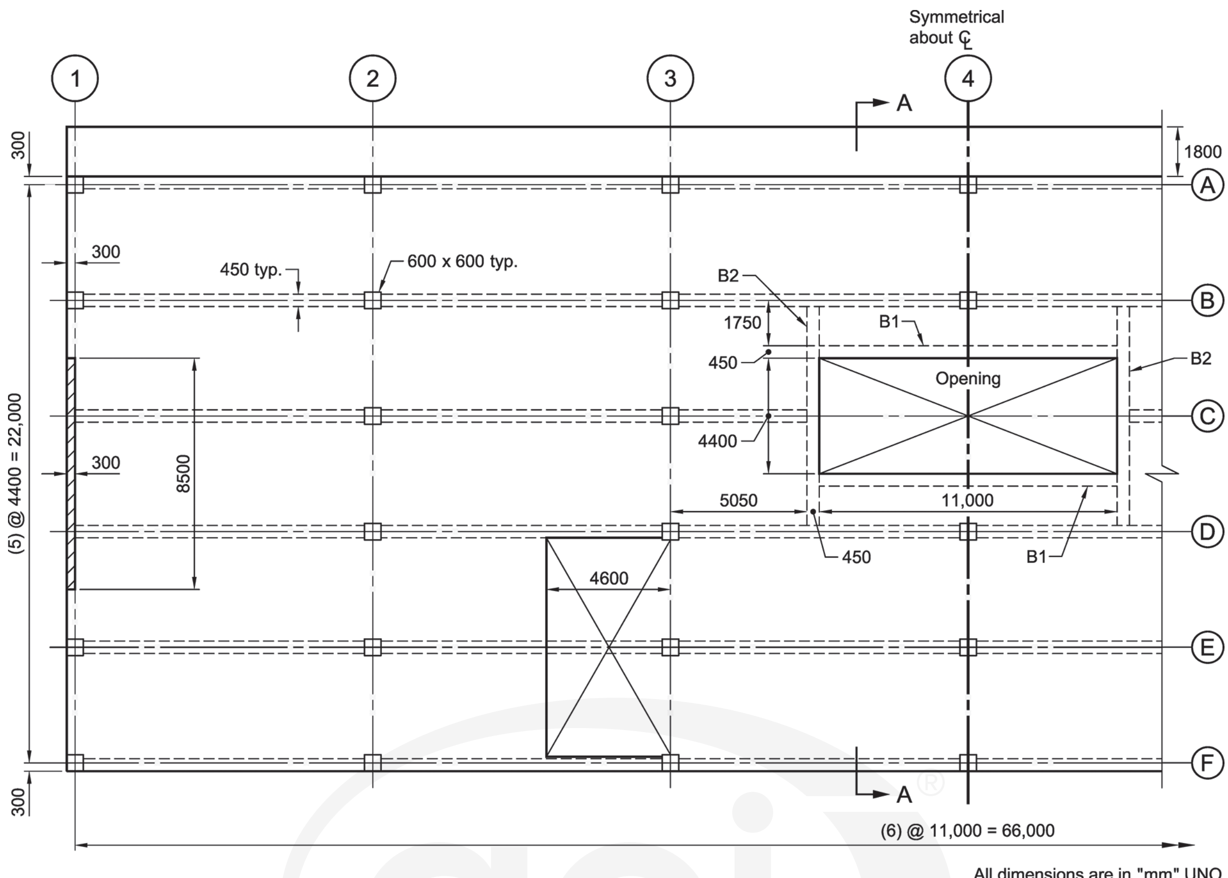
The structural system is an ordinary concrete shear wall in the north/south direction and an ordinary concrete moment frame in east/west direction. These basic systems were chosen as a starting point for the examples. Member examples may be expanded to show how they may be designed in intermediate or special systems but a new structural analysis is not done. The following analysis results provide the moments, shears, and axial loads given in the examples in other chapters in the manual. Those examples may modify this initial data to demonstrate some specific code requirement.

1.2—Building plans and elevation

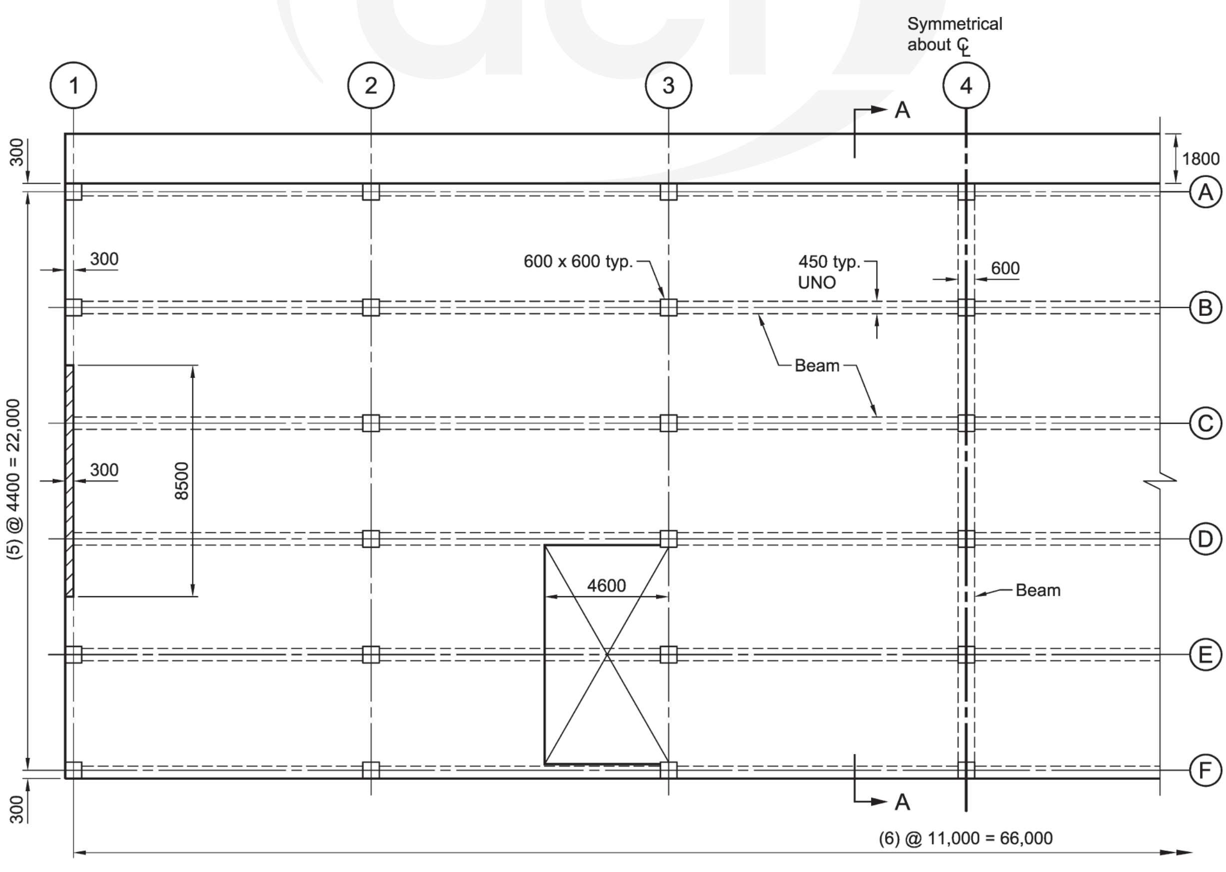
The following building plans and elevation provide the illustration of the example building.



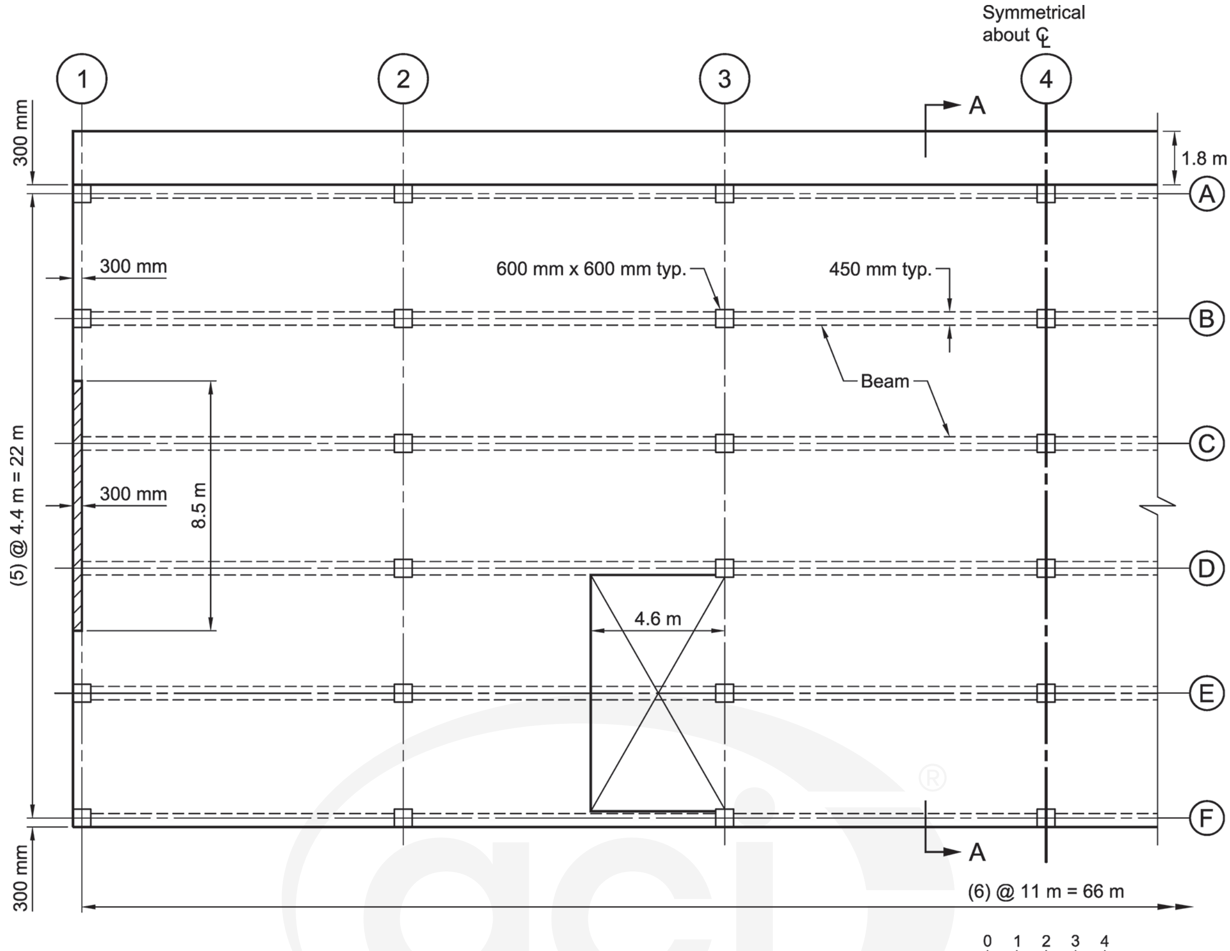
First Floor Plan



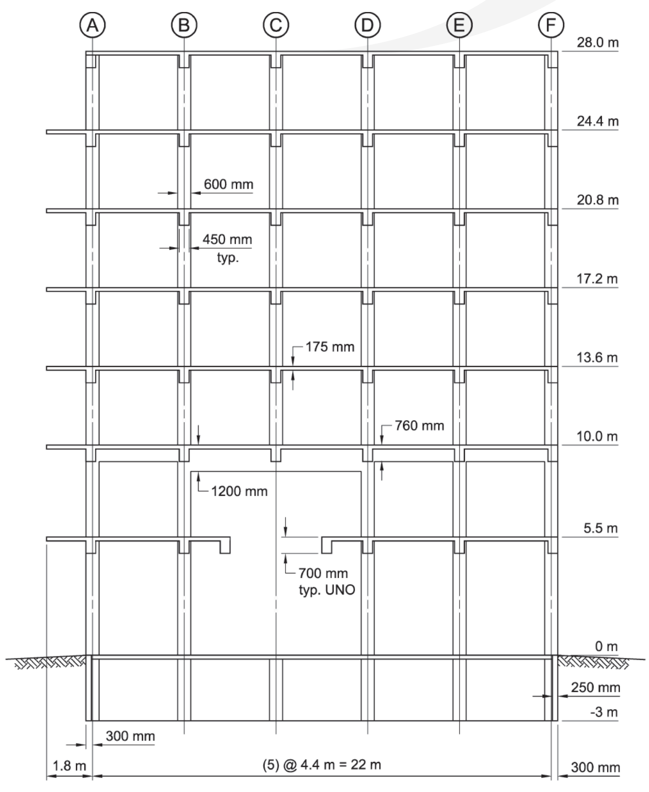
Second Floor Plan



Third Floor Plan



Typical Floor Plan 4th-7th



1.3—Loads

The following loads for the example building are generated in accordance with ASCE 7-10. The Risk Category is II.

Gravity Loads

Dead Load, *D*:

- Self weight
- Additional D = 0.75 kN/m^2
- Perimeter walls = 0.75 kN/m^2

Live Load:

- 1st and 2nd Floors: Lobbies, public rooms, and corridors serving them = 4.8 kN/m^2
- Typical Floor: Private rooms and corridors serving them = 3.0 kN/m^2

Roof Live Load:

- Unoccupied = 1.7 kN/m^2

Snow Load:

- Ground load, P_g = 0.96 kN/m^2
- Thermal, C_t = 1.0
- Exposure, C_e = 1.0
- Importance, I_s = 1.0
- Flat roof load, P_f = 0.96 kN/m^2

Lateral Loads

Wind Load:

- Basic (ultimate) wind speed = 185 km/h
- Exposure category = C
- Wind directionality factor, K_d = 0.85
- Topographic factor, K_{st} = 1.0
- Gust-effect factor, G_f = 0.85 (rigid)
- Internal pressure coefficient, $GC_{pi} = \pm 0.18$
- Directional Procedure

Seismic Load:

- Importance, I_e = 1.0
- Site class = *D*
- $S_S = 0.15$, $S_{DS} = 0.16$
- $S_1 = 0.08$, $S_{D1} = 0.13$
- Seismic design category = *B*
- Equivalent lateral force procedure
- Building frame system; ordinary reinforced concrete shear walls in the north-south direction
    - $R = 5$
    - $C_s = 0.046$
- Moment-resting frame system; ordinary reinforced concrete moment frame in the east-west direction
    - $R = 3$
    - $C_s = 0.032$

1.4—Material properties

The material properties for any building should have a reasonable knowledge of locally available concrete and steel materials. As a preliminary value for this example, a specified concrete compressive strength, f_c', of 28 MPa usually provides for a satisfactory floor design. In the US, reinforcing steel for floor design is usually specified as 420 MPa. The f_c' for columns and walls in multi-story buildings may be different than the f_c' used for the floor system. Concrete placement usually proceeds in two stages for each story; first, the vertical members, such as columns, and second, the floor members, such as beams and slabs. It is desirable to keep the concrete strengths of the vertical members within a ratio of 1.4 of the floor concrete strength. Section 15.3.1 in ACI 318M-14 states that if this ratio is exceeded, the floor concrete in the area immediately around the vertical members must be "puddled" with higher strength concrete. Usually this situation only becomes an issue for taller buildings.

For this example, the building height is moderate and the loads are typical. The locally available aggregate is a durable dolomitic limestone. Thus, the concrete can readily have a higher f_c' than the initial assumption of 28 MPa. A check of the durability requirements of Table 19.3.2.1 in ACI 318M-14 shows that 35 MPa will satisfy the minimum f_c' for all exposure classes. For this concrete, a check of Table 19.2.1.1 in ACI 318M-14 shows that all the code minimum limits are satisfied. The following concrete material properties are chosen:

- f_c' = 35 MPa
- Normalweight, w_c = 23.5 kN/m^3
- E_c = 27,800 MPa
- $\nu = 0.2$
- $e_{th} = 10 \times 10^{-6}$/°C

The use of lightweight concrete can reduce seismic forces and foundation loads. Based on local experience, however, this type of building won't greatly benefit from the use of lightweight. The modulus of elastic for concrete, E_c, is calculated according to 19.2.2 in ACI 318M. For normalweight concrete, Eq. 19.2.2.1.b in ACI 318M is applicable. Software programs using finite element analysis can account for the Poisson effect. The Poisson ratio can vary due to material properties, but an average value for concrete is 0.2. Recommendations for the thermal coefficient of expansion, e_{th}, of concrete can be found in ACI 209R.

The most common and most available nonprestressed reinforcement is Grade 60. Higher grades are available but 20.2.2.4 in ACI 318M-14 limits many uses of reinforcing steel to 420 MPa. The modulus of elastic for reinforcement, Es, is given in 20.2.2.2 in ACI 318M.

Reinforcement Material Properties

- f_y = 420 MPa
- f_{yt} = 420 MPa
- E_s = 200,000 MPa

REFERENCES

American Concrete Institute

ACI 209R-92—Prediction of Creep, Shrinkage, and Temperature Effects in Concrete Structures