ACI 347-04

Guide to Formwork for Concrete

An ACI Standard

Reported by ACI Committee 347

American Concrete Institute®

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Objectives of safety, quality, and economy are given priority in these guidelines for formwork. A section on contract documents explains the kind and amount of specification guidance the engineer/architect should provide for the contractor. The remainder of the report advises the formwork engineer/contractor on the best ways to meet the specification requirements safely and economically. Separate chapters deal with design, construction, and materials for formwork. Considerations peculiar to architectural concrete are also outlined in a separate chapter. Other sections are devoted to formwork for bridges, shells, mass concrete, and underground work. The concluding chapter on formwork for special methods of construction includes slipforming, preplaced-aggregate concrete, tremie concrete, precast, and prestressed concrete.

Keywords: anchors; architectural concrete; coatings; concrete; construction; falsework; form ties; forms; formwork; foundations; quality control; reshoring; shoring; slipform construction; specifications; tolerances.

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PREFACE

Before the formation of ACI Committee 347 (formerly ACI Committee 622) in 1955, there had been an increase in the use of reinforced concrete for longer span structures, multistoried structures, and increased story heights.

The need for a formwork standard and increased knowledge concerning the behavior of formwork was evident from the rising number of failures, sometimes resulting in the loss of life. The first report by the committee, based on a survey of current practices in the United States and Canada, was published in the ACI JOURNAL in June 1957.[1.1] The second committee report was published in the ACI JOURNAL in August 1958.[1.2] This second report was an in-depth review of test reports and design formulas for determining lateral pressure on vertical formwork. The major result of this study and report was the development of a basic formula establishing form pressures to be used in the design of vertical formwork.

The first standard was ACI 347-63. Subsequent revisions were ACI 347-68 and ACI 347-78. Two subsequent revisions, ACI 347R-88 and ACI 347R-94, were committee reports because of changes in the ACI policy on the style and format of standards. ACI 347-01 returned the guide to the standardization process.

A major contribution of the committee has been the sponsorship and review of *Formwork for Concrete*[1.3] by M. K. Hurd, first published in 1963 and currently in its sixth edition. Now comprising more than 490 pages, this is the most comprehensive and widely used document on this subject. (The Japan National Council on Concrete has published a Japanese translation.)

The paired values stated in inch-pound and SI units are usually not exact equivalents. Therefore, each system is to be used independently of the other. Combining values from the two systems may result in nonconformance with this document.

CHAPTER 1—INTRODUCTION

1.1—Scope

This guide covers:

- A listing of information to be included in the contract documents;
- Design criteria for horizontal and vertical forces on formwork;
- Design considerations, including safety factors, to be used in determining the capacities of formwork accessories;
- Preparation of formwork drawings;
- Construction and use of formwork, including safety considerations;
- Materials for formwork;
- Formwork for special structures;
- Formwork for special methods of construction; and
- Qualification of personnel for inspection and testing.

This guide is based on the premise that layout, design, and construction of formwork should be the responsibility of the formwork engineer/contractor. This is believed to be fundamental to the achievement of safety and economy of formwork for concrete.

1.2—Definitions

The following definitions will be used in this guide. Many of the terms can also be found in ACI 116R:

backshores—shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area at a time, without allowing the slab or member to deflect; thus, the slab or other member does not yet support its own weight or existing construction loads from above.

bugholes—surface air voids: small regular or irregular cavities, usually less than 0.6 in. (15 mm) in diameter, resulting from entrapment of air bubbles in the surface of formed concrete during placement and consolidation. Also called blowholes.

centering—specialized temporary support used in the construction of arches, shells, and space structures where the entire temporary support is lowered (struck or decentered) as a unit to avoid introduction of injurious stresses in any part of the structure.

climbing form—a form that is raised vertically for succeeding lifts of concrete in a given structure.

diagonal bracing—supplementary formwork members designed to resist lateral loads.

engineer/architect—the engineer, architect, engineering firm, architectural firm, or other agency issuing project plans and specifications for the permanent structure, administering the work under contract documents, or both.

flying forms—large prefabricated, mechanically handled sections of formwork designed for multiple reuse; frequently including supporting truss, beam, or shoring assemblies completely unitized. Note: Historically, the term has been applied to floor forming systems.

form—a temporary structure or mold for the support of concrete while it is setting and gaining sufficient strength to be self-supporting.

formwork—total system of support for freshly placed concrete, including the mold or sheathing that contacts the concrete and all supporting members, hardware, and necessary bracing.

formwork engineer/contractor—engineer of the formwork system, contractor, or competent person in charge of designated aspects of formwork design and formwork operations.

ganged forms—large assemblies used for forming vertical surfaces; also called gang forms.

horizontal lacing—horizontal bracing members attached to shores to reduce their unsupported length, thereby increasing load capacity and stability.

preshores—added shores placed snugly under selected panels of a deck-forming system before any primary (original) shores are removed. Preshores and the panels they support remain in place until the remainder of the complete bay has been stripped and backshored, a small area at a time.

reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a large area, requiring the new slab or structural member to deflect and support its own weight and existing construction loads to be applied before installation of the reshores.

scaffold—a temporary elevated platform (supported or suspended) and its supporting structure used for supporting workers, tools, and materials; adjustable metal scaffolding can be used for shoring in concrete work, provided its structure has the necessary load-carrying capacity and structural integrity.

shores—vertical or inclined support members designed to carry the weight of the formwork, concrete, and construction loads above.

slipform—a form that is pulled or raised as concrete is placed; may move in a horizontal direction to lay concrete for concrete paving or on slopes and inverts of canals, tunnels, and siphons; or may move vertically to form walls, bins, or silos.

1.3—Achieving economy in formwork

The engineer/architect can help overall economy in the structure by planning so that formwork costs are minimized. The cost of formwork in the United States can be as much as 60% of the total cost of the completed concrete structure in place and sometimes greater. This investment requires careful thought and planning by the engineer/architect when designing and specifying the structure and by the formwork engineer/contractor when designing and constructing the formwork.

Formwork drawings, prepared by the formwork engineer/contractor, can identify potential problems and should give project site employees a clear picture of what is required and how to achieve it. The following guidelines show how the engineer/architect can plan the structure so that formwork economy may best be achieved:

- To simplify and permit maximum reuse of formwork, the dimensions of footings, columns, and beams should be of standard material multiples, and the number of sizes should be minimized;
- When interior columns are the same width as or smaller than the girders they support, the column form becomes a simple rectangular or square box without boxouts, and the slab form does not have to be cut out at each corner of the column;
- When all beams are made one depth (beams framing into beams as well as beams framing into columns), the supporting structures for the beam forms can be carried on a level platform supported on shores;
- Considering available sizes of dressed lumber, plywood, and other ready-made formwork components and keeping beam and joist sizes constant will reduce labor time;
- The design of the structure should be based on the use of one standard depth wherever possible when commercially available forming systems, such as one- or two-way joist systems, are used;
- The structural design should be prepared simultaneously with the architectural design so that dimensions can be better coordinated. Room sizes can vary a few inches to accommodate the structural design;
- The engineer/architect should consider architectural features, depressions, and openings for mechanical or electrical work when detailing the structural system, with the aim of achieving economy. Variations in the structural system caused by such items should be shown on the structural plans. Wherever possible, depressions in the tops of slabs should be made without a corresponding break in elevations of the soffits of slabs, beams, or joists;
- Embedments for attachment to or penetration through the concrete structure should be designed to minimize random penetration of the formed surface; and
- Avoid locating columns or walls, even for a few floors, where they would interfere with the use of large formwork shoring units in otherwise clear bays.

1.4—Contract documents

The contract documents should set forth the tolerances required in the finished structure but should not attempt to specify the manner in which the formwork engineer/contractor designs and builds the formwork to achieve the required tolerances.

The layout and design of the formwork and its construction should be the responsibility of the formwork engineer/contractor. This approach gives the necessary freedom to use skill, knowledge, and innovation to safely construct an economical structure. By reviewing the formwork drawings, the engineer/architect can understand how the formwork engineer/contractor has interpreted the contract documents. Some local areas have legal requirements defining the specific responsibilities of the engineer/architect in formwork design, review, or approval.

1.4.1 *Individual specifications*—The specification writer is encouraged to refer to this guide as a source of recommendations that can be written into the proper language for contract documents.

The specification for formwork will affect the overall economy and quality of the finished work; therefore, it should be tailored for each particular job, clearly indicate what is expected of the contractor, and ensure economy and safety.

A well-written formwork specification tends to equalize bids for the work. Unnecessarily exacting requirements can make bidders question the specification as a whole and make it difficult for them to understand exactly what is expected. They can be overly cautious and overbid or misinterpret requirements and underbid.

A well-written formwork specification is of value not only to the owner and the contractor, but also to the field representative of the engineer/architect, approving agency, and the subcontractors of other trades. Some requirements can be written to allow discretion of the contractor where quality of finished concrete work would not be impaired by the use of alternative materials and methods.

Consideration of the applicable general requirements suggested herein will not be sufficient to make a complete specification. Requirements should be added for actual materials, finishes, and other items peculiar to and necessary for the individual structure. The engineer/architect can exclude, call special attention to, strengthen, or make more lenient any general requirement to best fit the needs of the particular project. Helpful and detailed information is given in *Formwork for Concrete*.[1.3]

1.4.2 *Formwork materials and accessories*—If the particular design or desired finish requires special attention, the engineer/architect can specify in the contract documents the formwork materials and such other features necessary to attain the objectives. If the engineer/architect does not call for specific materials or accessories, the formwork engineer/contractor can choose any materials that meet the contract requirements.

When structural design is based on the use of commercially available form units in standard sizes, such as one-way or two-way joist systems, plans should be drawn to make use of available shapes and sizes. Some latitude should be permitted for connections of form units to other framing or centering to reflect the tolerances and normal installation practices of the form type anticipated.

1.4.3 *Finish of exposed concrete*—Finish requirements for concrete surfaces should be described in measurable terms as precisely as practicable. Refer to Section 3.4 and Chapter 5.

1.4.4 *Design, inspection, review, and approval of formwork*—Although the safety of formwork is the responsibility of the contractor, the engineer/architect or approving agency may, under certain circumstances, decide to review and approve the formwork, including drawings and calculations. If so, the engineer/architect should call for such review or approval in the contract documents.

Approval might be required for unusually complicated structures, structures whose designs were based on a particular method of construction, structures in which the forms impart a desired architectural finish, certain post-tensioned structures, folded plates, thin shells, or long-span roof structures.

The following items should be clarified in the contract documents:

- Who will design the formwork;
- Who will inspect the specific feature of formwork and when will the inspection be performed; and
- What reviews, approvals, or both will be required—
  - a. For formwork drawings;
  - b. For the formwork before concreting and during concreting; and
  - c. Who will give such reviews, approvals, or both.

1.4.5 *Contract documents*—The contract documents should include all information about the structure necessary for the formwork engineer/contractor to design the formwork and prepare formwork drawings, such as:

- Number, location, and details of all construction joints, contraction joints, and expansion joints that will be required for the particular job or parts of it;
- Sequence of concrete placement, if critical;
- Tolerances for concrete construction;
- The live load and superimposed dead load for which the structure is designed and any live-load reduction used. This is a requirement of ACI 318;
- Intermediate supports under stay-in-place forms, such as metal deck used for forms and permanent forms of other materials; supports, bracing, or both, required by the structural engineer's design for composite action; and any other special supports;
- The location and order of erection and removal of shores for composite construction;
- Special provisions essential for formwork for special construction methods and for special structures such as shells and folded plates. The basic geometry of such structures, as well as their required camber, should be given in sufficient detail to permit the formwork engineer/contractor to build the forms;
- Special requirements for post-tensioned concrete members. The effect of load transfer and associated movements during tensioning of post-tensioned members can be critical, and the contractor should be advised of any special provisions that should be made in the formwork for this condition;
- Amount of required camber for slabs or other structural members to compensate for deflection of the structure. Measurements of camber attained should be made at the soffit level after initial set and before removal of formwork supports;
- Where chamfers are required or prohibited on beam soffits or column corners;
- Requirements for inserts, waterstops, built-in frames for openings and holes through concrete; similar requirements where the work of other trades will be

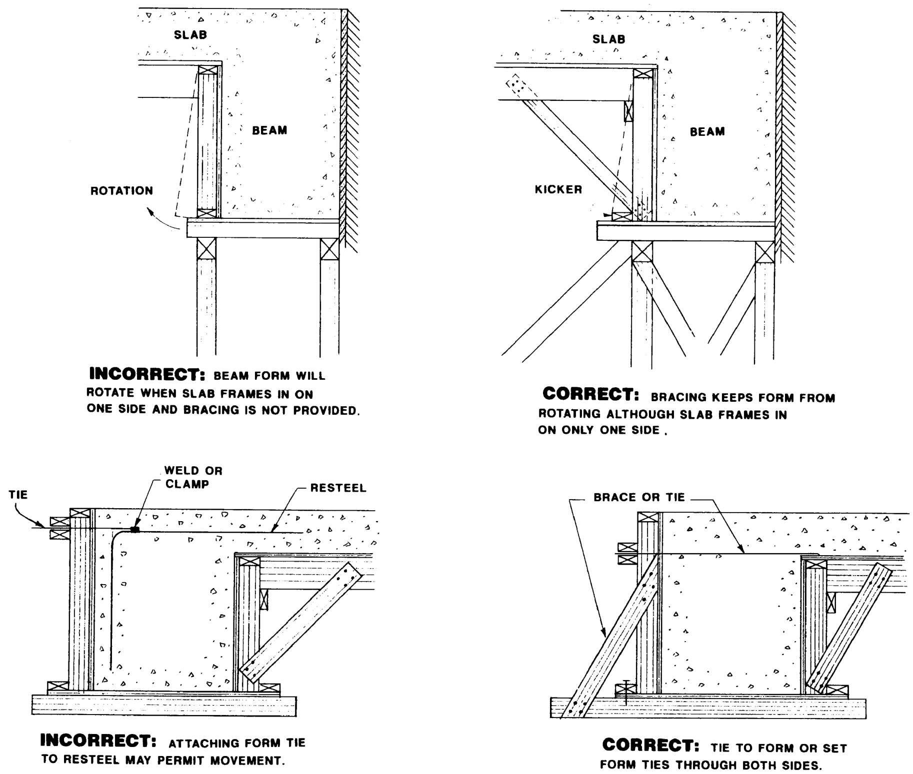

Fig. 2.1—Prevention of rotation is important where the slab frames into the beam form on only one side.

attached to, supported by, or passed through formwork;

- Where architectural features, embedded items, or the work of other trades could change the location of structural members, such as joists in one- or two-way joist systems, such changes or conditions should be coordinated by the engineer/architect; and
- Locations of and details for architectural concrete. When architectural details are to be cast into structural concrete, they should be so indicated or referenced on the structural plans because they can play a key role in the structural design of the form.

CHAPTER 2—DESIGN

2.1—General

2.1.1 *Planning*—All formwork should be well planned before construction begins. The amount of planning required will depend on the size, complexity, and importance (considering reuses) of the form. Formwork should be designed for strength and serviceability. System stability and member buckling should be investigated in all cases.

2.1.2 *Design methods*—Formwork is made of many different materials, and the commonly used design practices for each material are to be followed (refer to Chapter 4). For example, wood forms are designed by working-stress methods recommended by the American Forest and Paper Association. When the concrete structure becomes a part of the formwork support system, as in many multistory buildings, it is important for the formwork engineer/contractor to recognize that the concrete structure has been designed by the strength method. Accordingly, in communication of the loads, it should be clear whether they are service loads or factored loads.

Throughout this guide, the terms design, design load, and design capacity are used to refer to design of the formwork. Where reference is made to design load for the permanent structure, structural design load, structural dead load, or some similar term is used to refer to unfactored service loads on the structure.*

2.1.3 *Basic objectives*—Formwork should be designed so that concrete slabs, walls, and other members will have the correct dimensions, shape, alignment, elevation, and position within established tolerances. Formwork should also be designed so that it will safely support all vertical and lateral loads that might be applied until such loads can be supported by the concrete structure. Vertical and lateral loads should be carried to the ground by the formwork system or by the in-place construction that has adequate strength for that purpose. Responsibility for the design of the formwork rests with the contractor or the formwork engineer hired by the contractor to design and be responsible for the formwork.

2.1.4 *Design deficiencies*—Some common design deficiencies that can lead to failure are:

- Lack of allowance in design for loadings such as wind, power buggies, placing equipment, and temporary material storage;
- Inadequate reshoring;
- Overstressed reshoring;
- Inadequate provisions to prevent rotation of beam forms where the slabs frame into them on only one side (Fig. 2.1);
- Insufficient anchorage against uplift due to battered form faces;

*As defined by ACI 318, both dead load and live load are unfactored loads.