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ACI 117/117R-90

Standard Specifications for Tolerances for Concrete Construction and Materials (ACI 117-90) and Commentary (117R-90)

An ACI Standard

Reported by ACI Committee 117

aci international®

american concrete institute
P.O. BOX 9094
FARMINGTON HILLS, MICHIGAN 48333-9094

Ninth Printing, February 2001

Standard Specifications for Concrete Construction and Materials (ACI 117-90) and Commentary (117R-90)

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ISBN 0-87031-015-1

Standard Specifications for Tolerances for Concrete Construction and Materials (ACI 117-90)

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This specification provides standard tolerances for concrete construction. This document is intended to be used as the reference document for establishing tolerances for concrete construction by specification writers and ACI committees writing Standards.

Keywords: bending (reinforcing steels); building codes; **concrete construction**; concrete piles; concretes; floors; formwork (construction); masonry; mass concrete; piers; precast concrete; prestressed concrete; reinforcing steels; **specifications**; splicing; **standards**; **tolerances (mechanics)**.

FOREWORD

F1. This foreword is included for explanatory purposes only; it is not a part of Standard Specification 117.

F2. Standard Specification 117 is a Reference Standard which the Architect/Engineer may cite in the Project Specifications for any construction project, together with supplementary requirements for the specific project.

This standard is not intended to apply to special structures not cited in the standard such as nuclear reactors and containment vessels, bins and silos, and prestressed circular structures. It is also not intended to apply to the specialized construction procedure of shotcrete.

F3. Standard Specification 117 *addresses each of the Three-Part Section Format* of the Construction Specifications Institute, *organized by structural elements, structural components and types of structures;* the numbering system *reflects this organization.* The language is imperative and terse to preclude an alternative.

F4. A Specification Checklist is included as a preface to, but not forming a part of, Standard Specification 117. The purpose of this Specification Checklist is to assist the Architect/Engineer in properly choosing and specifying the necessary mandatory and optional requirements for the Project Specification.

PREFACE TO SPECIFICATION CHECKLIST

P1. Standard Specification 117 is intended to be used in its entirety by reference in the Project Specification. Individual sections, articles, or paragraphs should not be copied into the Project Specifications since taking them out of context may change their meaning.

P2. Building codes establish minimum requirements necessary to protect the public. Some of the requirements in this Standard Specification may be more stringent than the minimum in order to insure the level of quality and performance that the Owner expects the structure to provide. Adjustments to the needs of a particular project should be made by the Architect/Engineer by reviewing each of the items in the Specification Checklist and then including the Architect/Engineer's decision on each item as a mandatory requirement in the Project Specifications.

P3. These mandatory requirements should designate the specific qualities, procedures, materials, and performance criteria for which alternatives are permitted or for which provisions were not made in the Standard Specification. Exceptions to the Standard Specification should be made in the Project Specifications, if required.

P4. A statement such as the following will serve to make Standard Specification ACI 117 an official part of the Project Specifications:

> Tolerances for Concrete Construction and Materials shall conform to all requirements of ACI 117, Standard Specifications for Tolerances for Concrete Construction and Materials, published by the American Concrete Institute, Detroit, Michigan, except as modified by the requirements of these Contract Documents.

Adopted as a Standard of the American Concrete Institute in November 1989 in accordance with the Institute's standardization procedures

*Chairman during initial development of this document.

P5. The Specification Checklist that follows is addressed to each item of the Standard Specification where the Architect/Engineer must or may make a choice of alternatives; may add provisions if not indicated; or may take exceptions. The Specification Checklist consists of two columns; the first identifies the sections, parts, and articles of the Standard Specification and the second column contains notes to the Architect/Engineer to indicate the type of action required by the Architect/Engineer.

MANDATORY SPECIFICATION CHECKLIST

Section/Part/Article	Notes to the Architect/Engineer
Section 2—Materials	
2.2—Reinforcement	Tolerances for fabrication, placement, and lap splices for welded wire fabric must be specified by the specifier.
Section 3—Foundations	
3.1.1 Drilled piers	Specify category of caisson. The designer should be aware that the recommended vertical alignment tolerance of 1.5 percent of the shaft length indicated in Category B caissons is based on experience in a wide variety of soil situations combined with a limited amount of theoretical analysis using the beam on elastic foundation theory and minimum assumed horizontal soil restraint.
Section 4—Cast-in-place concrete for buildings	
4.5.4 Form offsets	Designate class of surface (A, B, C, D): Class A — For surfaces prominently exposed to public view where appearance is of special importance. Class B — Coarse-textured concrete-formed surfaces intended to receive plaster, stucco, or wainscoting. Class C — General standard for permanently exposed surfaces where other finishes are not specified. Class D — Minimum quality surface where roughness is not objectionable, usually applied where surfaces will be concealed.
4.5.5 Floor finish	Specify floor finish tolerance measurement method (either Section 4.5.6 *or* Section 4.5.7).
4.5.5.1 For Section 4.5.6	Designate floor classification (15/13; 20/15; 30/20; or, 50/30).
4.5.5.2 For Section 4.5.7	Designate maximum gap under a freestanding straightedge (½ in., 5/16 in., 3/16 in., or ⅛ in.).

OPTIONAL SPECIFICATION CHECKLIST

Section 1 — General	
1.1.2 Scope	Tolerance values affect construction cost. Specific use of a toleranced item may warrant less or more stringent tolerances than contained in the specification. Such variances must be individually designated by the specifier in the contract documents.
1.1.2 Scope	Tolerances in this specification are for standard concrete construction and construction procedures. Specialized concrete construction or construction procedures require specifier to include specialized tolerances. ACI committee documents covering specialized construction may provide guidance on specialized tolerances. The tolerances in this Specification do not apply to special structures or procedures not cited in the document such as nuclear reactors and containment vessels, bins and silos, circular prestressed concrete tank structures and shotcrete.
1.2.3 Requirements	Where a specific application uses multiply toleranced items that together yield a toleranced result, the specifier must analyze the tolerance envelope with respect to practical limits and design assumptions and specify its value where the standard tolerances values in this specification are inadequate or inappropriate.

OPTIONAL SPECIFICATION CHECKLIST, continued

Section 2 — Materials	
2.2.3 Concrete cover	The tolerance for reduction in cover in reinforcing steel may require a reduction in magnitude where the reinforced concrete is exposed to chlorides or the environment. Where possible excess cover or other protection of the reinforcing steel should be specified in lieu of reduced tolerance because of the accuracy of locating reinforcing steel utilizing standard fabrication accessories and installed procedures.
2.3.2 Embedded items	Tolerance given is for general application. Specific design use of embedded items may require the specifier to designate tolerances of reduced magnitude for various embedded items.
Section 3 — Cast-in-place concrete for foundations	
3.4.1.2 Footings	Plus tolerance for the vertical dimensions is not specified because no limit is imposed. Specifier must designate plus tolerance if desired.
Section 4 — Cast-in-place concrete for buildings	
4.5.5 Floor finish	The procedures for specifying and measuring floor finish tolerances set forth herein are not appropriate for narrow aisle warehouse floors with defined traffic lanes designed for use by specialized wheeled equipment. Consult specific equipment manufacturers for their recommendations.
Section 5 — Precast concrete	The tolerances for precast concrete are intended to apply to all types of precast concrete construction cast onsite *(including tilt-up)* and offsite except as set forth below. Variations to these tolerances may be advisable after consideration of panel size and construction techniques required. Tolerances set forth herein are not intended to apply to plant production of patented or copyrighted structural systems and/or elements. Designers, specifiers and contractors should contact the Licensors of such systems and/or products for applicable tolerances.
5.1.4 Camber	For members with a span-to-depth ratio equal to or exceeding 30, the stated camber tolerance may require special production measures and result in cost premiums. Where feasible, a greater tolerance magnitude should be utilized where the span-to-depth ratio is equal to or greater than 30.
5.3 Planer elements	Industrial precast products may not conform to the planar tolerances. Manufacturers should be consulted for appropriate tolerances for their products.

CONTENTS

SECTION 1 — GENERAL REQUIREMENTS

1.1 — Scope

1.1.1 This specification designates standard tolerances for concrete construction.

1.1.2 The indicated tolerances govern unless otherwise specified.

1.2 — Requirements

1.2.1 Concrete construction shall meet the specified tolerances.

1.2.2 Tolerances shall not extend the structure beyond legal boundaries.

1.2.3 Tolerances are not cumulative. The most restrictive tolerance controls.

1.2.4 Plus (+) tolerance increases the amount or dimension to which it applies, or raises a level alignment. Minus (−) tolerance decreases the amount or dimension to which it applies, or lowers a level alignment. A nonsigned tolerance means + or −. Where only one signed tolerance is specified (+ or −), there is no limit in the other direction.

1.3 — Definitions

Arris — The line, edge, or hip in which two straight or curved surfaces of a body, forming an exterior angle, meet; a sharp ridge, as between adjoining channels of a Doric column.

Bowing — The displacement of the surface of a planar element from a plane passing through any three corners of the element.

Clear distance — In reinforced concrete, the least distance between the surface of the reinforcement and the referenced surface, i.e., the form, adjacent reinforcement, embedment, concrete, or other surface.

Concealed surface — Surface not subject to visual observation during normal use of the element.

Contract documents — The project contract, the project drawings, and the project specifications.

Cover — In reinforced concrete, the least distance between the surface of the reinforcement and the outer surface of the concrete.

Flatness — The degree to which a surface approximates a plane.

Lateral alignment — The location relative to a specified horizontal line or point in a horizontal plane.

Level alignment — The location relative to a specified horizontal plane. When applied to roadways, bridge decks, slabs, ramps, or other nominally horizontal surfaces established by elevations, level alignment is defined as the vertical location of the surface relative to the specified profile grade and specified cross slope.

Levelness — The degree to which a line or surface parallels horizontal.

Precast linear element — Beam, column, or similar unit.

Precast planar element — Wall panel, floor panel, or similar unit.

Project Specifications — The building specifications which employ ACI 117 by reference, and which serve as the instrument for making the mandatory and optional selections available under these and for specifying items not covered herein.

Relative alignment — The distance between two or more elements in any plane, or the distance between adjacent elements, or the distance between an element and a defined point or plane.

Spiral — As used in circular stave silo construction, is defined as the distortion that results when the staves are misaligned so that their edges are inclined while their outer faces are vertical. The resulting assembly appears twisted with the vertical joints becoming long-pitch spirals.

Specified surface, plane, or line — A surface, plane, or line specified by the contract documents; specified planes and lines may slope and specified surfaces may have curvature.

Tolerance —

1. The permitted variation from a given dimension or quantity.

2. The range of variation permitted in maintaining a specified dimension.

3. A permitted variation from location or alignment.

Vertical alignment — The location relative to specified vertical plane or a specified vertical line or from a line or plane reference to a vertical line or plane. When applied to battered walls, abutments or other nearly vertical surfaces, vertical alignment is defined as the

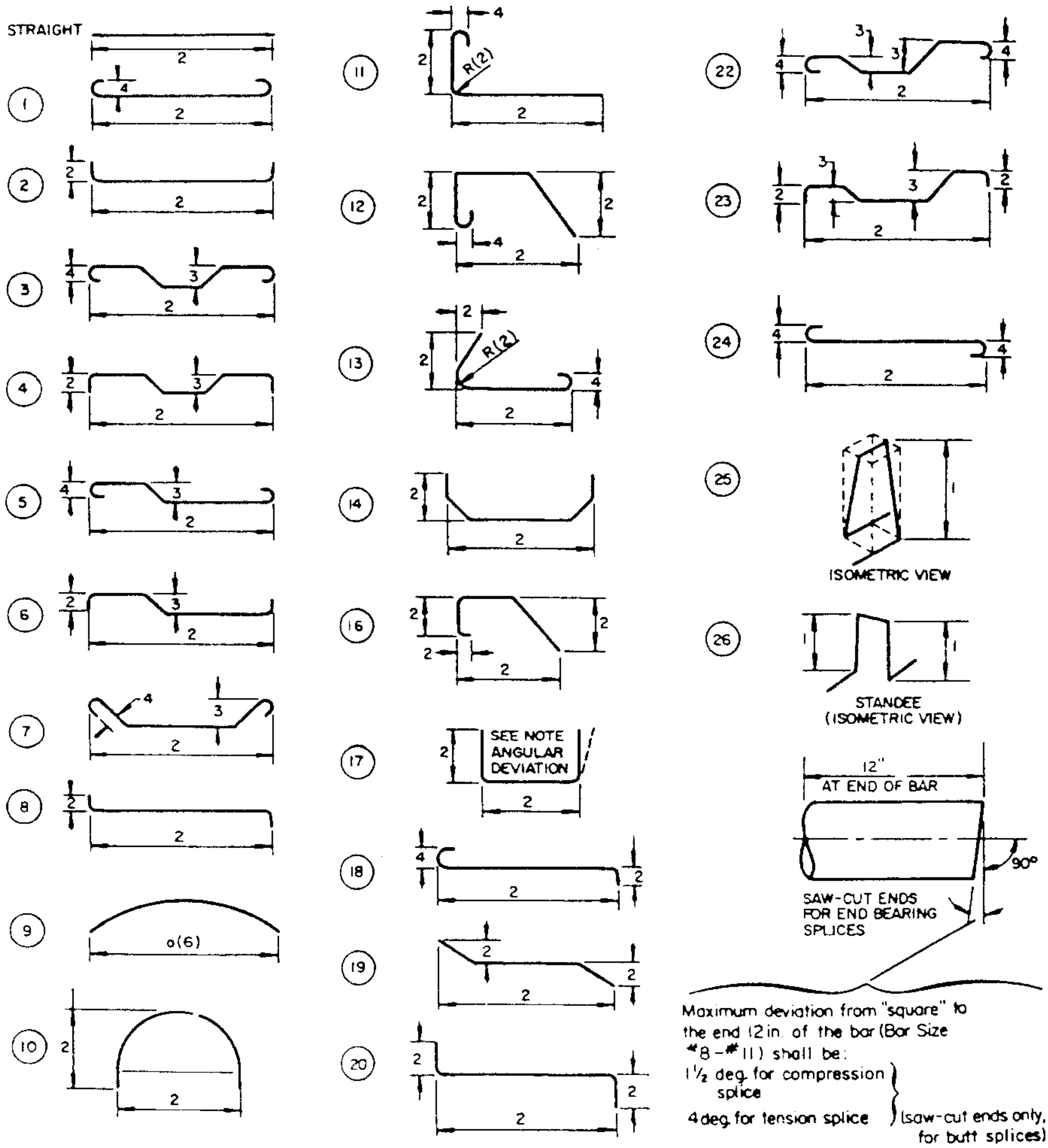
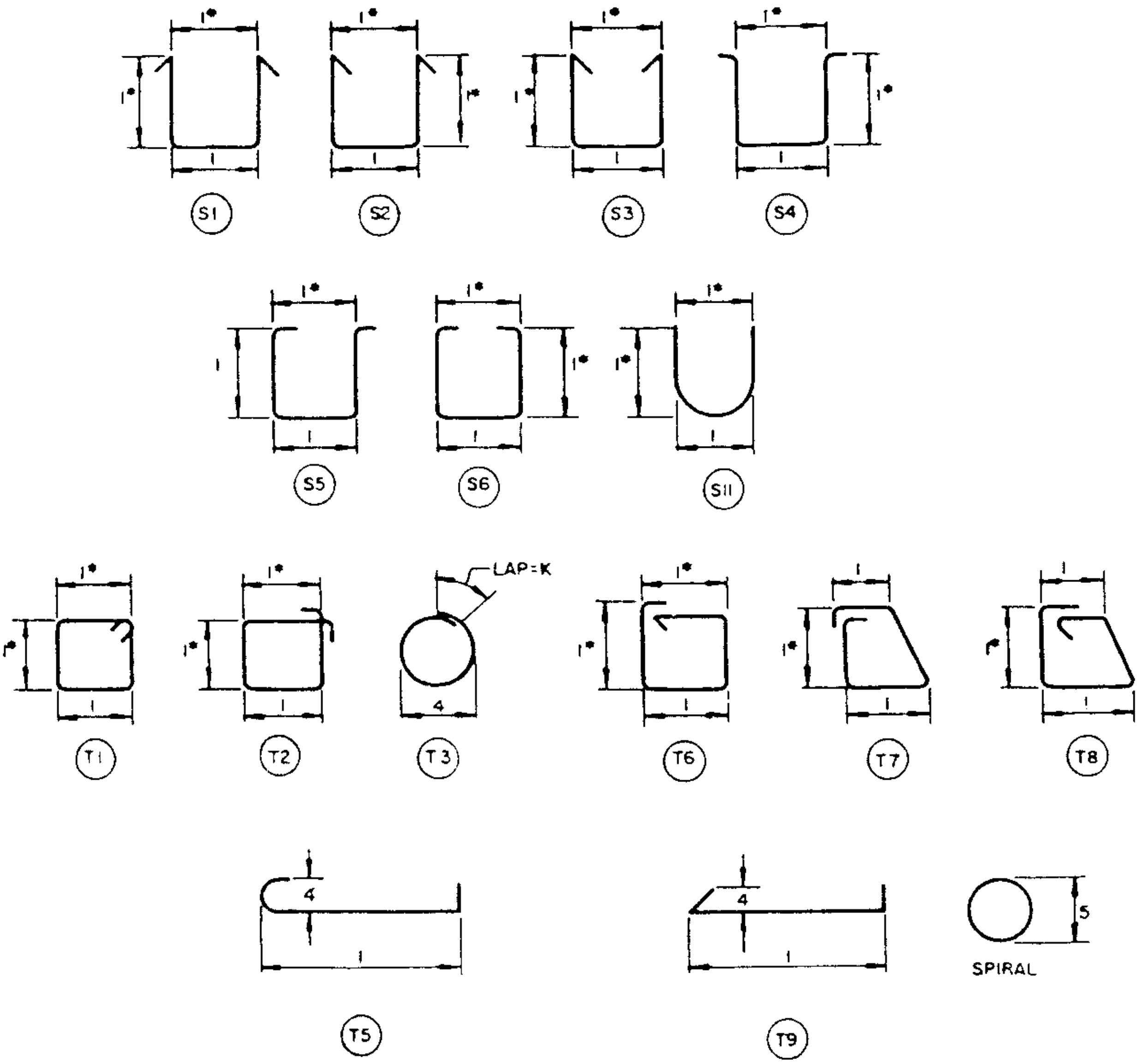


Fig. 2.1(a) — Standard fabricating tolerances for bar sizes #3 through #11



NOTES:

Entire shearing and bending tolerances are customarily absorbed in the extension past the last bend in a bent bar.

All tolerances single plane and as shown. Tolerances for Types S1 through S6, S11, and T1 through T9 apply only the Bar Sizes #3 through #8.

*Dimensions on this line are to be within tolerance shown, but are not to differ from opposite parallel dimension more than ½ in.

Angular deviation—Maximum plus or minus 2½ deg or plus or minus ½ in. per ft, but not less than ½ in., on all 90-deg hooks and bends.

TOLERANCE SYMBOLS:

1. Bar Sizes #3, #4, #5:
   = plus or minus ½ in. when gross bar length $<$ 12 ft
   = plus or minus 1 in. when gross bar length $\geq$ 12 ft
2. Plus or minus 1 in.
3. Plus 0, minus ½ in.
4. Plus or minus ½ in.
5. Plus or minus ½ in. for diameter $\leq$ 30 in.
   Plus or minus 1 in. for diameter $>$ 30 in.
6. Plus or minus 1.5 percent of o dimension $\geq$ plus or minus 2 in minimum. If application of positive tolerance to Type 9 results in a chord length equal to or greater than the arc or bar length, the bar may be shipped straight.

Fig. 2.1(a) — Standard fabricating tolerances for bar sizes #3 through #11

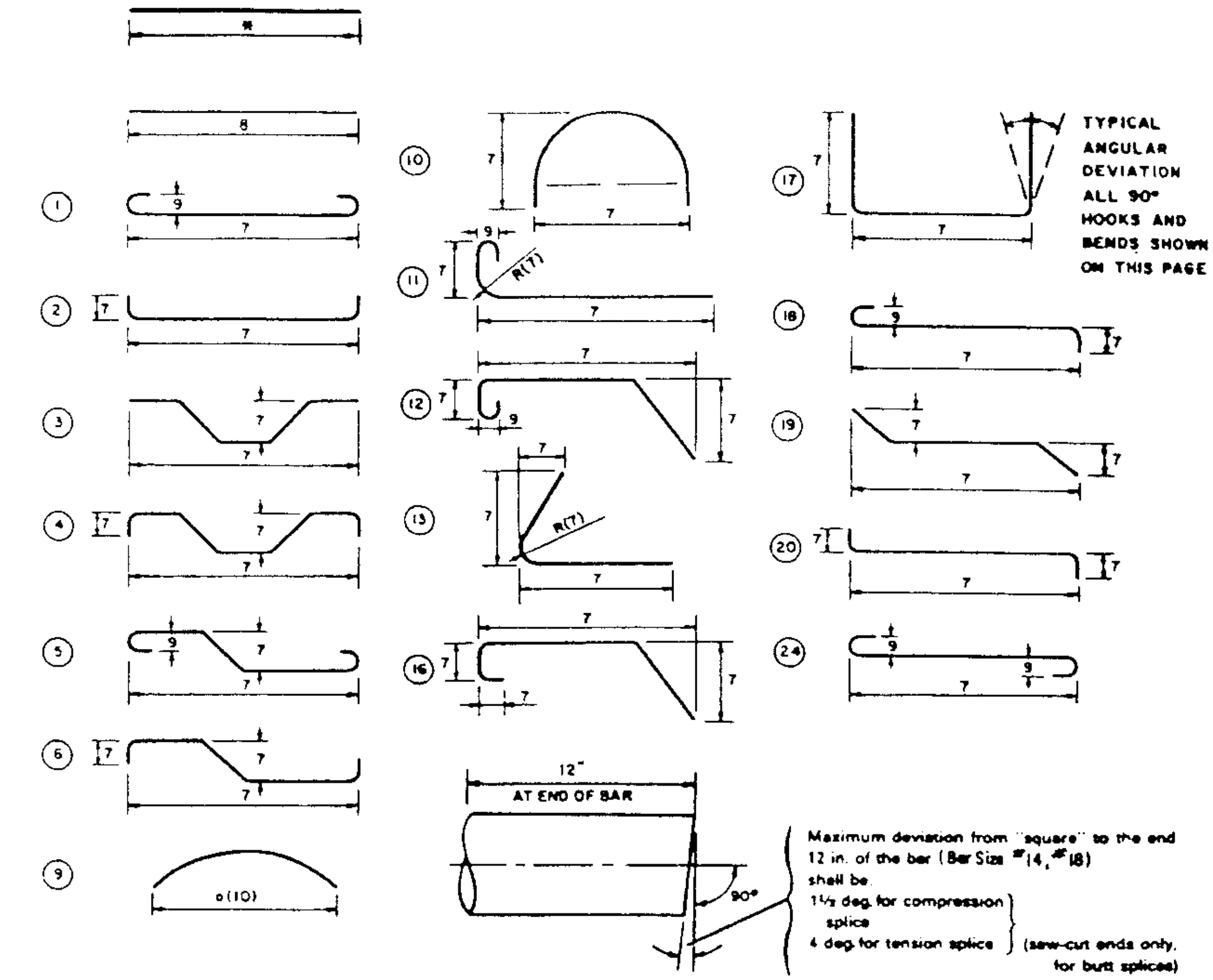
horizontal location of the surface relative to the specified profile.

Warping — The displacement of the surface, portion, or edge of a planar element from a plane passing through any three corners of the element.

SECTION 2 — MATERIALS

2.1 — Reinforcing steel fabrication

For bars #3 and # 11 in size, see Fig. 2.1(a).
For bars #14 and #18 in size, see Fig. 2.1(b).



NOTES:

Entire shearing and bending tolerances are customarily absorbed in the extension past the last bend in a bent bar.

All tolerances single plane and as shown.

Angular deviation—Maximum plus or minus 2½ deg or plus or minus ½ in. per ft on all 90-deg hooks and bends.

TOLERANCE SYMBOLS:

	#14	#18
7. Plus or minus	2½ in.	3½ in.
8. Plus or minus	2 in.	2 in.
9. Plus or minus	1½ in.	2 in.
10. Plus or minus 2 percent × o dimension ≥	±2½ in.* min.	±3½ in.* min.

Fig. 2.1(b) — Standard fabricating tolerances for bar sizes #14 and #18

2.2 — Reinforcement placement

2.2.1 *Tolerances shall not permit a reduction in cover except as set forth in Section 2.2.3 hereof.*

2.2.2 *Clear distance to side forms and resulting concrete surfaces and clear distance to formed and resulting concrete soffits in direction of tolerance*

When member size is 4 in. or less........ + ¼ in.
.... – ⅜ in.

When member size is over 4 in. but not over 12 in. .... ⅜ in.

When member size is over 12 in. but not over 2 ft .... ½ in.

When member size is over 2 ft................1 in.

2.2.3 *Concrete cover measured perpendicular to concrete surface in direction of tolerance*

When member size is 12 in. or less ...... – ⅜ in.

When member size is over 12 in. .... – ½ in.

Reduction in cover shall not exceed one-third specified concrete cover.

Reduction in cover to formed soffits shall not exceed .... ¼ in.

2.2.4 *Distance between reinforcement:*

One-quarter specified distance not to exceed .... 1 in.

Providing that distance between reinforcement shall not be less than the greater of the bar diameter or 1 in. for unbundled bars.

For bundled bars, the distance between bundles shall not be less than the greater of 1 in. or 1.4 times the individual bar diameter for 2 bar bundles, 1.7 times the individual bar diameter for 3 bar bundles and 2 times the individual bar diameter for 4 bar bundles.

2.2.5 *Spacing of nonprestressed reinforcement, deviation from specified location*

In slabs and walls other than stirrups and ties .... 3 in.

Stirrups ..... depth of beam in inches/12 × 1 in.

Ties .... least width of column in inches/12 × 1 in.

However, total number of bars shall not be less than that specified.

2.2.6 *Placement of prestressing reinforcement or prestressing steel ducts*

2.2.6.1 *Lateral placement*

Member depth (or thickness) 24 in. or less .... ½ in.

Member depth (or thickness) over 24 in. .... 1 in.

2.2.6.2 *Vertical placement*

Member depth (or thickness) 8 in. or less .... ¼ in.

Member depth (or thickness) over 8 in. but not over 24 in. .... ⅜ in.

Member depth (or thickness) more than 24 in. .... ½ in.

2.2.7 *Longitudinal location of bends and ends of bars:*

At discontinuous ends of members .... 1 in.

At other locations .... 2 in.

Table 2.4

Material	Tolerance
Cementitious materials	
30% of scale capacity or greater	1% of cumulative weight
Less than 30% of scale capacity	−0% to +4% of the required cumulative weight
Water	
Added water or ice	1% of the total water content which includes added water, ice, and water on aggregates
Total water content	3% of total water content
Aggregates	
a) Cumulative batching	
Over 30% of scale capacity	1% of the required cumulative weight
30% of scale capacity or less	0.3% of scale capacity or 3% of the required cumulative weight, whichever is less
b) Individual material batching	2% of the required weight
Admixtures	3% of the required amount

2.2.8 *Embedded length of bars and length of bar laps:*

#3 through #11 bar sizes .... −1 in.

#14 and #18 bar sizes (embedment only) −2 in.

2.2.9 *Bearing plate for prestressng tendons, deviation from specified plane* .... 1 degree

2.3 — Placement of embedded items

2.3.1 *Clearance to reinforcement the greater of the bar diameter or* .... 1 in.

2.3.2 *Vertical alignment, lateral alignment, and level alignment* .... 1 in.

2.4 — Concrete batching

See Table 2.4.

2.5 — Concrete properties

2.5.1 *Slump, where specified as "maximum" or "not to exceed," for all values* .... +0 in.

Specified slump 3 in. or less .... −1½ in.

Specified slump more than 3 in. .... −2½ in.

Slump, when specified as a single value

Specified slump 4 in. or less .... 1 in.

Specified slump more than 4 in. .... 1½ in.

Where range is specified there is no tolerance.

2.5.2 *Air content, where no range is specified and specified air content by volume is 4 percent or greater* .... 1½ percent

Where range is specified, there is no tolerance.

SECTION 3 — FOUNDATIONS

3.1 — Vertical alignment

3.1.1 *Drilled piers*

3.1.1.1 *Category A* — For unreinforced shafts extending through materials offering no or minimal lateral restraint (i.e., water, normally consolidated organic soils, and soils that might liquefy during an earthquake) — 12.5 percent of shaft diameter.

3.1.1.2 *Category B* — For unreinforced shafts extending through materials offering lateral restraint (soils other than those indicated in Category A) — not more than 1.5 percent of the shaft length.

3.1.1.3 *Category C* — For reinforced concrete shafts — not more than 2.0 percent of the shaft length.

3.2 — Lateral alignment

3.2.1 *Footings*

As cast to the center of gravity as specified; 0.02 times width of footing in direction of misplacement but not more than .... 2 in.

Supporting masonry .... ½ in.

3.2.2 *Drilled piers*

3.2.2.1 $\frac{1}{24}$ of shaft diameter but not more than .... 3 in.

3.3 — Level alignment

3.3.1 *Footings*

3.3.1.1 *Top of footings supporting masonry* ½ in.

3.3.1.2 *Top of other footings* .... +½ in.
.... −2 in.

3.3.2 *Drilled piers*

3.3.2.1 *Cut-off elevation* .... +1 in.
.... −3 in.

3.4 — Cross-sectional dimensions

3.4.1 *Footings*

3.4.1.1 *Horizontal dimension of formed members*
.... + 2 in.
.... − 1/2 in.

3.4.1.2 *Horizontal dimension of unformed members cast against soil*
2 ft. or less .... + 3 in.
.... − 1/2 in.
Greater than 2 ft. but less than 6 ft........ + 6 in.
..... − 1/2 in.
Over 6 ft.. + 12 in.
.... − 1/2 in.

3.4.1.3 *Vertical dimension (thickness)* − 5 percent

3.5 — Relative alignment

3.5.1 Footing side and top surfaces may slope with respect to the specified plane at a rate not to exceed the following amounts in 10 ft.................................1 in.

SECTION 4 — CAST-IN-PLACE CONCRETE FOR BUILDINGS

4.1 — Vertical alignment

4.1.1 *For heights 100 ft or less*
Lines, surfaces, and arrises ....1 in.
Outside corner of exposed corner columns and control joint grooves in concrete exposed to view.. 1/2 in.

4.1.2 *For heights greater than 100 ft*
Lines, surfaces, and arrises, 1/1000 times the height but not more than.................................6 in.
Outside corner of exposed corner columns and control joint grooves in concrete, 1/2000 times the height but not more than........................3 in.

4.2 — Lateral alignment

4.2.1 *Members* ....1 in.

4.2.2 *In slabs, centerline location of openings 12 in. or smaller and edge location of larger openings* .. 1/2 in.

4.2.3 *Sawcuts, joints, and weakened plane embedments in slabs* .... 3/4 in.

4.3 — Level alignment

4.3.1 *Top of slabs:*

4.3.1.1 Elevation of slabs-on-grade .... 3/4 in.

4.3.1.2 Elevation of top surfaces of formed slabs before removal of supporting shores
.... 3/4 in.

4.3.2 *Elevation of formed surfaces before removal of shores* .... 3/4 in.

4.3.3 *Lintels, sills, parapets, horizontal grooves, and other lines exposed to view* .... 1/2 in.

4.4 — Cross-sectional dimensions

4.4.1 *Members, such as columns, beams, piers, walls (thickness only), and slabs (thickness only)*
12 in. dimension or less.................... + 3/8 in.
.... − 1/4 in.
More than 12 in. dimension but not over 3 ft dimension .... + 1/2 in.
.... − 3/8 in.
Over 3 ft dimension .... + 1 in.
.... − 3/4 in.

4.5 — Relative alignment

4.5.1 *Stairs*
Difference in height between adjacent risers
.... 1/8 in.
Difference in width between adjacent trends
.... 1/4 in.

4.5.2 *Grooves*
Specified width 2 in. or less .... 1/8 in.
Specified width more than 2 in. but not more than 12 in. .... 1/4 in.

4.5.3 *Formed surfaces may slope with respect to the specified plane at a rate not to exceed the following amounts in 10 ft*

4.5.3.1 Vertical alignment of outside corner of exposed corner columns and control joint grooves in concrete exposed to view
.... 1/4 in.

4.5.3.2 All other conditions..................... 3/8 in.

4.5.4. *The offset between adjacent pieces of formwork facing material shall not exceed:*
Class of surface:
Class A .... 1/8 in.
Class B.. 1/4 in.
Class C.. 1/2 in.
Class D ....1 in.

4.5.5 *Floor finish tolerances shall meet the requirements of either Section 4.5.6 or 4.5.7, as set forth by the specifier.*

4.5.6 *Floor finish tolerances as measured in accordance with ASTM E 1155-87 Standard Test Method for Determining Floor Flatness and Levelness Using the F-Number System (Inch-Pound Units)*

Floor profile quality classification	Minimum F_F F_L number required			
	Test area		Minimum local F number	
	Flatness F_F	Level F_L	Flatness F_F	Level F_L
Conventional				
Bullfloated	15	13	13	10
Straightedged	20	15	15	10
Flat	30	20	15	10
Very flat	50	30	25	15

4.5.6.1 The F_L levelness tolerance shall not apply to slabs placed on unshored form surfaces and/or shored form surfaces after the removal of shores. F_L levelness tolerances shall not apply to cambered or inclined surfaces and shall be measured within 72 hr after slab concrete placement.

4.5.7 Floor finish tolerances as measured by placing a freestanding (unleveled) 10 ft. straightedge anywhere on the slab and allowing it to rest upon two high spots within 72 hr after slab concrete placement. The gap at any point between the straightedge and the floor (and between the highspots) shall not exceed:

Classification:
Conventional
Bullfloated .... 1/2 in.
Straightedged.................................. 5/16 in.

Flat ... 3/16 in.
Very flat ... 1/8 in.

4.6 — Openings through members

4.6.1 *Cross-sectional size of opening* ... − 1/4 in.
... + 1 in.

4.6.2 *Location of centerline of opening* ... 1/2 in.

SECTION 5 — PRECAST CONCRETE

5.1 — Fabrication tolerances in linear elements except piles

5.1.1 *Length of member*
Per 10 ft ... 1/8 in.
Total not more than ... 1/4 in.

5.1.2 *Cross-sectional dimensions*
6 in. or less ... 1/8 in.
Over 6 in. but not over 18 in. ... 3/16 in.
Over 18 in. but not over 36 in. ... 1/4 in.
Over 36 in. ... 3/8 in.

5.1.3 *Lateral alignment (sweep) of noncambered member surfaces relative to centerline of member*
Member length
40 ft and less ... 1/4 in.
Over 40 ft but not over 60 ft ... 3/8 in.
Over 60 ft ... 1/2 in.

5.1.4 *Camber variation from design chamber, at time of erection*
For nonprestressed elements, 1/8 in. per 10 ft of length but not more than ... 1/2 in.
For prestressed elements, 1/4 in. per 10 ft of length but not more than ... 1 in.

5.1.5 *Surface irregularities, deviation from a 10 ft straightedge* ...
For elements which will not receive topping ... 1/4 in.
For elements to receive topping ... 1/2 in.
For elements to be used as concrete guideways support and steering surfaces ... 1/8 in.

5.2 — Fabrication tolerances for piles

5.2.1 *Length* ... + 6 in.
... − 2 in.

5.2.2 *Cross-sectional dimensions*
Overall ... 3/8 in.
Wall thickness of hollow sections ... + 1/2 in.
... − 0 in.

5.2.3 *Lateral alignment of pile surfaces relative to pile centerline in length of pile, per 10 ft.* ... 1/8 in.

5.2.4 *Location of internal void* ... 3/8 in.

5.2.5 *Pile head*
From the plane perpendicular to the longitudinal axis of pile, 1/4 in. in 12 in. but not more than ... 1/2 in.

5.2.6 Surface irregularities
Pile head ... 1/8 in.
Other surfaces, deviation from a 10 ft. straightedge ... 1/4 in.

5.3 — Fabrication tolerances in planar elements

5.3.1 *Length and width*
10 ft or less ... 1/8 in.
Over 10 ft but not over 20 ft. ... + 1/8 in.
... − 3/16 in.
Over 20 ft but not over 40 ft. ... 1/4 in.
Each additional 10 ft increment in excess of 40 ft. ... 1/16 in.
Difference in length of the two diagonals, of a rectangular member the greater of 1/8 in. per 6 ft of diagonal or ... 1/2 in.

5.3.2 *Cross-sectional dimensions*
thickness ... + 1/4 in.
... − 1/8 in.

5.3.3 *Openings in panels*
Size of opening ... 1/4 in.
Location of centerline of opening ... 1/4 in.

5.3.4 *Lateral alignment of embedded items*
Reglets for glazing gaskets ... 1/8 in.
Bolts ... 1/4 in.
Flashing reglets ... 1/4 in.
Flashing reglets at panel edge ... 1/8 in.
Electrical outlets and pipe sleeves ... 1/2 in.
Weld plates ... 1 in.
Inserts ... 1/2 in.

5.3.5 *Bowing and warping at time of erection*
Bowing
1/360 times the panel diagonal dimension in inches but not more than ... 1 in.
Warping
1/16 in. per ft. of distance from nearest adjacent corner but not more than ... 1 in.

5.4 — Erection tolerances

5.4.1 *Vertical, lateral, and level alignment*

5.4.1.1 *Building elements*
Same as for cast-in-place concrete in Section 4.0.

5.4.1.2 *Concrete guideways*
Concrete guideway construction misalignment of support or steering surfaces shall not exceed ... 1/16 in.

5.4.2 *Alignment of exposed wall panels*

5.4.2.1 Width of joints between exposed wall panels ... 1/4 in.

5.4.2.2 Taper (difference in width) of joint between adjacent exposed wall panels, the greater of, 1/40 in. per linear foot of joint, or ... 3/16 in.
Not to exceed ... 3/8 in.

5.4.2.3 Alignment of joints at adjoining corners ... 1/4 in.

5.4.2.4 Offset in exterior face of adjacent panels ... 1/4 in.

5.4.3 *Offset of top surfaces of adjacent elements in erected positon . . .*
With topping slab ... 3/4 in.
Floor elements without topping slab ... 1/4 in.
Roof elements without topping slab ... 3/4 in.
Guideway elements to be used as riding surface ... 1/16 in.

SECTION 6 — MASONRY

6.1 — Vertical alignment

In surface of wall .... ¼ in.
In alignment of head joints .... ½ in.

6.2 — Lateral alignment

6.2.1 *Vertical members* .... ½ in.

6.3 — Level alignment

6.3.1 *In bed joints and top of wall,*
exposed .... ½ in.
Not exposed ....1 in.
6.3.2 *Top of wall used for a bearing surface* ... ½ in.
6.3.3 *Top of wall, other than a bearing surface* .... ¼ in.

6.4 — Cross-sectional dimensions

6.4.1 *Multiwythed walls* .... + ½ in.
.... − ¼ in.
6.4.2 *Other members* .... + ½ in.
.... ¼ in.
6.4.3 *Joint thickness* .... ⅛ in.

6.5 — Relative alignment

6.5.1 *Masonry surfaces may slope with respect to the specified plane at a rate not to exceed the following amounts in 10 ft*
6.5.1.1 *Walls and columns* .... ¼ in.
6.5.1.2 *Bed joints, head joints, and top of wall* .... ¼ in.
6.5.1.3 *Top of wall* .... ¼ in.

SECTION 7 — CAST-IN-PLACE, VERTICALLY SLIPFORMED BUILDING ELEMENTS

7.1 — Vertical alignment

7.1.1 *Translation and rotation from a fixed point at the base of the structure:*
For heights 100 ft. or less ....2 in.
For heights greater than 100 ft., 1/600 times the height but not more than ....8 in.

7.2 — Lateral alignment

Between adjacent elements......................2 in.

7.3 — Cross-sectional dimensions

Walls .... + ¼ in.
.... − ⅛ in.

7.4 — Relative alignment

Formed surfaces may slope with respect to the specified plane at a rate not to exceed the following amount in 10 ft......................... ¼ in.

SECTION 8 — MASS CONCRETE STRUCTURES OTHER THAN BUILDINGS

8.1 — Vertical alignment

8.1.1 *Surfaces*
Visible surfaces ....1¼ in.
Concealed surfaces ....2½ in.
8.1.2 *Side walls for radial gates and similar watertight joints* .... $\frac{3}{16}$ in.

8.2 — Lateral alignment

Visible surfaces ....1¼ in.
Concealed surfaces............................2½ in.

8.3 — Level alignment

8.3.1 *General*
Visible flatwork and formed surfaces ...... ½ in.
Concealed flatwork and formed surfaces ...1 in.
8.3.2 *Sills for radial gates and similar watertight joints* .... $\frac{3}{16}$ in.

8.4 — Relative alignment

8.4.1 *Formed surfaces may slope with respect to the specified plane at a rate not to exceed the following amount in 10 ft*
8.4.1.1 *Slopes in lateral and level alignments*
Visible surfaces .... ¼ in.
Concealed surfaces.............................. ½ in.
8.4.1.2 *Slopes in vertical alignment*
Visible surfaces .... ½ in.
Concealed surfaces...............................1 in.

SECTION 9 — CANAL LINING

9.1 — Lateral alignment

9.1.1 *Alignment of tangents* ....2 in.
9.1.2 *Alignment of curves*.............................4 in.
9.1.3 *Width of section at any height: 0.0025 times specified width* W *plus one in.* .... $0.0025W + 1$ in.

9.2 — Level alignment

9.2.1 *Profile grade* ....1 in.
9.2.2 *Surface of invert* .... ¼ in.
9.2.3 *Surface of side slope* .... ½ in.
9.2.4 *Height of lining:* 0.005 times established height *H* plus one in.................................. $0.005H + 1$ in.

9.3 — Cross-sectional dimensions

Thickness of lining cross section: 10 percent of specified thickness provided average thickness is maintained as determined by daily batch volumes.

SECTION 10 — MONOLITHIC SIPHONS AND CULVERTS

10.1 — Lateral alignment

10.1.1 *Centerline alignment*...........................1 in.
10.1.2 *Inside dimensions:*
.......................0.005 times inside dimension

10.2 — Level alignment

10.2.1 *Profile grade*.....................................1 in.
10.2.2 *Surface of invert*............................... ¼ in.
10.2.3 *Surface of side slope*......................... ½ in.

10.3 — Cross-sectional dimensions

10.3.1 *Cross section at any point*
Increase thickness: greater of 0.05 times thickness, or .... + ½ in.
Decrease thickness: greater of 0.25 times thickness, or .... − ¼ in.

SECTION 11 — CAST-IN-PLACE BRIDGES

11.1 — Vertical alignment

11.1.1 *Exposed surfaces* .... ¾ in.
11.1.2 *Concealed surfaces* .... 1½ in.

11.2 — Lateral alignment

Centerline alignment .... 1 in.

11.3 — Level alignment

11.3.1 *Profile grade* .... 1 in.
11.3.2 *Top of other concrete surfaces and horizontal grooves*
Exposed .... ¾ in.
Concealed .... 1½ in.

11.3.3 *Mainline pavements in longitudinal direction, the gap below a 10 ft unleveled straightedge resting on highspots shall not exceed* .... ⅛ in.

11.3.4 *Mainline pavements in transverse direction, the gap below a 10 ft unleveled straightedge resting on highspots shall not exceed* .... ¼ in.

11.3.5 *Ramps, sidewalks, and intersections, in any direction, the gap below a 10 ft unleveled straightedge resting on highspots shall not exceed* .... ¼ in.

11.4 — Cross-sectional dimensions

11.4.1 *Bridge slabs vertical dimension (thickness)* .... + ¼ in.
.... – ⅛ in.

11.4.2 *Members such as columns, beams, piers, walls, and other (slabs thickness only)* .... + ½ in.
.... – ¼ in.

11.4.3 *Openings through concrete members* .... ½ in.

11.5 — Relative alignment

11.5.1 *Location of openings through concrete members* .... ½ in.

11.5.2 *Formed surfaces may slope with respect to the specified plane at a rate not to exceed the following amounts in 10 ft*
Watertight joints .... ⅛ in.
Other exposed surfaces .... ½ in.
Concealed surfaces .... 1 in.

11.5.3 *Unformed exposed surfaces, other than pavements and sidewalks, may slope with respect to the specified plane at a rate not to exceed the following amounts*
In 10 ft .... ¼ in.
In 20 ft .... ⅜ in.

SECTION 12 — PAVEMENTS AND SIDEWALKS

12.1 — Lateral alignment

12.1.1 *Placement of dowels* .... 1 in.
12.1.2 *Alignment of dowels, relative to centerline of pavement, 18 in. or less projection* .... ¼ in.
greater than 18 in. projection .... *Not established*

12.2 — Level alignment

12.2.1 *Mainline pavements in longitudinal direction, the gap below a 10 ft unleveled straightedge resting on highspots shall not exceed* .... ⅛ in.

12.2.2 *Mainline pavements in transverse direction, the gap below a 10 ft unleveled straightedge resting on highspots shall not exceed* .... ¼ in.

12.2.3 *Ramps, sidewalks, and intersections, in any direction, the gap below a 10 ft unleveled straightedge resting on highspots shall not exceed* .... ¼ in.

SECTION 13 — CHIMNEYS AND COOLING TOWERS

13.1 — Vertical alignment

Translation, rotation or variance form vertical axis the greater of 1/1000 times the height at time of measurement, or 1 in.

In any 10 ft of height the centerpoint shall not change more than 1 in.

13.2 — Diameter

Outside shell diameter 1/100 times the specified diameter plus 1 in.

13.3 — Wall thickness

The average of four wall thickness measurements taken over a 60 deg arc.

Specified wall thickness 10 in. or less .... – ¼ in.
.... + ½ in.
Specified wall thickness greater than 10 in. .. – ½ in.
.... + 1 in.

SECTION 14 — NONREINFORCED CAST-IN-PLACE PIPE

14.1 — Wall thickness

Minimum wall thickness at any point shall be 1/12 times the specified internal diameter of the pipe plus ½ in., but in no case less than .... 2 in.

14.2 — Pipe diameter

The internal diameter at any point shall not be less than 95 percent of the specified diameter, the average of any four measurements taken at 45 deg intervals shall not be less than the specified diameter.

14.3 — Offsets

At formlaps and horizontal edges shall not exceed:

For pipe with an internal diameter not greater than 42 in. .... ½ in.

For pipe with an internal diameter 43 through 72 in. .... ¾ in.

For pipe with an internal diameter greater than 72 in. .... 1 in.

14.4 — Surface indentations

Maximum allowable .... ½ in.

This standard was submitted to letter ballot of the committee and approved in accordance with the Institute's balloting procedures

Commentary on Standard Specifications for Tolerances for Concrete Construction and Materials (ACI 117-90)

Reported by ACI Committee 117

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This report is a commentary on the Standard Specifications for Tolerances for Concrete Construction and Materials. It is intended to be used with ACI 117 for clarity of interpretation and insight into the intent of the committee regarding the application of the tolerances set forth therein.

Keywords: bending (reinforcing steels); building codes; **concrete construction**; concrete piles; concretes; floors; formwork (construction); masonry; mass concrete, piers; precast concrete; prestressed concrete; reinforcing steels, **specifications**; splicing; **standards**; **tolerances (mechanics)**

INTRODUCTION

This commentary pertains to "Standard Specifications for Tolerances for Concrete Construction and Materials (ACI-117)." The purpose of the report is to provide graphic and written interpretations for the specification and its application.

No structure is exactly level, plumb, straight, and true. Fortunately, such perfection is not necessary. Tolerances are a means to establish permissible variation in dimension and location, giving both the designer and the contractor parameters within which the work is to be performed. They are the means by which the designer conveys to the contractor the performance expectations upon which the design is based or the use of the project requires. Such specified tolerances should reflect design assumptions and project needs, being neither overly restrictive nor lenient. Necessity rather than desirability should be the basis of selecting tolerances.

As the title "Standard Specifications for Tolerances for Concrete Construction and Materials (ACI 117)" implies, the tolerances given are standard or usual tolerances that apply to various types and uses of concrete construction. They are based upon normal needs and common construction techniques and practices. Specific tolerances at variance with the standard values can cause both increases and decreases in the cost of construction.

The required degree of accuracy of performance depends on the interrelationship of several factors:

Structural strength and function requirements

The structure must be safe and strong, reflecting the design assumptions, and accurate enough in size and shape to do the job for which it was designed and constructed.

Esthetics

The structure must satisfy the appearance needs or wishes of the owner and the designer.

Economic feasibility

The specified degree of accuracy has a direct impact on the cost of production and the construction method. In general, the higher degree of accuracy required, the higher the cost of obtaining it.

Relationship of all components

The required degree of accuracy of individual parts can be influenced by adjacent units and materials, joint and connection details, and the possibility of the accumulation of tolerances in critical dimensions.

*Chairman during initial developemen of this document

Construction techniques

The feasibility of a tolerance depends on available craftsmanship, technology, and materials.

Properties of materials

The specified degree of accuracy for shrinkage and prestressed camber should recognize the degree of difficulty of predetermining deflection due to shrinkage and prestressed camber.

Compatibility

Designers are cautioned to use finish and architectural details that are compatible with the type and anticipated method of construction. Finish and architectural details used should be compatible with the concrete tolerances which are achievable.

Job conditions

Unique job situations and conditions must be considered. The designer must specify and clearly identify those items that require either closer or more lenient tolerances as the needs of the project dictate.

Measurement

Mutually agreed-upon control points and bench marks must be provided as reference points for measurements to establish the degree of accuracy of items produced and for verifying the tolerances of the items produced. Control points and bench marks should be established and maintained in an undisturbed condition until final completion and acceptance of the project.

Project document references

ACI Specification documents—The following American Concrete Institute documents provide mandatory requirements for concrete construction and may be referenced in the Project Documents:

ACI 117	Standard Specifications for Tolerances for Concrete Construction and Materials
ACI 301	Specifications for Structural Concrete for Buildings
ACI 531.1	Specification for Concrete Masonry Construction

ACI informative documents—ACI Committee Reports, Guides, Standard Practices, and Commentaries are intended for guidance in designing, planning, executing, or inspecting construction and in preparing plans and specifications. Reference to these Reports, Guides, and Standard Practices should not be included in the Project Documents. If the Architect/Engineer desires to include items found in these ACI documents in the Project Documents, they should be rephrased in mandatory language and incorporated into the Project Documents.

The documents of the following American Concrete Institute Committees cover practice, procedures, and state-of-the-art guidance for the categories of construction as listed.

General building	ACI 302, 303, 304, 318, 347
Special structures	ACI 307, 313, 316, 325, 332, 334, 344, 345, 349, 350, 357, 358
Precast construction	ACI 347
Masonry construction	ACI 531
Materials	ACI 211, 223, 302, 304, 315, 318, 531, 543

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1.3—Definitions

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Flatness—See Fig. 1.3.2.
Lateral alignment—See Fig. 1.3.3.
Level alignment—See Fig. 1.3.4.
Relative alignment—See Fig. 1.3.5.
Vertical alignment—See Fig. 1.3.6.
Warping—See Fig. 1.3.7.

Level alignment, lateral alignment, and vertical alignment are used to establish a tolerance envelope within which permissible variations can occur. Relative alignment, in addition to designating allowable relative displacements of elements, is used to determine the rate of change of adjacent points (slope tolerance) occurring within the tolerance envelope. In this fashion the slope and smoothness of surfaces and lines within a tolerance envelope are controlled. Abrupt

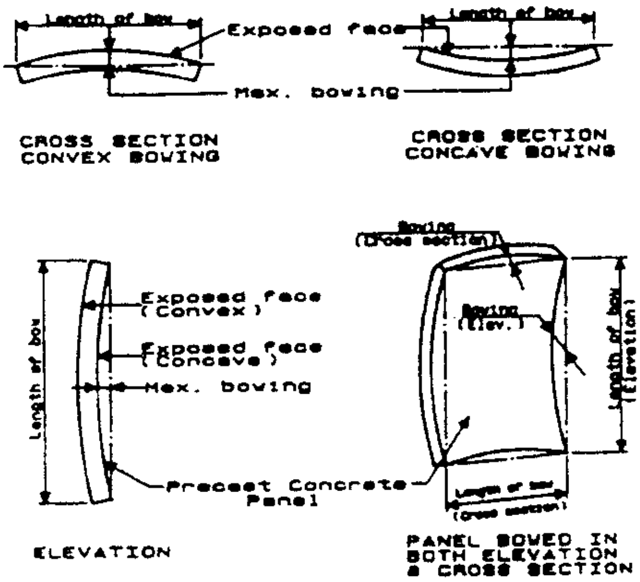

Fig. 1.3.1—Bowing

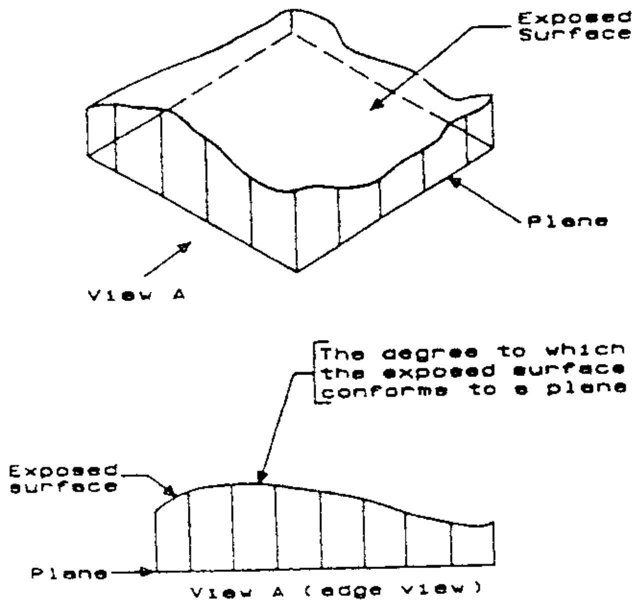

Fig. 1.3.2—Flatness

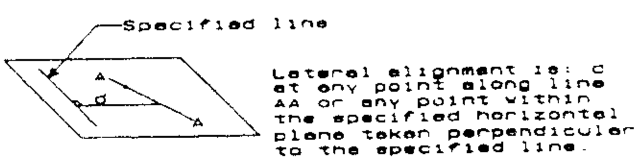

Fig. 1.3.3—Lateral alignment

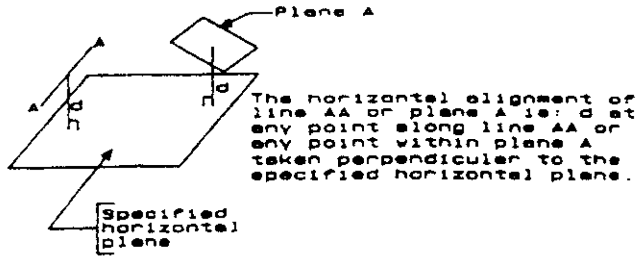

Fig. 1.3.4—Level alignment

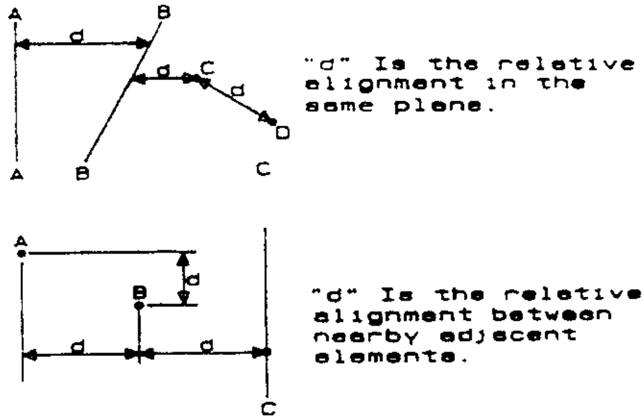

Fig. 1.3.5—Relative alignment

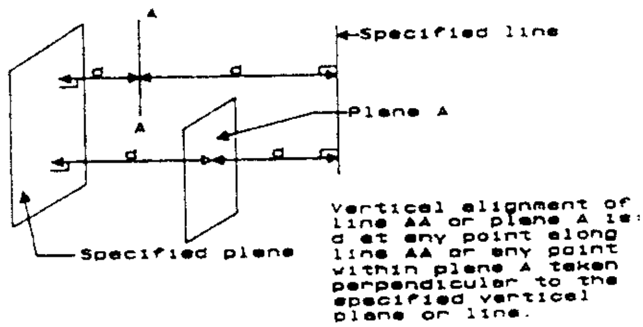

Fig. 1.3.6—Vertical alignment

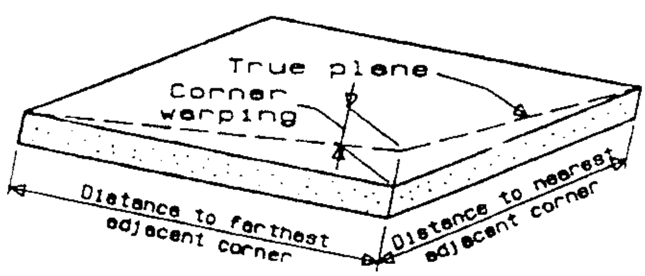

Fig. 1.3.7—Warping

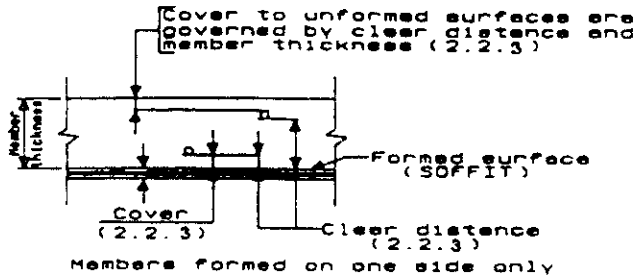

Fig. 2.2.2(a)—Reinforcement placement

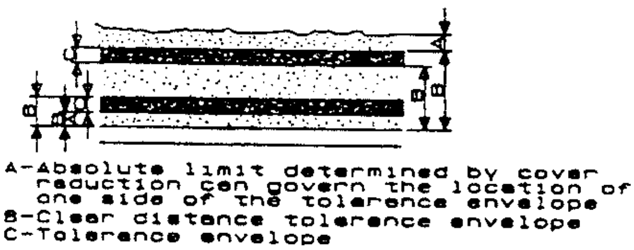

Fig. 2.2.2(b) and 2.2.3(b)—Reinforcement placement

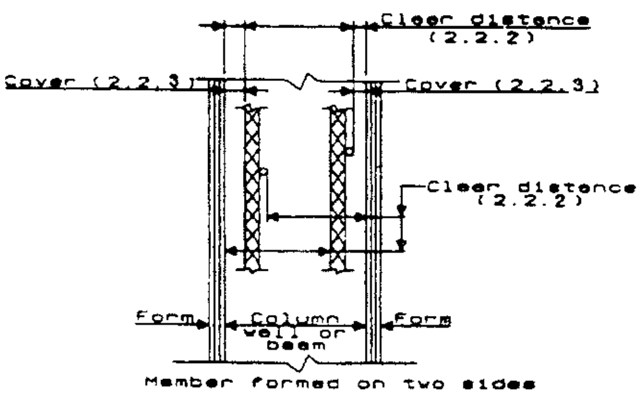

Fig. 2.2.3(a)—Reinforcement placement

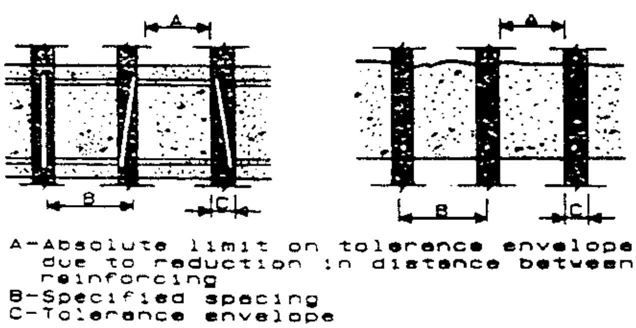

Fig. 2.2.4 and 2.2.5—Reinforcement placement

changes, offsets, sawtoothing, sloping, etc., of lines and surfaces properly located within a tolerance envelope may be objectionable when exposed to view. The acceptable relative alignment of points on a surface or line is determined by using a slope tolerance.

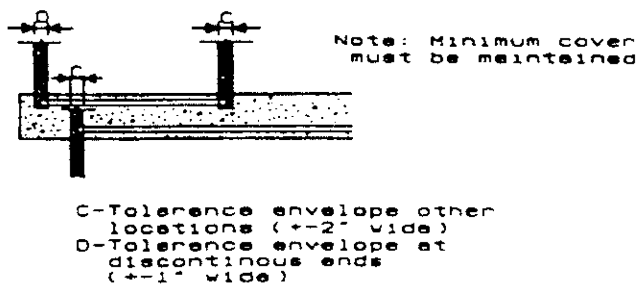

Fig. 2.2.7—Reinforcement placement, longitudinal location

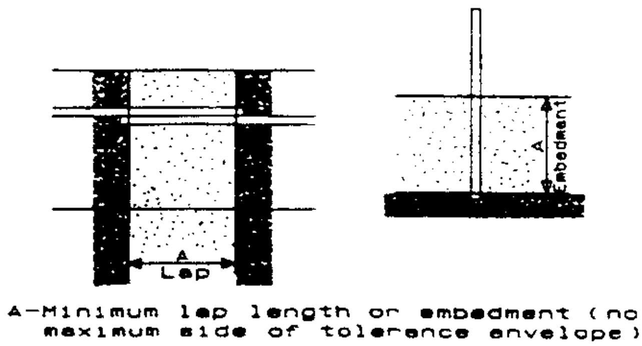

Fig. 2.2.8—Reinforcement placement, embedment and laps

SECTION 2—MATERIALS

2.2—Reinforcement

In the absence of specific design details shown or specified on the contract documents, CRSI MSP-1, Appendix D, should be followed by estimators, detailers, and placers.

2.2.2 and 2.2.3 The tolerance for placing reinforcing steel is predicated upon measurements of the formed surfaces for quality control during construction and from the resulting surfaces for forensic analysis. It consists of an envelope with an absolute limitation on one side of the envelope determined by the limit on the reduction in cover. See Fig. 2.2.2(a), 2.2.2(b), 2.2.3(a), and 2.2.3(b).

2.2.4 and 2.2.5 The spacing tolerance of reinforcing consists of an envelope with an absolute limitation on one side of the envelope determined by the limit on the reduction in distance between reinforcement. In addition, the allowable tolerance on spacing shall not cause a reduction in the specified number of reinforcing bars utilized. See Fig. 2.2.4 and 2.2.5.

2.2.6 The vertical deviation tolerance should be considered in establishing minimum prestressing tendon covers, particularly in applications exposed to deicer chemicals or salt water environments where use of additional cover is recommended to compensate for placing tolerances. Slab behavior is relatively insensitive to horizontal location of tendons.

2.2.7 and 2.2.8 The tolerance for the location of the ends of reinforcing steel is determined by these two sections. See Fig. 2.2.7 and 2.2.8.

2.5—Concrete

2.5.1 Where the specification has specified slump as a maximum, the project specifications should provide for the addition of water at the jobsite for slump adjustment. This is because the concrete must be batched at a lesser slump to avoid rejection because of a lack of a plus tolerance for the slump. The water added at the jobsite must be within the water/cement limitations of the specifications or approved mixture proportions.

Flowable concrete achieved by the incorporation of high range water reducers (HRWR) (superplasticizers), are difficult to control within tight tolerances at specified slumps of 7 in. or greater. In addition, it is difficult to accurately measure high slumps. Consideration should be given to eliminating a maximum slump when a HRWR is used to achieve flowable concrete.

When a slump range is specified, caution should be exercised and jobsite conditions should be considered and evaluated to determined if the range is suitable for delivery and placing requirements.

2.5.2 When an air content range is specified, care should be given to address aggregate size and jobsite requirements. The range should be adequately wide to accommodate the preceding.

SECTION 3—FOUNDATIONS

3.2—Lateral alignment

3.2.1 Determines the permissible location of a footing. The magnitude of tolerance for the location of footings is governed by the width (i.e., least dimension in plan view) of the footing with an absolute limit depending on the subsequent construction material supported by the footing. See Fig. 3.2.1.

3.3—Level alignment

Determines the location of any point on the top surface of a footing relative to the specified plane. See Fig. 3.3.1.

3.4—Cross-sectional dimension

Determines the permissible size of a footing. See Fig. 3.4.

3.5—Relative alignment

The relative alignment of points on the surfaces cannot exceed the distance determined by the slope tolerance. Determines the permissible top surface roughness or irregularity of a footing. See Fig. 3.5.

SECTION 4—CAST-IN-PLACE CONCRETE FOR BUILDINGS

4.1, 4.4, and 4.5—Vertical and relative alignment and thickness

Determines the permissible location of surfaces and lines in a vertical plane and the smoothness of those surfaces or straightness of lines and the relative location of adjacent surfaces in a vertical plane. See Fig. 4.1(a) and (b) and 4.5.3(a) and (b).

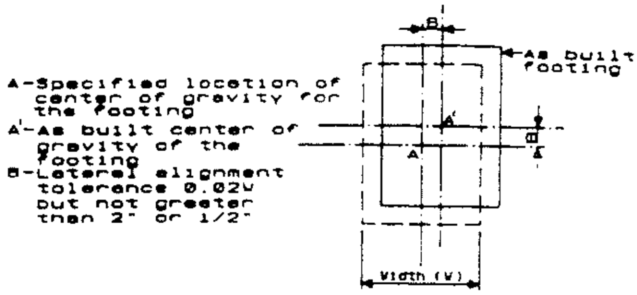

Fig. 3.2.1—Footing lateral alignment

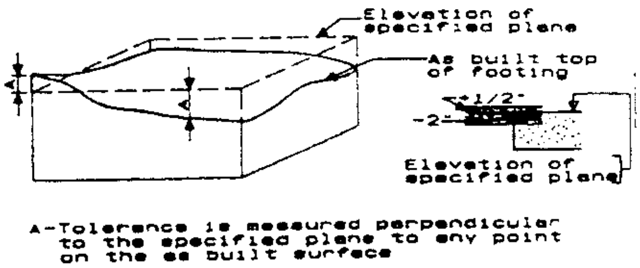

Fig. 3.3.1—Level alignment

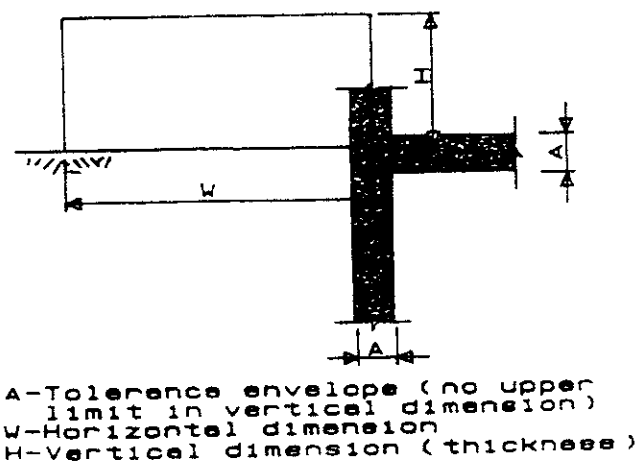

Fig. 3.4—Footing cross-sectional dimension

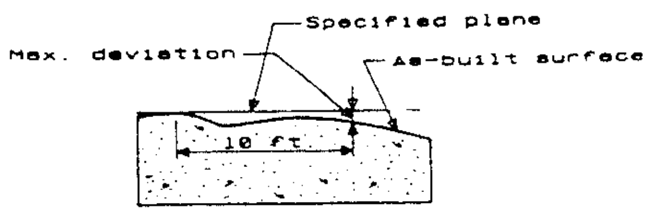

Fig. 3.5—Relative alignment of footing surface

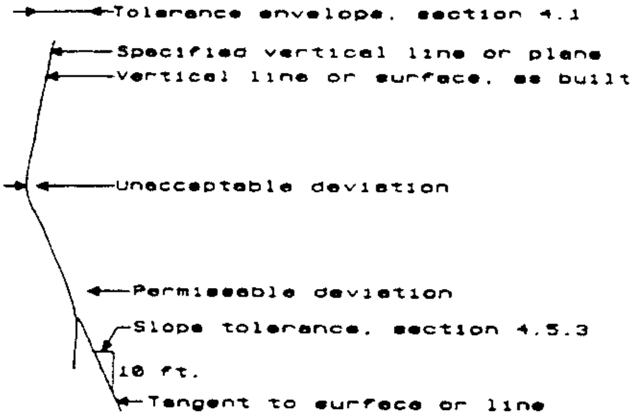

Fig. 4.1(a) and 4.5.3(a)

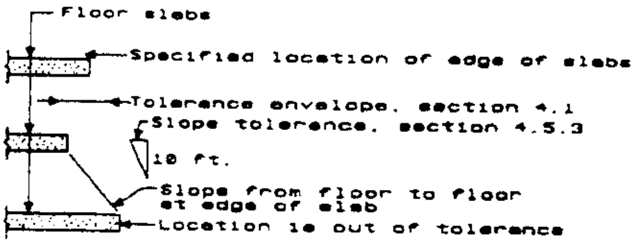

Fig. 4.1(a), (b) and 4.5.3(a), (b)—Vertical and relative alignment

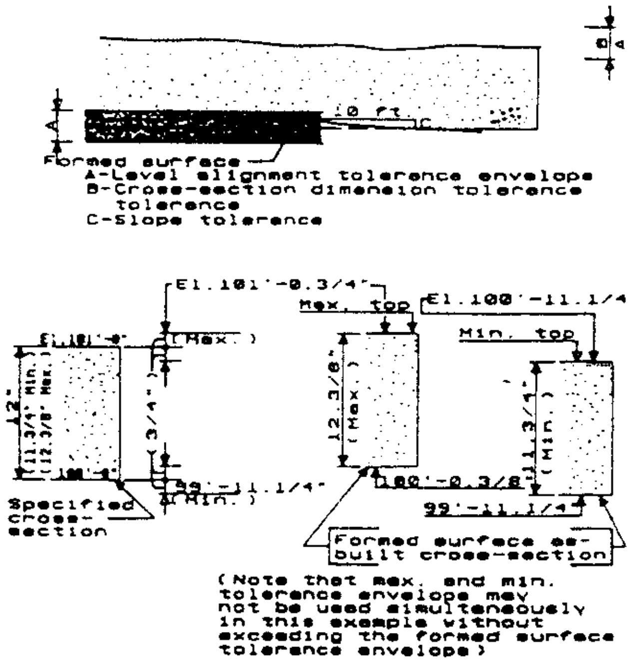

Fig. 4.3, 4.4, and 4.5.3(c)—Level and relative alignment cross-sectional dimension

4.3, 4.4, and 4.5—Level and vertical alignment and cross-sectional dimensions

If the level and cross-sectional dimension tolerances are given, then a suspended (elevated) slab is fully toleranced.

Example: 12 in. slab—The envelope for the slab element extends $^3/_4$ in. above the specified surface elevation to ¼ in. below the specified soffit elevation. Thus the slab surface and/or soffit can be $^3/_4$ in. higher or lower than specified. The slab thickness can be $^3/_8$ in. greater or $^1/_4$ in. less than specified; the rate of change in slope of the top surface is toleranced by the F_L, and the soffit is toleranced by the relative alignment and formed surface tolerances. See Fig. 4.3, 4.4, and 4.5.3 (c).

The acceptable elevation envelope of the slab surface and soffit is ± $^3/_4$ in. The rate of change of the adjacent surface elevation points within the acceptable elevation is governed by specification Section 4.5.5.

4.5.5 Floor profile finish quality has traditionally been measured by limiting the gap to be measured under either a freestanding or leveled 10-ft straightedge, according to the specifier's requirements. The technology for measuring floor profiles has rapidly evolved in response to the needs of random vehicular traffic industrial users. This technology provides a welcome alternative and a solution to the generally recognized inadequacies of the 10 ft straightedge to describe and define floor surfaces. It is not the intention of the ACI 117 specification to limit floor finish measurement technology to that currently available. As new technology is developed, improved, and perfected, specifiers may consider utilizing alternate techniques for specifying and measuring floor finish tolerances. Random sampling and statistical analysis is particularly appropriate for high-performance floors or portions of floors where irregularities must be rigidly controlled.

The specifying of narrow aisle warehouse floors with defined traffic lanes requires specialized techniques not addressed in this specification.

4.5.6 The F_F-F_L system set forth in Section 4.5.6 of this specification provides the specifier, contractor, and owner with a convenient and precise method of communication, measurement, and determination of compliance of the floor surfaces required and achieved, using the procedures set forth in ASTM E 1155. Floor profile quality has traditionally been specified by limiting the size of the gap to be observed under a freestanding or leveled 10 ft long straightedge. However, recent improvements in floor profile measurement technology have surpassed all variations of this "gap-under-the-straightedge" format.[1]

F-numbers provide a convenient means for specifying the local floor profile in statistical terms. Two distinct profile variables are controlled:

- The 12 in. incremental curvature q measures the local *flatness* of the floor. See Fig. 4.5.6(a).
- The 120 in. elevation difference d measures the local *levelness* of the floor. See Fig. 4.5.6(b).

The required data may be gathered by several methods, including measurements taken from leveled straightedges, optical levels, and instruments developed for this purpose.

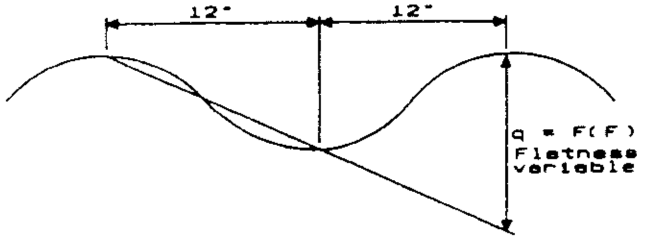

Fig. 4.5.6(a)—Flatness of the floor

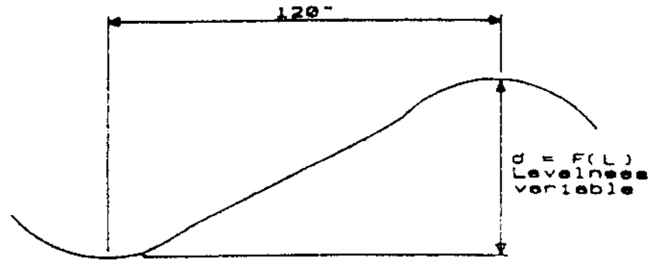

Fig. 4.5.6(b)—Levelness of the floor

Samples of q and d readings are collected from the floor according to the procedures set forth in ASTM E 1155. The means q and d and standard deviations S_q and S_d of these q and d reading samples are calculated, and these statistics are then used to determine the floor's flatness and levelness F-numbers.

Any individual floor section that measures less than either of the specified minimum local F-numbers is rejected. If, after combining all of the individual section results, the entire floor measures less than either of the specified overall F-numbers, then the whole floor is rejected.

To aid in the determination of equitable remedy, the system provides a method for calculating the exact percentage compliance between the floor's specified and estimated F-numbers. To avoid any dispute regarding remedy, the specification should clearly state the specific corrective measures to be applied in the event of an out-of-tolerance result.

Shrinkage, curling, and deflection can all adversely affect floor levelness. Measuring F_L within 72 hr after floor slab installation and before shores and/or forms are removed insures that the floor's "as-built" levelness is accurately assessed. None of the conventional concrete placement techniques in use today can adequately compensate for form or structure deflections that occur during the concrete placement and, for this reason, it is inappropriate to specify levelness tolerances on unshored floor construction.

Since neither deflection nor curling will significantly change a floor's F_F value, there is no time limit on the measurement of this characteristic. Nonetheless, the prudent specifier will provide for the measurement of both F_F and F_L as soon as possible after slab installation to avoid any possible conflict over the acceptability of the floor (and to alert the contractor of the need to modify finishing techniques on subsequent placements if necessary to achieve compliance.)

While there is no direct equivalent between F-numbers and straightedge tolerances (see Fig. 4.5.6c), the following table does give a rough correlation between the two systems:

F-number	Gap under an unleveled 10-ft straightedge
$F_F 12$	$^1/_2$ in.
$F_F 20$	$^5/_{16}$ in.
$F_F 25$	$^1/_4$ in.
$F_F 32$	$^3/_{16}$ in.
$F_F 50$	$^1/_8$ in.

The F-numbers to be obtained using different floor construction methods are given in ACI 302.1R. An increase in flatness from F_F 15 to F_F 20 may generally be achieved by the use of a highway straightedge (or equivalent) rather than a bull-float following the strike-off. The values listed are for general guidance only. Particular job requirements and conditions can result in F-numbers significantly different from those shown.

To insure user satisfaction, the F_F-F_L values required may be determined by measuring successful installations. of projects with similar uses.

Note that ASTM E 1155 excludes measurements within 2 ft of an imbed or a construction joint. The specifier should provide a limitation on the variation and possible offset potential at these locations appropriate to the use and function of the structure.

Other statistical floor tolerancing systems are being developed and may be used at the option of the specifier providing such methods are shown to give comparable results.

IN GENERAL, TO ACHIEVE HIGHER FLOOR FLATNESS/LEVELNESS VALUES WILL REQUIRE MORE INTENSIVE EFFORT WITH ATTENDANT INCREASES IN LABOR AND CONSTRUCTION COSTS.

4.5.7 Although the 10 ft straightedge procedure has been used for more than 50 years for judging floor irregularities, the procedure has a number of serious deficiencies. These include:

- The difficulty in testing large areas of floors.
- The difficulty of randomly sampling floors.
- The inability to reproduce testing results.
- The inability using normal construction procedures to meet the tolerance limits normally specified, that is, $^1/_8$ in. in 10 ft or $^1/_4$ in. in 10 ft and the widespread lack of conformance and lack of testing for conformance of slab surfaces.
- Failure of the method to predict acceptability of irregularities or roughness in the floor surface. The evaluation of the roughness for a given amplitude should be based upon the frequency of the wave forms.[2]
- The inability of the unleveled straightedge to evaluate levelness of the surface.

The major deficiency of the straightedge measuring system in evaluating floor finishes is demonstrated in Fig. 4.5.6(c).

The unleveled straightedge measuring system is adversely affected by shrinkage and curling; therefore, measurements

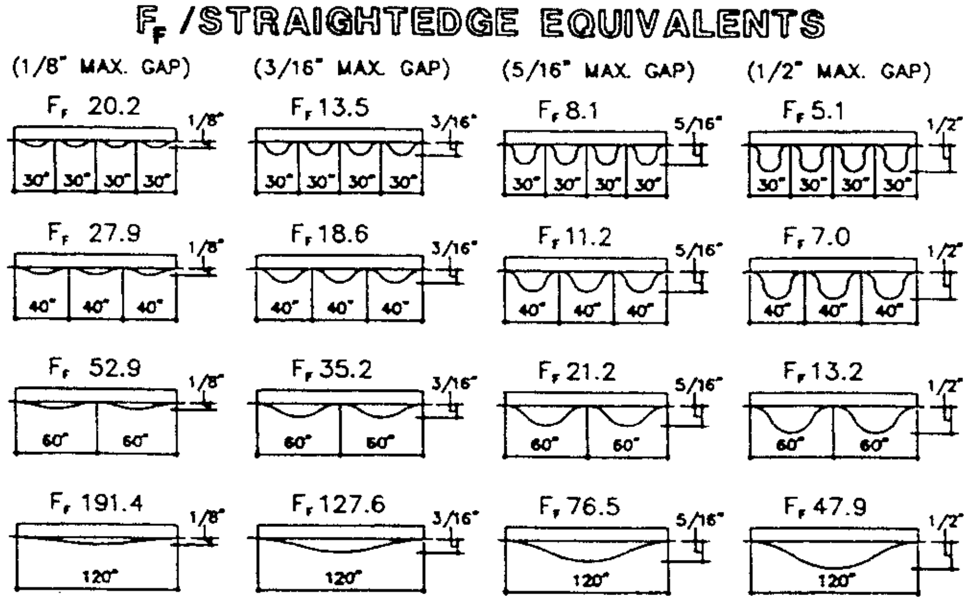

Fig. 4.5.6(c)—F-number system is clearly superior to the "gap under a straightedge" approach for distinguishing between the surfaces of obviously different qualities shown in this diagram

are to be taken within 72 hr after floor slab installation and before shores and/or forms are removed.

SECTION 5—PRECAST CONCRETE

5.0

For guidance and recommended tolerances for precast elements not set forth in ACI 117, the specifier should refer to "Tolerances for Precast and Prestressed Concrete," published in *Journal*, Prestressed Concrete Institute, V. 30, No. 1, Jan.-Feb. 1985, pp. 26 to 112.[3]

5.1—Fabrication tolerances

5.1.1 The fabricated length can be longer or shorter than specified by an amount dependent on its design length with an absolute limit of either $^3/_4$ in. shorter or $^3/_4$ in. longer. See Fig. 5.1.1.

DESIGNERS ARE CAUTIONED TO PROVIDE LONGER BEARING ELEMENTS TO ACCOMMODATE SHORTER MEMBER LENGTHS AND ROOM FOR OVERLENGTH MEMBERS (WITHIN TOLERANCES.)

5.1.3 The lateral alignment is the displacement of any point on the surface relative to the centerline of the as- built member. The centerline is determined by passing a line through the midpoint of the as-built end. See Fig. 5.1.3 and 5.2.3.

5.1.4 Camber is measured at the midpoint between the as-built ends of the member. The allowable deviation is a function of the length of the member with an absolute limit. Camber tolerances in prestressed members may require reevaluation after initial member castings due to the inaccuracies inherent in initial engineering predications based upon the member design. The specified camber may require adjustment based upon the actual camber that results from the specified design or the design may require modification. See Fig. 5.1.4.

5.1.5 *Surface irregularities*—See Fig. 5.1.5.

5.2—Fabrication tolerances for piles

5.2.3 Tolerance determination is similar to Section 5.1.1. The exception is that there is no absolute limit applied to the tolerance envelope.

5.2.5 The slope across the pile head can vary as a function of the width of the pile head with an absolute limit. The width is the diameter of circular piles and the cross-sectional dimension in the direction of slope measurement of noncircular piles. See Fig. 5.2.5.

5.3—Fabrication tolerances in planar elements

5.3.1 The allowable skew of planar elements is determined by comparing the length of the diagonals. This pre-presumes rectangular units for the application of this fabrication control. For irregularly shaped units the comparison of diagonals may not be possible or meaningful and the concept of skew may not apply. See Fig. 5.3.1.

5.4—Erection tolerances

5.4.2.2 The allowable taper of the joint between exposed panels is a function of the length of the joint with absolute limits on the minimum and maximum width of the tolerance envelope. See Fig. 5.4.2.2.

5.4.3 The control over the offset of top surfaces of adjacent elements applies to members immediately adjacent to each other or separated members that will ultimately be joined in the structure (see Fig 5.4.3). The roofing system must be coordinated with the tolerance for roof elements without topping slabs. Roofing systems that are to be applied directly to the precast surface may require a leveling grout to fill and feather the resulting offset.

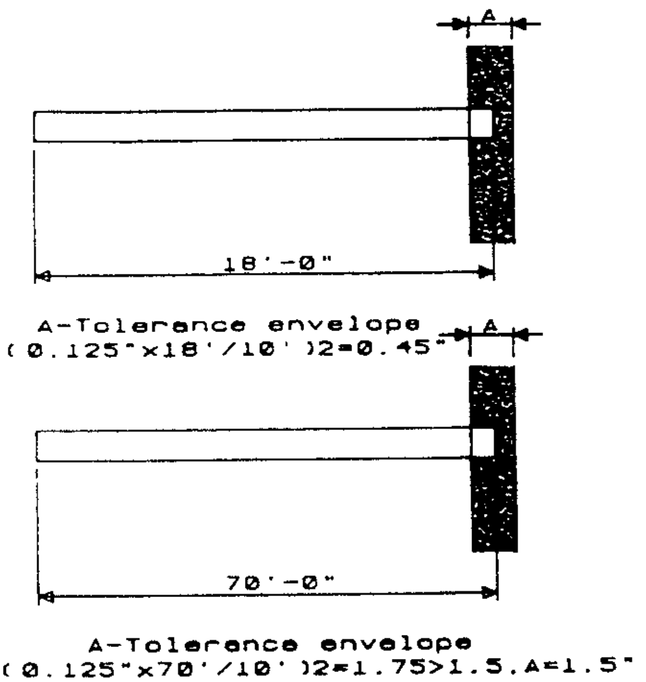

Fig. 5.1.1—Length of member

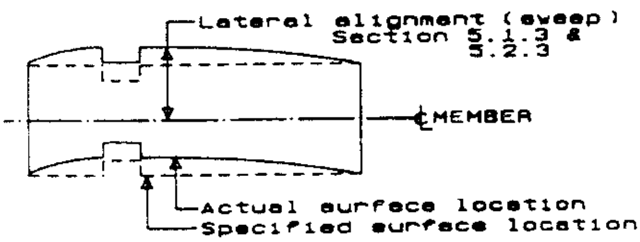

Fig. 5.1.3 and 5.2.3—Lateral alignment

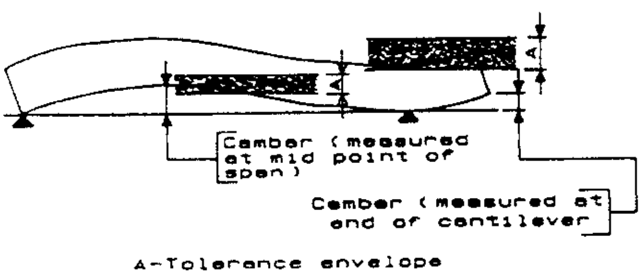

Fig. 5.1.4—Camber

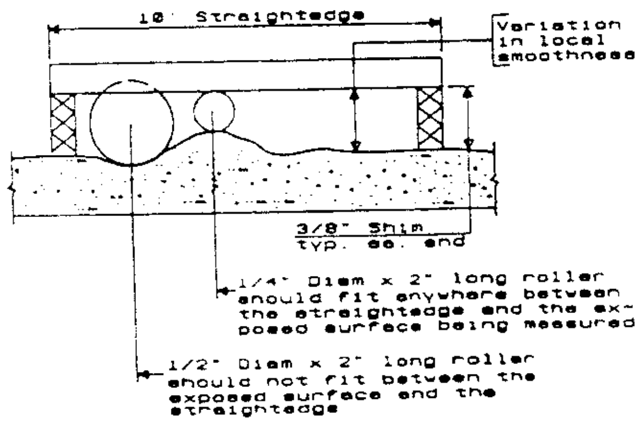

Fig. 5.1.5—Surface irregularities

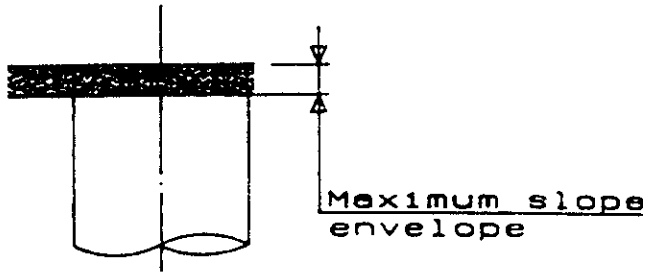

Fig. 5.2.5—Pile head

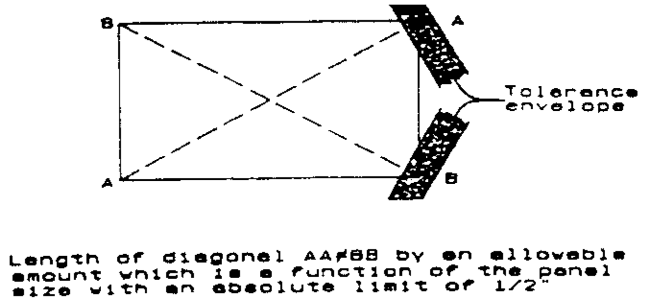

Fig. 5.3.1—Panel length and width

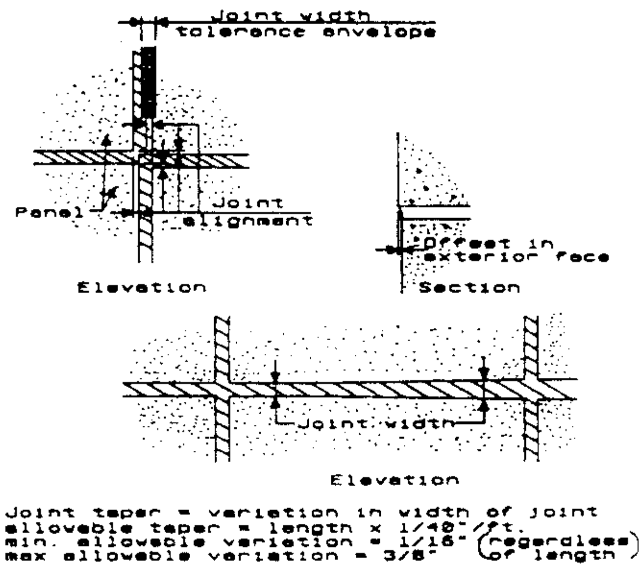

Fig. 5.4.2.2—Alignment of panels

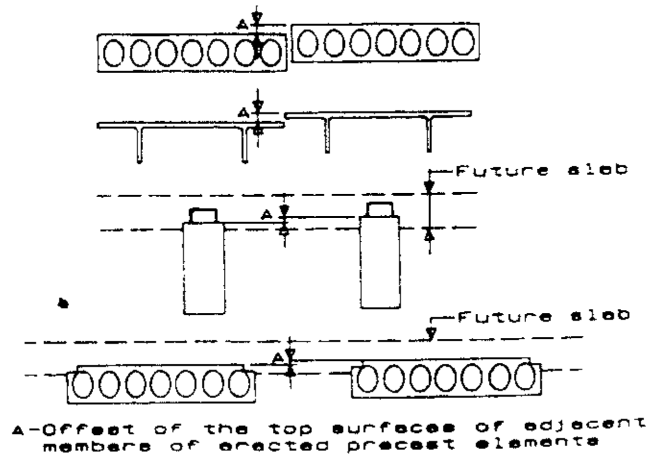

Fig. 5.4.3—Difference in elevation

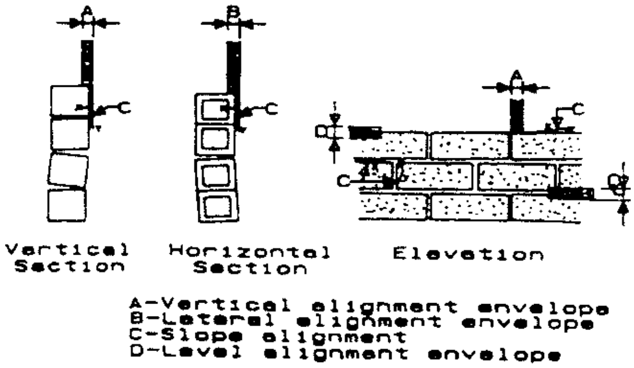

Fig. 6.1, 6.2, 6.3, and 6.5—Masonry alignment

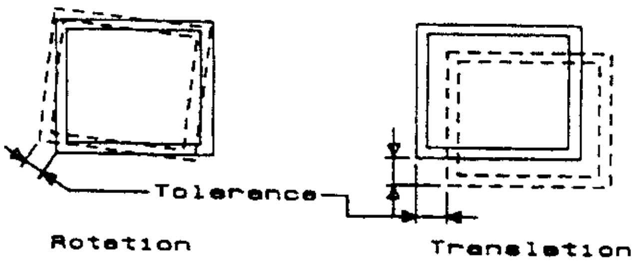

Fig. 7.1—Slipform vertical alignment

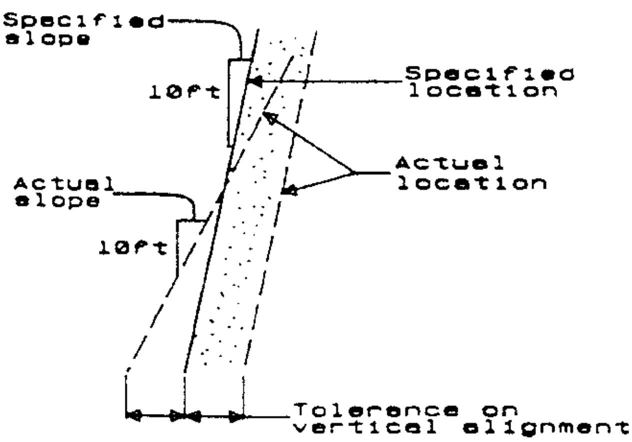

Fig. 11.1 and 11.5.2—Vertical section

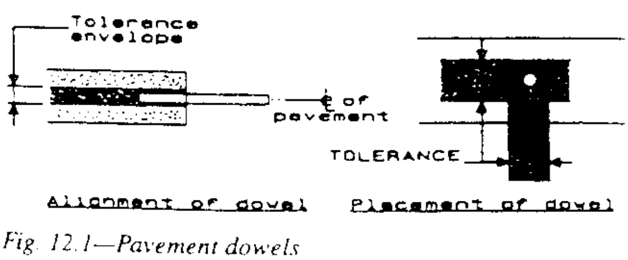

Fig. 12.1—Pavement dowels

SECTION 6—MASONRY

6.1, 6.2, 6.3, and 6.5—Alignments

See Fig. 6.1., 6.2, 6.3, and 6.5.

SECTION 7—CAST-IN-PLACE, VERTICALLY SLIPFORMED BUILDING ELEMENTS

7.1—Vertical alignment

See Fig. 7.1.

7.2, 7.3, and 7.4

Refer to the commentary in Section 4.

SECTION 8—MASS CONCRETE STRUCTU RES OTHER THAN BUILDINGS

8.1, 8.2, 8.3, and 8.4

Refer to the commentary in Section 4.

SECTION 9—CANAL LINING

9.1, 9.2, and 9.3

Refer to the commentary in Section 4.

SECTION 10—MONOLITHIC SIPHONS AND CULVERTS

10.1, 10.2, and 10.3

Refer to the commentary in Section 4.

SECTION 11—CAST-IN-PLACE BRIDGES

11.1, 11.2, 11.3, 11.4, and 11.5

Refer to the commentary in Section 4. See Fig. 11.1 and 11.5.2.

SECTION 12—PAVEMENT

12.1—Lateral alignment

12.1.1 *Placement of dowels*—See Fig. 12.1.

SECTION 13—CHIMNEYS AND COOLING TOWERS

13.1 Tolerances on the size and location of openings and embedments in the concrete shell cannot be uniformly established due to the varying degree of accuracy required depending on the nature of their use. Appropriate tolerances for opening and embedment sizes and locations should be established for each chimney.

SECTION 14—CAST-IN-PLACE NONREINFORCED PIPE

14.1 Cast-in-place concrete pipe tolerances relate to the accuracy of construction that can be achieved with tracked excavators.

SECTION 15—REFERENCES

15.1—Recommended references

The documents of the various standards producing organizations referred to in this document are listed below with their serial designation.

American Concrete Institute

211.1-81 (Revised 1985)	Standard Practice for Selecting Proportions for Normal, Heavyweight and Mass Concrete
223-83	Standard Practice for the Use of Shrinkage-Compensating Concrete
302.1R-80	Guide for Concrete Floor and Slab Construction
303R-74 (Revised 1982)	Guide to Cast-in-Place Architectural Concrete Practice
304R-85	Guide for Measuring, Mixing, Transporting, and Placing Concrete
307-88	Design and Construction of Cast-in-Place Reinforced Concrete Chimneys
313-77 (Revised 1983)	Recommended Practice for Design and Construction of Concrete Bins, Silos, and Bunkers for Storing Granular Materials
315-80	Details and Detailing of Concrete Reinforcement
316R-82	Recommendations for Construction of Concrete Pavements and Concrete Bases
318R-83	Commentary on Building Code Requirements for Reinforced Concrete (318-83)
325.3R-85 (Revised 1987)	Guide for Design of Foundations and Shoulders for Concrete Pavements
332R-84	Guide to Residential Cast-in-Place Concrete Construction
334.1R-64 (Revised 1982) (Reapproved 1986)	Concrete Shell Structures-Practice and Commentary
344R-W	Design and Construction of Circular Wire and Strand Wrapped Prestressed Concrete Structures
344R-T	Design and Construction of Circular Prestressed Concrete Structures with Circumferential Tendons
345-82	Standard Practice for Concrete Highway Bridge Deck Construction
347-78 (Reapproved 1984)	Recommended Practice for Concrete Formwork
349R-85	Commentary on Code Requirements for Nuclear Safety Related Concrete Structures
350R-83	Concrete Sanitary Engineering Structures
357R-84	Guide for the Design and Construction of Fixed Offshore Concrete Structures
358R-80	State-of-the-Art Report on Concrete Guideways
531R-79 (Revised 1983)	Commentary on Building Code Requirements for Concrete Masonry Structures
531. 1-76 (Revised 1983)	Specifications for Concrete Masonry Construction
543R-74 (Reapproved 1980)	Recommendations for the Design, Manufacture, and Installation of Concrete Piles

ASTM

E1155-87	Standard Test Method for Determining Floor Flatness and Levelness Using the F-Number System (Inch-Pound Units)

Concrete Reinforcing Steel Institute

MSP-1-86	Manual of Standard Practice (24th Edition)

The preceding publications may be obtained from the following organizations:

American Concrete Institute
P.O. Box 9094
Farmington Hills, MI 48333-9094

ASTM
100 Barr Harbor Dr.
West Conshohocken, Pa. 19428

Concrete Reinforcing Steel Institute
933 North Plum Grove Road
Schaumburg, IL 60173-4758

15.2—Cited references

1. Face, Allen, "Specification and Control of Concrete Floor Flatness," *Concrete International: Design & Construction*, V. 6, No. 2, Feb. 1984, pp. 56-63.

2. Hudson, W. Ronald; Halbach, Dan; Zaniewski, John P.; and Moser, Len, "Root-Mean-Square Vertical Acceleration as a Summary Roughness Statistic," *Measuring Road Roughness and its Effect on User Cost and Comfort*, STP-884, pp. 20-21.

3. PCI Committee on Tolerances, "Tolerances for Precast and Prestressed Concrete," *Journal*, Prestressed Concrete Institute, V. 30, No. 1, Jan.-Feb. 1985, pp. 26-112.

This report was submitted to letter ballot of the committee and was approved in accordance with the Institute's balloting procedures

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Standard Specifications for Tolerances for Concrete Construction and Materials and Commentary

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