
Tolerances for Precast and Prestressed Concrete

by

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COMMITTEE STATEMENT

The PCI Committee on Tolerances has been charged with the mission of developing tolerances for the precast prestressed concrete industry. The final committee report will consist of five chapters:

1. Introduction
2. Tolerance Related Problems
3. Product Tolerances
4. Erection Tolerances
5. Interfacing Tolerances

This current report is an interim document which includes Chapters 1 and 3. The Committee recognizes the extreme importance of completing the entire report, particularly the chapters on erection and interfacing; it therefore encourages readers to respond not only to the contents of this partial report but also to fac-

tors which may influence the committee's future efforts.

This report has received considerable review. It has been distributed to all producer members of PCI; subsequent questionnaires have been distributed to all hollow-core slab producers so that this product could be handled appropriately. It has received the full consensus review and approval procedure through the PCI Technical Activities Committee and the PCI Board of Directors.

Close coordination has been maintained with ACI Committee 117, Tolerances, and significant harmony exists between this report and the Proposed ACI Standard: "Tolerances for Concrete Construction and Materials," published in the August 1980 issue of *Concrete International*.

PREFACE

The PCI Committee on Tolerances was formed in early 1977 with the mission of developing dimensional tolerances for precast and prestressed concrete including fabrication, erection and relationships to other construction such as masonry, cast-in-place concrete and structural steel.

Much has been accomplished toward this end through the dedication of the committee's small membership.

The current report includes only Chapter 1—Introduction and Chapter 3—Product Tolerances. No effort has been

made to edit these to reflect that chapters on erection tolerances and interfacing tolerances are missing. The committee recognizes the extreme importance of these other chapters and their overall integration with the information covered in the current report.

The committee also recognizes the importance of "feedback" from all categories of membership (Producer, Associate, Professional, Affiliate and Student). This partial report is intended to satisfy the need to put the information developed into use and to obtain the feedback which will influence the committee's future efforts.

CHAPTER 1—INTRODUCTION

This document is intended to be a working reference on the dimensional control of precast concrete construction.* It is designed to improve the understanding of expected tolerances related to precast concrete products and construction and thereby eliminate problems of dimensional control.

The information contained in this document should be used by architects, engineers, general contractors, precast and precast, prestressed concrete producers, quality control agencies and other related or interfacing trades.

The groups of tolerances which should be established as part of precast concrete design and to which final component details should conform are:

1. Product Tolerances—The dimensions and dimensional relationships of the individual precast concrete elements. Chapter 3 provides a comprehensive compilation of recommended product tolerances for various product types and a discussion regarding the specification of these values and the methods to verify tolerances after casting.

2. Erection Tolerances—Those tolerances which are required for the acceptable matching of the precast elements after they are erected. Chapter 4 provides, with detailed examples, a comprehensive discussion of the principles and considerations relative to precast concrete erection tolerances. Information is provided pertaining to erection tolerances that must be anticipated in the design and construction of precast concrete structures.

3. Interfacing Tolerances—Those tolerances which are associated with other materials in contact with or close proximity to precast concrete and includes materials so related either before or after precast erection. Chapter 5 utilizes

precast product and erection tolerances to provide guidelines for the proper dimensional specification of interfacing materials. The principles and considerations which apply to interfacing tolerance design are discussed and examples are provided to demonstrate the effects of tolerances of interfacing materials on precast design and detailing.

Tolerances should be established for these three categories for the following reasons:

1. **Structural**—To insure that structural design properly accounts for factors sensitive to variations in dimensional control. Examples include eccentric loading conditions, bearing areas, hardware and hardware anchorage locations, and locations of reinforcing or prestressing steel.

2. **Feasibility**—To insure acceptable performance of joints and interfacing materials in the finished structure.

3. **Visual**—To insure that the variations will be controllable and result in an acceptable looking structure.

4. **Economic**—To insure ease and speed of production and erection by having a known degree of accuracy in the dimensions of precast elements.

5. **Legal**—To avoid encroaching on building lines.

6. **Contractual**—To establish a known acceptability range.

The practice with regard to the responsibility for dimensional control of a project is variable both geographically and within firms. The conceptual design of a precast project is the place to begin to deal with dimensional control considerations. Architectural and structural concepts should be developed with the practical limitations of dimensional control in mind.

This fact indicates that the architect and engineer should have the primary responsibility for conceiving the overall dimensional control concepts for the project and specifying the tolerances

*Intended to cover plant-cast or site-cast precast and precast, prestressed concrete.

required for the various individual elements. The specified tolerances or required performance should fall within generally accepted limits and should not be made more rigid and therefore more costly unless absolutely necessary. Situations in which one trade is within its tolerances and the precast is within its tolerances and yet the components do not fit in the construction are to be prevented.

After having specified the tolerances for the various elements and having designed connection details which account for erection and interfacing tolerances, the architect and the engineer will have started the dimensional control effort on the proper course.

It is then the responsibility of the precast and precast prestressed concrete manufacturer to produce the precast elements to the specified tolerances. The producer's plant engineering and quality control effort must assure that all critical tolerances are met and that the pieces are suitable for their intended use.

The erector is responsible for erecting the elements within the specified tolerances and completing the connections in the manner specified. Prior to precast erection the general contractor, in consultation with the erector, should check the dimensions of the interfacing structure. After precast erection the general contractor, again in consultation with the erector, should check that the precast elements are erected within recommended tolerances. Possible problems of concurrent construction require special consideration.

On many projects the architect-engineer may be engaged to define and institute an overall project quality assurance plan, one facet of which should be definition and implementation of a dimensional control plan. As stated previously, although the responsibilities for various phases of the project are often shifted substantially by changes in relationships, the overall

concepts of dimensional control which result in sound, smooth construction must not be overlooked.

It should be understood by all involved in the design and construction process that tolerances shown in this document must be considered as guidelines for an acceptability range and not limits for rejection.

If these tolerances are met the product should be accepted. If these tolerances are exceeded the product may be accepted if:

1. Exceeding the tolerance does not affect the structural integrity or architectural performance of the product.
2. The product can be brought within tolerance by structurally and architecturally satisfactory means.
3. The total erected assembly can be modified to meet all structural and architectural requirements.

Definitions

Tolerance—The definition can include:

1. The permitted variation from a basic dimension or quantity.
2. The range of variation permitted in maintaining a basic dimension.
3. A permitted variation from location or alignment.

Variation—The difference between the actual dimension and the basic dimension. Variations may be either negative (less) or positive (greater).

Clearance—Interface space between two items. Normally specified for concrete coverage of reinforcing and prestressing steel. Normally specified to allow for tolerance and for structural movement caused by volume change or elastic deformation.

Basic Dimension—The dimensions shown on the contract drawings or called for in the specifications. The basic dimension applies to size, location, and relative location.

Working Dimension—The planned

dimension of the element arrived at from both its basic dimension and joint or clearance dimensions. It is to this dimension that the element tolerance is applied.

Actual Dimension—The measured dimension of the element after casting. This dimension differs from the working dimension due to the construction and material induced variation.

* * *

CHAPTER 3—PRODUCT TOLERANCES

Product tolerances are those within which precast components should be made. They are a measure of dimensional accuracy of the individual components which will provide information, prior to delivery, of the probability that the component will fit into the structure without difficulty.

The architect-engineer must specify product tolerances or require performance within a generally accepted range. In any case, he must account for the components function in the construction, its *fit* in the construction and the *compatibility* of these tolerances to those of interfacing materials (see Chapter 5). Tolerances for manufacturing are standardized throughout the industry and should not be made more rigid, and therefore more costly, unless absolutely necessary.

It must be emphasized (see Chapter 1) that the tolerances listed in this chapter are to be used only as an acceptability range and not limits for rejection.

These tolerances are generally based on a degree of accuracy which is practical and achievable while preventing costs from becoming prohibitive.

Several considerations should be understood by the architect-engineer in the establishment of product tolerances for a specific project. The two most important relate to the type of forms that are used and the measuring techniques used in the manufacturing process.

Tolerances are normally established by economical and practical production considerations of how the component must fit into the overall construction and its relationship to adjacent units. The cost of manufacturing to close tolerances decreases with increased repetition. These factors when coupled with the individual skill of the operator, will determine the final degree of accuracy. It must be noted that the particular selection of casting forms and measuring techniques are often based on economic and functional reasons rather than the manufacturer's capability to follow the most sophisticated methods.

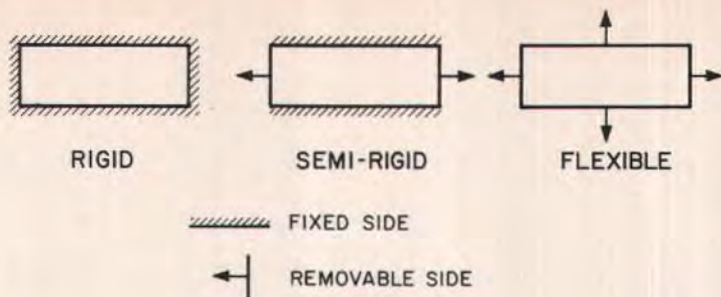
To further explain this concept, the following typical items for which dimensional tolerances are established are discussed:

1. Overall Plan Dimensions

A. FORMS

Forms are, in general, of three types (as shown in the diagram).

Rigid Forms have all its sides fixed and insure a higher degree of accuracy than other types. The same degree of accuracy is possible in both directions. These forms are often used in the fabrication of customized products, such as architectural precast panels, where appearance or function dictates the need for closer tolerances and where repetitive use makes its initial cost economi-



cally viable. Side forms for rigid forms must have suitable draft. Draft is the slope or taper required on the forms to permit stripping of the product.

Semi-Rigid Forms have two of its sides rigidly fixed and the other sides are made by using end dividers for long line casting or removable side forms for individual pieces. These end dividers or removable side forms are not rigidly attached to the form and thus can move slightly during the placement and vibration of the concrete which results in a somewhat lesser degree of accuracy in linear plan dimensions than rigid forms.

Flexible Forms have none of its sides rigidly fixed. The typical product using such forms is a double tee with blocked-out flanges. Such forms result in the least degree of dimensional accuracy in all directions of the three types.

B. MEASURING TECHNIQUES

The most common measuring method is the use of metallic tapes. Again, for economic and functional reasons, the use of more sophisticated measuring instruments is almost non-existent.

The degree of accuracy in using tapes depends on the particular dimension. The greater the linear dimension, the lower is the degree of accuracy. This is due to the fact that slope, sag and temperature effects are seldom taken into account. To compound this difficulty, members are often measured in increments creating the possibility of a cumulative error.

2. Blockouts

A tolerance for both the size and the location should be considered. It is important that the eventual function of the blockout be properly considered. For example, a window blockout into which will fit a prefabricated frame must be more rigid than a blockout through which a field installed piping system will be placed. The possible need for draft on the sides of blockouts must also be considered.

3. Horizontal Alignment

Horizontal misalignment usually occurs as a result of form tolerances and those for the width of the member. It can also result from prestressing with lateral eccentricity thus causing a sweep in the component. This should be a consideration of design.

4. Position of Tendons

It is a common practice to use $\frac{3}{8}$ in. (16 mm) diameter holes in end dividers (bulkheads, headers) for all strand sizes [$\frac{1}{2}$, $\frac{7}{16}$, and $\frac{3}{8}$ in. (13, 11, and 9.5 mm) diameter] since it is costly to switch to new end dividers for different strand diameters. Subsequently, better accuracy is achieved when using larger diameter strands.

5. Handling Devices

Handling devices are often embedded after the placement of concrete to facilitate the concrete finishing process.

It is, therefore, important that these devices be embedded as soon as possible to insure early covering of concrete. However, it is also necessary to recognize the importance of handling device locations in different directions. For example, for a long span prestressed product it is more important to have tighter tolerances in the transverse direction than in the direction of the span. This is to insure the minimum required cover around the lifting devices, as for example in the stems of tees, and also to minimize the introduction of tension stresses.

6. Camber and Differential Camber

Some of the factors affecting camber variation and subsequent differential camber are:

1. Tolerance of strand location.
2. Curing methods can influence concrete strength (and consequent modulus of elasticity) at time of prestress.
3. Storage configuration
 - Support locations and effect on span
 - Element position with respect to sun which may result in differential temperature between top and bottom of element.
4. Design
 - Pieces with same strand pattern with special width or blockouts usually have more camber.
 - Elements with a high span/depth ratio are more sensitive to camber variations.
5. Time-dependent effects
 - Modulus of elasticity
 - Creep
 - Shrinkage
 - Strand relaxation

It is very important to maintain uniformity in the time of camber measurement. For example, the camber measured on the top piece of a pile of double tees in mid afternoon on a hot sunny day will be considerably differ-

ent from the camber of the bottom piece in the pile on the same day or the same top piece on a cold damp day. Measuring camber in the early hours of the day and checking all elements at the same age will provide the most useful results.

7. Squareness of Ends

Squareness of ends will depend greatly on the type of forms, as explained in Item (1) above.

8. Position of Weld Plates

In general, it is easier to hold plates to closer tolerances at the bottom of the products (or against the side form) than plates cast on top. The main reason is that bottom plates are to some extent less susceptible to movement against vibration effects and can be fastened to the pallet by various means.

9. Tipping and Flushness of Weld Plates

For the same reasons as Item 8 above, plates cast on the top of products will tend to tip more than bottom plates. Another reason is that bottom plates get uniform bearing from the pallet whereas top plates are often embedded after placement of the concrete, and thus are aligned by visual inspection only. Flushness is the relationship of the plate surface to concrete surface.

10. Haunches of Columns and Wall Panels

The importance of dimensions to haunches is usually a function of the type of connection used at the base of the component. Since this type of connection most often allows some flexibility, it is usually more important to control dimensions from haunch to haunch in multi-tiered columns rather than to maintain tight control of actual haunch dimensions.

11. Location of Sleeves Cast in Prestressed Products

This tolerance may be affected by the location of prestressing strands especially when these are depressed.

12. Reinforcing Steel Tolerance

Refer to ACI Standard: "Tolerances for Concrete Construction and Materials," by ACI Committee 117.

13. Position of Deflection Points

Hold downs and other strand deflection methods frequently have their positions dictated by fixed devices, either in the form itself or the form support, so that suitable capacity is achieved. This can frequently result in positions being as much as ± 20 in. (± 510 mm) [for 40 in. (1020 mm) lattice spacing on form] from the intended position. Cantilevers and other special conditions may require more careful placement of the deflection points.

Special considerations of the function and the manufacturing technique used to produce certain elements are important. Architectural panels, for example, require more rigid tolerances due to the visual effects in the final construction. For this reason they are usually manufactured as purely architectural panels with a high degree of precision.

Double tees and hollow-core slabs are often used for "architectural" wall panels. The same high degree of accu-

racy for these panels should not be expected since the manufacturing technique is the same as for the structural product for which these elements are more commonly used. If more rigid tolerances are actually required, special emphasis must be focused toward this and the subsequent higher cost anticipated.

Statistical concepts are not usually employed in the dimensional control of precast products; however, it may be advantageous for producers to consider this approach for at least two reasons.

First, a random sampling of specific measurements and subsequent statistical analysis of these measurements can create economies on projects which have a large number of identical pieces with stringent tolerance requirements. Concrete railroad tie production is an example of such an instance.

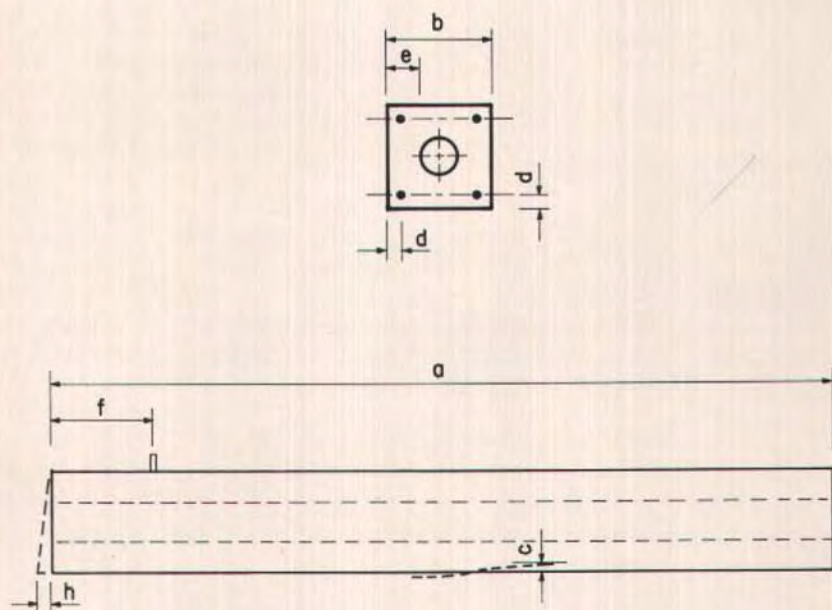
Secondly, statistical concepts can be used in developing the tolerance control requirements for specific production operations. By proper sampling and analysis, one can determine more precisely which type of measurements require more attention and this can be implemented in the quality control program. For information regarding this type of statistical approach one should refer to appropriate publications.

The following pages show dimensional requirements for several standard products. It must be emphasized that these are guidelines only and that each project must be considered individually to insure that those tolerances shown are applicable.

SELECTED REFERENCES

1. *PCI Design Handbook, Precast Prestressed Concrete* (Second Edition), Prestressed Concrete Institute, Chicago, Illinois, 1978.
2. *PCI Manual for Structural Design of Architectural Precast Concrete*, Prestressed Concrete Institute, Chicago, Illinois, 1977.
3. *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products*, Prestressed Concrete Institute, Chicago, Illinois, 1977.
4. *Manual for Quality Control for Plants and Production of Architectural Precast Concrete*, Prestressed Concrete Institute, Chicago, Illinois, 1977.

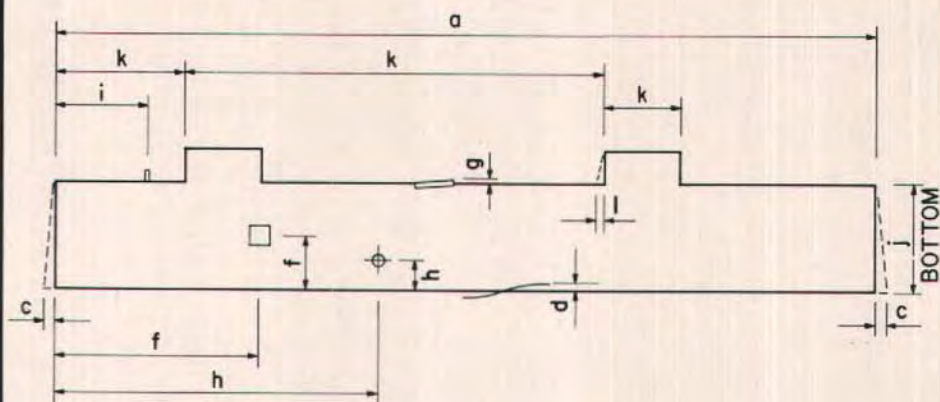
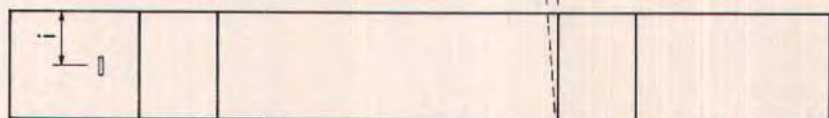
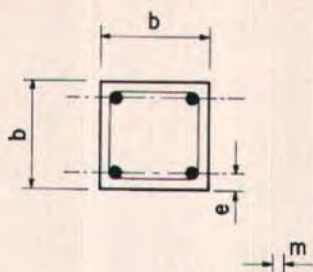
PILING



- a = Length ± 1 in. (± 25 mm)
- b = Width or diameter $\pm \frac{3}{8}$ in. (± 9.5 mm)
- c = Alignment (variation from straight line
parallel to centerline of member) $\pm \frac{1}{8}$ in. per 10 ft
(± 3 mm per 3 m)*
- d = Position of tendons $\pm \frac{1}{4}$ in. (± 6 mm)
- e = Wall thickness $\pm \frac{1}{4}$ in. (± 6 mm)
- f = Position of handling devices ± 6 in. (± 150 mm)
- g = Position of steel driving tips $\pm \frac{1}{2}$ in. (± 13 mm)
- h = End squareness $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{1}{2}$ in. max.
(± 3 mm per 300 mm, ± 13 mm max.)

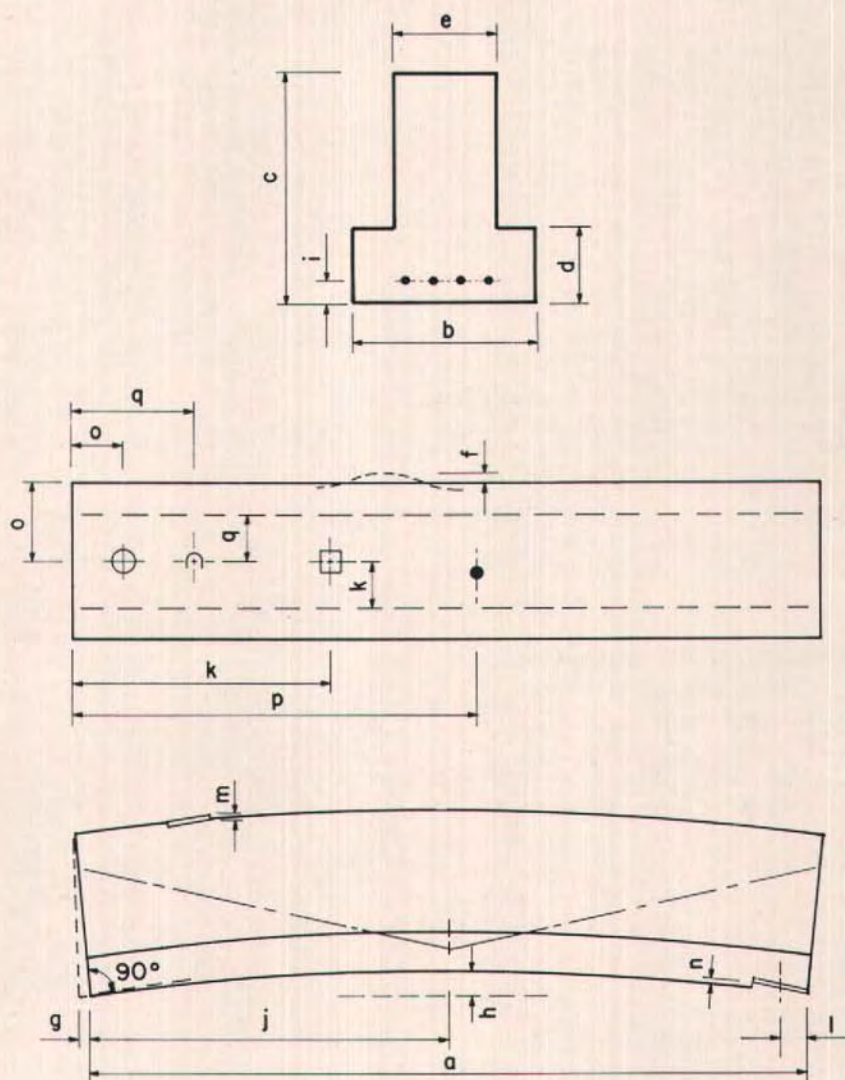
*Consider this to be a form tolerance.

COLUMNS



- a = Length $\pm \frac{1}{2}$ in. (± 13 mm)
- b = Cross section dimensions $\pm \frac{1}{4}$ in. (± 6 mm)
- c = End squareness $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{3}{8}$ in. max.
(± 3 mm per 300 mm, ± 9.5 mm max.)
- d = Alignment (variation from straight line
parallel to centerline of member) $\pm \frac{1}{8}$ in. per 10 ft., $\pm \frac{1}{2}$ in. max.
(± 3 mm per 3 m, ± 13 mm max.)
- e = Position of tendons $\pm \frac{1}{4}$ in. (± 6 mm)
- f = Position of weld plates ± 1 in. (± 25 mm)
- g = Tipping and flushness of weld plates $\pm \frac{1}{4}$ in. (± 6 mm)
- h = Position of inserts for structural
connections $\pm \frac{1}{2}$ in. (± 13 mm)
- i = Position of handling devices
Parallel to length ± 3 in. (± 76 mm)
Transverse to length ± 1 in. (± 25 mm)
- j = Base plate overall dimensions $\pm \frac{1}{4}$ in. (± 6 mm)
- k = Haunch size and locations $\pm \frac{1}{4}$ in. (± 6 mm)
- l = Squareness of bearing $\pm \frac{1}{8}$ in. (± 3 mm)
- m = Squareness of bearing $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{3}{8}$ in. max.
(± 3 mm per 300 mm, ± 9.5 mm max.)

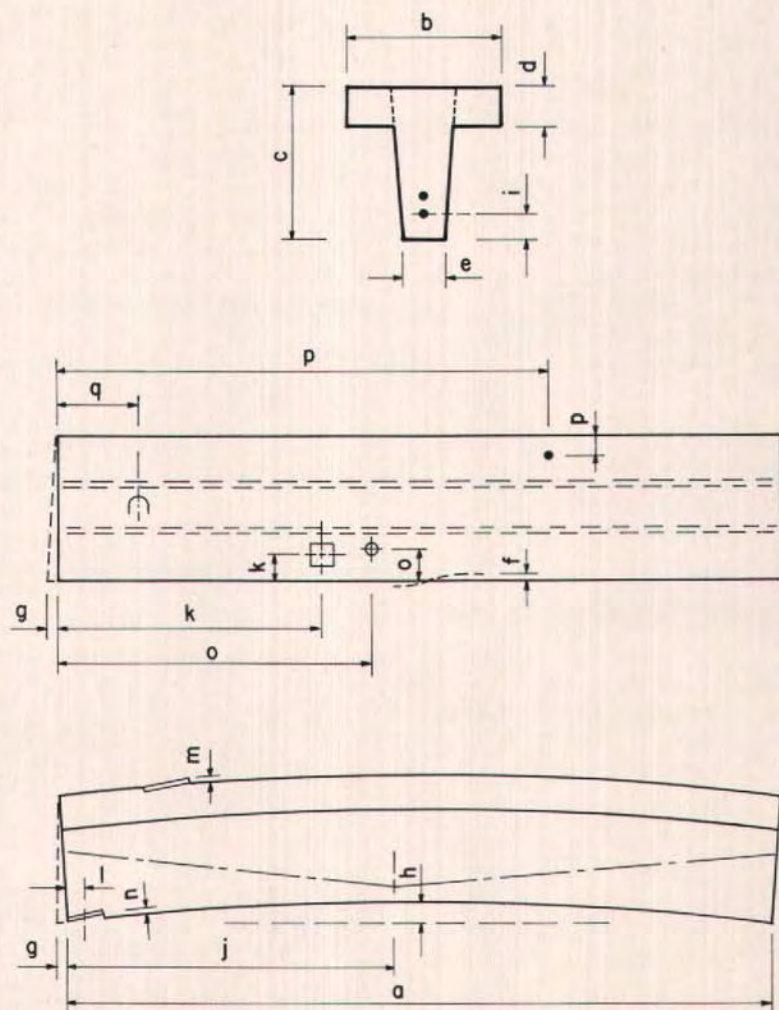
BUILDING BEAMS



BUILDING BEAMS

a = Length	 $\pm \frac{3}{4}$ in. (± 19 mm)
b = Width (overall)	 $\pm \frac{1}{4}$ in. (± 6 mm)
c = Depth (overall)	 $\pm \frac{1}{4}$ in. (± 6 mm)
d = Depth (ledge)	 $\pm \frac{1}{4}$ in. (± 6 mm)
e = Stem width	 $\pm \frac{1}{4}$ in. (± 6 mm)
f = Alignment (variation from straight line parallel to centerline of member)	
Up to 40 ft (12 m) length	 $\pm \frac{1}{4}$ in. (± 6 mm)
40 to 60 ft (12 to 18 m) length	 $\pm \frac{1}{2}$ in. (± 13 mm)
Greater than 60 ft (18 m)	 $\pm \frac{5}{8}$ in. (± 16 mm)
g = End squareness	 $\pm \frac{1}{8}$ in. per 12 in. depth, $\pm \frac{1}{2}$ in. max. (± 3 mm per 300 mm depth, ± 13 mm max.)
h = Camber variation from design camber	 $\pm \frac{1}{8}$ in. per 10 ft, $\pm \frac{1}{2}$ in. max. (± 3 mm per 3 m, ± 13 mm max.)
i = Position of tendons	
Individual	 $\pm \frac{1}{4}$ in. (± 6 mm)
Bundled	 $\pm \frac{1}{2}$ in. (± 13 mm)
j = Position of deflection points for deflected strands	 ± 6 in. (± 150 mm)
k = Position of weld plates	 ± 1 in. (± 25 mm)
l = Position of bearing plates	 $\pm \frac{1}{2}$ in. (± 13 mm)
m = Tipping and flushness of plates	 $\pm \frac{1}{4}$ in. (± 6 mm)
n = Tipping and flushness of bearing plates	 $\pm \frac{1}{8}$ in. (± 3 mm)
o = Position of sleeves cast in stems	 ± 1 in. (± 25 mm) in both horizontal and vertical plane
p = Position of inserts for structural connections	 $\pm \frac{1}{2}$ in. (± 13 mm)
q = Position of handling devices	
Parallel to length	 ± 6 in. (± 150 mm)
Transverse to length	 ± 1 in. (± 25 mm)

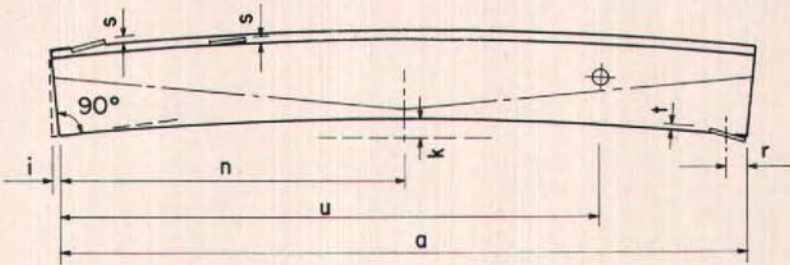
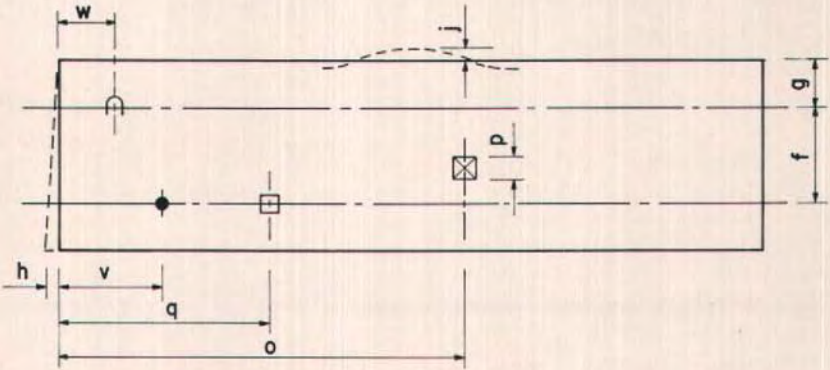
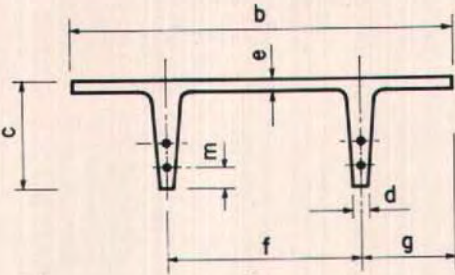
TEE JOISTS OR KEYSTONE JOISTS



TEE JOISTS OR KEYSTONE JOISTS

a = Length	 $\pm 3/4$ in. (± 19 mm)
b = Width	 $\pm 1/4$ in. (± 6 mm)
c = Depth	 $\pm 1/4$ in. (± 6 mm)
d = Flange thickness	 $+ 1/4$, $- 1/8$ in. ($+6$, -3 mm)
e = Stem width	 $\pm 1/8$ in. (± 3 mm)
f = Alignment (variation from straight line parallel to centerline of member)	 $\pm 1/4$ in. (± 6 mm)
g = End squareness	 $\pm 1/8$ in. per 12 in., $\pm 1/2$ in. max. (± 3 mm per 300 mm, ± 13 mm max.)
h = Camber variation from design camber	 $\pm 1/8$ in. per 10 ft., $\pm 1/2$ in. max., (± 3 mm per 3 m, ± 13 mm max.)
i = Position of tendons	
Individual	 $\pm 1/4$ in. (± 6 mm)
Bundled	 $\pm 1/2$ in. (± 3 mm)
j = Position of deflection points for deflected strands	 ± 6 in. (± 150 mm)
k = Position of weld plates	 ± 1 in. (± 25 mm)
l = Position of bearing plates	 $\pm 1/2$ in. (± 13 mm)
m = Tipping and flushness of plates	 $\pm 1/4$ in. (± 6 mm)
n = Tipping and flushness of bearing plates	 $\pm 1/8$ in. (± 3 mm)
o = Position of sleeves cast in stems	 ± 1 in. (± 25 mm) in both horizontal and vertical plane
p = Position of inserts for structural connections	 $\pm 1/2$ in. (± 13 mm)
q = Position of handling devices	
Parallel to length	 ± 6 in. (± 150 mm)
Transverse to length	 ± 1 in. (± 25 mm)

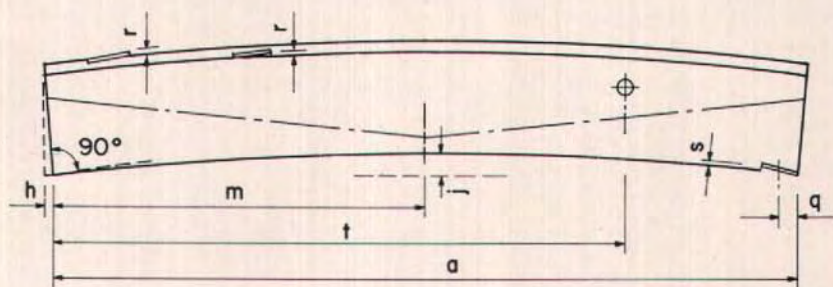
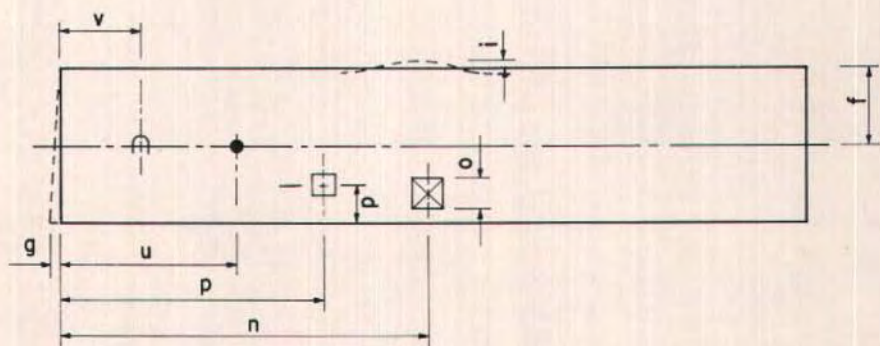
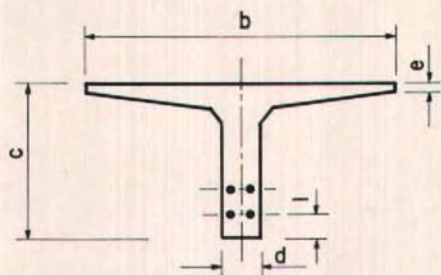
DOUBLE TEES



DOUBLE TEES

a = Length	.....	±1 in. (±25 mm)
b = Width (overall)	.....	±¼ in. (±6 mm)
c = Depth	.....	±¼ in. (±6 mm)
d = Stem width	.....	±½ in. (±3 mm)
e = Flange thickness	.....	+¼ in., -½ in. (±6 mm, -3 mm)
f = Distance between stems	.....	±½ in. (±3 mm)
g = Stem to edge of top flange	.....	±¼ in. (±6 mm)
h = Flange squareness	.....	±½ in. per 12 in. width, ½ in. max. (±3 mm per 300 width, 13 mm max.)
i = End squareness		
	Greater than 24 in. (600 mm) depth	±½ in. per 12 in., ±½ in. max. (±3 mm per 300 mm, ±13 mm max.)
	Less than 24 in. (600 mm) depth	±¼ in. (±6 mm)
j = Alignment (variation from straight line parallel to center of member)		
	Up to 40 ft (12 m) length	±¼ in. (±6 mm)
	40 to 60 ft (12 to 18 m) length	±¾ in. (±9.5 mm)
	Greater than 60 ft (18 m)	±½ in. (±13 mm)
k = Camber variation from design camber	.....	±¼ in. per 10 ft. ±¾ in. max. (±6 mm per 3 m, ±19 mm max.)
l = Differential camber between adjacent members of the same design	.....	±¼ in. per 10 ft., ±¾ in. max. (±6 mm per 3 m, ±19 mm max.)
m = Position of tendons		
	Individual	±¼ in. (±6 mm)
	Bundled	±½ in. (±13 mm)
n = Position of deflection points for deflected strands	.....	±6 in. (±150 mm)
o = Position of blockouts	.....	±1 in. (±25 mm)
p = Size of blockouts	.....	±½ in. (±13 mm)
q = Position of weld plates	.....	±1 in. (±25 mm)
r = Position of bearing plates	.....	±½ in. (±13 mm)
s = Tipping and flushness of plates	.....	±¼ in. (±6 mm)
t = Tipping and flushness of bearing plates	.....	±½ in. (±3 mm)
u = Position of sleeves cast in stems	.....	±1 in. (±25 mm) in both horizontal and vertical plane
v = Position of inserts for structural connections	.....	±½ in. (±13 mm)
w = Position of handling devices		
	Parallel to length	±6 in. (±150 mm)
	Transverse to length	±1 in. (±25 mm)

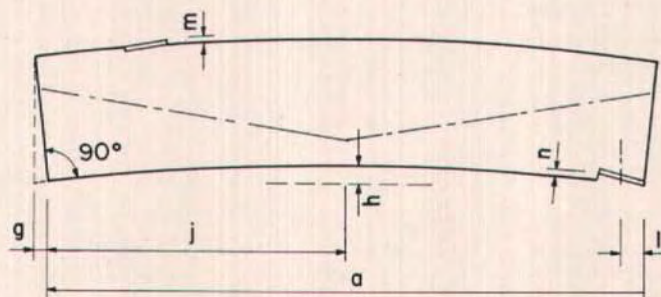
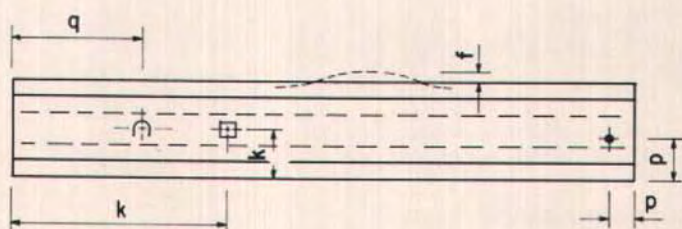
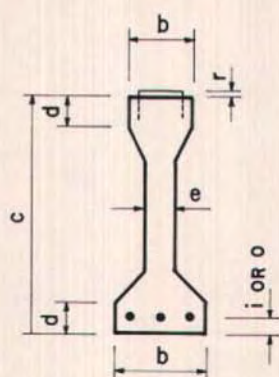
SINGLE TEES



SINGLE TEES

a = Length	 ± 1 in. (± 25 mm)
b = Width (overall)	 $\pm \frac{1}{4}$ in. (± 6 mm)
c = Depth	 $\pm \frac{1}{4}$ in. (± 6 mm)
d = Stem width	 $\pm \frac{1}{4}$ in. (± 6 mm)
e = Flange thickness	 $+\frac{1}{4}$ in., $-\frac{1}{8}$ in. ($+6$ mm, -3 mm)
f = Stem to edge of top flange	 $\pm \frac{1}{4}$ in. (± 6 mm)
g = Flange squareness	 $\pm \frac{1}{8}$ in. per 12 in., $\frac{1}{2}$ in. max. (± 3 mm per 300 mm, 13 mm max.)
h = End squareness	 $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{1}{2}$ in. max. Greater than 24 in. (600 mm) depth ... $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{1}{2}$ in. max. (± 3 mm per 300 mm, ± 13 mm max.) Less than 24 in. (600 mm) depth $\pm \frac{1}{4}$ in. (± 6 mm)
i = Alignment (variation from straight line parallel to centerline of member)	Up to 40 ft (12 m) length $\pm \frac{1}{4}$ in. (± 6 mm) 40 to 60 ft (12 to 18 m) length $\pm \frac{3}{8}$ in. (± 9.5 mm) Greater than 60 ft (18 m) $\pm \frac{1}{2}$ in. (± 13 mm)
j = Camber variation from design camber	 $\pm \frac{1}{4}$ in. per 10 ft., $\pm \frac{3}{4}$ in. max. (± 6 mm per 3 m, ± 19 mm max.)
k = Differential camber between adjacent members of the same design	 $\pm \frac{1}{4}$ in. per 10 ft., $\pm \frac{3}{4}$ in. max. (± 6 mm per 3 m, ± 19 mm max.)
l = Position of tendons	Individual $\pm \frac{1}{4}$ in. (± 6 mm) Bundled $\pm \frac{1}{2}$ in. (± 13 mm)
m = Position of deflection points for deflected strands	 ± 6 in. (± 150 mm)
n = Position of blockouts	 ± 1 in. (± 25 mm)
o = Size of blockouts	 $\pm \frac{1}{2}$ in. (± 13 mm)
p = Position of weld plates	 ± 1 in. (± 25 mm)
q = Position of bearing plates	 $\pm \frac{1}{2}$ in. (± 13 mm)
r = Tipping and flushness of plates	 $\pm \frac{1}{4}$ in. (± 6 mm)
s = Tipping and flushness of bearing plates	 $\pm \frac{1}{8}$ in. (± 3 mm)
t = Position of sleeves cast in stems	 ± 1 in. (± 25 mm) in both horizontal and vertical plane
u = Position of inserts for structural connections	 $\pm \frac{1}{2}$ in. (± 13 mm)
v = Position of handling devices	Parallel to length ± 6 in. (± 150 mm) Transverse to length ± 1 in. (± 25 mm)

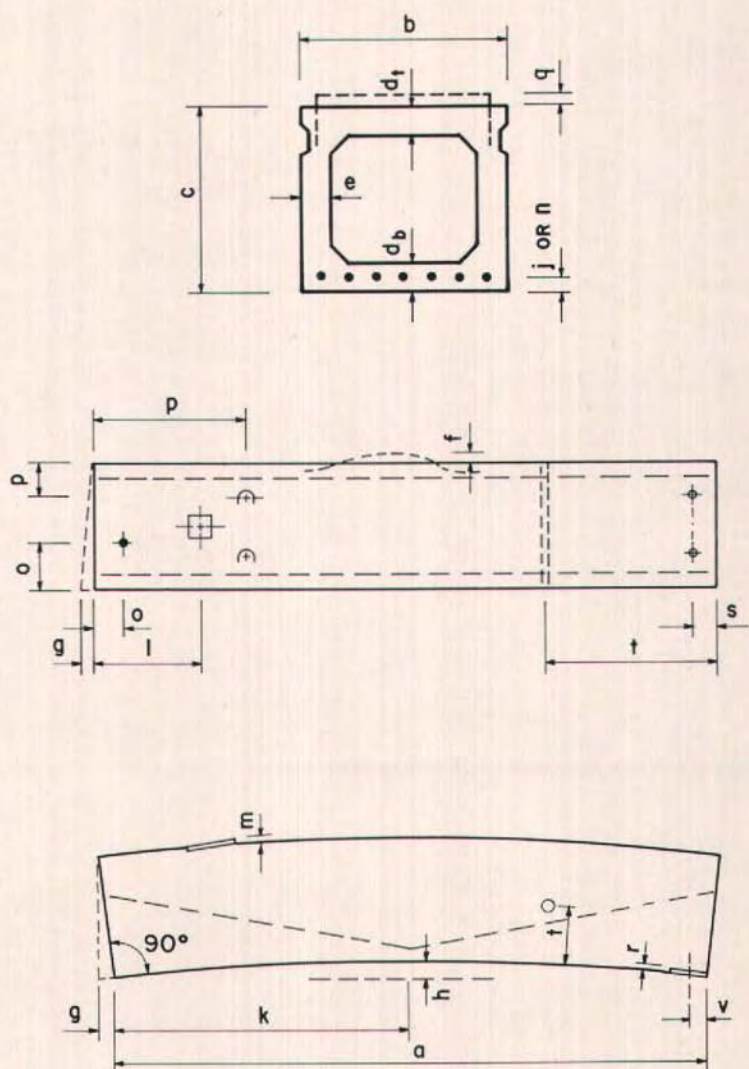
I BEAMS



I BEAMS

a	= Length	 $\pm \frac{3}{4}$ in. (± 19 mm)
b	= Width (overall)	 $+\frac{3}{8}$ in., $-\frac{1}{4}$ in. ($+9.5$ mm, -6 mm)
c	= Depth (overall)	 $+\frac{1}{2}$ in., $-\frac{1}{4}$ in. ($+13$ mm, -6 mm)
d	= Depth (flanges)	 $\pm \frac{1}{4}$ in. (± 6 mm)
e	= Width (web)	 $+\frac{3}{8}$ in., $-\frac{1}{4}$ in. ($+9.5$ mm, -6 mm)
f	= Alignment (variation from straight line parallel to centerline of member	
	Up to 40 ft (12 m) length	 $\pm \frac{1}{2}$ in. (± 13 mm)
	40 to 60 ft (12 to 18 m) length	 $\pm \frac{3}{4}$ in. (± 19 mm)
	Greater than 60 ft (18 m)	 ± 1 in. (± 25 mm)
g	= End squareness	 $\pm \frac{1}{8}$ in. per 12 in. depth, $\pm \frac{1}{2}$ in. max. (± 3 mm per 300 mm depth, ± 13 mm max.)
h	= Camber variation from design camber	 $\pm \frac{1}{8}$ in. per 10 ft, $\pm \frac{1}{2}$ in. max. (± 3 mm per 3 m, ± 13 mm max.)
i	= Position of tendons	
	Individual	 $\pm \frac{1}{4}$ in. (± 6 mm)
	Bundled	 $\pm \frac{1}{4}$ in. (± 6 mm)
j	= Position of deflection points for deflected strands	 ± 6 in. (± 150 mm)
k	= Position of weld plates	 ± 1 in. (± 25 mm)
l	= Position of bearing plates	 $\pm \frac{1}{2}$ in. (± 13 mm)
m	= Tipping and flushness of plates	 $\pm \frac{1}{4}$ in. (± 6 mm)
n	= Tipping and flushness of bearing plates	 $\pm \frac{1}{8}$ in. (± 3 mm)
o	= Position of post-tensioning duct	 $\pm \frac{1}{4}$ in. (± 6 mm)
p	= Position of inserts for structural connections	 $\pm \frac{1}{2}$ in. (± 13 mm)
q	= Position of handling devices	
	Parallel to length	 ± 6 in. (± 150 mm)
	Transverse to length	 ± 1 in. (± 25 mm)
r	= Position of stirrups	
	Longitudinal spacing	 ± 1 in. (± 25 mm)
	Projection above top	 $+\frac{1}{4}$ in., $-\frac{3}{4}$ in. ($+6$ mm, -19 mm)

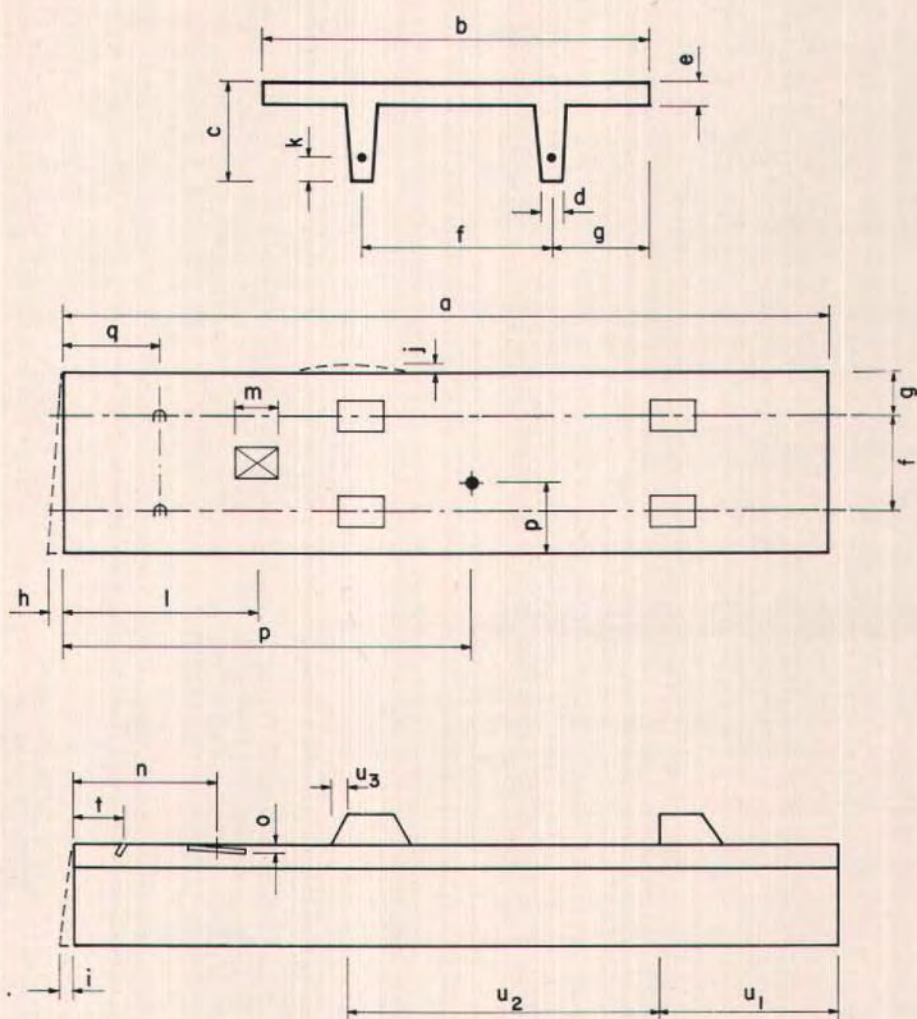
BOX BEAMS



BOX BEAMS

a	= Length	 $\pm \frac{3}{4}$ in. (± 19 mm)
b	= Width (overall)	 $\pm \frac{1}{4}$ in. (± 6 mm)
c	= Depth (overall)	 $\pm \frac{1}{4}$ in. (± 6 mm)
d _t	= Depth (top flange)	 $\pm \frac{1}{2}$ in. (± 13 mm)
d _b	= Depth (bottom flange)	 $+\frac{1}{2}$ in., $-\frac{1}{8}$ in. ($+13$ mm, -3 mm)
e	= Width (web)	 $\pm \frac{3}{8}$ in. (± 9.5 mm)
f	= Alignment (variation from straight line parallel to centerline of member)	
	Up to 40 ft (12 m) length	 $\pm \frac{1}{4}$ in. (± 6 mm)
	40 to 60 ft (12 to 18 m) length	 $\pm \frac{3}{8}$ in. (± 9.5 mm)
	Greater than 60 ft (18 m)	 $\pm \frac{1}{2}$ in. (± 13 mm)
g	= End squareness	
	Horizontal	 $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{1}{2}$ in. max. (± 3 mm per 300 mm, ± 13 mm max.)
	Vertical	 $\pm \frac{1}{2}$ in. (± 13 mm)
h	= Camber variation from design camber	 $\pm \frac{1}{8}$ in. per 10 ft, $\pm \frac{1}{2}$ in. max. (± 3 mm per 3 m, ± 13 mm max.)
i	= Differential camber between adjacent members of the same design	 $\pm \frac{1}{4}$ in. per 10 ft, $\pm \frac{3}{4}$ in. max. (± 6 mm per 3 m, ± 19 mm max.)
j	= Position of tendons	
	Individual	 $\pm \frac{1}{4}$ in. (± 6 mm)
	Bundled	 $\pm \frac{1}{4}$ in. (± 6 mm)
k	= Position of deflection point for deflected strands	 ± 6 in. (± 150 mm)
l	= Position of weld plates	 ± 1 in. (± 25 mm)
m	= Tipping and flushness of plates	 $\pm \frac{1}{4}$ in. (± 6 mm)
n	= Position of post-tensioning duct	 $\pm \frac{1}{4}$ in. (± 6 mm)
o	= Position of inserts for structural connections	 $\pm \frac{1}{2}$ in. (± 13 mm)
p	= Position of handling devices	
	Parallel to length	 ± 6 in. (± 150 mm)
	Transverse to length	 ± 1 in. (± 25 mm)
q	= Position of stirrups	
	Longitudinal spacing	 ± 1 in. (± 25 mm)
	Projection above top	 $+\frac{1}{4}$ in., $-\frac{3}{4}$ in. ($+6$ mm, -19 mm)
r	= Tipping of beam seat bearing area	 $\pm \frac{1}{8}$ in. (± 3 mm)
s	= Position of dowel tubes	 $\pm \frac{1}{2}$ in. (± 13 mm)
t	= Position of tie rod tubes	
	Parallel to length	 $\pm \frac{1}{2}$ in. (± 13 mm)
	Vertical	 $\pm \frac{3}{8}$ in. (± 9.5 mm)
u	= Position of slab void	
	End of void to center tie hole	 $\pm \frac{1}{2}$ in. (± 13 mm)
	Adjacent to end block	 ± 1 in. (± 25 mm)

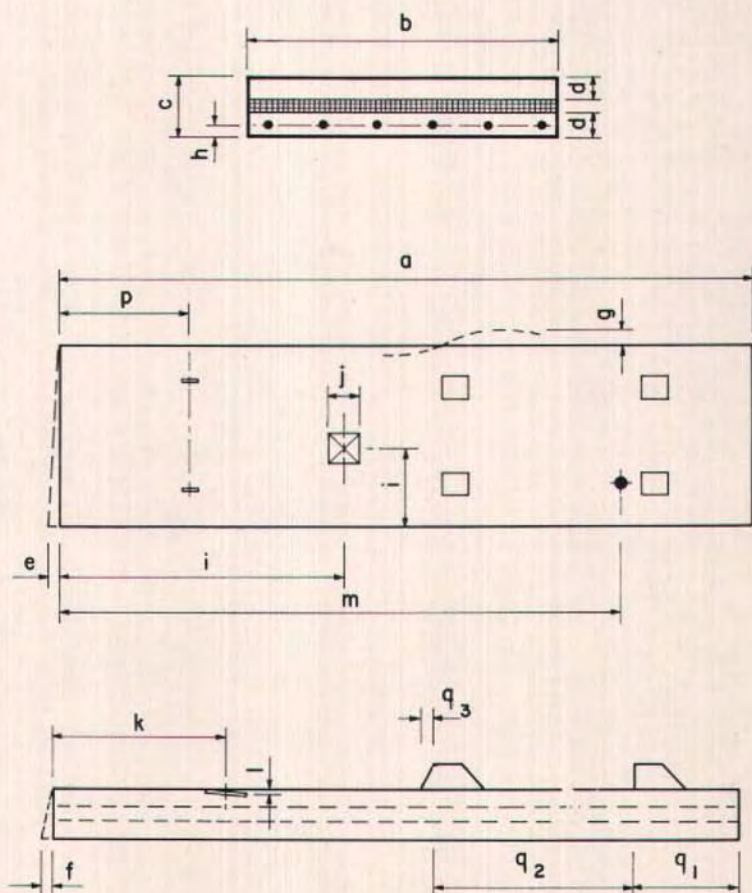
RIBBED WALL PANELS



RIBBED WALL PANELS

a	= Length	 $\pm \frac{1}{2}$ in. (± 13 mm)
b	= Width	 $\pm \frac{1}{4}$ in. (± 6 mm)
c	= Depth	 $\pm \frac{1}{4}$ in. (± 6 mm)
d	= Stem width	 $\pm \frac{1}{8}$ in. (± 3 mm)
e	= Flange thickness	 $+\frac{1}{4}$ in., $-\frac{1}{8}$ in. ($+6$ mm, -3 mm)
f	= Distance between stems	 $\pm \frac{1}{8}$ in. (± 3 mm)
g	= Stem to edge of top flange	 $\pm \frac{1}{8}$ in. (± 3 mm)
h	= Flange squareness	 $\pm \frac{1}{8}$ in. per 12 in. width, $\pm \frac{1}{4}$ in. max. (± 3 mm per 300 mm width, ± 6 mm max.)
i	= End squareness	 $\pm \frac{1}{8}$ in. per 12 in. (± 3 mm per 300 mm)
j	= Alignment (variation from straight line parallel to centerline of member)	
	Up to 40 ft (12 m) length	 $\pm \frac{1}{4}$ in. (± 6 mm)
	40 ft (12 m) and greater	 $\pm \frac{3}{8}$ in. (± 9.5 mm)
k	= Position of tendons	 $\pm \frac{1}{4}$ in. (± 6 mm)
l	= Position of blockouts	 $\pm \frac{1}{2}$ in. (± 13 mm)
m	= Size of blockouts	 $\pm \frac{1}{2}$ in. (± 13 mm)
n	= Position of weld plates	 $\pm \frac{1}{2}$ in. (± 13 mm)
o	= Tipping and flushness of plates	 $\pm \frac{1}{4}$ in. (± 6 mm)
p	= Position of inserts for structural connections	 $\pm \frac{1}{2}$ in. (± 13 mm)
q	= Position of handling devices	
	Parallel to length	 ± 6 in. (± 150 mm)
	Transverse to length	1 in. (± 25 mm)
r	= Bowing	 $L/360$ max.
s	= Differential bowing	 $\pm \frac{1}{4}$ in. (± 6 mm)
t	= Position of flashing reglets	 $\pm \frac{1}{4}$ in. (± 6 mm)
u	= Haunches	
	1. Bearing elevation from bottom of panel	 $\pm \frac{1}{4}$ in. (± 6 mm)
	2. Relative position of bearing elevation in vertical plane	 $\pm \frac{1}{8}$ in. (± 3 mm)
	3. Haunch bearing area	 $\pm \frac{1}{8}$ in. per 18 in., $\pm \frac{1}{4}$ in. max. (± 3 mm per 450 mm, ± 6 mm max.)

INSULATED WALL PANELS— SINGLE-STORY STRUCTURES



INSULATED WALL PANELS— SINGLE-STORY STRUCTURES

a	= Length	 $\pm \frac{1}{2}$ in. (± 13 mm)
b	= Width	 $\pm \frac{1}{4}$ in. (± 6 mm)
c	= Depth (overall)	 $\pm \frac{1}{4}$ in. (± 6 mm)
d	= Wythe thickness	 $\pm \frac{3}{8}$ in. (± 9.5 mm)
e	= Wythe squareness	 $\pm \frac{1}{8}$ in. per 12 in. width, $\pm \frac{1}{2}$ in. max. (± 3 mm per 300 mm width, ± 13 mm max.)
f	= End squareness	 $\pm \frac{1}{8}$ in. per 12 in. (± 3 mm per 300 mm)
g	= Alignment (variation from straight line parallel to centerline of member)	 $\pm \frac{1}{8}$ in. per 20 ft, $\pm \frac{3}{8}$ in. max. (± 3 mm per 6 m, ± 9.5 mm max.)
h	= Position of tendons	 $\pm \frac{1}{4}$ in. (± 6 mm)
i	= Position of blockouts	 ± 1 in. (± 25 mm)
j	= Size of blockouts	 $\pm \frac{1}{2}$ in. (± 13 mm)
k	= Position of weld plates	 ± 1 in. (± 25 mm)
l	= Tipping and flushness of weld plates	 $\pm \frac{1}{4}$ in. (± 6 mm)
m	= Position of inserts for structural connections	 $\pm \frac{1}{2}$ in. (± 13 mm)
n	= Bowing	 $L/360$ max.
o	= Differential bowing	 $\pm \frac{1}{4}$ in. (± 6 mm)
p	= Handling devices	
	Parallel to length	 ± 6 in. (± 150 mm)
	Transverse to length	 ± 1 in. (± 25 mm)
q	= Haunches	
	1. Bearing elevation from bottom of panel	 $\pm \frac{1}{4}$ in. (± 6 mm)
	2. Relative position of bearing elevation in vertical plane	 $\pm \frac{1}{8}$ in. (± 3 mm)
	3. Haunch bearing area	 $\pm \frac{1}{8}$ in. per 18 in., $\pm \frac{1}{4}$ in. max. (± 3 mm per 450 mm, ± 6 mm max.)

HOLLOW-CORE SLABS

Hollow-core slabs are somewhat unique due to the many different production methods used, each of which has inherent features which influence its ability to achieve certain tolerances. As such, hollow-core slabs are considered separately from other product types.

The properties of hollow-core slabs for which common tolerances can be achieved, regardless of the production method, are as follows:

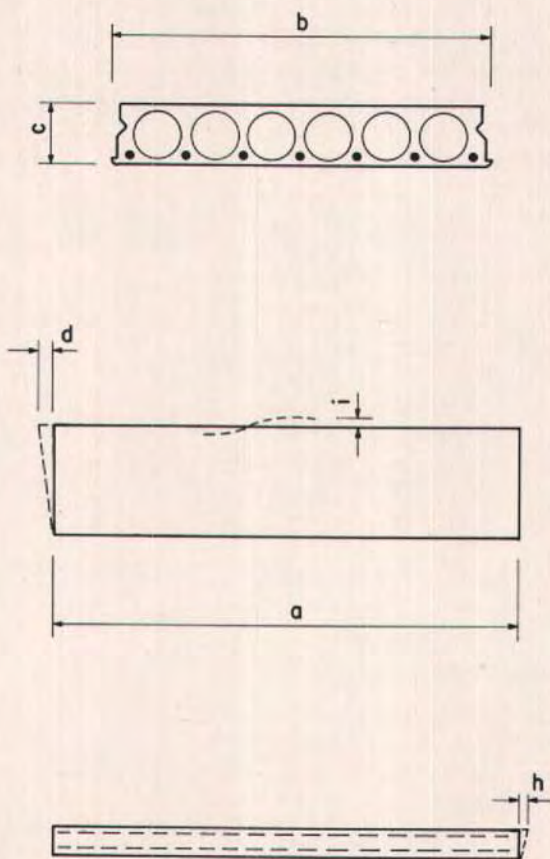
- a. Length
- b. Width
- c. Depth
- d. Flange squareness
- h. End squareness
- i. Variation from straight line (sweep)

Tolerances for these properties are considered for hollow-core slabs used in conventional floor and roof construction. Use of the product for direct carpet overlay application, as an architectural element, or other special use requires careful reconsideration of these tolerances in cooperation with local manufacturers.

Other features often checked in other products which vary with different hollow-core production methods, as well as among producers of the same product, include the desirability of embedded plates, blockouts, inserts, and lifting devices. The unit weight, strand position, camber and section properties relate closely to design and the production method.

The variations of all these items should be discussed carefully with potential suppliers for a project during the design phase.

HOLLOW-CORE SLABS



- a = Length $\pm \frac{1}{2}$ in. (± 13 mm)
- b = Width $\pm \frac{1}{4}$ in. (± 6 mm)
- c = Depth $\pm \frac{1}{4}$ in. (± 6 mm)
- d = Flange squareness $\pm \frac{1}{8}$ in. per 12 in., $\pm \frac{1}{2}$ in. max.
(± 3 mm per 300 mm, ± 13 mm max.)
- h = End squareness $\pm \frac{1}{2}$ in. (± 13 mm)
- i = Alignment (variation from straight line
parallel to centerline of member) $\pm \frac{1}{4}$ in. (± 6 mm)

ARCHITECTURAL PANELS

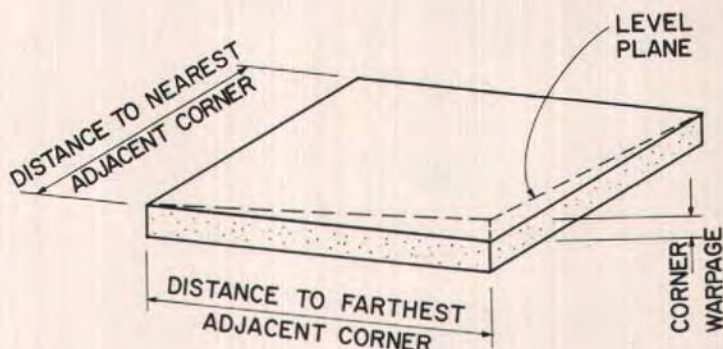
Architectural panels, primarily as a result of their intended function, often require more rigid tolerances and special considerations than structural elements. Two such considerations which apply particularly to architectural panels are warpage and bowing.

1. Warpage—Maximum permissible

warpage of one corner out of plane of the other three shall be $\frac{1}{16}$ in. per ft (5 mm/m) distance from the nearest adjacent corner.

2. Bowing (concave or convex) of any part of a flat surface shall not exceed:

$$\frac{\text{length of bow}}{360}$$



PANEL THICKNESS

Table 3.1. Guidelines for warpage tolerance consideration vs. panel dimensions.*

Panel Dimensions	8'	10'	12'	16'	20'	24'	28'	32'
4'	3"	4"	4"	5"	5"	6"	6"	7"
6'	3"	4"	4"	5"	6"	6"	6"	7"
8'	4"	5"	5"	6"	6"	7"	7"	8"
10'	5"	5"	6"	6"	7"	7"	8"	8"

*This table represents a relationship between overall flat panel dimensions and thicknesses below which suggested warpage tolerances should be reviewed and possibly increased. For ribbed panels, the equivalent thickness should be the overall thickness of such ribs if continuous from one end of the panel to the other.

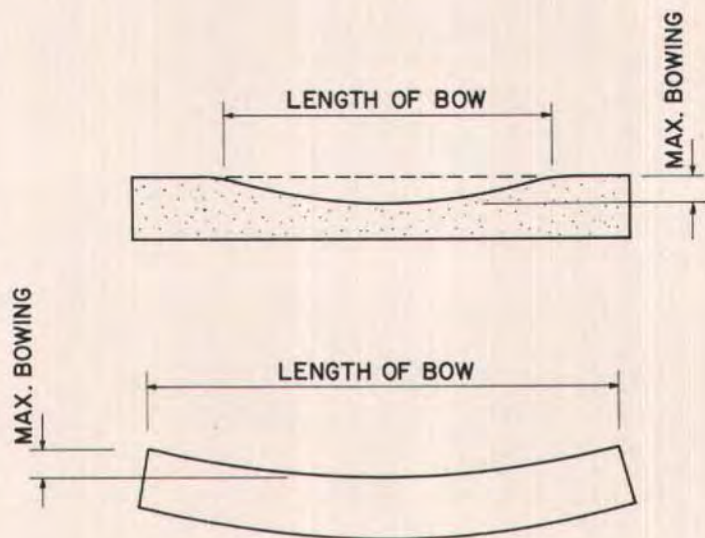
Note: 1 in. = 25 mm; 1 ft = 300 mm = 0.3 m.

with a maximum of $\frac{3}{4}$ in. (19 mm); differential bowing between adjacent members of the same design shall not exceed $\pm \frac{1}{4}$ in. (± 6 mm).

Slender panels should not be subjected to the standard tolerances for bowing and warpage. Table 3.1 gives width and length dimensions, in relation to panel thickness, below which warpage tolerances should be reviewed for each individual project. For panels below the range shown in Table 3.1 and/or for panels with large aggregates [above $\frac{3}{4}$ in. (19 mm)], these tolerances should be increased.

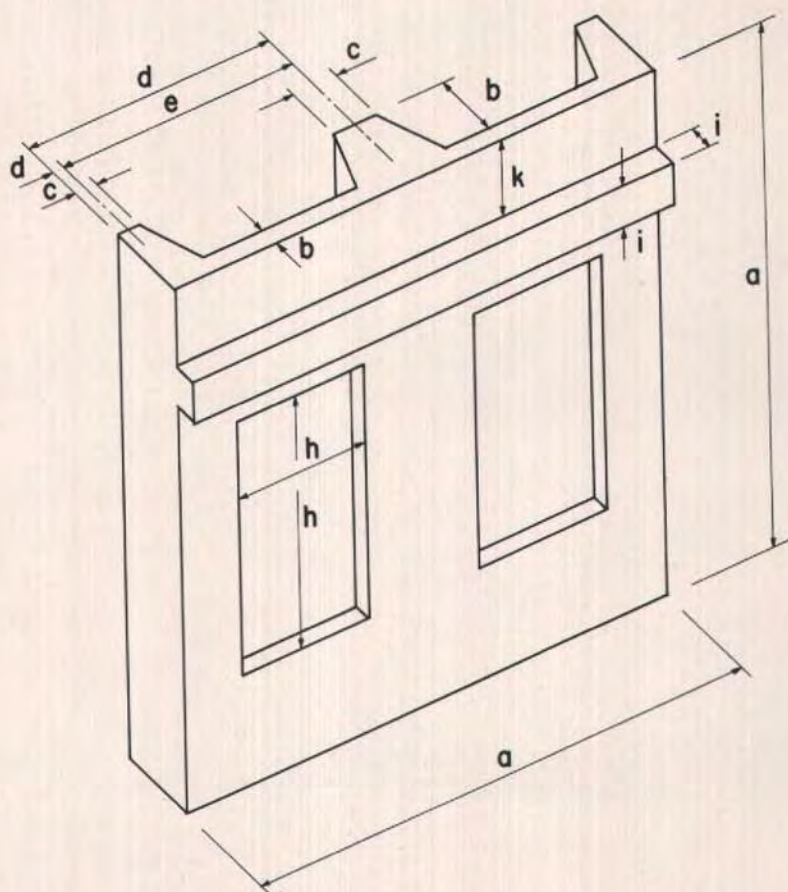
Tolerances for units which are not homogeneous (consisting of either two widely different concrete mixes or natural stone veneer with concrete backup) should be specifically reviewed and may also have to be increased. The major criteria for maintaining or relaxing bowing and warpage tolerances will be type and spacing of connections, appearance requirements, and the advice of local precasters for feasibility.

Alignment of ribbed panels (variation from straight lines parallel to centerline of panel and/or designated skew) shall be as follows:



Up to 40 ft (12 m) lengths	$\pm \frac{3}{16}$ in. (± 5 mm)
40 to 60 ft (12 to 18 m) lengths	$\pm \frac{1}{4}$ in. (± 6 mm)

ARCHITECTURAL PANELS



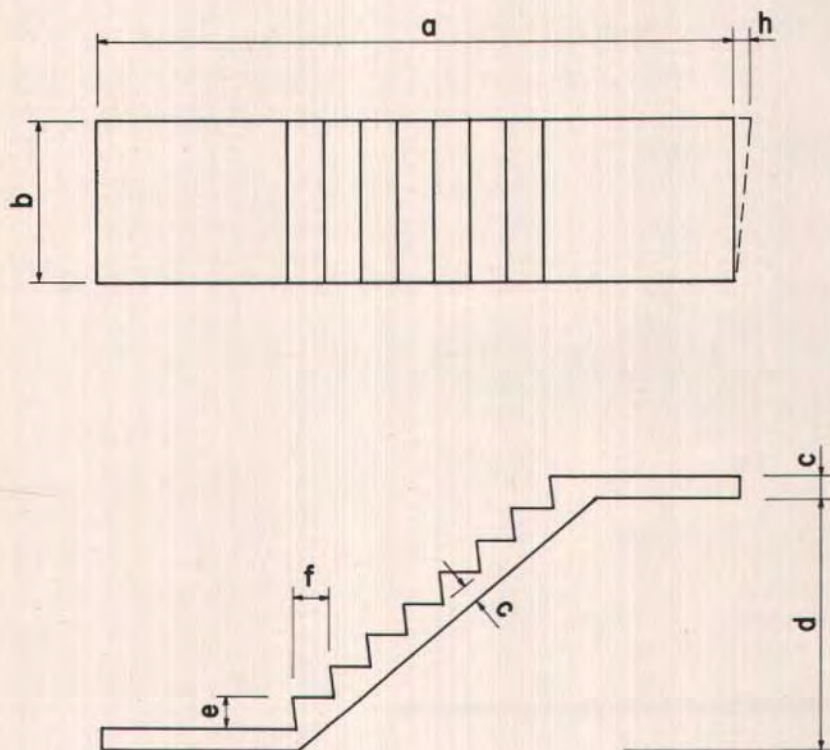
- a = Overall height and width measured at the face adjacent to the mold at time of casting or neutral axis of ribbed members
- | | |
|-----------------------------|--|
| 10 ft (3 m) or under | $\pm \frac{1}{8}$ in. (± 3 mm) |
| 10 to 20 ft (3 to 6 m) | $+\frac{1}{8}$ in., $-\frac{3}{16}$ in. (+3 mm, -5 mm) |
| 20 to 30 ft (6 to 9 m) | $+\frac{1}{8}$ in., $-\frac{1}{4}$ in. (+3 mm, -6 mm) |
| Each additional 10 ft (3 m) | $\frac{1}{16}$ in. (± 1.5 mm) per 10 ft (3 m) |
| | or $\pm \frac{1}{4}$ in. (± 6 mm) |
| | whichever is greater |
- b = Total thickness or flange thickness $-\frac{1}{8}$ in., $+\frac{1}{4}$ in. (-3 mm, +6 mm)
- c = Rib thickness $\pm \frac{1}{8}$ in. (± 3 mm)
- d = Rib to edge of flange $\pm \frac{1}{8}$ in. (± 3 mm)

- e = Distance between ribs $\pm \frac{1}{8}$ in. (± 3 mm)
- f = Angular variation of
plane of side mold $\frac{1}{32}$ in. (1 mm) per 3 in. (75 mm)
of depth or $\frac{1}{16}$ in. (1.5 mm)
total, whichever is greater
- g = Variation from square or designated
skew (difference in length of
the two diagonal measurements) ... $\frac{1}{8}$ in. (3 mm) per 6 ft (2 m) or $\frac{1}{4}$ in.
(6 mm) total, whichever is greater
- h = Length and width of
blockouts and openings
within one unit $\pm \frac{1}{4}$ in. (± 6 mm)
- i = Dimensions of haunches $\pm \frac{1}{4}$ in. (± 6 mm)
- j = Haunch bearing surface
deviation from specified
plane $\pm \frac{1}{8}$ in. (± 3 mm)
- k = Difference in relative position
of adjacent haunch bearing
surfaces from specified
relative position $\pm \frac{1}{4}$ in. (± 6 mm)
- l = Tolerances on any dimension not
specified above the numerically greater of $\pm \frac{1}{16}$ (± 1.5 mm)
in. per 10 ft (3 m) or $\pm \frac{1}{8}$ in. (± 3 mm)

Position tolerances. For cast-in-items measured from datum line locations as shown on the approved erection drawings:

- Weld plates ± 1 in. (± 25 mm)
- Inserts $\pm \frac{1}{2}$ in. (± 13 mm)
- Handling devices ± 3 in. (± 75 mm)
- Reinforcing steel and
welded wire fabric $\pm \frac{1}{4}$ in. (± 6 mm) where position has
structural implications or affects
concrete cover, otherwise $\pm \frac{1}{2}$ in. (± 13 mm)
- Tendons $\pm \frac{1}{8}$ in. (± 3 mm)
- Flashing reglets $\pm \frac{1}{4}$ in. (± 6 mm)
- Flashing reglets, at edge of panel $\pm \frac{1}{8}$ in. (± 3 mm)
- Reglets for glazing gaskets $\pm \frac{1}{16}$ in. (± 1.5 mm)
- Groove width for glazing gaskets $\pm \frac{1}{16}$ in. (1.5 mm)
- Electrical outlets, hose bibs, etc. $\pm \frac{1}{2}$ in. (± 13 mm)
- Openings and blockouts $\pm \frac{1}{4}$ in. (± 6 mm)
- Some types of window and equipment
frames require openings more accurately
placed, and when this is the case, the
minimum practical tolerance is $\pm \frac{1}{8}$ in. (± 3 mm)
- Haunches $\pm \frac{1}{4}$ in. (± 6 mm)

STEP UNITS



- a = Length $\pm \frac{1}{2}$ in. (± 13 mm)
 b = Width $\pm \frac{3}{8}$ in. (± 9.5 mm)
 c = Thickness $\pm \frac{1}{4}$ in. (± 6 mm)
 d = Height $\pm \frac{1}{2}$ in. (± 13 mm)
 e = Riser
 Height $\pm \frac{1}{4}$ in. (± 6 mm)
 Maximum difference between two risers $\pm \frac{1}{4}$ in. (± 6 mm)
 f = Tread width $\pm \frac{1}{4}$ in. (± 6 mm)
 g = Variation from square or designated skew (difference
 in length of two diagonals) $\pm \frac{1}{8}$ in. (± 3 mm) per 6 ft (1.8 m) or
 $\pm \frac{1}{4}$ in. (± 6 mm), whichever is greater
 h = End squareness $\pm \frac{1}{4}$ in. (± 6 mm)