Tolerances for Precast Concrete Structures

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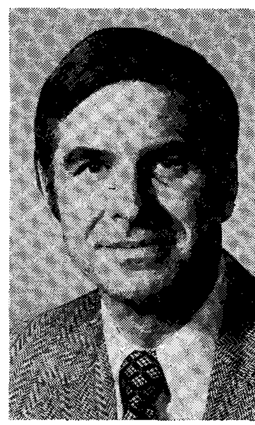

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Tolerances must be selected and specified in order to properly design and build precast concrete structures. At the present time, published lists of tolerances do not completely cover all the critical areas for individual and combined concrete members.

The proposed list of tolerances was developed for concrete structures with a precast concrete structural system. The included examples illustrate the application of tolerances to design and construction. Work should be done by the building industry to develop more complete criteria for specifying tolerances and clearances for building components.

Optimal design of precast concrete structures requires, in addition to technical competence, a comprehensive knowledge of the capabilities of general contractors, precast concrete manufacturers, and precast concrete erectors. A structure must be designed and detailed in such a manner that the complete structure will be safe, functional, aesthetically appealing, and economical.

Detailed clearances, between precast concrete members and cast-in-place concrete or other precast concrete members, must be realistic. Tolerances, defined as specified permissible variations from the dimensions and relationships shown on the drawings, must be economically attainable.

The design engineer must consider tolerances when sizing members, establishing clearances, designing joints, and designing connections. The contractor, precaster, and erector must carefully monitor tolerances in order to construct the structure as designed.

Tolerances create a common ground for the designer and builder. Designers work to absolute dimensions—sometimes to the hundredth of an inch. It is impossible to construct buildings to these absolute dimensions. Buildings are built by people and people are not error free.

Tolerances must be compatible with the engineer's design to insure that, when used to the limits, the elements are not overstressed. Tolerances must be compatible with abilities of the fabricator, erector, and builder. Also, they must be compatible with the desired architectural expression and detail.

Tolerances must be chosen by the architect and engineer to meet the specific requirements of the structure. They must also be included in the project specifications, thereby establishing rules for the acceptability of the building components in their individual and combined states.

Tabulations of tolerances for cast-in-place concrete and precast concrete are listed in various industry publications.[1-5] In project concrete specifications our design firm includes by reference "Specifications for Structural Concrete for Buildings (ACI 301-72)"[2] as the standard governing all cast-in-place concrete. Table 4.3.1 in ACI 301-72 gives tolerances for formed surfaces in reinforced concrete buildings.

In the past, we have also specified *Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products (PCI MNL-116-70)*[3] as the standard for precast concrete tolerances.

By monitoring the construction of numerous precast concrete structures, we found that many times a tolerance question developed that was not covered by our specified tolerances. A careful search of ACI and PCI literature revealed to us that we could not solve these tolerance questions by including additional published standards in our project specifications.

After consultation with general contractors, precast concrete manufacturers and precast concrete erectors, we developed a list of tolerances for buildings designed with a precast concrete structural system. Many of the following tolerances have not been previously published, except in the authors' project specifications.

These tolerances were developed to eliminate the indecision created in the plant and at the job site when variations occurred from the project plan and detail dimensions—variations which were not specified.

Specifically, this paper will cover tolerances in the following major areas:

A. Tolerances for manufacture of precast concrete members
B. Tolerances for construction of cast-in-place concrete site work that relates to precast concrete
C. Tolerances for erection of precast concrete members

A. Tolerances for Manufacture of Precast Concrete Members

In this section, tolerances are given for the following members:

1. Columns
2. Vertical ribbed wall panels
3. Flat wall panels
4. Beams and spandrel panels
5. Double tee deck units
6. Single tee deck units

1. Columns (Fig. 1)*

a. Length: ±½ in.

b. Cross-sectional dimensions: ±¼ in.

c. Vertical alignment (deviation from straight line parallel to longitudinal centerline of column):
   - ¼ in. up to 40-ft lengths
   - ⅜ in. 40 to 60-ft lengths
   - ½ in. greater than 60-ft lengths

d. Deviation from square or designated skew:
   - ⅛ in. per 12 in. of width, any cross section
   - ¼ in. maximum, any cross section
   - ¼ in. any end (with longitudinal centerline)

e. Position of haunches and pockets: ±¼ in.

f. Dimensions of haunches and pockets: ±¼ in.

g. Haunch and pocket bearing surface deviation from specified plane: ⅛ in.

h. Difference in relative position of

* No tolerances are given in *PCI MNL-116-70* for manufacture of precast concrete columns.

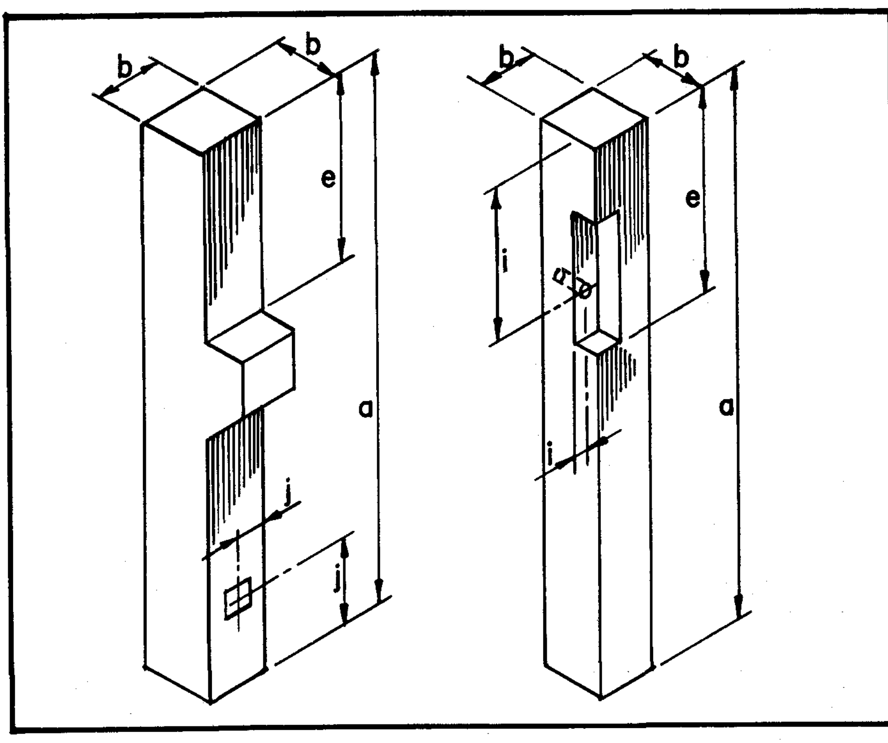

Fig. 1. Columns

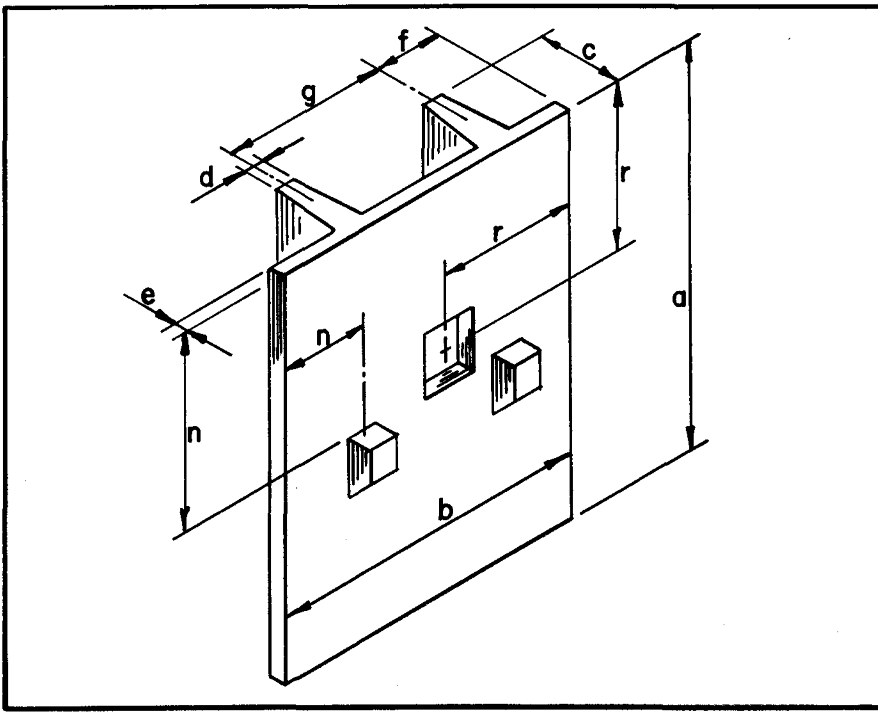

Fig. 2. Vertical ribbed wall panels.

adjacent haunch and/or pocket bearing surfaces from specified relative position: ¼ in.

i. Position of sleeves and inserts: ±¼ in.
j. Position of weld plates: ±½ in.
k. Position of anchor bolt holes in base plate: ±⅛ in.
l. Position of base plates and bearing plates: ±¼ in.
m. Position of handling devices: ±3 in.

2. Vertical Ribbed Wall Panels (Fig. 2)†

a. Length: ±¼ in.
b. Width (over-all): ±⅛ in.
c. Depth: ±¼ in.
d. Stem thickness: ±⅛ in.
e. Flange thickness: +¼ in., −⅛ in.

† No tolerances are given in *PCI MNL-116-70* for manufacture of precast concrete ribbed wall panels.

f. Stem to edge of flange: ±⅛ in.
g. Distance between stems: ±⅛ in.
h. Vertical alignment (deviation from straight line parallel to longitudinal centerline of panel):

   Abutting panels:
   ⅛ in. up to 40-ft lengths
   3/16 in. 40 to 60-ft lengths
   ¼ in. greater than 60-ft lengths

   Non-abutting panels:
   ¼ in. up to 40-ft lengths
   ⅜ in. 40 to 60-ft lengths
   ½ in. greater than 60-ft lengths

i. Bowing: same as **h.** above
j. Differential bowing between adjacent members of the same design: ¼ in.
k. Warpage (one corner out of the plane of the other three): ¼ in.
l. Deviation from square or designated skew:

¼-in. ends, flange and stems
¼-in. openings and block-outs

m. Position of tendons: ±⅛ in.
n. Position of haunches: ±¼ in.
o. Dimensions of haunches: ±¼ in.
p. Haunch bearing surface deviation from specified plane: ⅛ in.
q. Difference in relative position of adjacent haunch bearing surfaces from specified relative position: ¼ in.
r. Position of openings and block-outs: ±¼ in.
s. Dimensions of openings and block-outs: ±¼ in.
t. Position of sleeves and inserts: ±¼ in.
u. Position of weld plates: ±½ in.
v. Position of flashing reglets: ±¼ in.
w. Position of anchor bolt holes in base plate: ±⅛ in.
x. Position of base plates and bearing plates: ±¼ in.
y. Position of handling devices: ±3 in.

3. Flat Wall Panels (Fig. 3)‡

a. Length and width:
   ±⅛ in. 10 ft or under
   ±⅛ in., −3/16 in. 10 to 20 ft
   ±⅛ in., −¼ in. 20 to 30 ft
   ±¼ in. maximum, greater than 30 ft
b. Thickness: ±¼ in., −⅛ in.
c. Horizontal and vertical alignment (deviation from straight lines parallel to center line(s) and/or designated skew):
   1/16 in. per 10 ft of length
   ¼ in. maximum
d. Bowing: (length of bow)/(480)
e. Differential bowing between adjacent members: ¼ in.
f. Warpage (one corner out of the plane of the other three): ¼ in.
g. Difference in length of the two di-

‡ No tolerances are given in *PCI MNL-116-70* for manufacture of precast concrete flat wall panels.

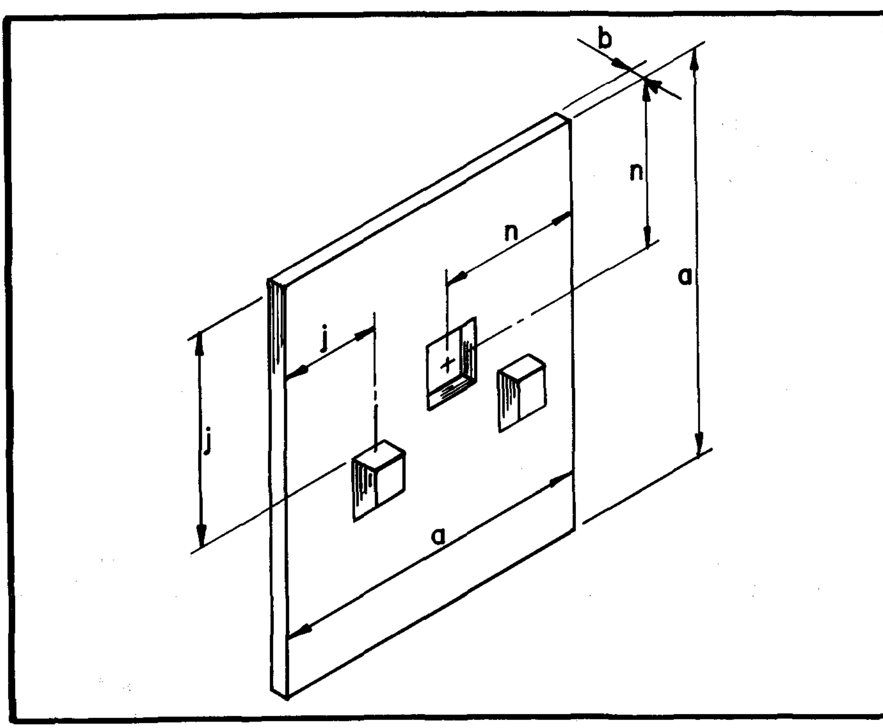

Fig. 3. Flat wall panels.

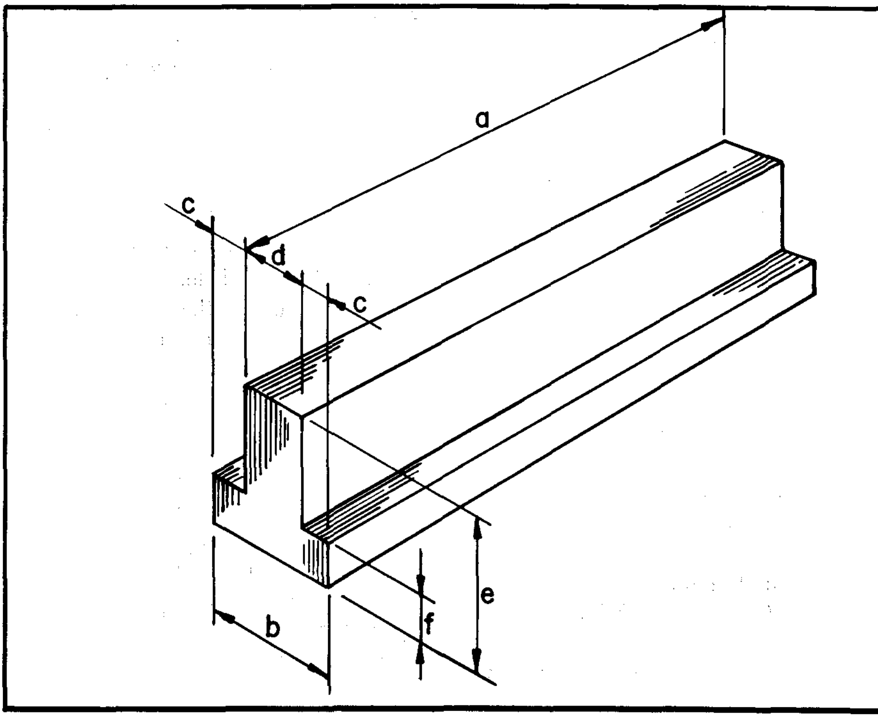

Fig. 4. Beams and spandrel panels.

agonal measurements:
1/8 in. per 6 ft with 1/4 in. maximum (square members)
1/4 in. square openings and block-outs

h. Position of tendons: ±1/8 in.
i. Position of reinforcement: ±1/4 in.
j. Position of haunches: ±1/4 in.
k. Dimensions of haunches: ±1/4 in.
l. Haunch bearing surface deviation from specified plane: 1/8 in.
m. Difference in relative position of adjacent haunch bearing surfaces from specified relative position: 1/4 in.
n. Position of openings and block-outs: ±1/4 in.
o. Dimensions of openings and block-outs: ±1/4 in.
p. Position of sleeves and inserts: ±1/4 in.
q. Position of weld plates: ±1/2 in.
r. Position of flashing reglets: ±1/4 in.
s. Position of handling devices: ±3 in.

4. Beams and Spandrel Panels (Fig. 4)*

a. Length: ±1/2 in.
*d. Width (over-all) ±1/4 in.
c. Ledge width: ±1/4 in.
*d. Beam width: ±1/4 in.
*e. Beam depth: ±1/4 in.
*f. Ledge depth: ±1/4 in.
g. Horizontal alignment (deviation from a straight line parallel to longitudinal centerline of member):
1/4 in. up to 40-ft lengths
3/8 in. 40 to 60-ft lengths
1/2 in. greater than 60-ft lengths
*h. Camber deviation from specified design camber:
1/8 in. per 10 ft but not greater than 1/2 in.
i. End deviation from square or designated skew:

* Tolerances taken from *PCI MNL-116-70*, 5.5.6.

¼ in. horizontal and vertical

*j. Position of tendons: ±⅛ in.

*k. Position of deflection point for deflected strands: ±6 in.

l. Position of openings and blockouts: ±¼ in.

m. Dimensions of openings and blockouts: ±¼ in.

n. Position of sleeves and inserts: ±¼ in.

o. Position of weld plates: ±½ in.

p. Position of bearing plates: ±¼ in.

q. Bearing surface deviation from specified plane: ±⅛ in.

r. Position of handling devices: ±3 in.

5. Double Tee Deck Units (Fig. 5)*

*a. Length: ±½ in.

*b. Width (over-all): ±¼ in.

* Tolerances taken from *PCI MNL-116-70*, 5.5.2.

*c. Depth: ±¼ in.

*d. Stem thickness: ±⅛ in.

*e. Flange thickness: +¼ in., −⅛ in.

*f. Stem to edge of top flange: ±⅛ in.

*g. Distance between stems: ±⅛ in.

*h. Horizontal alignment (deviation from a straight line parallel to longitudinal centerline of member):
¼ in. up to 40-ft lengths
⅜ in. 40 to 60-ft lengths
½ in. greater than 60-ft lengths

*i. Camber deviation from specified design camber:
¼ in. per 10 ft but not greater than ¾ in.

j. Differential camber between adjacent members of the same design:
¼ in. per 10 ft but not greater than ¾ in. for topped decks
⅛ in. per 10 ft but not greater than ⅜ in. for untopped decks

k. End deviation from square or designated skew:

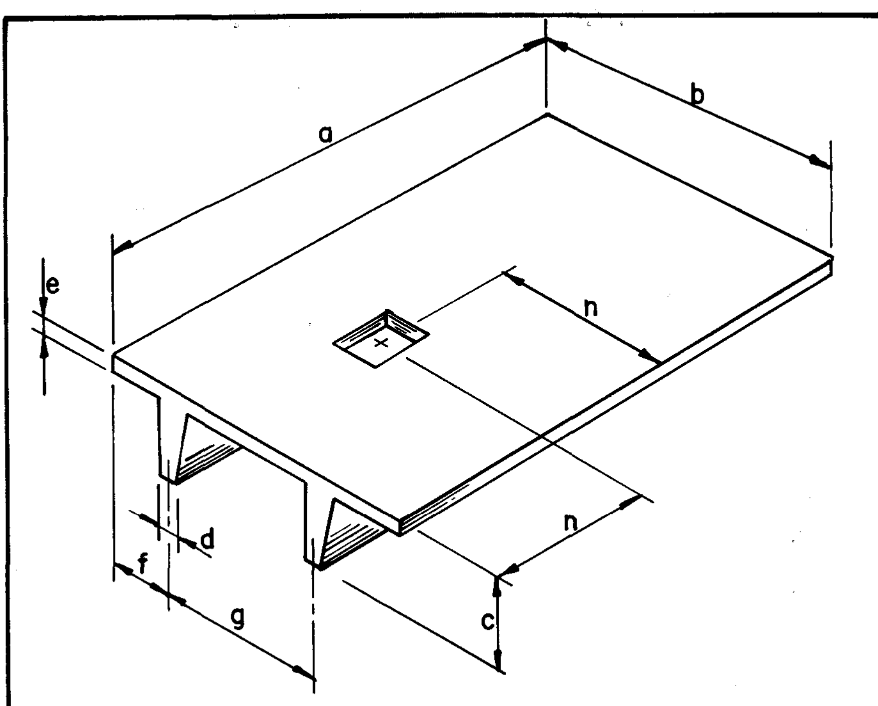

Fig. 5. Double tee deck units.

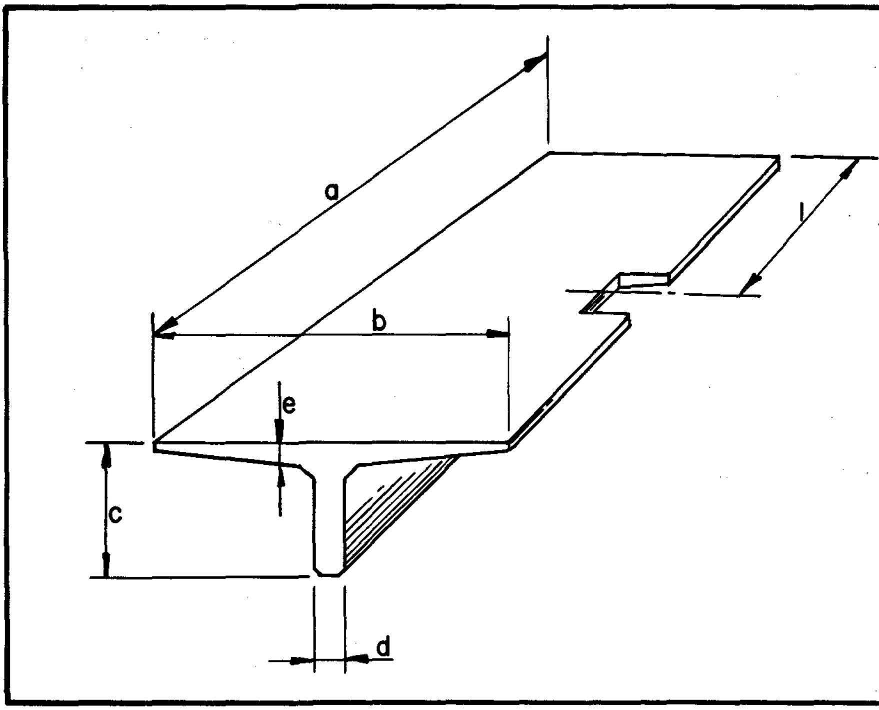

Fig. 6. Single tee deck units.

¼ in. horizontal and vertical

*l. Position of tendons: ±⅛ in.

*m. Position of deflection points for deflected strands: ±6 in.

*n. Position of block-outs: ±½ in.

o. Dimensions of block-outs: ±¼ in.

p. Position of sleeves and inserts: ±¼ in.

q. Position of weld plates: ±½ in.

r. Position of bearing plates: ±¼ in.

s. Bearing surface deviation from specified plane: ⅛ in.

t. Difference in relative position of adjacent stem bearing surfaces from specified relative position: ¼ in.

u. Position of handling devices: ±3 in.

6. Single Tee Deck Units (Fig. 6)*

a. Length: ±½ in.

*b. Width (over-all): ±¼ in.

*c. Depth: ±¼ in.

*d. Width (stem): ±³⁄₁₆ in.

*e. Flange thickness: +¼ in., –⅛ in.

*f. Horizontal alignment (deviation from a straight line parallel to longitudinal centerline of member):
¼ in. up to 40-ft lengths
⅜ in. 40 to 60-ft lengths
½ in. greater than 60-ft lengths

*g. Camber deviation from specified design camber:
¼ in. per 10 ft but not greater than ¾ in.

h. Differential camber between adjacent members of the same design:
¼ in. per 10 ft but not greater than ¾ in. for topped decks
⅛ in. per 10 ft but not greater than ⅜ in. for untopped decks

i. End deviation from square or designated skew:
¼ in. horizontal and vertical

*j. Position of tendons: ±¼ in.

*k. Position of deflection point for de-

* Tolerances taken from *PCI MNL-116-70*, 5.5.3.

flected strands: ±6 in.

*l. Position of block-outs: ±½ in.

m. Dimensions of block-outs: ±¼ in.

n. Position of sleeves and inserts: ±¼ in.

o. Position of weld plates: ±½ in.

p. Position of bearing plates: ±¼ in.

q. Bearing surface deviation from specified plane: ⅛ in.

r. Position of handling devices: ±3 in.

B. Tolerances for Construction of Cast-in-Place Concrete Site Work That Relates to Precast Concrete

In this section tolerances are given for the following members:

1. Caisson, caisson caps, and pile caps
2. Footings
3. Piers, columns, and walls
4. Anchor bolts and sleeves

1. Caissons, Caisson Caps, and Pile Caps

a. Variation of center from specified center in plan: ±2 in.

b. Variation of bearing surface from specified elevation: ±½ in.

2. Footings

*a. Variation of dimensions in plan: +2 in., −½ in.

*b. Variation of center from specified center in plan:
2 percent of footing width in direction of variation
±2 in. maximum variation

c. Variation of bearing surface from specified elevation: ±½ in.

3. Piers, Columns, and Walls

a. Variation in cross-sectional dimensions of piers and columns and in thickness of walls: ±¼ in.

b. Variation in plan from specified location in plan:
±½ in. any member, any location

c. Deviation in plan from straight lines parallel to specified linear building lines:
1/40 in. per ft adjacent members less than 20 ft apart or any wall length less than 20 ft
½ in. adjacent members 20 ft or more apart or any wall length of 20 ft

*d. Deviation from plumb:
¼ in. any 10 ft of height
1 in. maximum for the entire height

e. Variation in elevation from specified elevation:
±½ in. any member, any location

f. Deviation in elevation from lines parallel to specified grade lines:
1/40 in. per ft adjacent members less than 20 ft apart or any wall length less than 20 ft
½ in. adjacent members 20 ft or more apart or any wall length of 20 ft

4. Anchor Bolts and Sleeves

a. Variation from specified location in plan: ±¼ in.

b. Variation from specified elevation: ±½ in.

* Tolerances taken from *ACI 301-72*, Table 4.3.1.

C. Tolerances for Erection of Precast Concrete Members

In this section tolerances are given for the following members:

1. Columns
2. Vertical ribbed wall panels

3. Flat wall panels
4. Beams and spandrel panels
5. Tee deck units

1. Columns

a. Variation in plan from specified location in plan:
±½ in. any column, any location

b. Deviation in plan from straight lines parallel to specified linear building lines:
1/40 in. per ft adjacent columns less than 20 ft apart
½ in. adjacent columns 20 ft or more apart

c. Difference in relative position of adjacent columns from specified relative position:
½ in. at any deck level

d. Deviation from plumb:
¼ in. any 10 ft of height
1 in. maximum for the entire height

e. Variation in elevation of bearing surfaces from specified elevations:
±½ in. any column, any location

f. Deviation in elevation of bearing surfaces from lines parallel to specified grade lines:
1/40 in. per ft adjacent columns less than 20 ft apart
½ in. adjacent columns 20 ft or more apart

g. Variation of specified clearance from adjacent independent member: ±¼ in.

2. Vertical Ribbed Wall Panels

a. Variation in plan from specified location in plan:
±½ in. any panel, any location

b. Deviation in plan from straight line parallel to specified linear building line:
1/40 in. per ft any panel or adjacent panels less than 20 ft apart
½ in. maximum between adjacent panels

c. Deviation from plumb:
¼ in. any 10 ft of height
1 in. maximum for the entire height

d. Variation in elevation of bearing surfaces from specified elevation:
±½ in. any panel, any location

e. Deviation in elevation of bearing surfaces from line parallel to specified grade line:
1/40 in. per ft adjacent panels less than 20 ft apart
½ in. maximum between adjacent panels

f. Jog in alignment of matching edges:
¼ in.

g. Variation from specified joint width:
±¼ in.

h. Variation of specified clearance from adjacent independent member: ±¼ in.

3. Flat Wall Panels

a. Variation in plan from specified location in plan:
±½ in. any panel, any location

b. Deviation in plan from straight line parallel to specified linear building line:
1/40 in. per ft any length less than 20 ft
½ in. maximum any 20 ft of length

c. Deviation from plumb:
¼ in. any 10 ft of height
½ in. maximum for the entire height

d. Variation in elevation of bearing surfaces from specified elevation:
±½ in. any panel, any location

e. Deviation in elevation of bearing surfaces from line parallel to specified grade line:
1/40 in. per ft any length less than 20 ft
½ in. maximum any 20 ft of length

f. Jog in alignment of matching edges:
¼ in.

g. Variation from specified joint width:
±¼ in.

h. Variation of specified clearance from adjacent independent member: ±¼ in.

4. Beams and Spandrel Panels

a. Variation in plan from specified location in plan:
±½ in. any beam, any location
b. Deviation in plan from straight line parallel to specified linear building line:
1/40 in. per ft any beam less than 20 ft
½ in. maximum any beam 20 ft or more in length
c. Variation from specified bearing length on support: ±¾ in.
d. Variation from specified bearing width on support: ±½ in.
e. Variation in elevation of bearing surfaces from specified elevation:
±½ in. any beam, any location
f. Deviation in elevation of bearing surfaces from lines parallel to specified grade lines:
1/40 in. per ft any length less than 20 ft
½ in. maximum any beam 20 ft or more in length
g. Deviation of top of spandrel from specified elevation:
½ in. any panel
h. Jog in alignment of matching edges: ¼ in.
i. Variation of specified clearance from adjacent independent member: ±¼ in.

5. Tee Deck Units

a. Variation in plan from specified location in plan:
±½ in. any tee, any location
b. Deviation in plan from straight line parallel to specified linear building line:
½ in. any tee
c. Variation from specified bearing length on support: ±¾ in.
d. Variation from specified bearing width on support: ±½ in.
e. Variation in elevation from specified elevation:
±¾ in. any tee, any end
f. Deviation in elevation from line parallel to specified grade line:
¾ in. longitudinal
⅜ in. transverse
g. Jog in alignment of adjoining flanges:
⅛ in. untopped decks
½ in. topped decks
h. Variation from specified flange joint width: ±¼ in.
i. Variation of specified clearance from adjacent independent member: ±¼ in.

General Discussion

It might be helpful to point out the distinction that is made between variation and deviation in the above-listed tolerances. A variation is defined as an additive or subtractive (plus or minus) difference from a specified dimension or relationship. A deviation is defined as an absolute difference from a specified relationship.

This distinction can be seen in the column erection tolerances given in C.l.e. and f. where the variation in elevation of column bearing surfaces from specified elevation is given as ±½ in. for any location while the deviation of bearing surfaces from a line parallel to a specified grade line is given as ½ in. for adjacent columns 20 ft or more apart.

We found it necessary to include in the erection tolerances a clearance variation for "adjacent independent members." Adjacent independent members are members that are close together but are not connected structurally.

These members may both be precast concrete or they may be combinations of precast concrete and cast-in-place, masonry, or steel. Typically, this clearance situation develops at an expansion joint or at the interface between a stair tower and a larger structure when

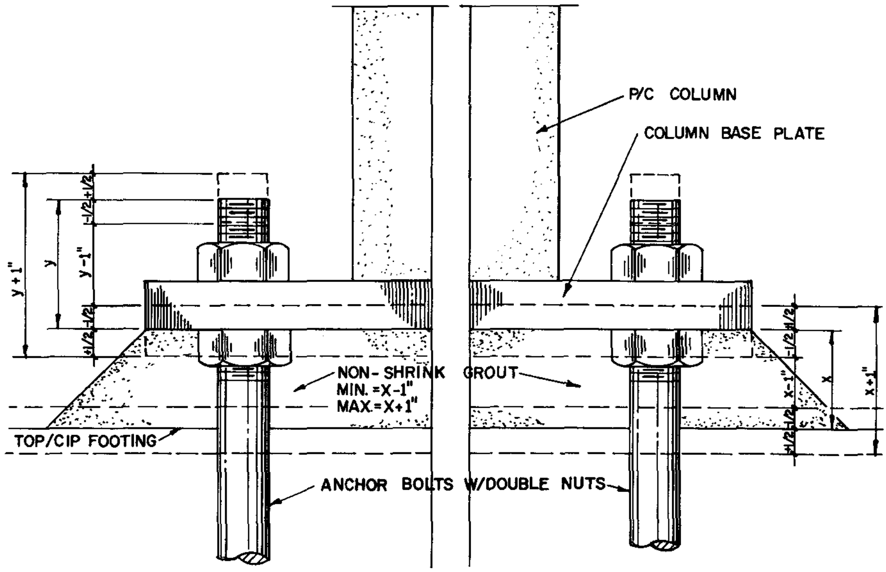

Fig. 7. Column/footing elevation tolerances.

the two are joined only by an expansion joint.

Careful inspection of the listed tolerances will reveal that many times one tolerance will override another. The column manufacturing tolerances in **A.l.e.** and **h.** allow for a variation in the position of a column haunch of ±¼ in. but restrict the relative position of adjacent haunch bearing surfaces to ¼ in. Thus, while any column haunch may be ¼ in. low or high, one haunch may not be ¼ in. low and the adjacent haunch ¼ in. high.

Similarly, according to erection tolerances **C.l.a.** and **C.4.a.**, a column and beam may both vary from specified location in plan by ±½ in. while according to **C.4.c.** the beam bearing length may only vary by ±¾ in. In this way, the beam bearing tolerance will not permit the column to be ½ in. off the specified location in one direction and the beam bearing on the column to be ½ in. off the specified location in the opposite direction.

Design Applications

Manufacturing, construction, and erection tolerances must be considered throughout the design phase of a precast concrete structure. This point is illustrated by two examples based on these tolerances.

Example 1—Clearance Between Precast Concrete Column and Footing

The column is to be connected to the footing by anchor bolts with non-shrink grout filling the void between the column base plate and the footing as shown in Fig. 7.

The minimum thickness of grout between the base plate and the footing is to be limited to 1 in. According to cast-in-place concrete tolerance **B.2.c.** and column erection tolerance **C.1.e.**, the bearing surfaces of the footing and column may vary ±½ in. from the specified elevation. The clearance must

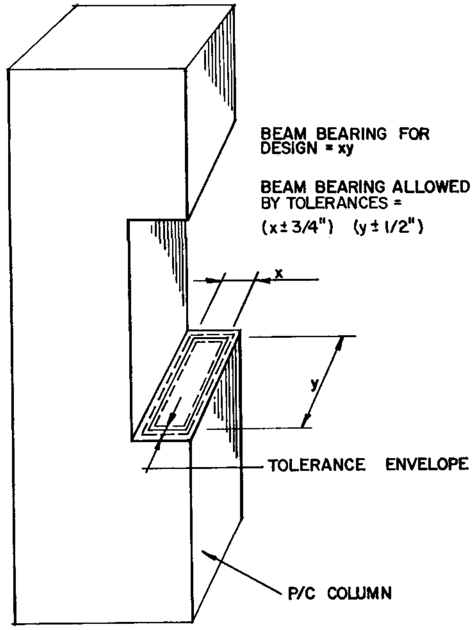

Fig. 8. Beam/column bearing tolerances.

then be detailed at 2 in. to allow for the possibility that the footing is ½ in. high and the column base plate ½ in. low.

The projection of the anchor bolts from the footing must also be checked since in cast-in-place concrete tolerance **B.4.b.** they are allowed to vary ±½ in. from the specified elevation.

Thus, the bolt must be detailed to project 1 in. more than required for the 2 in. clearance to allow for the possibility that the plate is ½ in. high and the bolt is ½ in. low.

The bolt must be detailed to have 1 in. more thread than required for the design connection to allow for the possibility that the bolt is ½ in. high and the plate is ½ in. low.

Example 2—Bearing of Beam in Column Pocket

A 24-in. wide beam is to bear 6 in. on a 7 x 22-in. raised surface within the column pocket. Both the end of the beam and the bottom of the pocket must be designed for the worst case of bearing.

According to erection tolerances **C.4.c.** and **d.** the beam bearing length may vary ±¾ in. and the beam bearing width may vary ±½ in. from the specified bearing in the pocket (see Fig. 8).

Instead of the specified bearing surface of 6.0 x 2.0 in. = 132.0 sq. in., the bearing surface could be 5.25 x 21.50 in. = 112.88 sq in.

The actual bearing stress could be (132.0)/(112.88) = 1.17 times greater than the bearing stress calculated by using the detailed dimensions.

Adding a factor of 0.12 to 1.17 (to insure that the connection area has a 10 percent greater design safety factor than the connected members) would give a reasonable *additional* load factor for the design of beam and pocket bearing of 1.29.

Concluding Remarks

The specification of tolerances for the manufacture and erection of precast concrete and for the construction of related cast-in-place concrete eliminates indecision and sets the ground rules for the acceptance of the complete structure. The specifying of tolerances helps engineers to arrive at logical rather than arbitrary load factors for connection design.

The construction of structures manufactured under these rules will go more smoothly because the specified tolerances will help to make all parties involved aware of their respective responsibilities. Careful selection and use of tolerances for each specific project can only help improve the quality of the project and insure a satisfied building owner.

On the precast concrete structural system projects, for which we have proposed the above listed tolerances, we have experienced a vast improvement in the design and construction sequence. The concrete building industry should develop more complete criteria for specifying tolerances in concrete structures. Work should also be done to develop criteria for specifying tolerances and clearances for the erection of precast concrete members on cast-in-place concrete and structural steel frames.

References

1. ACI Committee 347, "Recommended Practice for Concrete Formwork (ACI 347-68)," American Concrete Institute, Detroit, Michigan, 1968.
2. ACI Committee 301, "Specifications for Structural Concrete for Buildings (ACI 301-72)," American Concrete Institute, Detroit, Michigan, 1972.
3. *PCI MNL 116-70 Manual for Quality Control for Plants and Production of Precast Prestressed Concrete Products,* Prestressed Concrete Institute, Chicago, Illinois, 1970.
4. *PCI Architectural Precast Concrete,* Prestressed Concrete Institute, Chicago, Illinois, 1973.
5. *PCI Architectural Precast Concrete Drafting Handbook,* Prestressed Concrete Institute, Chicago, Illinois, 1975.

Discussion of this paper is invited.
Please forward your discussion to
PCI Headquarters by December 1, 1976.