



An ACI Manual

Formwork for Concrete

8th Edition

SP-4 (14)



American Concrete Institute
Always advancing

FORMWORK FOR CONCRETE

FORMWORK FOR CONCRETE

Eighth Edition

DAVID W. JOHNSTON

Edward I. Weisiger Distinguished Professor Emeritus

North Carolina State University

Prepared with the assistance of

ACI COMMITTEE 347, FORMWORK FOR CONCRETE

Kenneth L. Berndt, Chair
Matthew J. Poisel, Secretary

Rodney D. Adams
Mary Bordner-Tanck
George Charitou
Eamonn F. Connolly
James N. Cornell II
Jack L. David
Aubrey L. Dunham
Jeffrey C. Erson

N. John Gardner
Brian J. Golanowski
Timothy Hayes
G. P. Jum Horst
Jeffrey C. Jack
David W. Johnston
Roger S. Johnston
Robert G. Kent
Kevin R. Koogle
Jim Kretz
H. S. Lew

Robert G. McCracken
Eric S. Peterson
Steffen Pippig
Douglas J. Schoonover
Aviad Shapira
John M. Simpson
Rolf A. Spahr
Pericles C. Stivaros
Daniel B. Toon
Ralph H. Tulis



American Concrete Institute
Always advancing

Formwork for Concrete

8th Edition

First Printing: August 2014
Second Printing: December 2014
Third Printing: January 2016
Fourth Printing: February 2017
Fifth Printing: January 2018
Sixth Printing: September 2018

Errata changes as of October 31, 2019

Printed in Chelsea, Michigan

ISBN 978-0-87031-912-9
Copyright © 2014 by the American Concrete Institute.
All rights reserved.

This eighth edition has been revised to agree with "Guide to Formwork for Concrete (ACI 347R-14)," which is reprinted in full in the appendix. Other revisions have been made for consistency with ACI documents undergoing revision since previous editions of this manual were issued. Wood design stresses and procedures have been updated to agree with the 2012 National Design Specification[®] issued by the American Wood Council."

The drawings and examples in this book are based on typical designs and should not be used as working drawings or in place of making calculations for a particular project. They are intended to be helpful in the preparation of complete formwork plans that should be adapted to local conditions and comply with all applicable legal requirements. In no way is this book able to, or intended to, supplant the qualified designer or engineer to whom formwork should be entrusted.

Limitations of space and time make it impossible to show all of the methods, materials, and products available for formwork construction. Omission of any item therefore should not be regarded as a judgment that it is inferior or unsuitable.

Managing Editor: Michael Tholen, Ph.D., P.E.
Art Program: Claire Hiltz
Manager, Publishing Services: Barry Bergin
Production Editors: Carl Bischof, Kelli Slayden, Ashley Poirier, Kaitlyn Hinman
Page Design & Composition: Ryan Jay
Cover, Acknowledgements, and Foreword art courtesy Eric Peterson
Manufacturing: Marie Fuller

American Concrete Institute
38800 Country Club Drive
Farmington Hills, MI 48331
USA
www.concrete.org

DEDICATION

The eighth edition of *Formwork for Concrete* is dedicated to the memory and achievements of M. K. Hurd, author of the first seven editions and constant advocate for safety, economy, and quality of formwork. Mary Hurd (1926-2013), a civil engineering graduate of Iowa State University, began her career as a staff engineer with the American Concrete Institute in 1947. In the early 1960s, she was asked by ACI to work with the committee on Formwork for Concrete to develop a major publication on formwork that had been identified as an industry need. Over the years, as she moved at various times from ACI staff engineer to private consultant or editor of concrete industry publications, she was repeatedly engaged by ACI to update *Formwork for Concrete*. Well known and respected as an engineering writer and editor on concrete construction, formwork, and concrete aesthetics, she published over 230 articles on always-timely topics.

In the five decades since *Formwork for Concrete* made its first appearance, more than 130,000 copies have been printed and the book has become recognized as the “green bible” of the formwork industry. *Formwork for Concrete* has been and continues to be a cooperative effort supported by individuals, companies, public agencies, and industry and professional associations in large measure due to the groundwork laid and respect for *Formwork for Concrete* garnered through the pioneering efforts of Mary Hurd.



Mary K. Hurd in 1969

ACKNOWLEDGMENTS

The American Concrete Institute would like to acknowledge the hard work and support of several groups and individuals without whom the production of a document of this caliber would not be possible.

Without the vision and effort put forth by Mary K. Hurd and the members of ACI Committee 347 over the last 50 years, much of the basis for this document would not exist. Their work has established *Formwork for Concrete* as a well-known and respected reference in the concrete formwork industry and as an excellent teaching resource in classrooms across the United States.

David W. Johnston, Ph.D., P.E., took on the task of revising and bringing an iconic document up-to-date by including the latest design standards, design methods, procedures, products, and several new worked examples. In addition, he coordinated the selection of nearly 500 modern color photographs to enable the eighth edition of *Formwork for Concrete* to be the first edition in full color. Photos in this manual without photo credit were provided by Dr. Johnston. The assistance of Matthew Poisel in revising the document is also gratefully acknowledged.

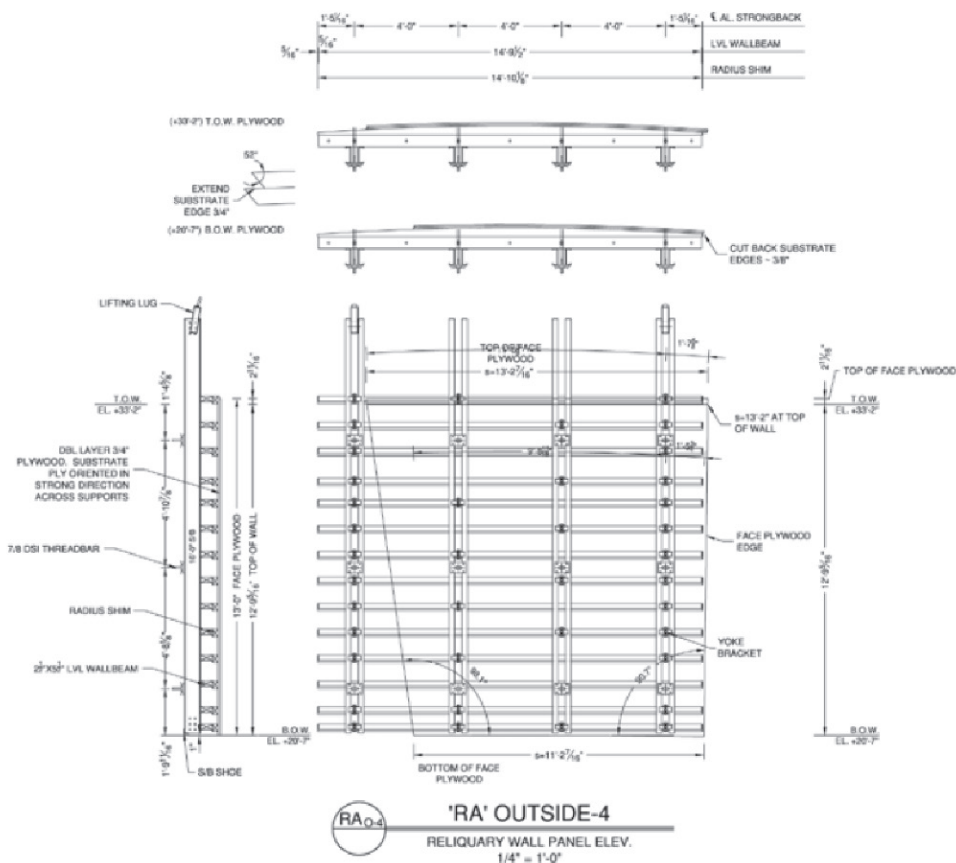
The assistance of the many formwork and construction companies that permitted the use of their photographs and illustrations allows *Formwork for Concrete* to show a breadth of formwork application that would not be possible otherwise. Specific acknowledgments for their contributions are found in the figure captions.

Members of ACI Committee 347, *Formwork for Concrete*, were engaged by the author during the process of revising the document, as they have been during the development of previous editions. Their comments and insight have brought a balanced viewpoint to the document that is not found in other documents on the topic.

Members of the ACI Educational Activities Committee (EAC), with the assistance of outside reviewers selected from ACI Committee 347, provided final review comments for chapters of the document. Responses by the author to these comments were reviewed and approved by the EAC members who commented on the chapter. These comments provided a fresh perspective and helped ensure that people reading the document for the first time would be able to quickly and easily understand the content. These reviewers also

made sure that the content of this work was consistent with other ACI documents. These suggestions have helped improve the document for the final end user.

Michael Tholen, Ph.D., P.E.
Managing Editor



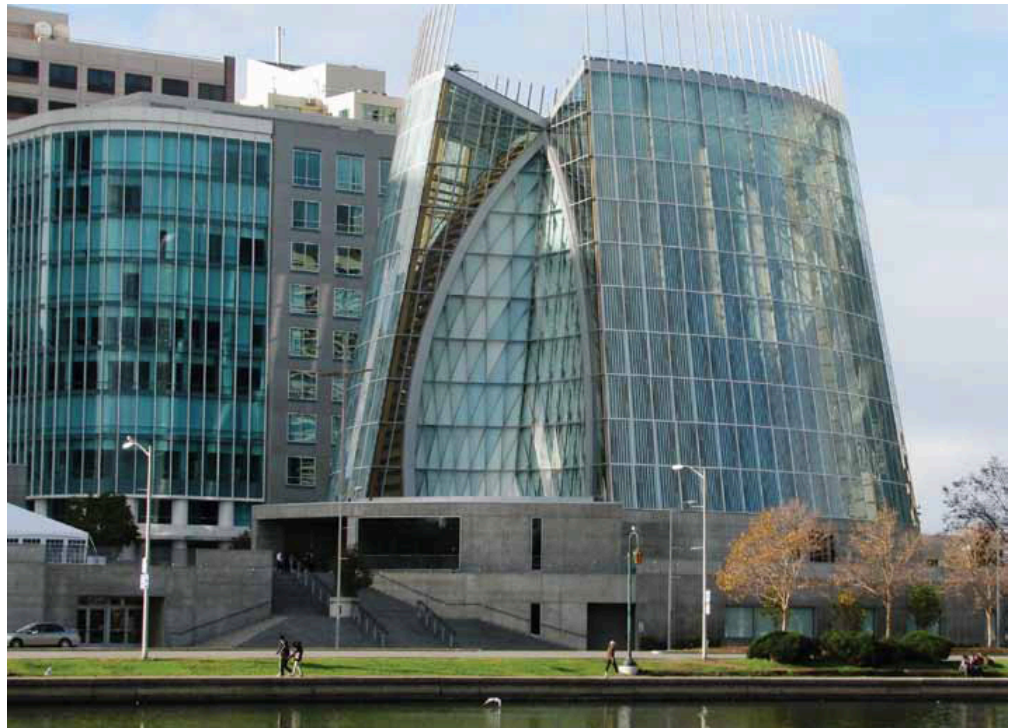
FOREWORD

Following in the footsteps of Mary K. Hurd is a challenge. My respect for her knowledge of formwork included recent decades of interaction with her on ACI Committee 347, but also extended back to my days as a student specializing in construction engineering and structural engineering. In 1965, I encountered the first edition of *Formwork for Concrete* as a construction engineering undergraduate student at North Carolina State University. During my years in industry and later as a faculty member, my appreciation of her pioneering and dedicated work on *Formwork for Concrete* and her contributions to ACI Committee 347 continued to grow.

The eighth edition, as all previous editions, follows the most recent guidelines established by ACI Committee 347 and documented in the committee report, now ACI 347R-14, which is reprinted in full in the appendix. This new edition of *Formwork for Concrete* considers the updated lateral pressure provisions now provided by ACI 347. Expanded coverage is provided for wind loads, analysis of the shoring and reshoring process, evaluation of concrete and structure strength to withstand shoring loads, and design of shoring and bracing elements. This edition also reflects the latest changes in wood design recommendations of the American Wood Council and introduces LRFD in addition to the primary coverage based on ASD procedures. The recent recommendations of other ACI committees have also been considered in the manual revisions and some related provisions of ACI 318 and OSHA have been extracted for convenient reference in the appendix. The growing number of standards related to design of the construction process and design of temporary structures, as well as a number of formwork industry products and practices adopted since the last edition was published, have been considered during development of the revisions. For instructional use, a series of problems and review questions have been provided following the appendix.

Drafts of revisions have been submitted for review and comment by members of ACI Committee 347, whose suggestions and advice have been most constructive. I am very grateful to the many committee members who shared their expertise and counsel during the preparation of the eighth edition. My special thanks to colleague Matthew Poisel, for his development of the data for the span tables of Chapter 9. The author is also grateful to the many individuals and organizations who have contributed nearly 500 new illustrations, drawings, and photo images to this first edition to be printed in color and to the many contractors who have provided access to their construction sites for photographs by the author, particularly United Forming, Inc., and Clancy & Theys Construction Co.

David W. Johnston, Ph.D., P.E.
July 2014



Chapters

1: INTRODUCTION

2: GENERAL OBJECTIVES IN FORMWORK BUILDING

3: OVERALL PLANNING

4: MATERIALS, ACCESSORIES, AND PROPRIETARY PRODUCTS

5: LOADS AND PRESSURES

6: SHORING AND FLOOR LOADS IN MULTI-STORY STRUCTURES

7: DESIGN OF SLAB, WALL, BEAM, AND COLUMN FORMS

8: DESIGN OF FORM SHORES AND BRACING

9: DESIGN TABLES

10: FORMWORK DRAWINGS

11: BUILDING AND ERECTING THE FORMWORK

12: USING THE FORMS

13: FORMED CONCRETE SURFACE QUALITY

14: FORMWORK FOR ARCHITECTURAL CONCRETE

15: BRIDGE FORMWORK

16: MASS CONCRETE FORMWORK

17: TUNNEL AND SHAFT FORMWORK

18: SPECIAL TECHNIQUES IN CONCRETE CONSTRUCTION

APPENDIX A—REFERENCED STANDARDS AND REPORTS

APPENDIX B—NOTATION

APPENDIX C—GLOSSARY

APPENDIX D—CONVERSIONS

APPENDIX E—ACI 347R-14 GUIDE

APPENDIX F—ACI 318-11 CODE AND COMMENTARY

APPENDIX G—OSHA REGULATIONS

APPENDIX H—PROBLEMS

INDEX

CONTENTS

1: INTRODUCTION

2: GENERAL OBJECTIVES IN FORMWORK BUILDING

2.1 Standards, Specifications, and Guides Related to Formwork	2-1
2.1.1 Regulations for Safety	2-1
2.1.2 Project Specifications for Quality	2-2
2.1.3 Guides and Specifications for Formwork Design and Construction	2-2
2.2 How Formwork Affects Concrete Quality	2-3
2.3 Planning for Safety	2-3
2.3.1 Supervision and Inspection	2-3
2.3.2 Platforms and Access for Workers	2-3
2.3.3 Control of Concreting Practices	2-4
2.3.4 Improving Soil Bearing and Bracing	2-4
2.3.5 Shoring and Reshoring	2-4
2.4 Causes of Failures	2-5
2.4.1 Improper Stripping and Shore Removal	2-5
2.4.2 Inadequate Bracing	2-6
2.4.3 Inadequate Concrete Strength Development	2-6
2.4.4 Vibration and Impact	2-6
2.4.5 Unstable Soil under Mudsills, Shoring Not Plumb	2-8
2.4.6 Inadequate Control of Concrete Placement	2-8
2.4.7 When Formwork Is Not at Fault	2-8
2.4.8 Lack of Attention to Formwork Details	2-10
2.5 Relationship of Architect, Engineer, and Contractor	2-10
2.5.1 Defining the Concrete Structure	2-10
2.5.2 Maintaining and Coordinating Tolerances	2-11
2.5.3 Preparing a Formwork Specification	2-11
2.5.4 Design, Inspection, and Approval of Formwork	2-12
2.5.5 Complex Structures	2-12
2.5.6 Stay-in-Place Forms	2-12
2.5.7 Composite Construction	2-12
2.5.8 Stripping and Decentering	2-12
2.5.9 Materials and Accessories Related to Formed Surface of Exposed Concrete	2-13
2.6 Achieving Economy of Formwork	2-13
2.6.1 Measurement and Payment for Formwork	2-14
2.6.2 How the Engineer/Architect Can Reduce Form Costs	2-14

3: OVERALL PLANNING

3.1 Development of a Basic System	3-1
3.1.1 Compare Alternate Methods	3-2
3.1.2 Examine Form Plan in Relation to Total Job	3-2
3.2 Key Areas of Cost Reduction	3-2
3.3 Planning for Maximum Reuse	3-3
3.3.1 Developing a Practical Reuse Plan	3-4
3.3.2 Comparing Reuse Schemes	3-4

3.4 Economical Form Construction	3-4
3.4.1 Job-Built Forms	3-4
3.4.2 Purchased or Rented Forms	3-6
3.5 Setting, Stripping, and Cycling Costs	3-6
3.6 Other Costs Affected by the Formwork Plan	3-7
3.6.1 Crew Efficiency	3-7
3.6.2 Cranes and Hoists	3-8
3.7 Formwork Planning Process	3-8
3.8 BIM for Planning Formwork Operations	3-13
3.8.1 How BIM is Used by a Formwork Contractor	3-13
3.8.2 Advantages of BIM	3-15

4: MATERIALS, ACCESSORIES, AND PROPRIETARY PRODUCTS

4.1 Lumber	4-1
4.1.1 Kinds of Lumber	4-2
4.1.2 Lumber Finish and Sizes	4-3
4.1.3 Stress Grading and Design Values	4-4
4.1.4 Adjustment Factors for Sawn Lumber Design Values	4-6
4.2 Engineered Wood Products	4-8
4.2.1 Glued Laminated Timber	4-9
4.2.2 Structural Composite Lumber	4-10
4.2.3 I-Joists	4-11
4.2.4 Wood Trusses	4-11
4.3 Plywood	4-11
4.3.1 Construction and Sizes Available	4-12
4.3.2 Types and Grades	4-12
4.3.3 Overlaid Plywood	4-14
4.3.4 Textured Surfaces	4-15
4.3.5 Strength Properties	4-15
4.3.6 Bending Plywood to Curved Surfaces	4-15
4.4 Other Framing and Facing Materials	4-16
4.4.1 Reconstituted Wood Materials	4-16
4.4.2 Steel	4-16
4.4.3 Aluminum	4-17
4.4.4 Glass Fiber-Reinforced Polymer	4-18
4.4.5 Other Polymeric Form Materials	4-18
4.4.6 Fabric and Porous Forms	4-19
4.4.7 Form Lining Materials	4-20
4.4.8 Insulation and Insulating Forms	4-22
4.5 Hardware and Fasteners	4-23
4.5.1 Nails	4-23
4.5.2 Wood Screws	4-26
4.5.3 Bolts, Lag Screws, and Other Connectors	4-28
4.5.4 Ties	4-31
4.5.5 Anchors	4-35
4.5.6 Hangers	4-36
4.5.7 Friction Collars and Support Brackets	4-36

4.5.8 Spacers and Spreaders	4-37
4.5.9 Steel Strapping	4-37
4.5.10 Column Clamps	4-38
4.6 Prefabricated Forms	4-38
4.6.1 Panel Forms and Forming Systems	4-38
4.6.2 Pans and Domes for Concrete Joist Construction	4-39
4.6.3 Void and Duct Forms	4-40
4.6.4 Column Forms	4-41
4.6.5 Stay-In-Place Forms	4-42
4.6.6 Special Purpose and Custom-Made Forms	4-43
4.7 Shoring	4-43
4.7.1 Single-Post Shores	4-44
4.7.2 Shoring Frames	4-44

5: LOADS AND PRESSURES

5.1 Notation for Loads and Pressures	5-1
5.2 Load Combinations	5-2
5.2.1 ASD Combinations	5-2
5.2.2 LRFD Combinations	5-2
5.3 Vertical Loads	5-3
5.3.1 Dead Loads	5-3
5.3.2 Live Loads	5-4
5.4 Lateral Pressure of Fresh Concrete	5-4
5.4.1 Factors Affecting Lateral Pressure	5-6
5.4.2 History of Lateral Pressure Values for Form Design	5-7
5.4.3 Lateral pressure of concrete equations	5-8
5.4.4 Bottom-Up Pumping of Concrete	5-9
5.4.5 Column Forms	5-10
5.4.6 Wall Forms	5-10
5.4.7 Pressure on Sloping Surfaces	5-11
5.5 Horizontal Loads	5-13
5.5.1 Minimum Horizontal Loads	5-13
5.5.2 Wind Loads	5-14
5.5.3 Shielding from Wind Pressure	5-17
5.5.4 Design Wind Load	5-18
5.5.5 Wind Load on Wall and Column Forms	5-18
5.5.6 Wind Loads on Elevated Slab Formwork	5-19
5.5.7 Starting and Stopping Equipment Loads	5-20
5.5.8 Seismic Loads	5-20
5.6 Other Loads	5-20

6: SHORING AND FLOOR LOADS IN MULTI-STORY STRUCTURES

6.1 Shoring of Multi-story Concrete Structures during Construction	6-1
6.2 Shoring and Reshoring Loads in Multi-story Structures	6-3
6.2.1 Analyzing the Loads	6-3
6.2.2 Comparison of Example Analysis Results	6-5

6.3 Backshoring	6-16
6.4 Drophead Shores	6-16
6.5 LRFD Analysis	6-17
6.6 Shoring System Design	6-21
6.7 Determining Concrete Strength for Stripping and Loading for Cycle Times	6-22
6.7.1 Analysis and Design Process for Slab Strength	6-22
6.7.2 Alternative Load Distributions	6-26
6.7.3 More Concentrated Shore Loads	6-26
6.7.4 Structures Designed for Composite Action	6-26
6.7.5 Post-Tensioned Structures	6-27
6.8 Effect of Early Loading on Slab Deflection	6-27
6.9 Monitoring Early Strength Gain of Concrete in the Field	6-27
6.9.1 Field-Cured Cylinders	6-27
6.9.2 Alternate Tests	6-27

7: DESIGN OF SLAB, WALL, BEAM, AND COLUMN FORMS

7.1 Notation	7-2
7.2 Basic Simplifications	7-3
7.3 Beam Formulas	7-4
7.4 Design Criteria for Wood Beams	7-7
7.4.1 Stresses and Deformations	7-7
7.4.2 Bending	7-7
7.4.3 Deflection	7-9
7.4.4 Shear	7-10
7.4.5 Bearing	7-13
7.5 Form Design	7-13
7.6 Wall Form Design	7-15
7.7 Slab Form Design	7-22
7.8 Beam Form Design	7-27
7.9 Column Form Design	7-30
7.9.1 Types of Column Forms	7-31
7.9.2 General Design Procedure	7-31
7.10 Form Accessories	7-33
7.10.1 Ties	7-36
7.10.2 Bearing Plates or Washers	7-37
7.10.3 Hangers	7-37

8: DESIGN OF FORM SHORES AND BRACING

8.1 Shoring and Bracing Members	8-1
8.2 Solid Wood Compression Members	8-2
8.3 Tubular Steel Shores	8-5
8.3.1 Slenderness Ratio	8-5
8.3.2 Compression Strength	8-5
8.3.3 Steel Shoring Frames	8-6

8.4 Other Manufactured Shoring Devices	8-7
8.5 Support for Shoring	8-8
8.6 Bracing for Lateral Loads	8-8
8.6.1 Wall Form Bracing Loads	8-8
8.6.2 Design of Braces	8-9
8.6.3 Bracing of Slab Forms Supported by Individual Shores	8-9
8.6.4 Design of Wood Bracing Connections	8-10
8.7 Camber and Adjustment for Settlement	8-10
8.7.1 Anticipated Deflection or Settlement of Formwork	8-10
8.7.2 Deflection of the Finished Structure	8-13
8.7.3 Total Allowance for Camber and Adjustments	8-13
8.8 Anchorage of braces	8-13
8.8.1 Deadmen	8-13
8.8.2 Concrete anchors	8-14
8.8.3 Ground anchors	8-14
8.8.4 Anchors	8-14

9: DESIGN TABLES

9.1 Equations for Calculating Safe Span	9-1
9.2 Sheathing Design: Tables 9.3 to 9.5	9-4
9.3 Joists, Studs, and Beams: Tables 9.6 to 9.8	9-4
9.4 Double Members: Tables 9.9 to 9.11	9-5
9.5 Wood Shores: Tables 9.12 and 9.13	9-5
9.6 Form Design Using the Tables	9-7

10: FORMWORK DRAWINGS

10.1 Preparing Effective Drawings	10-1
10.2 Line Drawings	10-2
10.3 General Layout and Detail Drawings	10-3
10.4 Checklist of Details	10-13
10.5 Recheck for Agreement with Structural Drawings	10-16
10.6 Drawing Review	10-16
10.7 BIM 3-D Graphical Views of Formwork	10-17

11: BUILDING AND ERECTING THE FORMWORK

11.1 Form Fabrication	11-2
11.1.1 Location of Shop at Project Site	11-2
11.1.2 Storage of Materials and Finished Parts	11-3
11.1.3 Equipment and Layout	11-3
11.2 Formwork Erection Safety	11-4
11.3 Footings	11-5
11.3.1 Wall Footings	11-5
11.3.2 Column Footings	11-6

11.4 Slab-on-Ground and Paving Work	11-7
11.4.1 Slabs-on-Ground	11-7
11.4.2 Highway and Airport Paving	11-8
11.4.3 Curb and Gutter Forms	11-9
11.5 Wall Forms	11-9
11.5.1 Job-Built Forms	11-9
11.5.2 Prefabricated Panel Systems	11-12
11.5.3 Ganged Panel Forms and Climbing Forms	11-12
11.5.4 Blind Side and Single-Side Wall Forming	11-14
11.5.5 Square Corners	11-14
11.5.6 Pilasters	11-14
11.5.7 Curved Walls and Round Corners	11-15
11.5.8 Wall Openings	11-17
11.5.9 Joints	11-17
11.5.10 Forms for External Vibration	11-18
11.5.11 ACI Tolerances for Walls	11-19
11.6 Column Forms	11-19
11.6.1 Erection Practices	11-19
11.6.2 Square or Rectangular Columns	11-21
11.6.3 Round and Flared Columns	11-21
11.6.4 Column Heads	11-22
11.6.5 ACI Column Tolerances	11-24
11.7 Beam or Girder Forms	11-24
11.7.1 Beam Bottoms	11-24
11.7.2 Beam Sides	11-25
11.7.3 Panel Assembly and Erection	11-26
11.7.4 Suspended Forms for Fireproofing and Composite Construction	11-27
11.7.5 Beam and Girder Tolerances	11-28
11.8 Slab Forms	11-28
11.8.1 Beam and Slab Construction	11-28
11.8.2 Flat Plates and Flat Slabs	11-29
11.8.3 Concrete Joist Construction	11-30
11.8.4 Flying Form Systems	11-32
11.8.5 Adjustable Steel Beams	11-33
11.8.6 Slabs Supported on Steel Beams or Precast Concrete Beams	11-34
11.8.7 Metal Decking	11-34
11.8.8 ACI Tolerances for Slab Work	11-34
11.9 Shoring	11-35
11.9.1 Shore Layout and Installation	11-35
11.9.2 Mudsills or Shoring Foundations	11-37
11.9.3 Wood Shores	11-37
11.9.4 Adjustable Shores	11-37
11.9.5 Drophead Shore Systems	11-38
11.9.6 Shoring Towers	11-38
11.9.7 Adjustment and Jacking	11-39
11.9.8 Permanent Shores and Back Shores	11-39
11.9.9 Composite Construction	11-40

12: USING THE FORMS

12.1 Placing Reinforcement and Inserts	12-2
12.1.1 Support for Reinforcing Bars	12-3
12.1.2 Positioning Bars; Placement Tolerances	12-4
12.2 Preparation for Concreting	12-5
12.2.1 Form Release Agents	12-5
12.2.2 Sticking and Staining Problems	12-7
12.2.3 Use of Water on the Forms	12-8
12.3 Inspection and Form Watching	12-8
12.3.1 Before Concreting	12-9
12.3.2 During and After Concreting	12-11
12.4 Placing and Vibrating—Effect on Formwork	12-11
12.5 Removal of Forms and Shores	12-12
12.5.1 Stripping Time Based on Concrete Strength	12-12
12.5.2 Form Removal Related to Curing Needs	12-14
12.5.3 Stripping Techniques	12-14
12.5.4 Multi-Story Buildings	12-16
12.6 Reshoring	12-16
12.7 Care and Storage of Forms and Accessories	12-18
12.8 Cold Weather Protection	12-19
12.8.1 Form Insulation and Heating	12-20
12.8.2 Avoiding Thermal Shock	12-23

13: FORMED CONCRETE SURFACE QUALITY

13.1 Overview of ACI 301 Formed Surface Provisions	13-1
13.1.1 General Requirements	13-2
13.1.2 As-Cast Surface Finishes	13-3
13.1.3 Rubbed Surface Finishes	13-3
13.2 Overview of ACI 347.3R Formed Concrete Surface Provisions	13-3
13.2.1 Determination of Surface Void Ratio	13-4
13.2.2 Specifications	13-5
13.2.3 Design Considerations	13-6
13.2.4 Construction	13-8
13.2.5 Evaluation of formed concrete surfaces and repair procedures	13-10

14: FORMWORK FOR ARCHITECTURAL CONCRETE

14.1 Specifications: Defining Quality	14-2
14.2 Architectural Formwork Design	14-3
14.2.1 Loads and Pressures	14-3
14.2.2 Design Standards	14-4
14.2.3 Formwork Details	14-5
14.3 Exposed Concrete Surfaces	14-5
14.3.1 Smooth As-Cast Surfaces	14-6
14.3.2 Textured As-Cast Surfaces	14-8
14.3.3 Precast Panels as Forms or Liners	14-10

14.4 Construction of Forms for Architectural Concrete	14-12
14.4.1 Walls	14-12
14.4.2 Columns and Pilasters	14-15
14.4.3 Spandrels and Parapets	14-16
14.4.4 Soffits	14-17
14.4.5 Cantilevers	14-17
14.4.6 Ornamental Detail	14-18
14.4.7 Erection Practices	14-21
14.4.8 Construction and Contraction Joints	14-23
14.5 Stripping	14-24
14.6 Cleanup and Repair	14-25

15: BRIDGE FORMWORK

15.1 Foundations	15-2
15.1.1 Caissons	15-2
15.1.2 Piles	15-4
15.1.3 Rock or Soil Offering Direct Support	15-4
15.2 Piers	15-5
15.2.1 Forms Moved for Reuse	15-5
15.2.2 Round Piers	15-6
15.2.3 Stonework Facing	15-6
15.2.4 Massive Piers	15-6
15.2.5 Vertical Alignment	15-6
15.2.6 Access for Workers	15-7
15.2.7 External Ties	15-7
15.2.8 Pier Caps and Tie Struts	15-7
15.3 Superstructures	15-8
15.3.1 Monolithic—Simple Slab, Beam, and Girder	15-8
15.3.2 Cast-in-Place Deck Supported on Steel or Precast Girders	15-9
15.3.3 Expansion Joints	15-10
15.3.4 Overhang, Sidewalks, Parapets, and Median Barriers	15-10
15.3.5 Support for Superstructure Forms	15-10
15.3.6 Stripping Bridge Forms	15-11
15.4 Arch Bridges	15-12
15.5 Segmental Box-Girder Bridge Construction	15-12
15.5.1 Cast-in-Place Segmental Construction	15-13
15.5.2 Precast Segmental Construction	15-13
15.5.3 Principal Erection Methods	15-14
15.5.4 Making Precast Bridge Segments	15-17
15.5.5 Voids, Inserts, Attachments	15-19
15.5.6 Joint Surfaces	15-19
15.5.7 Vibration	15-19
15.5.8 Heat Curing Considerations	15-19
15.5.9 Tolerance Requirements	15-20

16: MASS CONCRETE FORMWORK

16.1 Types of Cantilever Forms in Common Use	16-2
--	------

16.2 Design Considerations	16-3
16.2.1 Loads on the Formwork	16-4
16.2.2 Anchorage Accessories	16-5
16.2.3 Other Design Features	16-6
16.3 Handling, Erecting, Stripping	16-7
16.4 Non-Cantilevered Formwork	16-7
16.5 Facings for Roller-Compacted Mass Concrete and Dam Repair	16-8
16.6 Foundations or Starting Lifts	16-9
16.7 Curing, Joint Cleanup, Insulation	16-10
16.8 Planning and Supervision	16-11
16.9 Tolerances	16-11

17: TUNNEL AND SHAFT FORMWORK

17.1 Tunnel Forming Components	17-1
17.1.1 Curb Forms	17-2
17.1.2 Invert Forms	17-2
17.1.3 Arch Forms	17-3
17.1.4 Form Traveler Operations	17-5
17.2 Concrete Placement Methods	17-5
17.2.1 Continuous Advancing Slope	17-6
17.2.2 Bulkhead Method	17-6
17.2.3 Cut-and-Cover Construction	17-7
17.3 General Design Considerations	17-7
17.3.1 Influence of Placing Equipment	17-7
17.3.2 Loads and Pressures	17-8
17.3.3 Vibration and Form Access	17-9
17.4 Form Construction	17-9
17.5 Stripping Time	17-10
17.6 Tolerances	17-10
17.7 Shafts	17-11

18: SPECIAL TECHNIQUES IN CONCRETE CONSTRUCTION

18.1 Vertical Slipform Construction	18-1
18.1.1 Design and Construction Considerations	18-3
18.1.2 Jacking System	18-6
18.1.3 Sliding Operations	18-6
18.2 Horizontal Slip Forms	18-8
18.2.1 Design and Construction Considerations	18-9
18.2.2 Horizontal Applications	18-9
18.3 Tilt-Up	18-12
18.3.1 Curing and Bond-Breaking Compounds	18-13
18.3.2 Curved Tilt-Up Panels	18-13
18.4 Lift Method of Construction	18-13
18.4.1 Forming and Casting	18-14
18.4.2 Slab Separation	18-14

18.5 Shells, Domes, and Folded Plates	18-14
18.5.1 Shell Form Design Considerations	18-15
18.5.2 Building the Forms	18-16
18.5.3 Placing Concrete	18-16
18.5.4 Form Removal	18-16
18.5.5 Inflated Forming Methods	18-17
18.6 Traveling Forms	18-17
18.6.1 Applications	18-17
18.6.2 Design Considerations	18-18
18.7 Preplaced Aggregate Concrete	18-19
18.7.1 Lateral Pressure	18-19
18.7.2 Form Construction and Materials	18-20
18.8 Shotcrete	18-21
18.9 Tremie Concrete	18-21
18.10 Precast Concrete	18-23
18.10.1 Advantages of Precasting	18-23
18.10.2 Formwork Requirements	18-24
18.10.3 Stripping	18-26
18.10.4 Erection and Joints	18-26
18.11 Prestressed Precast Concrete	18-26
18.11.1 Forms for Post-Tensioning	18-27
18.11.2 Forms for Pretensioning	18-29

APPENDIX A—REFERENCED STANDARDS AND REPORTS

APPENDIX B—NOTATION

APPENDIX C—GLOSSARY

APPENDIX D—CONVERSIONS

APPENDIX E—ACI 347R-14 GUIDE

APPENDIX F—ACI 318-11 CODE AND COMMENTARY

APPENDIX G—OSHA REGULATIONS

APPENDIX H—PROBLEMS

INDEX



(Photo courtesy Morley Builders)

1: INTRODUCTION

Formwork development has paralleled the growth of concrete construction from its earliest uses through its many applications today. As concrete has been used for increasingly complex and significant structural and architectural tasks, formwork engineers and contractors have had to keep pace. Projects involving rapid construction schedules create challenges for the form designer and for the control of field forming operations. The increasing use of concrete as an architectural medium presents the form builder with several challenges, ranging from the selection of appropriate sheathing materials to the maintenance of rigid tolerances.

Sawn lumber, manufactured wood products, plywood, steel, aluminum, reinforced polymers, and other materials are widely used as formwork components. In addition, new and specialized accessories are frequently introduced by manufacturers. Form designers, builders, and manufacturers must keep abreast of advancing technology in other material fields to develop and implement the creative and innovative solutions required to maintain both quality and economy.

In the early days of the concrete industry, formwork was frequently built in place, used once, wrecked (or stripped), and discarded. Because of high labor costs in the United States and many other countries, the trend over the last several decades has been toward increased prefabrication, assembly in large units, erection by mechanical means (such as “flying” forms into place by crane), and reuse of the forms. These developments are in harmony with the increased mechanization often found in other fields and the desired use of sustainable systems. Consequently, the forming system selection is often a primary factor in locating cranes and in allocating site space for storage and fabrication.

Not all of the important ideas are new, however. As early as 1908, members of the American Concrete Institute (then called the National Association of Cement Users) were debating the relative merits of wood and steel formwork at their annual convention. The discussion followed a presentation proclaiming the advantages of a modular metal panel forming system.^{1.1} It could be adapted for most any project, had its own connecting hardware, and was good for extensive reuse. By 1910, steel forms for paving were being



Fig. 1.1: Manufactured metal formwork system for concrete floor slab construction (Photo courtesy MEVA Formwork Systems)

produced commercially and used in the field. Continuing refinement of basic ideas such as these represents another area of ongoing progress within the formwork industry. Today, formwork and forming systems have become an integral part of the entire equipment array on site and of the overall construction planning process. The comparison of metal versus wood and job-built versus manufactured systems (Fig. 1.1 and 1.2) continues today with many varieties in use and the decision ultimately based on factors of quality, safety, and economy for the individual project.

There are differences in forming practice details from one country to another and even from one region of the United States to another. Some of the differences are due to prevalent local material use, regional or country limits on supplies for manufacturers, or preference of a contractor for a particular system due to their own inventory and proficiency of their workers with the system. However, a trend of consolidation among form and accessory manufacturers is also resulting in several form manufacturers with broad international supply capability. Variations in formwork application are often most visible to the public in buildings (Fig. 1.3) and bridges (Fig. 1.4). Formwork is also extensively used for residential construction, stadiums, airports, harbors, water treatment plants, tunnels, dams, and other facilities. Although the information presented in this manual has been drawn from many sources worldwide, it is intended for application primarily in the United States. Suggestions for formwork economy have been based on conditions in countries where labor costs are high compared to material costs. In countries where labor costs are substantially lower in relation to the price of construction materials, many of the ideas presented regarding formwork economy likely will not have the same validity.

Many individuals, firms, and companies are usually involved in the design of the facility to be built and in the design and construction of the formwork. The facility team typically involves structural engineers and architects who determine the requirements for the concrete structure. For simplicity, the facility design team will usually be referred to as the *engineer/architect*, although they may be referred to separately in some situations. The formwork team may include the general contractor, formwork specialty subcontractors, formwork engineers, form manufacturers, and form suppliers. The participating companies and firms also have formwork designers and skilled workers executing many detailed tasks. For simplicity, the formwork team will usually be referred to as the *formwork engineer/contractor*, although they may be referred to separately in some situations.

Form building requires both job-site innovation and engineering understanding. There is certainly no substitute for the skill and sense of “know-how” that come with job-site experience. In a similar manner, many engineering principles can be used to improve the safety, quality, and economy of formwork.



Fig. 1.2: Job-built wall formwork constructed of wood materials