TOLERANCE MANUAL

FOR PRECAST AND PRESTRESSED CONCRETE CONSTRUCTION

MNL 135-00

PRECAST/PRESTRESSED
CONCRETE INSTITUTE

TOLERANCES

FOR PRECAST AND PRESTRESSED CONCRETE CONSTRUCTION

MNL-135-00

prepared by

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Substantial effort has been made to ensure that all data and information in this manual are accurate. However, PCI cannot accept responsibility for any errors or oversights in the use of material or in the preparation of engineering plans. This publication is intended for the use by personnel competent to evaluate the significance and limitations of its contents and able to accept responsibility for the application of the material it contains. Special conditions on a project may require more specific evaluation of practical engineering judgement.

While every effort has been made to prepare this publication as the national standards for the industry, it is possible that there may be some conflicts between the material herein and local practices.

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Tolerances for Precast and Prestressed Concrete Construction

FOREWORD

Precast concrete is a building system which depends on a system of realistic and consistent tolerances to meet the objectives of providing acceptable appearance, durability and economy.

This document is the compilation of over 50 years of Precast/Prestressed Concrete Industry experience that defines this essential tolerance system for each phase of the building project: design, production, erection and performance. This document also provides information on other building materials.

Design information for engineers, architects and building owners is presented to assist in the selection and design of Precast and Prestressed Concrete Products.

The Committee has designed this manual to complement and support the PCI quality control manuals: MNL-116 *Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products,* and MNL-117 *Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products*. Together, these three documents form the basis of quality design and quality fabrication and erection for Precast and Prestressed concrete products.

Tolerances For Precast and Prestressed Concrete

1.0 Preface To Tolerance Committee Report

1.1 General

This document is a working reference for the dimensional control of precast concrete products and construction. It covers both plant-cast or site-cast and precast and precast prestressed concrete.

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

The original tolerance committee report was published in the *PCI Journal* in 1985. A supplement to the original document was published in the *Journal* in 1993. Portions of this document have been republished in the Third, Fourth and Fifth Editions of the PCI *Design Handbook.* MNL-116 *Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products* and MNL-117 *Manual for Quality Control for Plants and Production of Architectural Precast Concrete Products* have included portions of the information published in 1985 for use in the Plant Certification program.

Since 1985, the PCI Committee on Tolerances has listened to concerns, answered questions and considered the reported use (and misuse) of the published tolerances. In response, this document addresses some of the most frequently asked questions and concerns.

Readers are encouraged to report any experiences, problems and concerns regarding tolerances for precast products and projects to the PCI technical staff.

1.2 Need for Collaboration

The owner, architect/engineer, general contractor, precaster and erector all have the same goal: a successful project. The overall building project involving precast concrete building members should be successful from all points of view, namely, client satisfaction, on time schedule performance, economy, aesthetics, constructability, and long term functional durability. It is essential that the members of the building team collaborate to provide an overall project tolerance system which will meet all of the project's functional needs and allow economical fabrication and erection for the precast concrete members and all of the interfacing building systems.

Contractual relationships which provide incentives for cooperation among the building project team members, full exchange of information regarding the needs of the various aspects of the project, and proactive communication approaches, such as project partnering, will help the building team successfully implement project tolerance plans.

1.3 Responsibility for the Overall Project Tolerance System

The concept of responsibility for specifying tolerances on precast concrete building projects has been misunderstood and at times misused. The consequences can be not only expensive, but damaging to customer/client relationships. Consider the following. It is not uncommon for the published tolerances for precast concrete products to be used as a tool for rejection (or conversely, as a tool for advocating acceptances), after a project has experienced tolerance related construction difficulties.

In some instances the architect/engineer may specify PCI documents MNL-116 or MNL-117 as a reference guide, believing that this will cover every situation. In other instances, building team members may review the published product tolerances only after fit up problems become apparent in the field.

Depending on the nature of the contractual relationships, the precast concrete manufacturer may follow the specifications and use them as proof of member tolerance compliance. In the event construction problems arise, the architect/engineer may take the position that the precast manufacturer is responsible for the proper fit of a precast member into the completed structure, regardless of whether or not the individual members meet PCI tolerances.

The tolerances defined by the Committee were set to provide a suitable reference point. Each of these tolerances was set based on current modern precast concrete production techniques. They are based on a standard of quality and craftsmanship that can be reliably accomplished by a PCI plant certified to produce the various member types. The published tolerances are not intended to be an unyielding and rigid set of tolerances used only as a measure of acceptance or rejection. The intent of the Committee was to provide both a feasible and economically reasonable set of starting tolerance tools that will enable the party responsible for tolerances to develop an overall project tolerance plan that can be followed to create a successful project.

1.4 Specifying Responsibility for Project Tolerances

The 1985 *PCI Journal* Tolerance Committee Report states:

"While the detailed assignment of responsibility for the dimensional tolerancing and control of the various members may vary, depending on the contractual arrangement for a particular project, it is very important that these responsibilities be clearly assigned and that these assignments be communicated to all members of the project team."

In addition, it is important that the responsibility for the overall project tolerance plan and the specification of member dimensional tolerances and appropriate interface details be specifically defined. The contractual relationships on a project and the associated compensation for the effort involved should recognize the entity charged with the responsibility for the development and implementation of the overall project tolerance plan.

As a matter of actual practice on many projects, either no entity is specifically designated with the responsibility to specify the required project tolerances or the tolerances are too tightly defined.

The first extreme, where responsibility has not been designated, may occur because the circumstances of projects vary considerably. The construction team member in the best position to handle the development and implementation of the project tolerance plan may change from project to project. On some projects the precast concrete manufacturer may be contractually defined as the engineer of record, possibly with only limited involvement of other architects or engineers. On some projects the owner may not retain a design team to develop specifications or contract drawings. In situations like these the precast concrete manufacturer may be contractually responsible for the development of the overall project tolerance plan.

The other extreme is the project that is tightly defined by the owner's architect/engineer of record. Members may be accurately sized and located and connections may be detail designed or defined in general concepts on the contract drawings and in the project specifications by the owner's architect/engineer. In this case the architect/engineer of record may be defined in the contract as contractually responsible to specify the overall project tolerance plan.

Similarly, project circumstances between the two extremes can be ill-defined with regard to the responsibility for the overall project tolerance plan. In many areas of the country these project conditions of ill defined responsibility for project tolerances are the most prevalent.

It should be noted that the precast member manufacturer may have no contractual control over the tolerances and the interface conditions created by other trades on the project. If this is the case, these tolerances and interface conditions may best be handled by the architect/engineer of record, the general contractor or other entity having the contractual authority necessary to specify and control interfacing system procurement and the performance of all of the various project trades.

There are definite advantages to having the responsibilities for project tolerances defined prior to the purchase contract for the precast concrete. This may prevent disputes over inappropriate or misunderstood tolerance specifications after the start of precast production.

See Appendix A for sample contract language regarding responsibility for tolerances.

Figure 1.4.1 shows how different types of project tolerances fit into the overall project tolerance plan and the subsequent implementation tasks. As indicated in this diagram "Special Project Tolerances", which are different from the typical PCI tolerances, may be required. Figure 1.4.2 shows a possible contractual relationship for the situation where the precaster enters into a design-build contract to provide a building project directly to an owner. Figure 1.4.3 shows a possible contractual relationship for the situation where the precaster bids members constructed to specified tolerances to a general contractor who then erects the members.

Figure 1.4.4 shows an example responsibility matrix for project tolerances where specific responsibilities for the various elements of the overall project tolerance plan have been set forth in the project contract. Appendix B contains a blank tolerance responsibility matrix that can be copied and filled out for use on new projects.

Fig. 1.4.1 Relationship of Project Tolerances to Functional Requirements

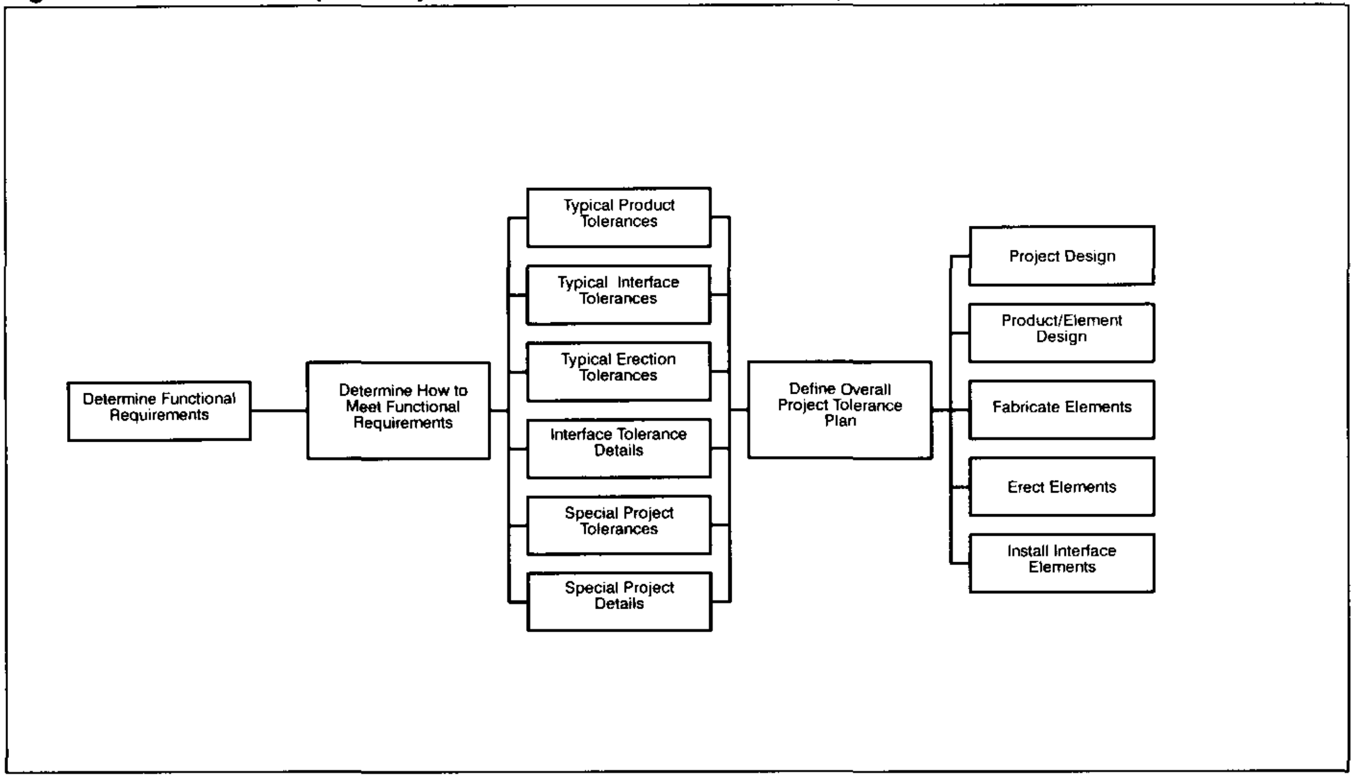


Fig. 1.4.2 Specifying Tolerances—Precaster Design-Build Contract

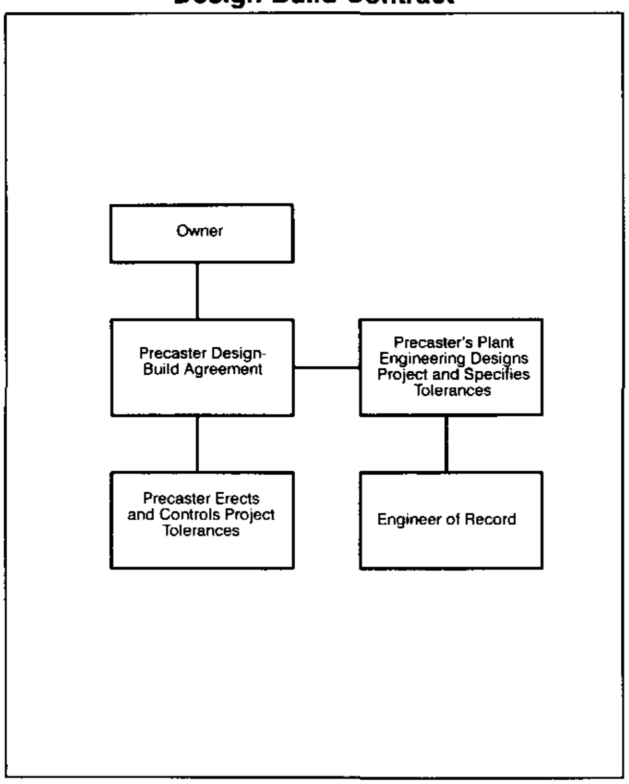


Fig. 1.4.3 Specifying Tolerances—Design-Bid Contract

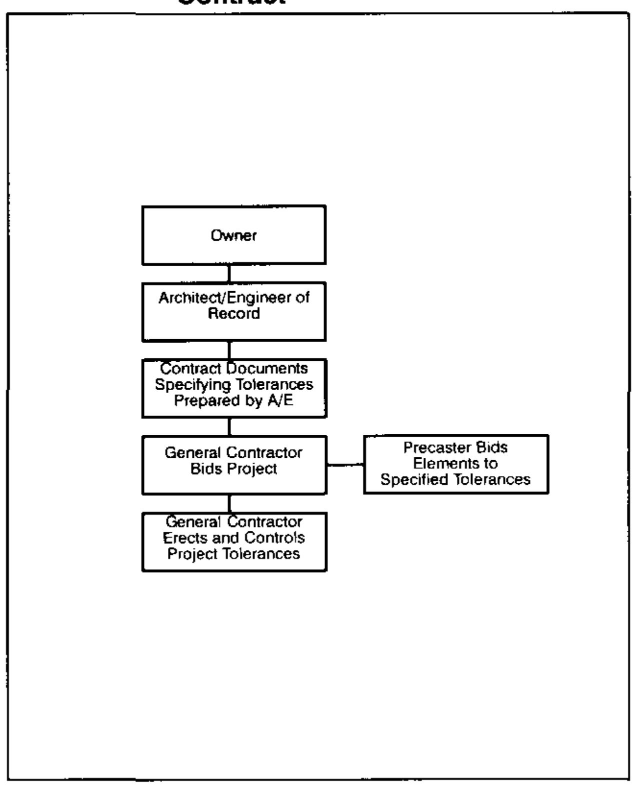


Fig. 1.4.4 Tolerance Responsibility*

Project Activity	Owner	Architect/ Engineer	General Contractor	Precast Plant Man-agement	Precast Plant Engineer-ing	Precast Plant Quality Control	Erector Manage-ment	Erection Quality Control	Comments
Set Requirements	P								
Determine How to Satisfy Requirements		P							
Define Overall Project Tolerance Plan		R/A	P	I	I				
Specify Typical Product Tolerances		P			I				
Specify Typical Interface Tolerances		P			I		I		
Specify Typical Erection Tolerances		P			I		I		
Select Interface Tolerance Details		R/A			P				
Identify Special Project Tolerances		P			I				
Accept Project Tolerances			R/A	R/A			R/A		
Confirm Product Tolerances Achieved						P			
Confirm Erection Tolerances Achieved								P	
Confirm Interface Tolerances Achieved			P						

Legend: P = Prime Responsibility R/A = Review and Approval Authority I = Input Required From

* The responsibility for various activities concerning tolerances varies from region to region and from project to project depending on differences in the contractual requirements.

1.5 Custom Nature of Building Construction

It should be noted that tolerance determination in building design and construction is substantially different from the practices used in machine design and assembly. Modern machine design relies on the ability to incorporate completely interchangeable close tolerance parts into the machine assembly. To accomplish this the machine industry has developed the concept of True Position Dimensioning which allows close tolerance mating parts to be produced independently with the assurance that if specified tolerances are met the parts will fit properly 100 percent of the time.

Precast concrete construction has moved toward the machine design tolerance philosophy when compared to most other large building element construction methods. However, design practice and economical fabrication and erection tolerance realities do not allow the same assurance of the 100 percent fit up 100 percent of the time, without giving special attention to the overall construction tolerances of all of the elements of the construction project.

Careful consideration of how the overall tolerance system (product tolerances, interface tolerances, joint clearances, and erection tolerances) accommodates tolerance variations is necessary. The use of tolerance accommodating details, which in some instances allow very significant tolerance variations to be appropriately handled, is also necessary in some instances.

Building construction principally involves custom work with relatively large dimensional tolerance variations. Thus even after appropriate member and erection tolerances are specified and appropriate interface details are incorporated in the design, the building team members must be vigilant in the early identification and resolution of out of tolerance situations which may develop in any aspect of the overall building system. By doing this, tolerance related rework will be minimized.

2.0 Introduction

The tolerance information contained here has been developed for use primarily by precast and precast prestressed concrete producers, erectors, quality control agencies, architects and engineers and related or interfacing trades unless other tolerances are noted in the project drawings or specifications.

In the event that the project tolerances are set by the precast producer, rather than the architect/engineer, all involved parties agree in advance of any production, what the project tolerances will be. If tolerances different from PCI standard tolerances are used on a project, the specified tolerances on that particular project should be shown on the project shop drawings and, as applicable, on the erection drawings. In lieu of showing tolerances on each shop drawing, a tolerance drawing for the project can be prepared to make the production personnel aware of the project tolerance requirements.

The producer's personnel should review the contract documents and make sure that the specified tolerances are appropriate to the individual components. If revisions are deemed necessary by the review the architect/engineer should be notified by the producer so that any proposed revisions can be approved and/or implemented by the architect/engineer.

2.1 Groups of Tolerance Issues

Final component details for precast concrete products should conform to three groups of tolerances which have been established as part of the precast concrete design process. These are product tolerances, erection tolerances and interfacing tolerances.

Product Tolerances

Product tolerances are defined as those tolerances related to the dimensions and dimensional relationships of the individual precast concrete members. Article 10.0 provides a compilation of recommended product tolerances for precast concrete products. Articles 7.0 through 9.0 discuss the specification of these values and the methods of verifying tolerances after casting.

Many times a control surface tolerance will control over a feature tolerance. This concept is discussed in detail in Article 6.0. The allowable variation for one element of the structure should not be such that it will cause another element of the structure to exceed its allowable variations.

Erection Tolerances

Erection tolerances are defined as those tolerances which are required for the acceptable matching of the precast members after they are erected. Article 11.0 provides a comprehensive discussion of the principles and considerations relative to precast concrete erection tolerances. Additional information pertaining to erection tolerances that should be anticipated in the tolerance specification review and construction of precast concrete structures is provided in Article 12.0.

Interfacing Tolerances

Interfacing tolerances are those tolerances which are associated with other materials or building systems in contact with or in close proximity to precast concrete, both before and after precast erection. Article 17.0 provides guidelines for the proper dimensional specification of interfacing materials in conjunction with precast product and erection tolerances.

2.2 Tolerance Categories

There are six categories of tolerance issues for the three tolerance groups given above. The principal concern of each category is as follows.

Structural

To control the member dimensions and dimensional interface in order to assure that dimensional variations do not change the loading configuration or capacity of a member as assumed by the designer. Tolerances which are critical for structural performance of members and or connections should be indicated as such by the architect/engineer on the project design drawings.

The architect /engineer should also indicate the tolerances that stem from the requirements of overall structural integrity.

Feasibility

To ensure acceptable performance of joints and interfacing materials in the finished structure and to ensure that designs and details are attainable with available manufacturing and construction techniques.

The established tolerances or required performance should fall within generally accepted limits and should not be made more stringent, and therefore more costly, than is absolutely necessary.

Tolerances more restrictive than those discussed in this document should be brought to the attention of the architect/engineer to ascertain that they are compatible and that the proposed restrictions can be met. For example, a requirement which states that "no bowing, warping, or movement is permitted" is not practical or possible to achieve.

Visual

The variations in the finished product should be controllable and result in an acceptable appearance. Tolerances related to visual effects or aesthetics may be significantly more stringent than those required for structural or functional reasons. Tolerances which are critical to project aesthetics should be indicated as such by the Architect/Engineer.

Economics

To ensure a reliable and efficient rate of production and erection by having a known degree of accuracy in the dimensions of precast concrete products. The cost of working to tighter than standard product tolerances should be evaluated for cumulative cost effects at the project level. That is, one should evaluate both the cost increases and cost savings for member fabrication, interfacing with subsystems and erection to determine the most economical approach to handling the project tolerance requirements.

Legal

To avoid encroaching on property lines and establish a tolerance standard against which the work can be compared in the event of a dispute.

It is very important to agree on the project tolerances in writing, particularly with special tolerances or in situations with critical visual aesthetics. Similarly, it is equally important to agree in advance how and when these tolerances will be verified (with due consideration for measurement methods, measurement locations, number of points to measure, support conditions, thermal conditions, and time of measurement).

Contractual

To establish a known acceptability range and assign responsibility for developing, achieving, and maintaining mutually agreed tolerances for the project. The producer's quality control staff should understand what the producer's contractual obligations are regarding project tolerances. The actual project tolerances contractually agreed to may be different from the charted values given here.

3.0 Responsibility for Project Dimensional Control

Once the tolerances for the various members have been specified and contractually agreed to by the producer, appropriate connection details which consider those tolerances should be designed by or approved by the party responsible for the tolerances. Then the production of the members should be organized to ensure that the specified tolerances are recognized and tolerance compliance is verified during the member fabrication process. An organized quality control program with a strong focus on dimensional tolerance control is a necessary part of the production effort.

While the detailed assignment of responsibility for the dimensional tolerance determination of the various elements of the construction project may vary (depending upon the contractual arrangement for a particular project), these responsibilities should be clearly assigned and communicated to all members of the project team.

In the erection phase of the project, the various elements must be assembled in accordance with the established erection tolerances. Erection quality assurance plans will include a clear definition of responsibilities for tolerance verification and adjustment, if necessary, of both the erected precast concrete structure and any interfacing structure.

In the event that fast track approval of shop drawings precludes use of formally "approved" shop drawings an alternative system should be developed to assure that the drawings in use by the production staff are the correct version of the drawings.

3.1 Handling a Pre-pour Tolerance Discrepancy

An out of tolerance discrepancy discovered in advance of the placement of concrete should always be corrected to nominal tolerance prior to the placement of concrete.

The plant should have documented procedures regarding the manner in which pre pour discrepancies noted by the quality control personnel are communicated to the production personnel for correction. These procedures should include a follow-up step to assure that noted discrepancies have in fact been corrected prior to concrete placement.

3.2 Handling a Post-Casting/Pre-Shipment Tolerance Discrepancy

An out of tolerance discrepancy discovered after the placement of concrete should be documented and evaluated to determine what, if any, corrective action is needed. The plant should have documented procedures regarding the manner in which post-pour discrepancies noted by the quality control personnel are communicated for evaluation. The procedure should outline which individual within the plant is authorized to evaluate the consequences of such discrepancies.

These procedures should include a follow-up step to assure that noted discrepancies have either been corrected or that other appropriate steps have occurred, (such as notification of the field erection crew if the problem can be solved during erection). It is always better to evaluate post-pour tolerance discrepancies before the member is shipped to the construction site. The producer's representative should evaluate whether or not the architect/engineer needs to be involved in the resolution of any specific discrepancy.

3.3 Handling a Tolerance Discrepancy Discovered During Erection

Because tolerance discrepancies discovered in the field must be handled in the field, the precast engineer should provide guidelines regarding the manner in which these sorts of problems are to be resolved. The producer's representative should evaluate whether notification of the design team regarding the problem is required. Adhere to any notification provisions in the contract.

In some cases it may be possible to substitute another similar piece and return the out of tolerance member to the plant for correction. In other instances a field repair crew may need to be deployed to the field on an immediate basis to make necessary corrections. Because of the potential cost and schedule consequences of this situation the plant quality control plan should be organized to minimize this occurrence.

4.0 Tolerance Acceptability Range

The tolerances shown in this document are guidelines for acceptability. Many projects involve situations which require variation from the published tolerances. Only the recognized and agreed upon "project tolerances" govern the production of the precast members.

Not all tolerances are critical in every case, particularly when the structural or architectural performance is not impaired. In some circumstances, the architect/engineer may accept an out of tolerance member if it conforms with any of the following:

a. Exceeding the project tolerances does not affect the structural integrity; or architectural performance of the member. Often the input of the Engineer of Record is necessary to evaluate the consequences of out of tolerance situations.

b. The member can be brought within project tolerance by structurally and architecturally satisfactory means. Repair methods used to correct tolerance problems should not compromise structural performance or long term durability.

c. The total erected assembly can be modified to meet all structural and architectural requirements.

Modification of erection activities to accommodate out of tolerance members requires close coordination between the producer's representative and the erector.

5.0 Definitions of Tolerance Related Terms

The following definitions should apply to tolerances for precast and precast prestressed concrete products:

Accuracy of measurement—Conformity with the actual value of the measurement.

Accuracy is not necessarily associated with the notion of close conformity with the true value, which is a measure of precision.

Architect of Record—The individual design professional responsible for, among other things, specifying the appearance of the finished structure. It may be necessary to gain the approval of the Architect of Record for any proposed tolerance repair methods which will be visible in the completed structure.

Architectural precast concrete— A precast concrete product with a specified standard of uniform appearance, surface details, color, and texture.

Tolerances for architectural precast products are generally more stringent than for structural products because of the increased importance of appearance. This class of product generally is associated with a premium cost.

Bowing—An overall out-of-planeness condition which differs from warping in that while two edges of the panel may fall in the same plane, the portion of the plane between the edges is out of plane. (See Warping.) Bowing tolerance is usually most important in wall panels that are exposed to view. Bowing can occur in more than one direction.

Building survey datum—The local survey datum established for the global erection of the building to the design plan layout and elevations.

Camber— (1) The deflection that occurs in prestressed concrete members due to the net bending resulting from stresses associated with the effects of the prestress force (not including dimensional inaccuracies); and (2) a built-in curvature to improve appearance.

Camber control is generally more of a concern in long prestressed members where there is increased potential for differential camber in adjacent members.

Groups and Categories of Products—The PCI Plant Certification Program is focused around four groups of products and categories within those groups designated as indicated in Table 5.0.1.

Table 5.0.1 Product groups and categories

Group A—Architectural Products	
	Category A1—Architectural cladding and load bearing members
	Category AT—Precast concrete architectural trim
Group B—Bridge Products	
	Category B1—Bridge products, not prestressed
	Category B2—Bridge products prestressed, excluding bridge beams
	Category B3—Bridge superstructure using straight prestressing
	Category B4—All products in Category B plus draped strand bridge superstructure
	Category BA—Bridge elements with special finishes
Group C—Commercial (Structural)	
	Category C1—Commercial products, not prestressed.
	Category C2—Prestressed hollow-core and similar products
	Category C3—Commercial products using straight prestressing
	Category C4—Commercial products using draped prestressing
	Category CA—Commercial structural elements with special finishes
Group G—Glass Fiber Reinforced Concrete Products	

Products in Group A are subject to architectural tolerances. Products in groups B, C, are subject to structural tolerances. Categories CA and BA are subject to structural tolerances unless they are specified category A1 with Special Project Tolerances which may be a combination of specially defined structural and architectural tolerances.

Group A—Architectural Products. These are products produced in accordance with the requirements of MNL-117. Within Group A, products in categories A1 – architectural cladding and load bearing members, and AT – architectural trim units are generally considered subject to architectural tolerances. This group includes concrete building elements all of which are exposed to view.

Category A1 is architectural cladding and load bearing members. This category includes concrete building elements such as exterior cladding, load bearing and non-load bearing wall panels, spandrels, beams, mullions, columns, column covers. Category AT is precast concrete architectural trim units, products with a high standard of finish quality and of relatively small size that can be installed with equipment of limited capacity. Included in this group are sills, lintels, coping, cornices, quoins, bollards, medallions, benches, planters, and pavers.

Group B Bridges—This group includes all bridge products. The group is subdivided into B1, B2, B3, and B4 categories. These products are considered structural products. Category B1 products are typically not prestressed, B2 products are prestressed bridge related products excluding bridge beams, B3 products are superstructure members using straight prestressing strand, B4 includes all products in B1 through B3 plus draped strand bridge members. Category BA includes products fabricated using forms and techniques common to the production of structural members (Group B) and having specified surface finishes that require uniformity and detailing more demanding than the typical requirements for structural products.

Group C Commercial (Structural)—This group includes all commercial products. The category is subdivided into C1, C2, C3, and C4 categories. These products are considered structural products. Category C1 products are typically not prestressed, C2 products are prestressed hollow-core and similar repetitive products, C3 products are prestressed members using straight strands, C4 are products using draped prestressing strands. Category CA, this category includes products fabricated using forms and techniques common to the production of structural members (Group C) and having specified surface finishes that require uniformity and detailing more demanding than the typical requirements for structural products.

The surface finish requirements for these members should be clearly specified and verified with appropriate samples and mockups. Included in this category are parking deck structural spandrels with a special finish. Typically these members are used on projects for reasons of economy. They are fabricated to structural tolerances unless Special Project Tolerances are specified, which may be a combination of structural and architectural tolerances.

Group G—Glass Fiber Reinforced Concrete. These products are reinforced with glass fibers that are randomly dispersed throughout the products and are made by spraying a glass fiber, cement, and sand slurry mixture into molds. This produces thin walled lightweight cladding panels. Products are manufactured according to the quality requirements of MNL-130.

Clearance—Interface space (distance) between two elements. Clearance is normally specified to allow for the effects of product and erection tolerances and for anticipated movement such as deflection, volume change movement, etc.

Clear distance—The least distance between the surface of the reinforcement and the referenced surface. The referenced surface may be the form, adjacent reinforcement, embedments, concrete surface, or other surfaces.

Concealed surface—Surface not visible during normal use of the member.

Tolerances for concealed surfaces may not be as critical as for surfaces which are exposed to view in the finished structure.

Connection—Device for the attachment of precast concrete members to each other, to the building or to the structure. Connection design must often account for the cumulative effects of all allowed tolerance variations.

Contract documents—General conditions, project specifications and design drawings issued on behalf of the owner by the design professionals of record (architect/ engineer) and from which the project shop drawings and production drawings are developed.

It is good practice to initially review the contract documents to see if tolerances for the precast members have been specified. If not, amend the contract to include specific definition of the planned approach to project tolerances. Blanket reference to this document without specifying specific tolerances should be avoided.

Control surfaces—The following are several different categories of surfaces relevant to precast concrete tolerance control and erection.

Alignment face—The face of a precast member which is to be set in alignment with the faces of adjacent members or features. The alignment face is usually a primary control surface. This is the member face that is usually exposed to view in the final structure.

Primary control surface—A surface or feature on a precast member, the dimensional location of which is specifically set and controlled in the erection process. Primary control surfaces are generally associated with the key dimensional features of the structure. (for example a column haunch support surface)

Secondary control surface—A surface or feature on a precast member, the dimensional location of which is dependent on the location tolerance of the member primary control surfaces plus the member feature tolerances. An example would be the elevation of a second-story corbel on a multistory column whose first-story corbel elevation is selected as the primary elevation control surface.

Cover—The distance between the surface of the reinforcement and the nearest concrete surface.

Creep—Dimensional change, usually shortening or camber change, which takes place as result of sustained compression loading and prestress force on concrete elements. The magnitude and rate of creep depends on various factors including concrete characteristics and the level of compression loading.

Dimensions—The following are several different categories of dimensions relevant to precast concrete fabrication.

Actual dimensions—The measured dimension of the precast member after casting.

The actual or as-built dimension may differ from the working dimension due to construction and material induced variation.

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. It may also be called the "nominal" dimension.

Working dimension—The planned dimension of the precast member obtained from its basic dimension the necessary joint or clearance dimensions, and other adjustments.

It is to this planned working dimension that the product tolerance is applied. For example, if a nominal 8 ft. [2.44 m] wide double tee wall panel is designed to have a nominal ¾ in. [19 mm] wide joint on either side, the working dimension for the member width would be 7 ft. 11¼ in. [4.42 m].

Discrepancy—Indicates the difference between planned dimension and actual dimension. The existence of a discrepancy frequently reveals the need for closer monitoring. Less precise measurement techniques tend to obscure problems that more precise techniques may reveal.

Draft—The taper given to features of a mold or form to allow the precast piece to be removed from the mold or form without damage. Draft can result in different feature dimensions between the front and back of a piece.

Engineer of Record—The design professional legally responsible for the overall structural design of a building or facility, for determining and setting the load requirements, and for coordinating the designs performed by a speciality engineer with the overall system. Generally this is the individual who has sealed the contract design drawings (not the precast shop drawings) with his or her professional engineer's stamp.

Errors in measurement—The following are different types of errors in measurement which must be considered.

Systematic error—An error that invariably has the same magnitude and the same sign under the same given conditions. Thus a cloth tape that has been stretched about 5 percent by overuse will consistently measure a 40 in. dimension as just over 38 in.

Natural errors—Systematic errors that arise from natural phenomena. They are really the effects of certain influences that operate to prevent the observer from seeing or reading directly the quantity being sought. Two instances are the refraction of light rays and the thermal variation of measuring devices. (for example thermal length changes in metal measuring tapes).

Instrumental errors—Are the systematic effects of imperfections in the construction or adjustment of instruments used in making measurements. Instances include the lack of concentricity of transit circles, graduation errors in scales, and maladjustment of the bubble tubes of levels.

Personal errors—This systematic error depends on the physical limitations and also on the habits of the observer. Some observers may have a slight tendency to observe to the right or left in estimating tenths, or have poorly coordinated vision. The amount of such error is usually small, though erratic.

Accidental Errors—These errors of observation are random; they are usually small and then have a tendency to be mutually compensating. The appearance of discrepancies in a series of measurements is one example.

Flatness—The degree to which a surface approximates a plane. See Smoothness. This tolerance is most important in wall and slab members.

Formed surface—A concrete surface that has been cast against form work.

Hardware—Items used in connecting precast concrete members or attaching or accommodating adjacent materials or equipment.

Generally suppliers of hardware can provide information regarding required placement tolerances for their hardware products.

Hardware is normally divided into the following three categories:

Contractor's hardware—Items to be placed on or in the structure in order to receive the precast concrete members, e.g., anchor bolts, angles, or plates with suitable anchors.

Since the precast members must interface with this hardware, it is important to understand the tolerance to which these elements are to be installed. Confirm the as-built location of this hardware in advance of the precast erection activities.

Plant hardware—Items to be embedded in the concrete members themselves, either for connections and precast concrete erector's work, or for other trades, such as mechanical, plumbing, glazing, miscellaneous iron, masonry, or roofing trades. The placement tolerances for this hardware often must consider the installation requirements of the systems the hardware must interface with.

Erection hardware—All loose hardware necessary for the installation of the precast concrete members.

Jig—A template or device to align parts of an assembly, usually for pre-assembling reinforcing steel and hardware cages and positioning of anchor bolts on site, with a minimum of measurement to attain consistent accuracy from one casting to the next. The use of templates in the plant and the same or matching template for placement of the contractor's hardware in the field is a good way to assure fit-up of mating connection elements.

Jog in alignment—The difference in elevation of the top or bottom of one wall panel relative to the adjacent wall panel measured at the mating edges of the panels.

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

Level alignment—The vertical 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.

Match casting—A precast concrete fabrication procedure whereby a segment is cast against the preceding segment thereby producing a matching interface that will permit re-establishment of the cast geometry at the time of erection. Match-casting may be accomplished by either the short line casting method or the long line casting method.

Short line match casting—The method of casting segments one at a time on the casting bed utilizing a fixed or movable bulkhead. The first segment is cast between bulkheads.

Successive segments are cast, one at a time, against the bulkhead on one end and the repositioned, previously cast segments on the other end.

Long line match casting—The method of casting segments on a casting bed of sufficient length to permit the cumulative casting of segments for the entire length between field closure pours without repositioning the segments on the casting bed. With this method, the first segment is cast between bulkheads and successive segments are cast between a movable bulkhead on one end and the previously cast segment on the other end.

PCI quality manuals—MNL-116 *Manual for Quality Control for Plants and Production of Precast and Prestressed Concrete Products*. This is the document prepared by PCI as a guideline for quality assurance of all precast concrete except architectural precast and glass fiber reinforced concrete (GFRC). MNL-117 *Manual for Quality Control for Plants and Production Of Architectural Precast Concrete Products*. This is the document prepared by PCI as a guideline for quality assurance of architectural precast concrete. MNL-130 *Manual for Quality Control for Plants and Production of Glass Fiber Reinforced Concrete*. This is the document prepared by PCI as a guideline for quality assurance of glass fiber reinforced concrete products.

Post-tensioning—A method of prestressing concrete whereby the tendon is kept from bonding to the plastic (wet) concrete, then stressed and anchored directly against the hardened concrete, imparting stresses through end bearing at an anchorage. Post-tensioning has the effect of shortening a member in the direction axial to the post-tensioning and may result in camber. This shortening and the effects of camber should be included in the length tolerance considerations.

Precast Engineer—The person or firm who designs precast concrete members for specified loads and who may also direct the preparation of the shop drawings. The responsibility for the design of the precast members and of the overall structure (including the overall tolerance plan) is determined by contract and should be specifically defined in the project contract.

Precast linear member—Beam, column, or similar member.

Precast planar member—Wall panel, floor panel or similar member.

Precision of measurement—A measure of the closeness of conformity with the actual value. Precision is related to the degree of care and refinement employed in making a measurement.

Accuracy of measurement is descriptive of the correctness of the result of the measurement.

Pre-tensioning—A method of prestressing concrete whereby the tendons are elongated, and then anchored while the concrete in the member is cast around the tendons. The tendons are then released when the concrete is strong enough to receive the forces from the tendon through bond.

Once the prestress force is transferred to the concrete member the member will shorten and possibly camber. These dimensional changes need to be considered in the product tolerances, the erection tolerances, and the interface tolerances.

Pre-topped systems—A construction approach, such as may be used for the floor system in parking garages, in which the flange for the floor member, often a double tee, is constructed to its final thickness in the plant, resulting in no cast-in-place topping being required in the field. This approach can be very efficient in that it reduces the amount of field construction work. It does however, require closer control of tolerances such as differential camber, flange connector placement and overall member depth.

Project specifications—The building or facility specifications which define specific requirements for the elements of the project. Specifications can employ PCI tolerance recommendations by reference to specific tolerances given in this document. The specifications serve as the instrument for making mandatory and optional selections available under the specific project specifications and for specifying items not covered in this document.

Quality—The appearance, strength, durability, and dimensional conformance which is appropriate for the specific product, its particular application and its expected performance requirements. Quality also refers to the totality of features and characteristics of a product that bear on its ability to satisfy stated needs.

Quality assurance (QA)— All those planned or systematic actions necessary to ensure that the final product or service will satisfy given requirements for quality; and performance of intended function. Typically, the quality assurance effort will focus on the requirements of the overall project, thus identifying the tolerance quality control requirements for member fabrication.

Quality control (QC)—Those planned actions , which provide a means to measure and control the characteristics of members and materials to predetermined quantitative criteria.

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.

Set-up—The process of preparing molds or forms for casting, including installation of materials (reinforcement and hardware) prior to the actual placing of concrete. The set-up process is second only to the mold or form construction in its importance in the achievement of specified member tolerances.

Shrinkage—The volume change in precast concrete members caused by drying that normally occurs during the curing and initial life of concrete members. The expected shrinkage must be subtracted from the form set up dimensions to determine the as-cast dimensions of a member.

Shop drawings—(1) Collective term used for erection drawings, production drawings and hardware details; and (2) Diagrams of precast concrete members and their connecting hardware, developed from information in the contract documents. Shop drawings show information needed for both field assembly (erection) and manufacture (production) of the precast concrete members.

Erection drawings—Those drawings which show the relationship of the precast members and their connections in the erected structure and which provide such information as is necessary to properly erect and connect the various members.

Production drawings—A set of instructions in the form of diagrams and text which contain all the information necessary for the manufacturer to produce the precast member. These documents are usually produced by or under the direction of the precast plant engineering department or by a party hired by the producer to do this.

Hardware details—Those drawing details which are used for the fabrication or procurement of hardware which is used either in the production of the precast member or in its erection and connection.

Smoothness—The absence of local irregularity or roughness. It does not refer to the overall shape of the member.

Speciality Engineer—A licensed engineer, not the Engineer of Record, who performs structural engineering functions necessary for the structure to be completed. He has shown experience and/or training in his specialty.

Specially finished structural precast concrete—A product fabricated using forms and techniques common to the production of structural members and having specified surface finishes that require uniformity and detailing more demanding than the typical requirements for structural members.

These surface finishes and any special tolerance requirements for this class of member should be clearly specified and verified with appropriate samples and mockups. These products are defined as Groups CA or BA if they use structural tolerances and Group A1 if they use architectural tolerances.

Statistical tolerance control concepts—A mathematically valid approach of sampling and monitoring tolerances on projects which have large numbers of identical pieces made using industrial tolerance control methods.

Step in face—The dimensional difference between the edges of the planar surfaces of two adjacent wall panels measured at the mating edges of the two panels. The more perfectly the panels match dimensionally at the edges the less the step in face.

Strand—A group of wires laid helically over a central-core wire. A seven-wire strand would thus consist of six outer wires laid over a single wire core. High strength steel strand is typically used to prestress concrete.

Structural precast concrete—Precast concrete members that are intended to support external structural loads in addition to their own weight. They are fabricated using methods which are optimized to economically produce members with specified structural properties. Appearance requirements for these members is secondary to their structural requirements. The fabrication techniques used for structural precast concrete (for example, long line casting in forms with movable bulkheads), limit some of the dimensional precision possibilities with this type of manufacturing process.

Sweep—A global variation in member horizontal alignment. This can sometimes be caused by horizontally eccentric prestress in narrow members.

Tendon—A high strength steel element consisting of one or more wires, strands, or bars or a bundle of such elements, which are stressed and used to impart prestress to the concrete.

In prestressed products the position of the tendons is one of the most important of all tolerances, as variation in tendon location affects the structural capacity of the element.

Theoretical casting curve—The curve of casting geometry followed at the casting bed for segmental precast members to achieve the theoretical profile of the completed structure after final deformations have taken place. This calculated curve takes into account deformations resulting from the sequence of erection and loads applied during erection.

Tolerance—Specified permissible variation from specified requirements such as dimensions, location and alignment such as:

- the permitted variation from a basic dimension or quantity, as in the length, width, and depth of a member.
- The range of variation permitted in maintaining a basic dimension, as in an alignment tolerance.
- A permitted variation from location or alignment.

Architectural tolerances—The tolerances given in Article 10.1 for architectural panels define architectural tolerances. Member finish and color are separate issues which are often important in the production of architectural concrete members. Architectural dimensional tolerances can be applied to other product types as special project tolerances. There is no intent to split tolerances between structural and architectural tolerances on the basis of finish or color. Finish and color are separate issues related to project aesthetic requirements.

Structural tolerances—The tolerances given in Article 10.0 with the exception of the architectural tolerances given in Article 10.1, architectural trim tolerances given in Articles 10.29, 10.30 and 10.31 for architectural trim elements and Article 10.28 for railroad ties. These tolerances apply to structural precast concrete members that are fabricated using methods designed to produce economically feasible members with specified structural properties.

Finish and color are usually less important for members governed by structural tolerances. When the finish and or color of structural members are important to the project, this should be specifically noted in the contract documents, as special measures may be required to achieve the desired result.

Project tolerances—The required tolerances for a specific project. If the specified tolerances differ from the tolerances given in this document for a specific product group or category, it is in the interest of all parties to agree in writing to the project tolerances.

Special project tolerances—Specially required tolerances, different from standard PCI tolerances given in this publication which are required to meet specific project requirements.

Tolerances different from those listed in this document may be agreed to for a specific project. These tolerances could be either less stringent or more stringent than the tolerances listed here.

It should be noted that the requirement for special project tolerances may have a significant impact on project price and schedule.

Product tolerances—Those allowable variations in dimensions relating to individual precast concrete members.

Control surface tolerance—Tolerances which are related to element control surfaces that are set or aligned to be within the specified project erection tolerances.

Feature tolerance—The allowable location or dimensional variation of a feature, such as a corbel or a blockout, with respect to overall member dimensions. Feature tolerances are a characteristic of the individual precast members.

Erection tolerances—Those allowable variations in dimensions of member placement in the completed structure required for acceptable matching of precast members after they are erected.

Erection tolerances are a characteristic of how the individual members are positioned both globally and relative to one another in the overall structure.

Interfacing tolerances—Those allowable variations in dimensions associated with other materials or systems in contact with or in close proximity to precast concrete.

Interface tolerances could include the tolerances of cast-in-place concrete footings, structural steel or cast-in-place concrete frames, and subsystems like windows, doors, heating and ventilating system elements, and the like.

True position dimensioning—A system of dimensioning used in the machine design industry to assure that close tolerance parts are universally interchangeable. Some of the concepts of this tolerancing system may be of interest to the precast producer for special situations. See the reference section for publications which address this tolerance system.

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

Vertical alignment—The location relative to a 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 horizontal location of the surface relative to the specified profile.

Warping—Twisting of a member, resulting in overall out-of-plane curvature of surfaces characterized by non-parallel edges.

Warping is most often a concern in panel members, although it can occur in other types of members.

6.0 Relationships Among the Different Tolerance Groups

The relationship among the different tolerance groups must be consistent in order to avoid tolerance related rework of building members. A careful review of which tolerances are primary and which secondary and a review of how product and erection tolerances relate on a particular building project will determine which tolerances are cumulative and which are not.

6.1 Relationship of Product Tolerances

Product tolerances define the limits of the size and dimensional precision of the individual precast members comprising the building or structure. The product tolerance also controls the location of the member features as they relate to the overall member dimensions.

In lieu of showing the member tolerances on each shop drawing, a project tolerance drawing can be used to convey the required project tolerances to the production personnel. The producer should review project specifications and design drawings to determine if surface and feature dimensional control requirements are clearly outlined. If clarifications are needed the architect/engineer should be notified.

6.2 Relationship of Erection Tolerances

Erection tolerances define the location and placement of the individual precast members in the assembled structure. The individual precast member is erected and positioned so that its primary erection control surface is in conformance with the established erection tolerances.

See Articles 11.0 and 12.0 for further discussion of erection tolerances.

During precast panel installation, priority is generally given to aligning the exterior face of the precast panels to meet aesthetic requirements. This may result in the interior precast panel face not being in a true plane.

Product tolerances for member primary control surfaces are not additive to the erection tolerances which govern the setting of the member primary erection control surfaces.

The secondary control surfaces of a member (for example the surfaces of a blockout) usually are not directly set during the erection process. Thus, the product tolerances for secondary control surfaces and features of the member are additive to the erection tolerances for the member. To ensure a trouble free installation, generally, the product tolerances must not conflict with the erection tolerances.

Erection tolerances and product tolerances for some features of a precast concrete member may be directly additive while others are not. This fact should be communicated to production, quality control and erection personnel and may be shown on the erection drawings if relevant to the erection activity. Knowing which member surfaces are the primary erection control surfaces is important to the erection effort.

If special project tolerances, other than standard PCI tolerances are used, in lieu of showing the erection tolerances for each piece, a tolerance drawing for each erection situation can be used to convey the required project tolerances to the erection personnel.

In instances where the tolerance of both primary and secondary control surfaces must be controlled during erection, the design should be reviewed by the producer and erector to assure that the details include provisions for secondary control surface adjustment. If revisions are indicated by the review, the architect/engineer should be notified, as problems in the tolerancing system are easier to resolve before the pieces are produced.

6.3 Relationship of Interfacing Tolerances

Interfacing tolerances are those associated with other materials or systems which interface with the precast concrete members. Interfacing tolerances apply whether the interfacing system is erected prior to or following precast erection.

For interfacing situations which involve multiple members, both product and erection tolerance effects may have to be accommodated within the interface tolerance.

Product tolerances, erection tolerances and interface tolerances together determine the dimensions of the completed structure. If it is critical to the project, the system tolerances which take precedence on the given project should be reflected in the contract documents and should also be indicated on the project shop drawings.

See Article 17.0 for a discussion of interfacing tolerances.

As written, American Concrete Institute (ACI) document 117 "Standard Tolerances for Concrete Construction and Materials" applies primarily to reinforced concrete construction. Similarly the American Institute for Steel Construction (AISC) code of standard practice applies only to structural steel construction. Neither of these standards addresses tolerances for buildings of composite construction (i.e. concrete floor slabs carried by steel columns or steel frames with precast concrete cladding) Nor are tolerances for fireproofing and masonry controlled by referencing these standards. The producer should review the contract documents to assure that the location of all such materials contiguous to the precast concrete members have been controlled within tolerances which are, at most, no less stringent than those specified in ACI 117. Notify the architect/engineer if revisions to the contract documents are indicated by this review.

6.4 Project Economic Considerations

The precedence of product and erection tolerances raises questions of project economics. The tolerance requirements and other costs associated with the connection details should be reviewed by the producer in conjunction with the erector.

When accepted by the producer and/or erector as contractual requirements, special tolerance requirements, details, and procedures should be clearly spelled out in the project shop drawings. Special tolerances or construction procedures should be noted by the producer, as these require early decisions based on overall project economics. Once these decisions about forming, fabrication methods, and erection procedures have been made, they should be reflected on the project shop drawings.

6.5 Relationship of Form Tolerances to Product Tolerances.

Product tolerances are directly dependent on form manufacturing tolerances, the flexibility of the form, and the precision with which the variable features of the form can be adjusted.

In some cases, when long production runs of close tolerance members are required, the investment in very rigid, close tolerance premium formwork may be the best investment that can be made. This will serve to minimize any tolerance related problems and the associated costs.

7.0 Product Tolerances

Product tolerances are a measure of dimensional accuracy of the individual members and ensure, prior to delivery to the job site, the high probability that the member will fit into the structure without requiring tolerance related rework. See Article 10.0 for a listing of product tolerances.

The applicable product tolerances should be considered in the overall project tolerance plan, along with the appropriate erection tolerances and the required interfacing tolerances.

Product tolerances are needed in any manufacturing process. They are determined by economics, practicality, function and appearance. Product tolerances are applied to physical dimensions of precast members such as thickness, length, width, squareness, and location and size of member features.

At times, the user of a precast concrete product will specify special project tolerances for a particular project or member type. For example railroad authorities or governmental bridge authorities may often specify the necessary tolerances for products that they incorporate into their infrastructure. Therefore, the designer should consider PCI tolerances in conjunction with the tolerances specified by the controlling authority. If a specifying agency has tolerances more restrictive than PCI tolerances in the project specification, the more restrictive agency tolerances will govern the production of the project members.

7.1 Specification of Product Tolerances

See Appendix A for sample specification language regarding product tolerances. Project tolerances for manufacturing precast members and other interfacing systems are standardized throughout the industry and should not be made more rigid and therefore more costly, unless absolutely necessary. The producer should review the contract documents to assure that the architect/engineer has specified project product tolerances within a generally accepted range or has defined special measures to achieve a different level of tolerance. The requirement for such special measures should be defined in the project contract documents.

The per unit cost of the preparations and actions necessary to manufacture members to close tolerances usually decreases with increasing repetition involved on projects which consist of many similar precast members.

8.0 Overall Plan Dimension Tolerance Considerations

The two most important considerations in achieving specified product tolerances are the effects of formwork and the measuring techniques used to set the forms and assess the various product dimensions.

When considering the effects of product tolerances the following items are significant: When new, relocated, or modified forms are used, the initial member cast should be carefully measured to assure that all features are correctly formed and that all member tolerances are met. This process should be repeated when there is any reason to believe that the condition of the form may have changed.

Length or width dimensions and straightness of a member will all affect the joint clearance dimensions, opening dimensions between members, and potentially the overall length of the structure which incorporates the member. Thickness variation of the precast concrete panel member becomes critical when interior surfaces are exposed to view. A non-uniform thickness of adjacent members will cause offsets of the front or rear faces of the panels.

8.1 Effect of Forms on Dimensions

Forms are generally one of three types: rigid, semirigid, or flexible. See Fig. 8.1.1. The tolerances to which the forms are made and the tolerances to which they can reliably be adjusted are an important determinant of the ability to achieve specified member tolerances. The proportion of the product tolerance variation which results from form manufacturing tolerances or adjustment precision should be considered in the plan to achieve specified member tolerances. One of the most important considerations which should be taken into account in the selection of the types of forms to be used is the precision of dimensional tolerance specified for the member.

Effects of Rigid Forms

Rigid forms are those which have all the sides of the form rigidly and permanently fixed, thus ensuring a higher degree of dimensional accuracy than other form types, in both the length and width directions. Rigid 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. Large runs of repetitive use of forms can make the higher initial cost economically viable.

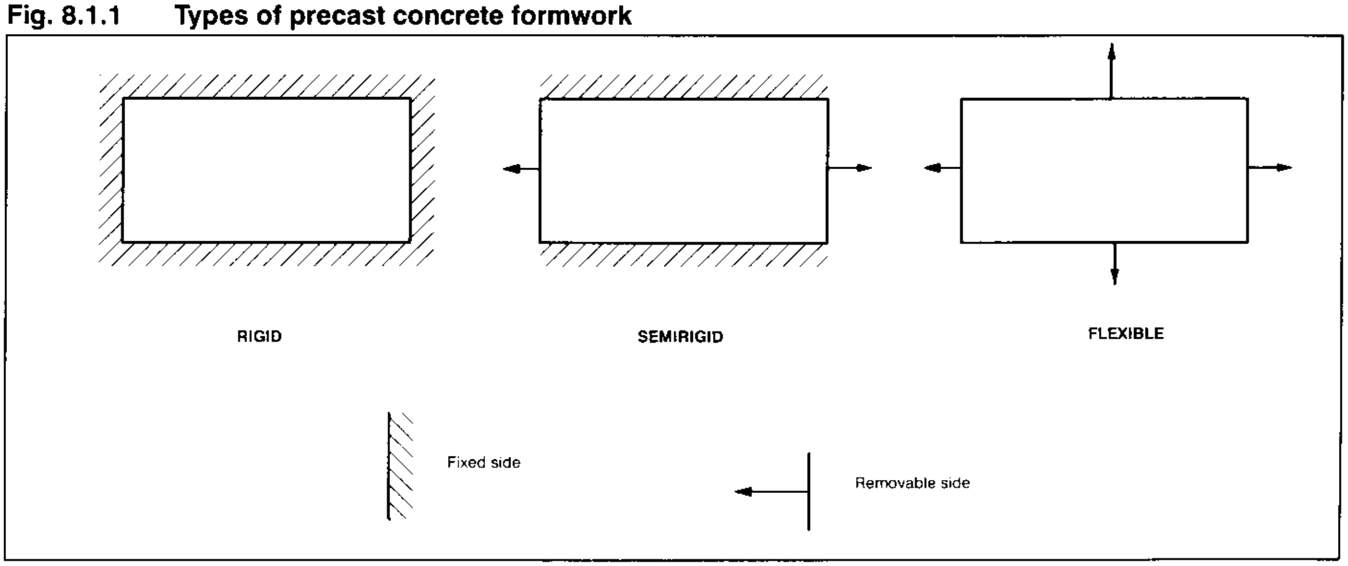
Side forms for rigid forms should have suitable draft. Draft is the slope or taper required on the forms to permit stripping of the precast member from the form.

Effects of Semirigid Forms

Semi-rigid forms are those which have two sides rigidly and permanently fixed. The other sides typically are made by using end dividers for long line casting or removable side forms to allow dimensional differences in individual pieces.

In semi rigid forms the end dividers or removable side forms are not permanently rigidly attached to the form, and thus must be set to the proper dimension for each panel casting. Because they must be set with each new casting length, they have the potential to move slightly during the placement and vibration of the concrete. This results in a lesser degree of achievable precision in linear plan dimensions than when rigid forms are used.

Fig. 8.1.1 Types of precast concrete formwork



Effects of Flexible Forms

Flexible forms have no permanent rigidly fixed sides. The typical product using such forms is a double tee with blocked-out flanges, or a flat wall panel on a project having many different sized wall panels. Of the three types of forms discussed here, flexible forms result in the least degree of achievable plan dimensional precision in both length and width.

8.2 Effects of Prestressing on Dimensions

The effects of prestressing can have a significant effect on member dimensions and should be considered in the plan to meet specified tolerances. The producer should assure that the effects of prestressing have been accounted for in determining the form setup dimensions for member casting.

It is very important to agree in advance on the conditions under which the tolerances of a member will be checked. (e.g. the agreed support conditions for measuring sweep of a long slender precast pile). In instances where stringent tolerances are required make sure that the affect of prestressing on member dimensions is clear within the project team. Put this agreement in writing prior to fabrication.

The prestress effects result in length changes, member camber, and end rotation all of which should be taken into account when determining the casting length for the member. The application of prestress force to the member can affect the overall length of the member in two ways. First, there is an axial shortening of the member as result of the applied axial compressive force of the prestress and second, the ends of the member may rotate in elevation as a result of the member camber caused by prestress eccentricity.

8.3 Effects of Time, Temperature, and Shrinkage on Dimensions

Because of concrete's tendency the creep under applied load or prestress, the shape and dimensional tolerance of a member has the potential to change over time. This is more of a concern for members which have high levels of eccentric prestress which can lead to changes in member camber or sweep over time.

Since the modulus of elasticity of concrete varies proportionally to its strength, the strength (and resulting modulus) of the concrete at the time of transfer of prestress may have an effect on member camber which can be significant enough to consider in the overall dimensional control program. This may be noticeable, for example, in differential camber of long cambered members which are cast on Friday and detensioned on Monday (less camber because of higher modulus at release) when compared with members cast during the week and detensioned the next morning after casting (more camber because of lower modulus at release).

If particular members within a project require high levels of dimensional stability over time, this requirement should be brought to the attention of the precast designer so that the prestress can be designed to reduce the potential effects of creep. Since this may involve the addition of more total prestress, it may have economic effects and this requirement should be treated as a special project tolerance.

The effects of differential temperature from one side of a member to another can cause the member to bow or camber. Similarly in long members the effect of lengthening and shortening due to wide extremes of temperature can be important to the overall length tolerance of members.

Solar heating of members stacked in the yard may cause sweep and camber variations due to differential temperature. These deformations may not be present in the completed structure if it is enclosed. Because of this it may be important to measure camber and sweep in the members at times when thermal effects in the piece are minimal. The opposite can occur with members that are exposed to thermal effects in the completed structure. The potential for undesirable deformation due to significant thermal effects should be brought to the attention of the precast design engineer for evaluation.

Shrinkage and differential shrinkage of the concrete members can also have an effect on the dimensional tolerances of precast concrete members. Although the great majority of the concrete shrinkage takes place during the initial curing of the member, its effect, particularly on large members, can be significant and should be accounted for in the tolerance control of the member. Differential shrinkage, particularly in members which have different mixes with different shrinkage characteristics, can result in member bowing, warping, or camber. Differential shrinkage of face and back up concrete mixes in architectural members or in different mixes which may be used for the interior and exterior wythes of insulated panels is something that should be assessed with regard to the effect on member bowing and warping tolerances.

8.4 Relation of Measuring Techniques to Tolerances

Accurate measuring devices and methods with the precision capability appropriate to the tolerance being controlled should be used for both setting and checking product, interface, and erection tolerances. Typically, the precision of the measuring technique used to verify a dimension, either pre or post casting, should be capable of reliably measuring to a precision of one-third the magnitude of the specified tolerance.

The most common measuring method used in precast plants is the use of metallic measuring tapes graduated in feet, inches and fractions of a inch. (meters and millimeters) For economic and functional reasons, the use of more sophisticated measuring instruments, such as surveying instruments, may be justified in some instances. To maximize accuracy, members should not be measured in increments in a manner which creates the possibility of cumulative error. (For example, use a tape long enough to measure the entire length of a member.) The degree of accuracy in using measuring tapes depends on the particular dimension of the member being measured. To attain greater precision in the linear dimensions of long members measuring tape slope, tape sag, tape tension, and temperature effects should be taken into account.

8.5 Tolerances for Blockouts and Openings

A tolerance, consistent with the eventual function, size and location of the block out should be indicated on the shop drawings. In lieu of showing blockout tolerances on each shop drawing, typical block out tolerances can be shown on a tolerance drawing for the overall project. For example, the tolerance on a window blockout, into which a prefabricated window frame will fit, should be more precise than a blockout through which a field-installed piping system will be placed. The possible need for draft on the sides of blockouts should also be considered.

Another special case which should be shown on the shop drawings is the set of required tolerance for dimensions controlling the matching of open shaped panels. These tolerances may have to be tighter than the standard dimensional tolerances by 50 to 75 percent in some cases to assure a visually acceptable match up. The producer should review these types of situations with the architect/engineer so that any anticipated tolerance problems can be solved in the design of the panel interfacing prior to fabrication.

8.6 Tolerances for Sweep or Horizontal Alignment

Horizontal alignment deviation can occur as result of form tolerances and member width tolerances. It can also result from the effects of prestressing which has a lateral eccentricity, thus causing a sweep (lateral camber) in the member. If prestressed induced sweep is noted to create an out of tolerance condition, the architect/engineer should be notified for possible design revisions.

8.7 Tolerances for Position of Tendons

Tolerance for position of prestressing tendons is one the key tolerances affecting the structural capacity of the member. If tighter or less stringent tolerances on strand location than given in this document are required by the contract documents, they should be specifically noted on the project shop drawings. Strand position tolerance is usually more important in shallow beam members than it is in deep beam members.

It is common practice to use ⅝ in. [16 mm] diameter holes in end dividers (bulkheads, headers) for all strand sizes ½ in., 7⁄16 in., ⅜ in., [13, 11, and 9.5 mm diameters]. This is done because it is costly to switch to new end dividers for different strand diameters. Thus, in most plants, more precision in strand location is achieved when using larger diameter strands.

8.8 Tolerances for Handling Device Locations

The relative importance of placing tolerances on handling device locations in different directions should be indicated by tolerances shown on the project shop drawings, especially in thin or narrow sections.

For example, closer lateral tolerances are necessary to ensure the minimum required cover around lifting devices embedded in the stems of tees. In lieu of showing the tolerance for handling devices on each shop drawing they may be shown on a tolerance sheet for the project.

8.9 Tolerances Considerations for Camber and Differential Camber

The importance of camber and differential camber between adjacent prestressed concrete members of similar design will vary depending on the project requirements. If differential cambers exceed recommended tolerances, additional effort is often required to erect the members in a manner satisfactory for the intended use.

The effects of differential camber on member to member connection details and overall function in pretopped systems should be considered in determining appropriate differential camber specifications.

The final installed differential elevation tolerance between two adjacent cambered members erected in the field may be the combined result of member differential cambers, variations in support elevations, and any elevation adjustments made to members during erection.

Member camber measurements should be performed in a consistent manner in order to understand the actual differences in camber. It is very important to maintain uniformity at the time of camber measurement both with regard to member temperature and solar exposure during the day and with regard to the age and support conditions of the member since casting.

For example, the camber measured on the top member of a stack of double tees in the mid afternoon on a hot sunny day will be considerably different from the measured camber of the bottom member of the stack on the same day (or of the same top piece on a cold cloudy day). Similar camber measurement differences will occur with long wall panels with one side exposed to the sun and the other side in the shade. The most consistent results are obtained by measuring camber in the early hours of the day, before the sun has begun to differentially heat the members.

Control of differential camber of adjacent members in pre-topped systems may require more stringent tolerances to meet functional requirements. When this is the case, special design and production measures may be required to achieve special project tolerances for differential camber. Some adjustment to design floor elevations may be necessary when working with pre-topped systems.

If variation in camber in excess of the specified tolerance is observed, the plant quality control inspector should look for the cause and inform the architect/engineer, who will determine the effects of the variation on member performance. Note that variations from expected design camber may indicate strand slippage after release of prestress.

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

Time–Dependent Effects on Camber

Since member camber can vary over time, the point in the life of the camber critical member to which the camber tolerance applies to should be defined in the contract documents.

Checking all members at the same prescribed age since casting is important for consistent camber measurement results.

The following are time related influences on camber.

a. Modulus of elasticity variations due to curing duration differences can result in different cambers for members of similar design.
b. Different age at release, ages of adjacent members, age at time of erection, age at addition of superimposed load.
c. Creep differences resulting from differing concretes or differing stress conditions within the member.
d. Shrinkage effects due to differences in exposure, humidity, or curing differences.
e. Strand relaxation which increases somewhat with time.
f. Thermal effects that vary with time.
g. Extent of member flexural cracking.

Effects of Curing Methods on Camber Tolerances

If special curing methods are needed to achieve member camber tolerances this should be noted on the project shop drawings. Curing methods can influence concrete strength (and consequent modulus of elasticity and resulting camber effects) at the time of prestress transfer to the member.

Storage Configuration Effect on Camber Tolerance

If special storage configurations are required to achieve product camber tolerances this should be noted on the project shop drawings.

The following storage related issues can have an effect on member camber.

a. Member support locations while in storage.
b. Member position with respect to the sun.
c. Member position in the storage stack and its effect on the storage loading of the member.

8.10 Tolerances for Squareness of Ends or Variation From Specified End Skew

The type of forms selected for a project should consider the tolerance precision requirements for the of squareness of member ends. Out of square panels and other members can cause tapered joints between adjacent panels and make the adjustment of adjacent members difficult.

A member end skew which is not 90 degrees will require special procedures during form set-up and during as-built measurement verification to assure that tolerances are met.

8.11 Tolerances for Position of Weld Plates

When selecting the positioning and installation methods for weld plates, consider the tolerance requirements on these items. In general, plates can be positioned to closer tolerances when the plates are embedded in the bottom of the member (or against the side form) than can plates cast into the top of the member.

The main reason for this difference in placement precision is that bottom and side plates can be held in position by fastening directly to the form, and hence are less susceptible to movement which may be caused by the placement and vibration of the concrete. Plates cast into the top of the member are usually supported by some type of frame which must be positioned on the form before casting.

8.12 Tolerance on Tipping and Flushness of Weld Plates

The tipping and flushness tolerance is also important when selecting the plate positioning method Flushness is the relationship of the weld plate surface to the concrete surface. For the same reasons as outlined above, plates cast on the top of members will tend to tip out of plane more than bottom plates.

Another reason for tolerance difference between top and bottom plates is that bottom plates get uniform bearing from the form surface whereas top plates must be supported by removable positioning fixtures which often are not an integral part of the form.

8.13 Tolerances on Haunches of Columns and Wall Panels

Measures taken to assure maintaining tolerance on haunch location dimensions which are also primary erection control surfaces should consider the tolerance requirements of the type of connection used at the base of the member. Since a panel or other member base connection often allows some positioning flexibility, it is often more important to control dimensions from haunch to haunch in multistory columns or walls rather than to maintain tight control of actual haunch location dimensions from the end of the member.

8.14 Tolerances on Location of Sleeves Cast in Prestressed Products

The sleeve location tolerance should be secondary to the location tolerance of the strands unless otherwise noted on the project shop drawings. The tolerance on sleeves may be affected by slight relocation of the sleeves necessitated by the location of prestressing strands within the member.

For horizontal and vertical sleeve location tolerances, consideration should be given to the location of both straight and deflected prestressed strands, the function of the sleeve, and its proximity to other sleeves.

8.15 Tolerance on Reinforcing Steel Bending and Placement

Reinforcing steel placement tolerances should be shown on the project shop drawings. Similarly, reinforcing bar bend tolerances should be shown on the bar list for the precast members. In lieu of showing these tolerances on each shop drawing, they may be given on a project tolerance drawing.

Reinforcing steel used in precast prestressed products is controlled by two tolerances. The first is the bar length and bending tolerance, and the second is the bar placement tolerance, which is to an extent also dependent on the bar bending tolerance.

Reinforcing bar bending and length tolerances as well as reinforcement placing tolerances are governed by the American Concrete Institute standards. The section on concrete feature tolerances (Section 2.2. from ACI 117-90 *Standard Tolerances for Concrete Construction and Materials*) is reproduced below in Table 8.15.1. See the current issue of ACI 117 for reinforcement bending and placing tolerances.

In situations where reinforcement embedded in and extending from a precast member must interface with other members, special measures are often required when planning the tolerances for the reinforcement and in the fabrication of the members. The achievable reinforcement bar bending tolerances possible with available bar bending equipment should be taken into consideration. This is especially important if hooked bars are used.

The overall tolerance plan for members with embedded reinforcement should consider the detailed clearances between adjacent reinforcing bars and the potential maximum tolerance variation possible in the location of the reinforcement extending from each of the interfacing elements. This is necessary to assure that adequate clearances exist throughout. Where the reinforcement extends out from the member, be sure to evaluate the position of the reinforcement relative to the features it must interface with, through all of the angles of motion involved in the erection process.

In special situations where complex reinforcement patterns must be interfaced during erection, steps should be taken to assure that the proposed arrangements are workable. A common error is to lay out a reinforcement clearance plan using reinforcing bar centerline to centerline dimensions and not appropriately considering the consequences of the bar diameter or the consequences of hook bending and length tolerances. This is more of a consideration with larger diameter reinforcing bars which are relatively closely spaced.

If a producer subcontracts the reinforcing bar bending to an outside supplier, early and frequent checks of bending accuracy should be made. Additionally, in some instances special bar bending tolerances may have to be specified in the contract with the bar bending fabricator.

Note that for some types of precast members, producers find that reinforcement bent to conform with ACI specified bending tolerances is not suitable to meet the tolerance requirements of member fabrication. For this reason some producers bend their own bars or require their suppliers to work to bending tolerances that are more stringent than those prescribed by ACI.

Fig. 8.15.1 Selected* Tolerances

ACI 117-90 Section No.	Item	Tolerance (in.)	Tolerance (mm)†
3	Foundations		
3.2	Lateral alignment		
3.2.1	Footings		
	As cast to the center of gravity as specified; 0.02 times the width of the footing in the direction of misplacement, but not more than	2	50
	Supporting masonry	½	13
3.3	Level alignment		
3.31	Footings		
3.3.1.1	Top of footings supporting masonry	½	13
3.3.1.2	Top of other footings	+½, −2	+13,−50
4	Cast-in-Place Concrete for Buildings		
4.1	Vertical Alignment		
4.1.1.1	For Heights less than 100 ft. [30 m]		
	Lines, surfaces, arrises	1	25
	Outside corner of exposed corner columns and control joint grooves in concrete exposed to view	½	13
4.1.2	For heights greater than 100 ft. [30 m]		
	Lines, surfaces and arrises 1/1000 times the height but not more than	6	150
	Outside corner of exposed corner columns and control joint grooves in concrete, 1/2000 times the height but not more than	3	75
4.2	Lateral alignment		
4.2.1	Members	1	25
4.2.2	In slabs, center line location of openings 12 in. [300 mm] or less and edge location of larger openings	½	13
4.2.3	Sawcuts, joints, and weakened plane embedments in slabs	¾	19
4.3	Level alignment		
4.3.1	Top of slabs		
4.3.1.1	Elevation of slabs on grade	¾	19
4.3.1.2	Elevation of top surfaces of formed slabs before removal of supporting shores	¾	19
4.3.2	Elevation of formed surfaces before removal of shores	¾	19
4.3.3	Lintels, sills, parapets, horizontal groves and other lines exposed to view	½	13

* See *Standard Specifications for Concrete Construction and Materials*, ACI 117-90, or current edition, for full listing.

† Metric conversions shown are "soft" (e.g. rounded to appropriate values).

8.16 Tolerance on Position of Strand Deflection Points

Strand hold-downs and other strand deflection devices frequently have their positions dictated by the requirement that they be fixed, either to the form itself or to the form support, so that suitable strand hold-down structural capacity is achieved. Often these hold down locations are on a lattice grid that may have a spacing as great as 40 in. [1020 mm] between location points.

These casting bed structural conditions affecting strand hold down location can frequently result in available hold down positions being as much as ±20 in. [±510 mm] from the specified location. If hold down locations are specified closer than this, the architect/engineer should be contacted prior to revision of any specified hold down tolerance.

Special strand hold down location tolerances may be required for cantilevers and other special conditions. More precise placement of strand deflection points will increase the cost of these members. The vertical position of the hold-down is usually more important than the horizontal position.

8.17 Tolerance Effects of Warping, Bowing and Local Smoothness of Panels

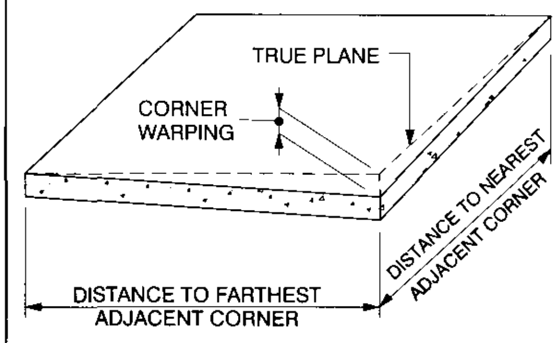
Panel warping and bowing tolerances are often important aspects of panel visual features, and also influence the ease of erection and functional performance of panel connections and panel interface elements.

Warping tolerances are stated in terms of the magnitude of the corner variation, as shown in Fig. 8.17.1. This tolerance is usually stated in terms of the allowable variation per foot of distance from the nearest adjacent corner with a not-to-exceed maximum value of corner warping.

While warping and bowing occur in both structural and architectural members, it is architectural members that usually demand special consideration. Warping and bowing tolerances have an important influence on the visual effects relating to edge match up during erection and on the visual appearance of the erected panels, both individually and when viewed together. Several possible bowing conditions are shown in Fig. 8.17.2.

Bowing and warping tolerances should be compared against panel global erection tolerance requirements which may be driven by tolerance requirements for panels as installed, with reference to joint widths, jog in alignment, and step in face tolerance. Compliance with these global requirements for some panel sizes and shapes may create more stringent requirements than the specific bowing and warping tolerances.

Fig. 8.17.1 Warping Definitions for Panels



Bowing and Warping Tolerances

Differential temperature effects and differential moisture absorption between the inside and outside faces of a panel, the effects of possible prestress eccentricity, and differential shrinkage between face and back-up concrete mixes can all contribute to panel bowing and warping.

Note that bowing and warping tolerances are of interest primarily at the time the panel is erected. Careful attention to pre-erection storage of panels is necessary, since storage conditions can be an important factor in achieving and maintaining panel bowing and warping within tolerances.

Differential bowing is a consideration for panels which are viewed together on the completed structure. If convex bowing is positive (+) and concave bowing is negative (−), then the magnitude of differential bowing for adjacent members can be determined by subtracting the bowing values.

For example in Fig. 8.17.3, if the maximum bowing of Panel 3 were +¼ in. [+6 mm] and the maximum bowing of Panel 4 was −¼ in. [−6 mm] then the differential bowing between these two adjacent panels is ½ in. [13 mm].

A special appearance related tolerance requirement may be necessary for honed or polished flat concrete walls where bowing or warping tolerances may have to be made more stringent by 50 percent to 75 percent of the bowing tolerances given in Article 11.0 in order to avoid possibly objectionable joint shadows.

Fig. 8.17.2 Definition of Bowing for Panels

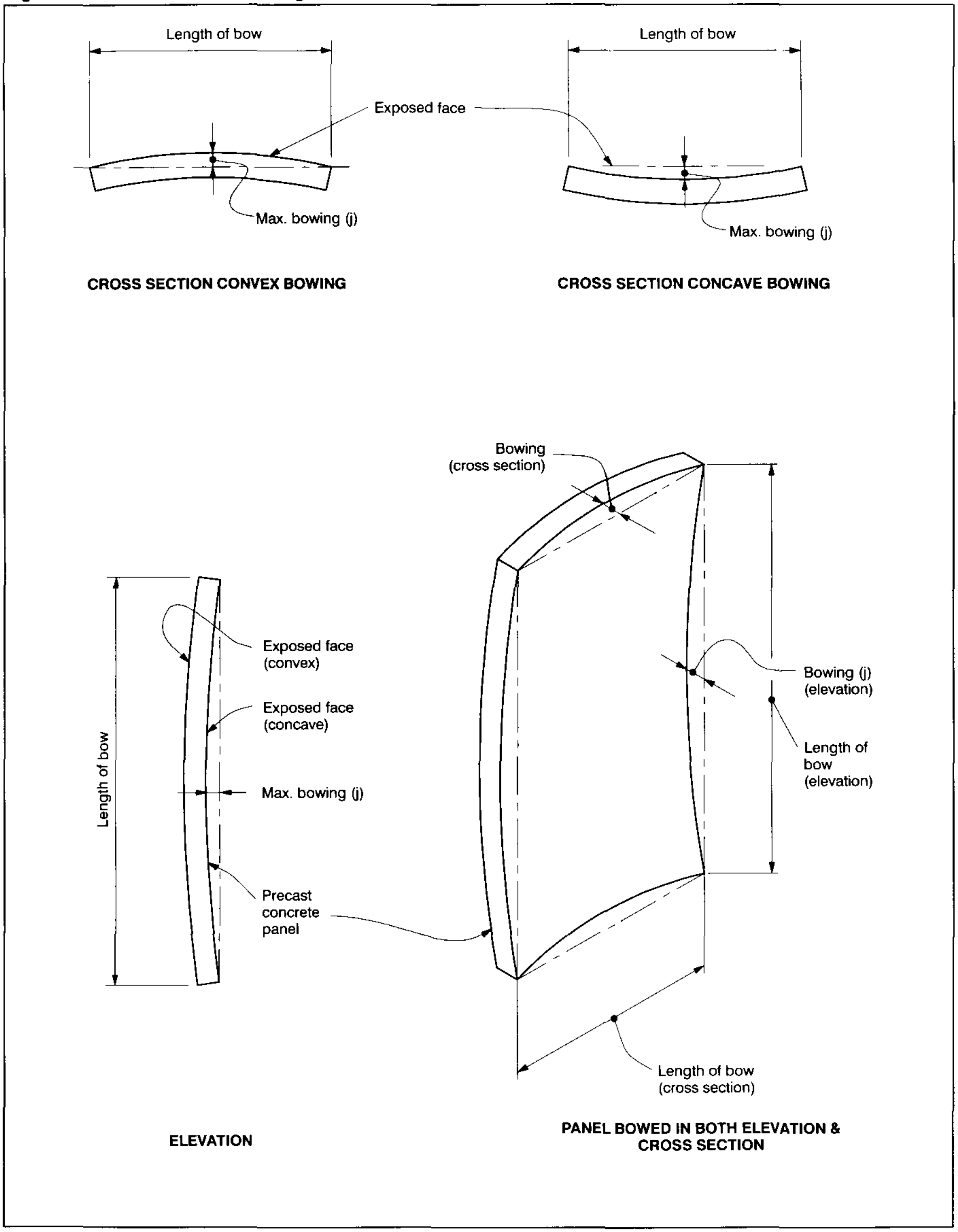
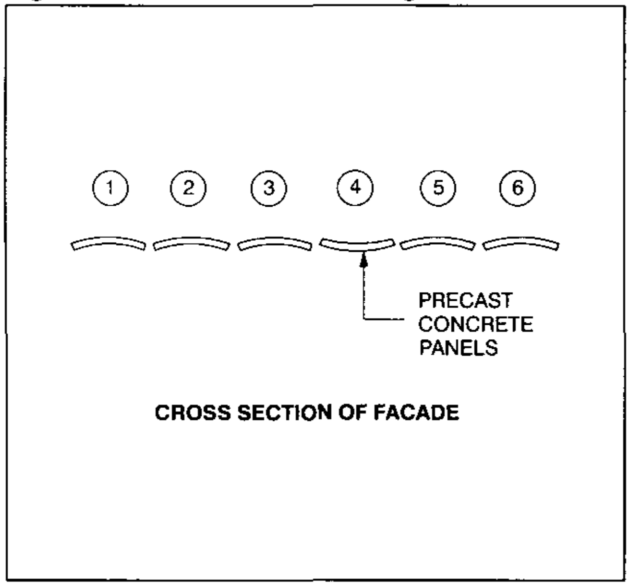


Fig. 8.17.3 Differential Bowing of Panels



Surface Out of Planeness Tolerance

Surface out of planeness, which is not a characteristic of the entire panel shape, is defined as a local smoothness variation rather than a bowing variation. Examples of local smoothness variation are shown in Fig. 8.17.4.

The tolerance for this type of variation is usually expressed in inches deviation from a 10 ft. [3 m] straight edge. The tolerance should be checked with a 10 ft. [3 m] straightedge or the equivalent, as shown in Fig. 8.17.4 unless other methods are specified or agreed to. Fig. 8.17.4 also shows how to determine if a surface meets a tolerance of ¼ in. [6 mm] as measured beneath a 10 ft. [3m] straightedge. A ¼ in. [6 mm] diameter by 2 in. [50 mm] long roller should fit anywhere between the straight edge and the member surface being measured when the straightedge is supported at its ends on ⅜ in. [9 mm] shims as shown. A ½ in. [13 mm] diameter by 2 in. [50 mm] long roller should not fit between the surface and the straightedge.

Panel Size to Thickness Ratio Effects on Tolerance

If the producer has concern about the likelihood of a panel to bow or warp in excess of the specified tolerances, the architect/engineer should be notified. The design of the panel and its relative stiffness or ability to resist deflection as a plate member must be consistent with the bowing and warping tolerances specified.

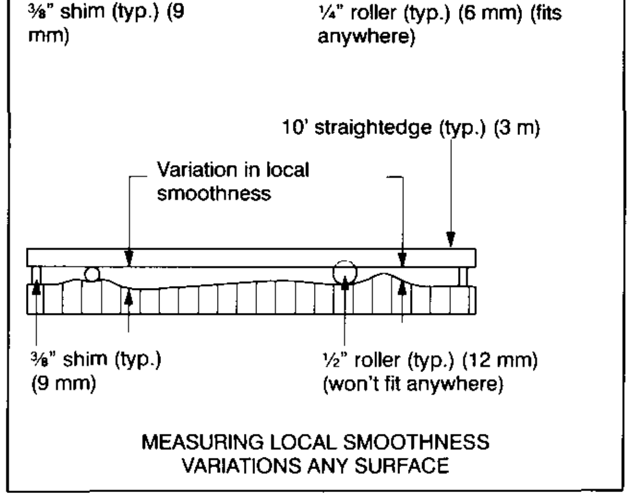
Panels which are relatively thin in cross section, when compared to their overall plan dimensions, are more likely to warp or bow as a result of a number of design, manufacturing, and environmental conditions.

To reduce the potential of panel warping or bowing after erection, consideration should be given by the architect/engineer for panel length, shape and the number and location of tie back connection points.

The producer and the architect/engineer should collaborate in the decisions regarding maintaining or relaxing bowing and warping tolerances. Appearance requirements, the required type and spacing of connections, and the experience of the local precaster regarding overall economic and construction feasibility of panels with various levels of bowing and warping tolerance should be discussed with the architect/engineer.

Similarly, panels which are manufactured using large aggregate concrete mixes (above ¾ in. [19 mm] aggregate) or members which are fabricated from non homogeneous materials such as two significantly different concrete mixes, special veneers, insulating mediums, etc., require more careful consideration of all aspects of fabrication, storage, and handling with regard to bowing and warping.

Fig. 8.17.4 Local Smoothness Variations



9.0 Special Tolerance Considerations

The function of members within the building or structure and the employment of special manufacturing techniques used to produce certain members may warrant special tolerance considerations which should be discussed by the producer with the architect/engineer.

For example groups of inserts or cast-in items which must be located in close relative tolerance to each other should not be separated onto two different panels by a joint unless special measures are taken to achieve the desired relative tolerances.

9.1 Considerations for Tolerances of Architectural Members

In the context of tolerances, "architectural panel or member" refers to the class of tolerances specified and not necessarily to the members' use in the final structure. Article 10.1 of this document defines architectural tolerances for typical architectural panels. Architectural panels, for example, require more stringent tolerances due to the visual considerations which apply to the final construction.

9.2 Tolerance Considerations for Visible Structural Members

Double tees and hollow-core slabs are often used for wall panels which are exposed as visible elements of a building. If more stringent special project tolerances are specified and required for these products when used as visual elements, special production methods and tolerance verification methods will be required. The same high degree of dimensional precision associated with purely architectural panels should generally not be specified for double tee or hollow-core panels since the manufacturing techniques for the product when used as a visible element is generally the same as for the structural product for which these elements are more commonly used.

9.3 Tolerances for Structural Members

Unless otherwise specified on the shop drawings, tolerances for structural members should be as outlined in Article 10.0 of this document for the members designated as "structural members" (excluding Article 10.1 and Articles 10.29, 10.30, and 10.31 which give architectural tolerances).

9.4 Statistical Tolerance Concepts

Any special measuring or record keeping methods specified in the contract documents should be observed by the plant quality control personnel. An understanding of statistical methods as they apply to dimensional control can be helpful in developing project tolerance control plans which account for member product tolerances, interface tolerances, and erection tolerances.

While statistical concepts may not be commonly employed in the dimensional control of precast products, it may be advantageous for producers to consider this approach in certain circumstances for at least two reasons: First, a random sampling of specific measurements and subsequent statistical analysis of these measurements can create quality control related economies on projects which have a large number of identical pieces with stringent tolerance requirements. Concrete railroad tie production and close tolerance interlocking tunnel liner elements are examples of such instances.

Second, statistical concepts can be used as a tool in developing the tolerance control requirements for specific production operations. By proper sampling and analysis, one can determine more precisely which types of member features require more attention in the fabrication process and this can be implemented in the production and quality control program. For information regarding this type of statistical approach to dimensional control, one should refer to appropriate publications as listed in the references for this document.

9.5 Tolerance Considerations for Segmental Precast

Segmental precast projects are, by definition, special projects from the tolerance point of view. These projects will have unique tolerance requirements and will require consideration of tolerances at all levels of the project, including design, member fabrication, erection, and sub system installation.

For precast segmental construction using short line forming techniques, precision surveying systems should be provided so that levels and horizontal alignment are measured to the very high levels of accuracy unique to each project using this construction method. For all other types of segmental construction, surveying should be provided to an accuracy of ±⅛ in. [3 mm].

For precast segmental construction using match-cast segments, careful checks of both measurements and computations of geometry should be made before moving segments from their casting position. Dimensions from segment to segment should be adjusted to compensate for any deviations within a single segment so that the overall alignment of the completed structure will conform to the dimensions shown on the plans. Computed as-built coordinates of all sections cast should be completed before casting a new segment. In addition to the computed as-built casting curves for vertical and horizontal deflections, a cumulative twist curve should be computed using the measured cross slopes of the individual units as a check on the extrapolated deflections. In computing set up elevations in the match-cast process, priority should be given to correcting twist errors by proper counter-rotation. The segment in the match cast position should not be subjected to stressing that would induce twist.

10.0 Product Tolerance Listings

The following pages give dimensional requirements for a range of standard precast concrete and precast, prestressed concrete products. These tolerances are guidelines only and each project may have project tolerances specified which are different from those shown. Article 10.1 defines architectural panel member tolerances. Articles 10.2 through 10.25 define tolerances for structural members. Article 10.26 Railroad Ties, is a special product tolerance. Articles 10.27 through 10.29 define tolerances for architectural trim elements.

During the pre and post pour check of precast member dimensions, the quality control inspector should have the approved version of shop drawings for reference. Any discrepancies found should be noted on the post pour record and transmitted to management or engineering for evaluation and resolution, which may include design of any structural or appearance revisions which may be necessary.

Product tolerances are necessary in any manufacturing process. They are normally determined by function and appearance requirements, and by economic and practical production considerations. Tolerances for manufacturing precast products are standardized throughout the industry and should not be reduced, and therefore made more costly, unless absolutely necessary.

The tolerances listed herein are the minimum acceptable criteria in the absence of other specifications. Projects under the control of special authorities, such as state highway departments for bridges, will often have a full set of tolerances specified. In these situations, the tolerances specified by the controlling authority may govern.

For products not specifically listed, select the appropriate tolerances from the listed type (or types) that most closely matches the function of the product.

A dimensional layout and measurement plan is needed to control the production of precast elements so that the measurement process does not result in unintended accumulation of tolerances. For example, the location of multiple embedments should always be measured from the appropriate control surface, rather than measuring some from a member edge and others from intermediate embedments. The member diagrams in this section show the location of features to which the tolerances apply. They are not intended to show the most appropriate reference feature for measurement. The appropriate dimensioning system to achieve the desired tolerances should be established by the engineer and shown on the production drawings.

Camber tolerances have special considerations. For members with a span-to-depth ratio at or exceeding 25, the camber tolerance given herein may not apply. If the application requires control of camber to the listed tolerance in beams with high span-to-depth ratio, special production measures may be required. The precaster should be consulted regarding this requirement.

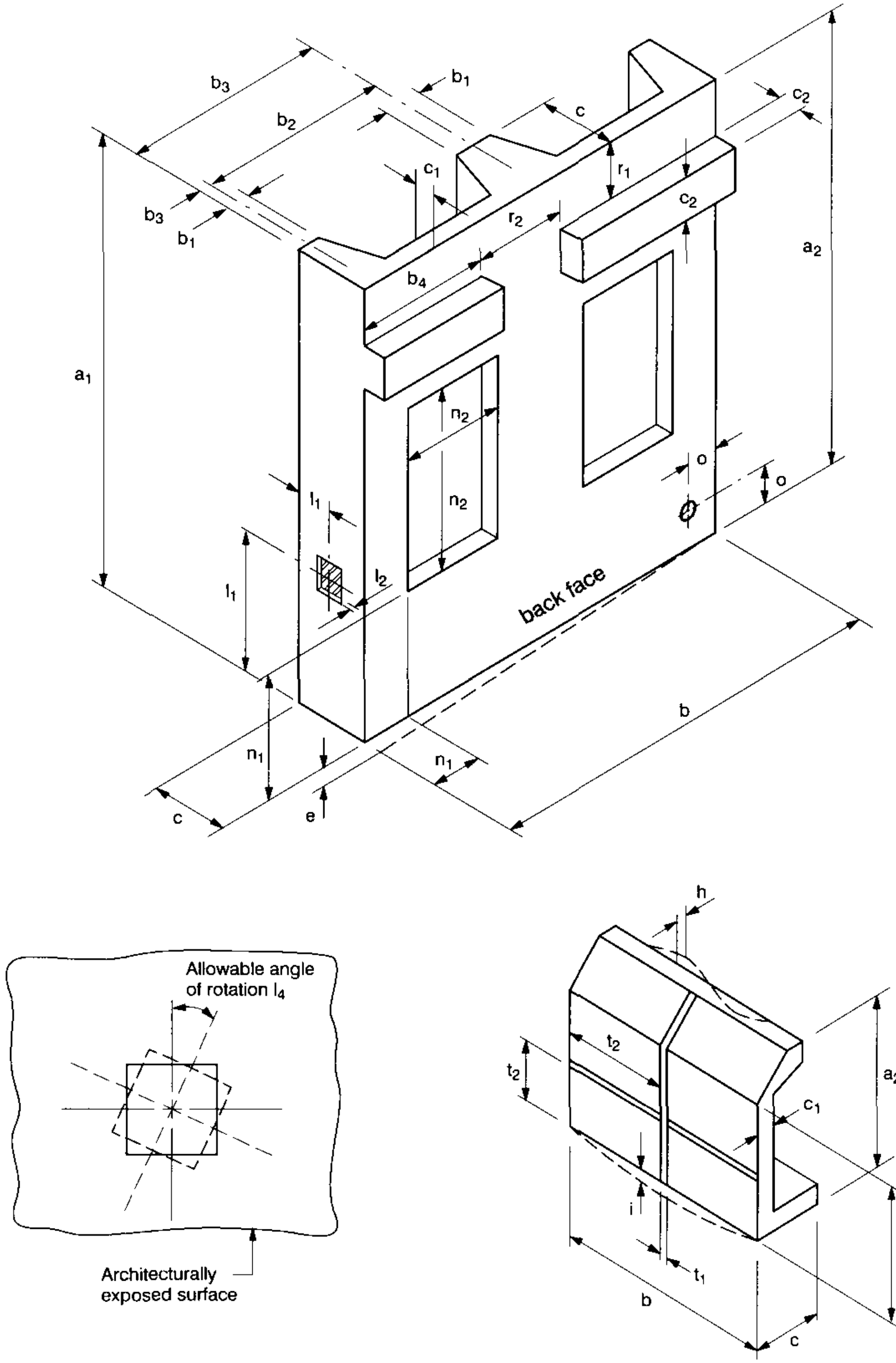
Prediction of camber in a prestressed member is based on empirical formulas. The accuracy of these estimates decreases with time. Measurement of camber for comparison to predicted design values should be completed within 72 hours of transfer of prestressing force.

Temperature variation across a member section can have a significant impact on the measured camber. Camber should be evaluated under conditions that minimize the effect of temperature variation due to solar radiation, such as early in the morning.

When the finished floor or deck surface is created by the precast elements as erected (pretopped), the overall depth of the member becomes a primary control feature and the deck surface becomes a primary control surface for both fabrication and erection. In order to achieve the desired tolerances on the overall floor or deck it may be necessary to use special production measures to control camber and differential camber among the adjacent elements.

Refer to Article 8.17 for a definition and discussion of bowing, warping, and local smoothness tolerances.

Fig. 10.1.1 Architectural Wall Panels



Architectural panels

10.1 Architectural Wall Panels*

a_1 = Overall height of unit measured at the face exposed to view:
- Up to 10 ft. [3 m] .... ±⅛ in. [±3 mm]
- 10 to 20 ft. [3 to 6 m] .... +⅛ in., −3/16 [+3 mm, −5 mm]
- 20 to 40 ft. [6 to 12 m] .... ±¼ in. [±6 mm]
- Greater than 40 ft. [12 m] .... ±1/16 in. per 10 ft. [±1.5 mm per 3 m]

a_2 = Overall height of unit measured at the face not exposed to view:†
- Up to 10 ft. [3 m] .... ±¼ in. [±6 mm]
- 10 to 20 ft. [3 to 6 m] .... +¼ in., −⅜ [+6, −10 mm]
- 20 to 40 ft. [6 to 12 m] .... ±⅜ in. [±10 mm]
- Greater than 40 ft. [12 m] .... ±⅛ in. per 10 ft. [±3 mm per 3 m]

b = Overall width of unit measured at the face exposed to view:
- Up to 10 ft. [3 m] .... ±⅛ in. [±3 mm]
- 10 to 20 ft. [3 to 6 m] .... +⅛ in., −3/16 [+3 mm, −5 mm]
- 20 to 40 ft. [6 to 12 m] .... ±¼ in. [±6 mm]
- Greater than 40 ft. [12 m] .... ±1/16 in. per 10 ft. [±1.5 mm per 3 m]

b_1 = Rib width .... ±⅛ in. [±3 mm]

b_2 = Distance between ribs .... ±⅛ in. [±3 mm]

b_3 = Rib to edge of flange .... ±⅛ in. [±3 mm]

b_8 = Overall width of unit measured at the face not exposed to view:
- Up to 10 ft. [3 m] .... ±¼ in. [±6 mm]
- 10 to 20 ft. [3 to 6 m] .... +¼ in., −⅜ in. [+6, −10 mm]
- 20 to 40 ft. [6 to 12 m] .... ±⅜ in. [±10 mm]
- Greater than 40 ft. [12 m] .... ±⅛ in. per 10 ft. [±3 mm per 3 m]

c = Total thickness .... +¼ in., −⅛ in.[+6, −3 mm]

c_1 = Flange thickness .... +¼ in., −⅛ in.[+6, −3 mm]

c_2 = Dimensions of haunches .... ±¼ in. [±6 mm]

e = Variation‡ from square or designated skew .... ±⅛ in. per 6 ft., ±½ in. minimum [±3 mm per 2 m, ±13 mm minimum]

h = Local smoothness, unconcealed surfaces .... ¼ in. per 10 ft. [±6 mm per 3 m]

i = Bowing .... ± Length/360, to a maximum of 1 in. [25 mm]

j = Warp (from adjacent corner) .... 1/16 in. per ft. [1.5 mm per 300 mm]

l_1 = Location of weld plates .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of plates .... ±¼ in. [±6 mm]

l_4 = Allowable rotation of plate, channel insert, electrical box .... 2 degrees
.... ¼ in. [6 mm] maximum measured at perimeter of insert

m_2 = Haunch bearing surface tipping and flushness of bearing plates .... ±⅛ in. [±3 mm]

m_3 = Difference in relative position of adjacent haunch bearing surfaces from specified relative position .... ±¼ in. [±6 mm]

n_1 = Location of opening within panel .... ±¼ in. [±6 mm]

n_2 = Length and width of blockouts and openings within one unit .... ±¼ in. [±6 mm]

n_3 = Location and dimensions of blockouts hidden from view and used for HVAC and utility penetrations .... ±¾ in. [±19 mm]

o	=	Position of sleeve	±½ in. [±13 mm]
p	=	Position of insert	±½ in. [±13 mm]
q	=	Position of handling devices	±3 in. [±75 mm]
r_1	=	Location of bearing surface from end of member	±¼ in. [±6 mm]
s_1	=	Reinforcing steel and welded wire reinforcement:	
		Where position has structural implications or affects concrete cover	±¼ in. [±6 mm]
		Otherwise	±½ in. [±13 mm]
s_3	=	Reinforcing steel extending out of member	±½ in. [±13 mm]
s_4	=	Location of strand:	
		Perpendicular to panel	±¼ in. [±6 mm]
		Parallel to panel	±1 in. [±25 mm]
t_1	=	Dimensions of architectural features and rustications	±⅛ in. [±3 mm]
t_2	=	Location of rustication joints	±⅛ in. [±3 mm]
w_1	=	Location of flashing reglets	±¼ in. [±6 mm]
w_2	=	Location of flashing reglets at edge of panel	±⅛ in. [±3 mm]
w_3	=	Size of reglets for glazing gaskets	±⅛ in. [±3 mm]
z	=	Electrical outlets, hose bibs, etc.	±½ in. [±13 mm]

* Units shall be manufactured so that the face of each unit which is exposed to view after erection complies with the following dimensional requirements.

† Unless joint width and fit-up requirements demand more stringent tolerance.

‡ Applies to both panel and to major openings in panel. Tolerances apply to the difference of the two diagonal measurements.

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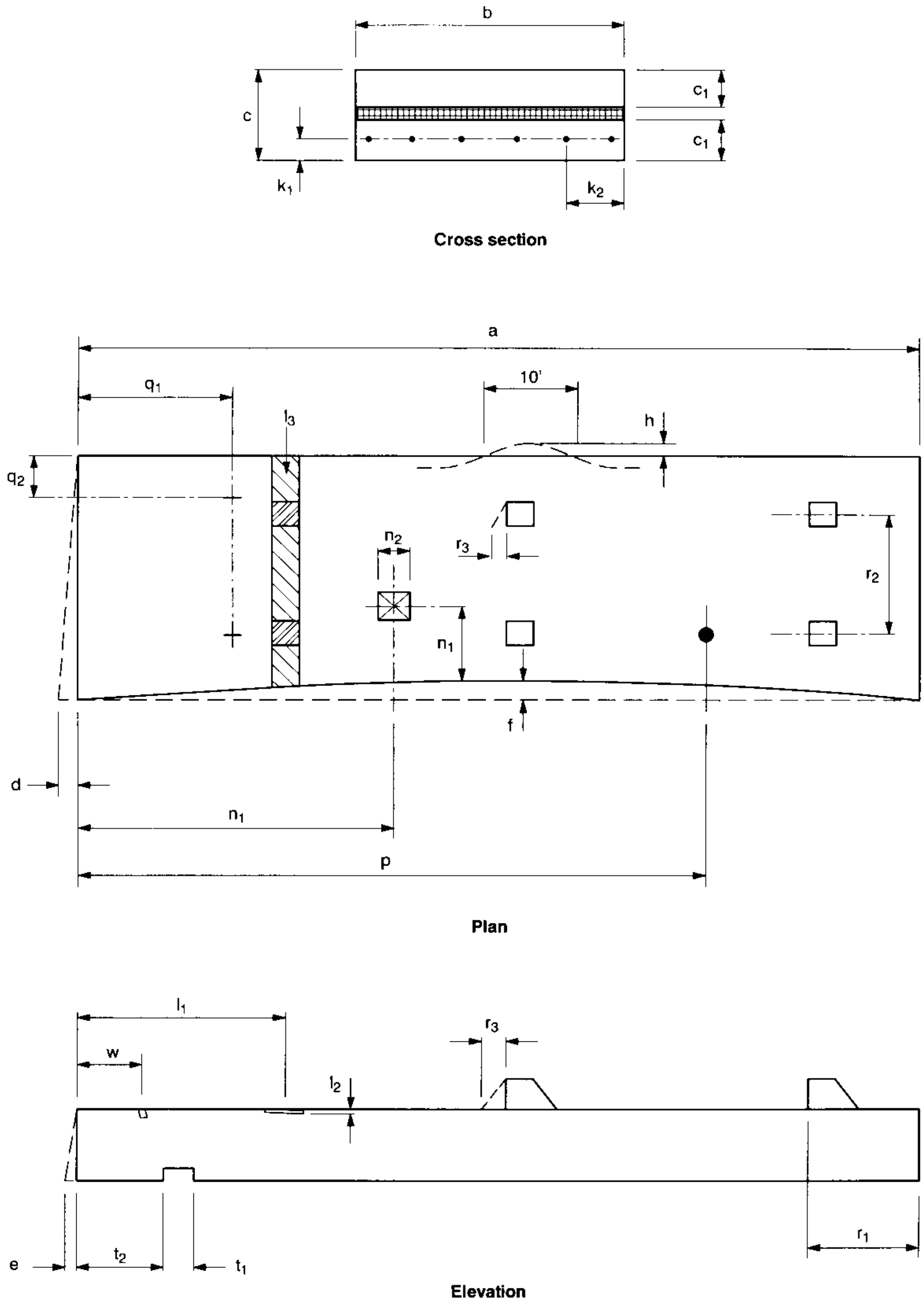
Fig. 10.2.1 Solid or Insulated Flat Structural Wall Panels



Solid or insulated flat wall panels

10.2 Solid or Insulated Flat Structural Wall Panels

a = Length .... ±½ in. [±13 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Wythe thickness .... ±⅜ in. [±10 mm]

d = Variation from specified plan end squareness or skew
.... ±⅛ in. per 12 in. width, ±½ in. maximum
[±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew .... ±⅛ in. per 12 in.
[±3 mm per 300 mm]

f = Sweep .... ±⅛ in. per 20 ft., ±⅜ in. maximum
[±3 mm per 6 m, ±10 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

i = Bow .... Length/360 maximum

i_1 = Differential bowing between adjacent panels of the same design .... ½ in. [13 mm]

j = Warp (from adjacent corner) .... 1⁄16 in. per foot [1.5 mm per 300 mm]

k_1 = Location of strand perpendicular to plane of panel .... ±¼ in. [±6 mm]

k_2 = Location of strand parallel to plane of panel .... ±1 in [±25 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

l_3 = Concrete surface between embedments to receive
continuous ledger, relative to plane of embedments . −¼ in., +0 in. [− 6 mm, +0 mm]

n_1 = Location of blockout .... ±1 in. [±25 mm]

n_2 = Size of blockouts .... ±½ in. [±13 mm]

p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of panel .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of panel .... ±1 in. [±25 mm]

r_1 = Location of haunch bearing elevation from end of panel .... ±¼ in. [±6 mm]

r_2 = Transverse distance between haunches .... ±¼ in. [±6 mm]

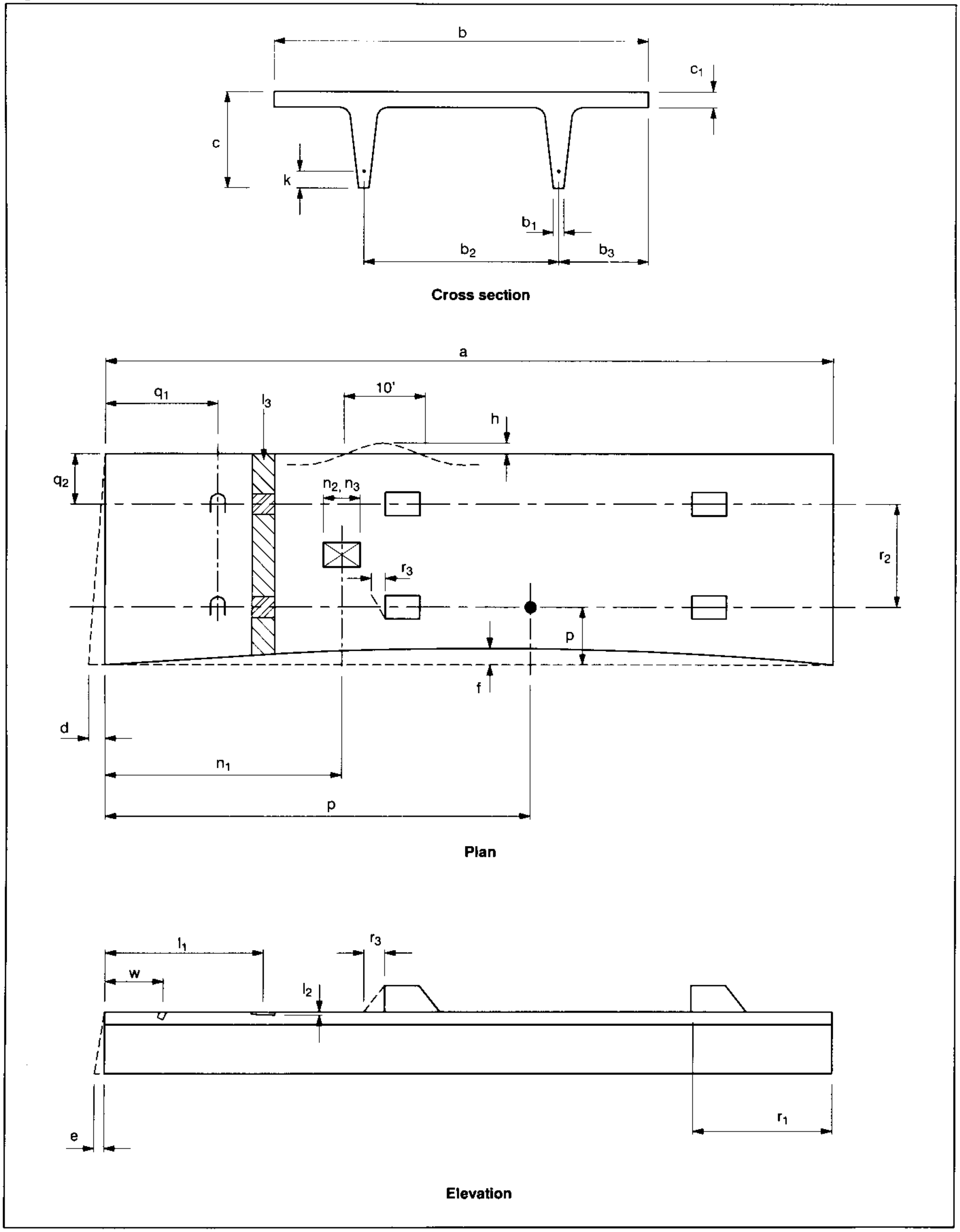
r_3 = Variation from specified haunch bearing surface slope
.... ±⅛ in. per 18 in., ±¼ in. maximum
[±3 mm per 450 mm, ±6 mm maximum]

t_1 = Size of architectural feature .... ±⅛ in. [±3 mm]

t_2 = Location of architectural feature .... ±⅛ in. [±3 mm]

w = Location of flashing reglet .... ±¼ in. [±6 mm]

Fig. 10.3.1 Ribbed Structural Wall Panels



10.3 Ribbed Structural Wall Panels

a = Length .... ±½ in. [±13 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Stem width .... ±⅛ in. [±3 mm]

b_2 = Distance between stems .... ±⅛ in. [±3 mm]

b_3 = Stem to edge of top flange .... ±⅛ in. [±3 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Flange depth .... +¼ in., −⅛ in. [+6 mm, −3 mm]

d = Variation from specified plan end squareness or skew .... ±⅛ in. per 12 in. width, ±½ in. maximum [±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew .... ±⅛ in. per 12 in. [±3 mm per 300 mm]

f = Sweep, for member length:
Up to 40 ft. [12 m] .... ±¼ in. [±6 mm]
40 ft. [12 m] or greater .... ±⅜ in. [±10 mm]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

i = Bow .... Length/360 maximum

i_1 = Differential bowing between adjacent panels of the same design .... ½ in. [13 mm]

j = Warp .... 1/16 in. per foot [1.5 mm per 300 mm]

k = Location of strand .... ±¼ in. [±6 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

l_3 = Concrete surface between embedments to receive continuous ledger, relative to plane of embedments . − ¼ in., +0 in. [−6 mm, +0 mm]

n_1 = Location of blockout .... ±1 in. [±25 mm]

n_2 = Size of rough opening .... ±1 in. [±25 mm]

n_3 = Size of finished opening .... ±½ in. [±13 mm]

p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of panel .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of panel .... ±1 in. [±25 mm]

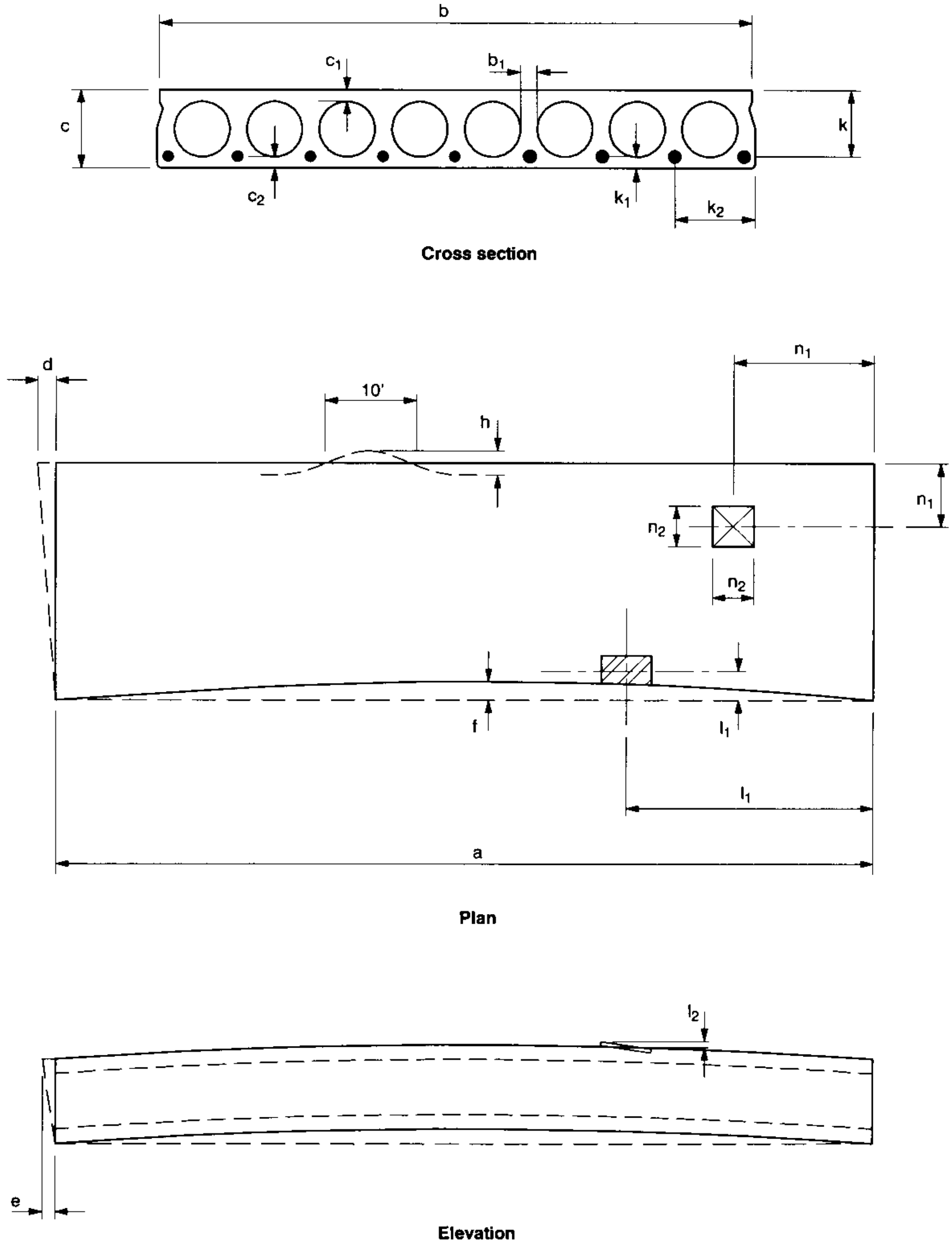
r_1 = Location of haunch bearing elevation from end of panel .... ±¼in. [±6 mm]

r_2 = Transverse distance between haunches .... ±¼ in. [±6 mm]

r_3 = Variation from specified haunch bearing surface slope .... ±⅛ in. per 18 in., ±¼ in. maximum [±3 mm per 450 mm, ±6 mm maximum]

w = Location of flashing reglet .... ±¼ in. [±6 mm]

Fig. 10.4.1 Hollow-core Wall Panels



10.4 Hollow-core Wall Panels

a = Length .... ±½ in. [±13 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Web width:
The total web width defined by the sum of the actual measured values of "b_1" shall not be less than 85 percent of the sum of the nominal web widths "$b_{1,\ nominal}$"

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Top flange depth:
Top flange area defined by the actual measured values of average "c_1" x "b" shall not be less than 85 percent of the nominal area calculated by "$c_{1,\ nominal}$" x "$b_{nominal}$"

c_2 = Bottom flange depth:
Bottom flange area defined by the actual measured values of average "c_2" x "b" shall not be less than 85 percent of the nominal area calculated by "$c_{2,\ nominal}$" x "$b_{nominal}$"

d = Variation from specified plan end squareness or skew .... ±½ in. [±13 mm]

e = Variation from specified elevation end squareness or skew
.... ±⅛ in. per 12 in. [±3 mm per 300 mm]

f = Sweep .... ±⅜ in. [±10 mm]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

i = Bow .... Length/360 maximum

i_1 = Differential bowing between adjacent panels of the same design .... ½ in. [13 mm]

j = Warp .... 1/16 in. per foot [1.5 mm per 300 mm]

k = Center of gravity (CG) of strand group .... ±¼ in. [±6 mm]

k_1 = Location of strand perpendicular to plane of panel .... ±½ in. [±13 mm]
Minimum cover .... ¾ in. [19 mm]

k_2 = Location of strand parallel to plane of panel .... ±¾ in. [±19 mm]
minimum cover .... ¾ in. [19 mm]

l_1 = Location of embedment* .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

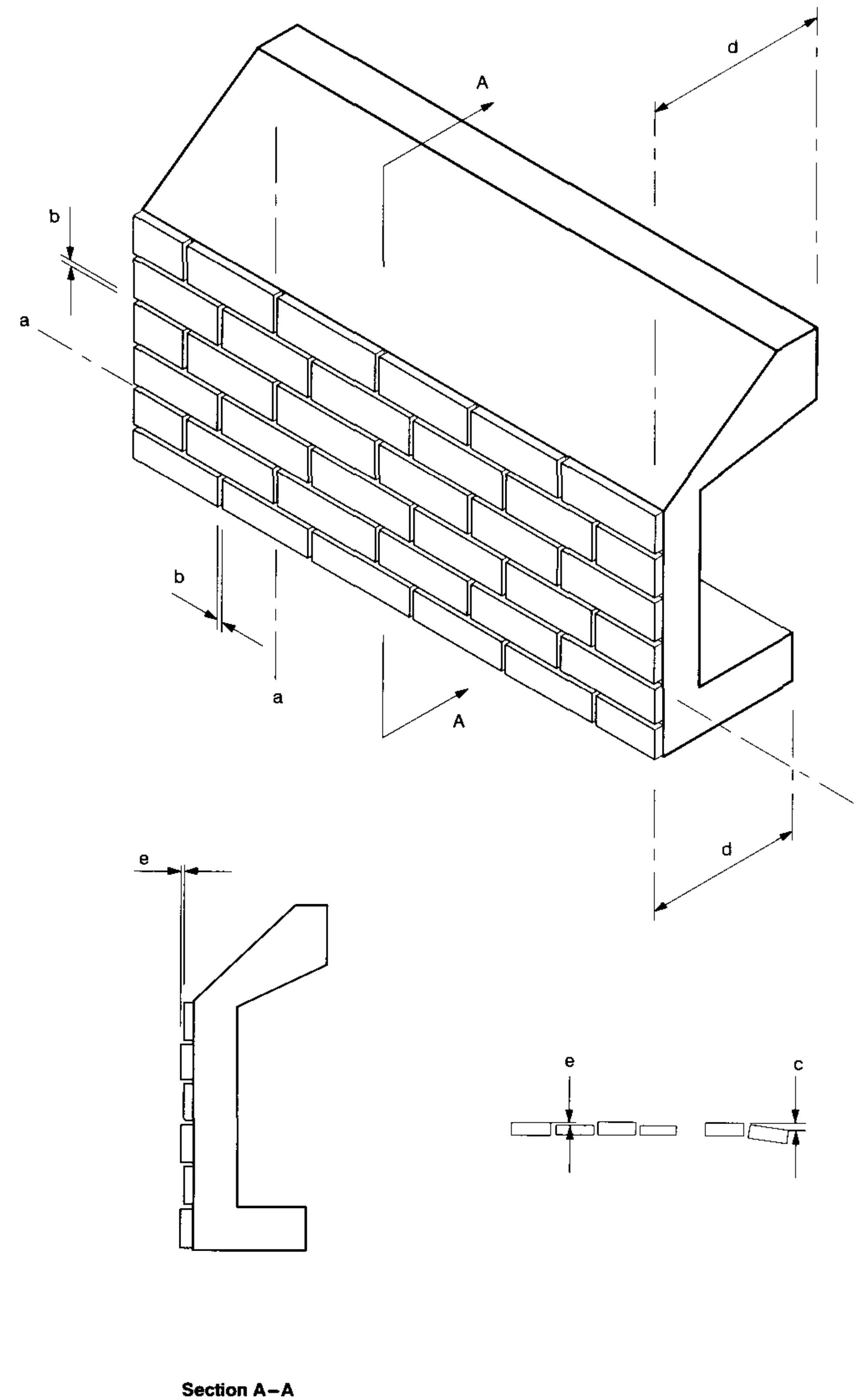
n_1 = Location of blockout .... ±1 in. [±25 mm]

n_2 = Size of blockouts .... ±½ in. [±13 mm]

x = Weight:
Actual measured value shall not exceed 110 percent of the nominal published unit weight used in the design.

* Some hollow-core production systems do not permit the incorporation of embedments. Contact local producers for suitable alternate details if embedments are not practical.

Fig. 10.5.1 Brick Faced Architectural Elements



10.5 Brick Faced Architectural Elements

a = Alignment of mortar joints:
Jog in alignment .... ⅛ in. [±3 mm]
Alignment with panel centerline .... ±⅛ in. [±3 mm]

b = Variation in width of exposed mortar joints .... ±⅛ in. [±9 mm]

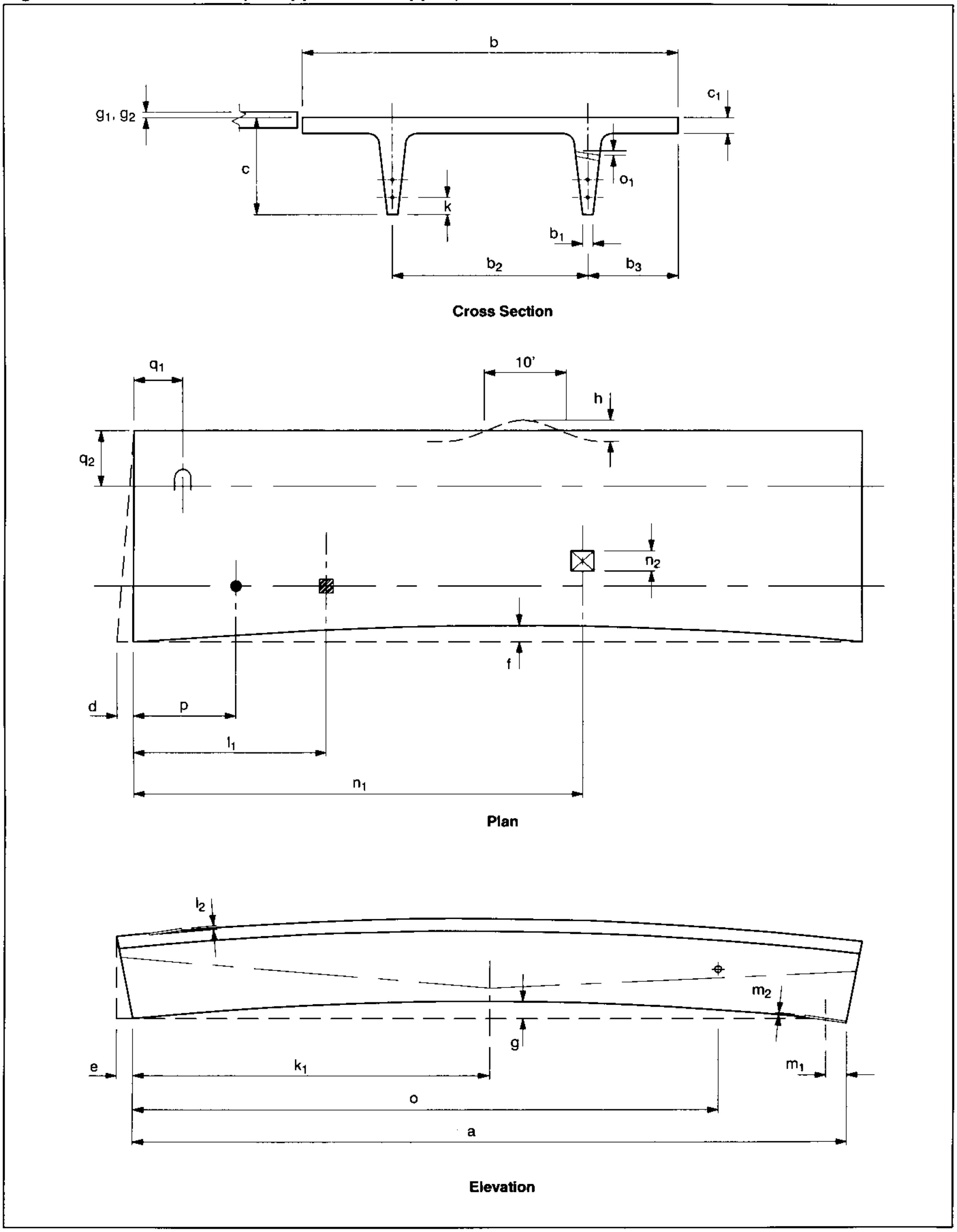
c = Tipping of individual bricks from the panel
plane of exposed brick surface .... +1⁄16 in., −¼ in, ≤ depth of form liner joint
[+1.5 mm, −6 mm]

d = Exposed brick surface parallel to primary
control surface of panel ....+¼ in., −⅛ in.[+6 mm, −3 mm]

e = Individual brick step in face from panel
plane of exposed brick surface .... +1⁄16 in., −¼ in, ≤ depth of form liner joint
[+1.5 mm, −6 mm]

Note: See other panel tolerances in Fig. 10.1.1.

Fig. 10.6.1 Double Tees (Untopped & Pretopped)



10.6 Double Tees (Untopped & Pretopped)

a = Length .... ±1 in. [±25 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Stem width .... ±⅛ in. [±3 mm]

b_2 = Distance between stems .... ±¼ in. [±6 mm]

b_3 = Stem to edge of top flange .... ±¼ in. [±6 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Flange thickness .... +¼ in., −⅛ in. [+6 mm, −3 mm]

d = Variation from specified plan end squareness or skew
.... ±⅛ in. per 12 in. width, ±½ in. maximum
[±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew:
24 in. [600 mm] or less depth .... ±¼ in. [±6 mm]
Greater than 24 in. [600 mm] depth .... ±⅛ in. per 12 in., ±½ in. maximum
[±3 mm per 300 mm, ±13 mm maximum]

f = Sweep, for member length:
Up to 40 ft. [12 m] .... ±¼ in. [±6 mm]
40 to 60 ft. [12 to 18 m] .... ±⅜ in. [±10 mm]
Greater than 60 ft. [18 m] .... ±½ in. [±13 mm]

g = Camber variation from design camber .... ±¼ in. per 10 ft., ±¾ in. maximum
[±6 mm per 3 m, ±19 mm maximum]

g_1 = Differential camber between adjacent untopped members
of the same design to receive topping .... ¼ in. per 10 ft., ¾ in. maximum
[6 mm per 3 m, ±19 mm maximum]

g_2 = Differential camber between adjacent pretopped members of the same design
.... ⅛ in. per 10 ft., ⅜ in. maximum
[3 mm per 3 m, ±10 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand:
Individual .... ±¼ in. [±6 mm]
Bundled .... ±½ in. [±13 mm]

k_1 = Location of harp points for harped strands from design location ... ±20 in. [±510 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

m_1 = Location of bearing assembly .... ±½ in. [±13 mm]

m_2 = Tipping and flushness of bearing assembly .... ±⅛ in. [±3 mm]

n_1 = Location of blockout .... ±1 in. [±25 mm]

n_2 = Size of blockouts .... ±½ in. [±13 mm]

o = Location of sleeves cast in stems, in both horizontal and vertical plane ±1 in. [±25 mm]

o_1 = Skew of sleeve ends, vertical or horizontal, end to end* .... ±½ in. [±25 mm]

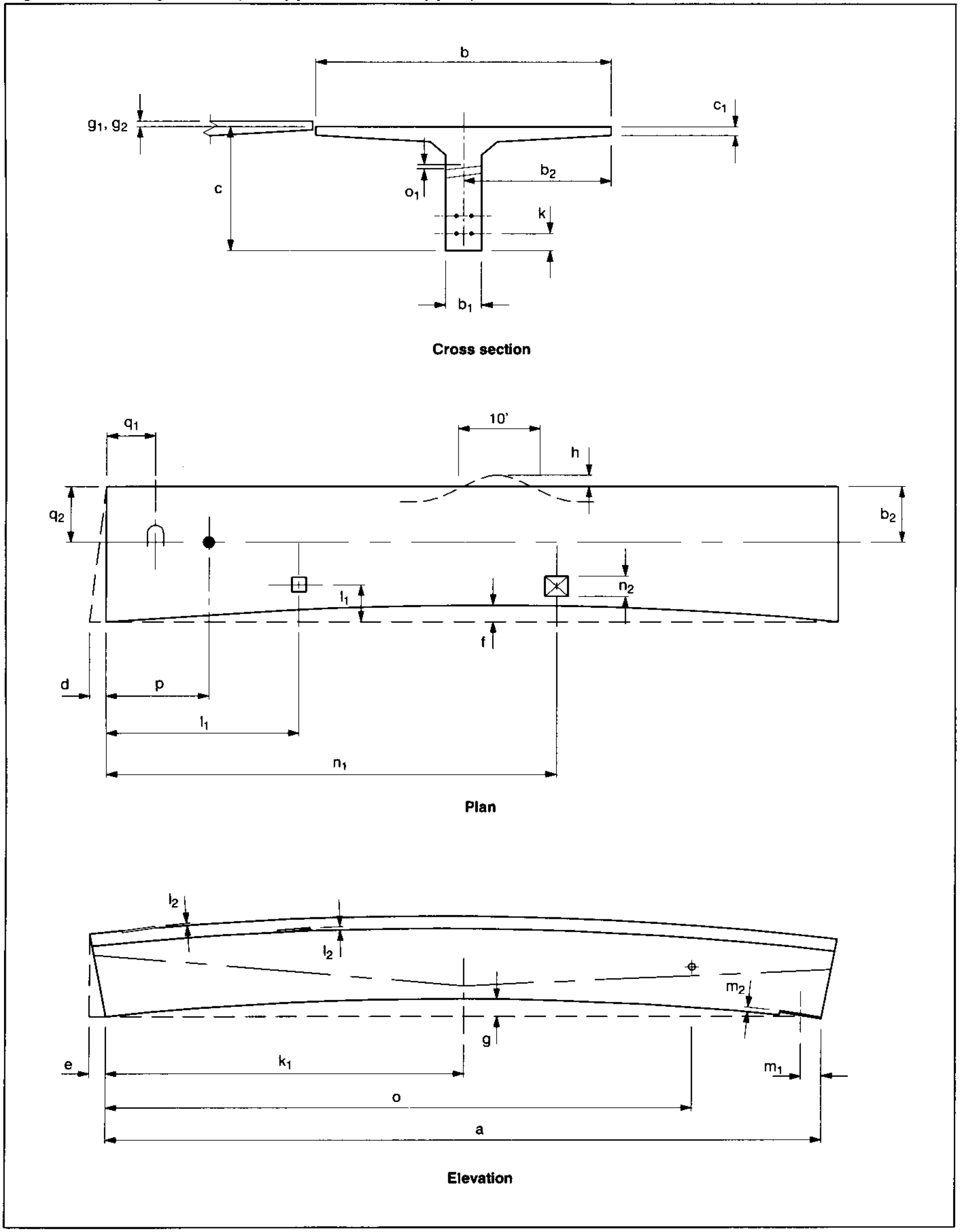
p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

* If skew tolerance of sleeves cast in stems is important for the function or other reason, it should be treated as a special project tolerance.

Fig. 10.7.1 Single Tees (Untopped and Pretopped)



10.7 Single Tees (Untopped and Pretopped)

a = Length .... ±1 in. [±25 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Stem width .... ±¼ in. [±6 mm]

b_2 = Stem to edge of top flange .... ±¼ in. [±6 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Flange thickness .... +¼ in., −⅛ in. [+6 mm, −3 mm]

d = Variation from specified plan end squareness or skew
.... ±⅛ in. per 12 in. width, ±½ in. maximum
[±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew:
Greater than 24 in. [600 mm] depth .... ±⅛ in. per 12 in., ±½ in. maximum
[±3 mm per 300 mm, ±13 mm maximum]
24 in. [600 mm] or less depth .... ±¼ in. [±6 mm]

f = Sweep, for member length:
Up to 40 ft. [12 m] .... ±¼ in. [±6 mm]
40 to 60 ft. [12 to 18 m] .... ±⅜ in. [±10 mm]
Greater than 60 ft. [18 m] .... ±½ in. [±13 mm]

g = Camber variation from design camber .... ±¼ in. per 10 ft., ±¾ in. maximum
[±6 mm per 3 m, ±19 mm maximum]

g_1 = Differential camber between adjacent untopped members of the same design to receive topping .... ¼ in. per 10 ft., ¾ in. maximum
[6 mm per 3 m, ±19 mm maximum]

g_2 = Differential camber between adjacent pretopped members of the same design .... ⅛ in. per 10 ft., ⅜ in. maximum
[3 mm per 3 m, ±10 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand:
Individual .... ±¼ in. [±6 mm]
Bundled .... ±½ in. [±13 mm]

k_1 = Location of harp points for harped strands from design location ... ±20 in [±510 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

m_1 = Location of bearing assembly .... ±½ in. [±13 mm]

m_2 = Tipping and flushness of bearing assembly .... ±⅛ in. [±3 mm]

n_1 = Location of blockout .... ±1 in. [±25 mm]

n_2 = Size of blockouts .... ±½ in. [±13 mm]

o = Location of sleeves cast in stems, in both horiz. and vertical planes .. ±1 in. [±25 mm]

o_1 = Skew of sleeve ends, vertical or horizontal, end to end* .... ±½ in. [±25 mm]

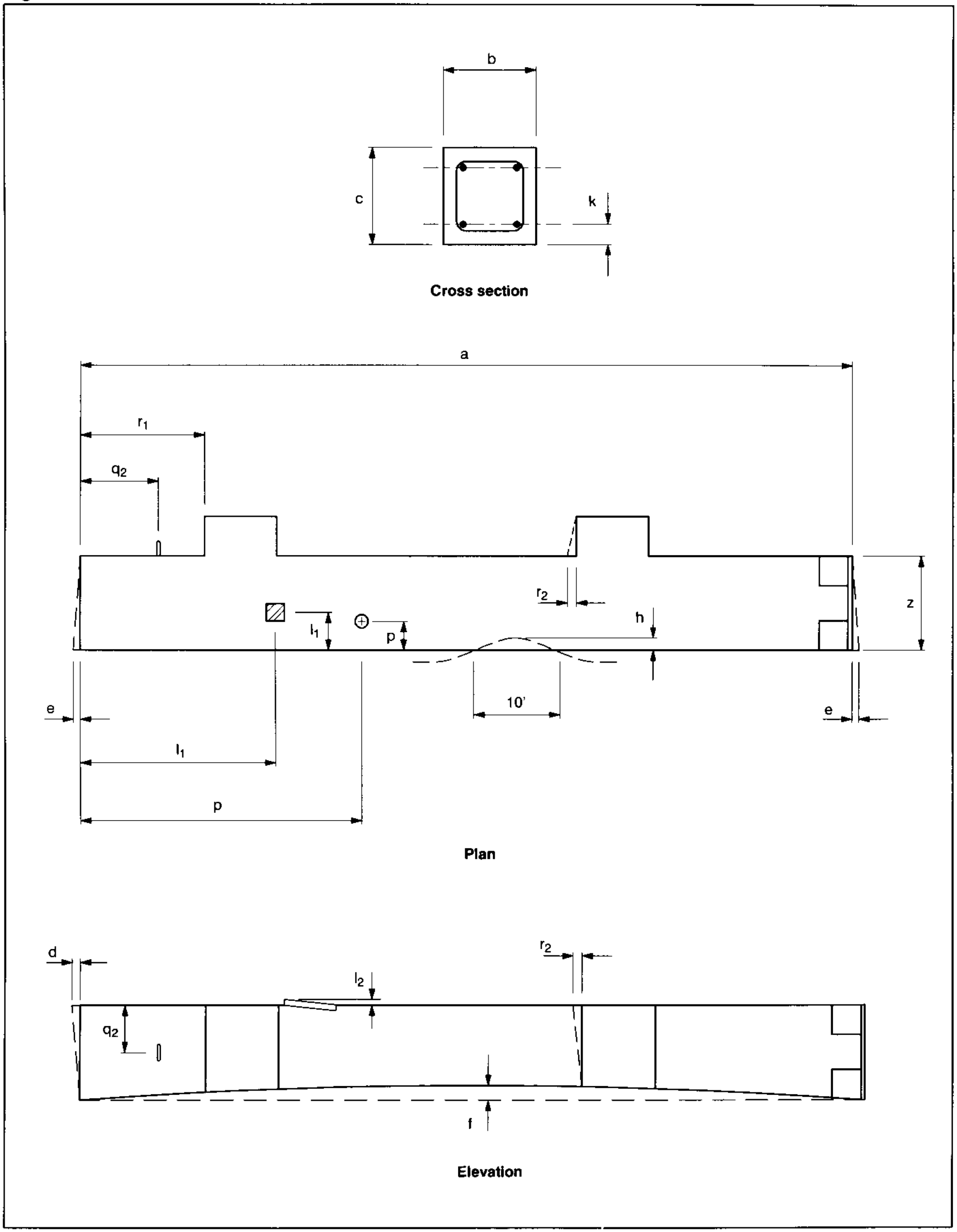
p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

* If skew tolerance of sleeves cast in stems is important for the function or other reason, it should be treated as a special project tolerance.

Fig. 10.8.1 Columns



10.8 Columns

a = Length .... ±½ in. [±13 mm]

b = Width .... ±¼ in. [±6 mm]

c = Depth .... ±¼ in. [±6 mm]

d = Variation from specified plan end squareness or skew
.... ±⅛ in. per 12 in., ±⅜ in. maximum
[±3 mm per 300 mm, ±10 mm maximum]

e = Variation from specified elevation end squareness or skew
.... ±⅛ in. per 12 in., ±⅜ in. maximum
[±3 mm per 300 mm, ±10 mm maximum]

f = Sweep .... ±⅛ in. per 10 ft., ±½ in. maximum
[±3 mm per 3 m, ±13 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand .... ±¼ in. [±6 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

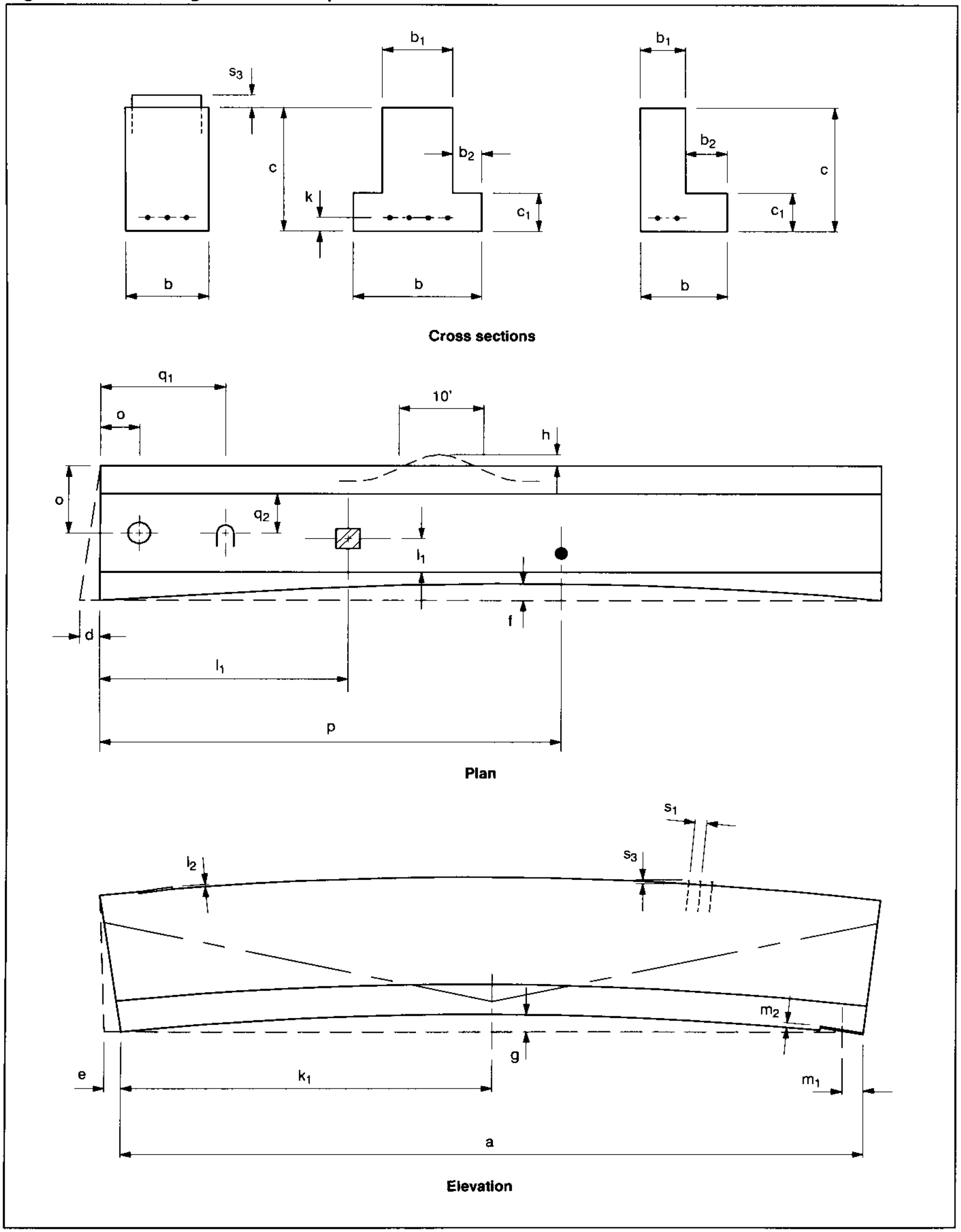
q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

r_1 = Location of haunch bearing elevation from end .... ±¼ in. [±6 mm]

r_2 = Variation from specified haunch bearing surface slope
.... ±⅛ in. per 12 in., ±⅜ in. maximum
[±3 mm per 300 mm, ±10 mm maximum]

z = Base plate overall dimensions .... ±¼ in. [±6 mm]

Fig. 10.9.1 Building Beams and Spandrel Beams



10.9 Building Beams and Spandrel Beams

a = Length .... ±¾ in. [±19 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Stem width .... ±¼ in. [±6 mm]

b_2 = Ledge width .... ±¼ in. [±6 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Ledge depth .... ±¼ in. [±6 mm]

d = Variation from specified plan end squareness or skew
.... ±⅛ in. per 12 in. width, ±½ in. maximum
[±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew
.... ±⅛ in. per 12 in. depth, ±½ in. maximum
[±3 mm per 300 mm, ±13 mm maximum]

f = Sweep, for member length:
Up to 40 ft. [12 m] .... ±¼ in. [±6 mm]
40 to 60 ft. [12 to 18 m] .... ±½ in. [±13 mm]
Greater than 60 ft. [18 m] .... ±⅝ in. [±16 mm]

g = Camber variation from design camber .... ±⅛ in. per 10 ft., ±¾ in. maximum
[±3 mm per 3 m, ±19 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand:
Individual .... ±¼ in. [±6 mm]
Bundled .... ±½ in. [±13 mm]

k_1 = Location of harp points for harped strands from design location for member length:
30 ft. [9 m] or less .... ±6 in. [±150 mm]
Greater than 30 ft. [9 m] .... ±12 in. [±300 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

m_1 = Location of bearing assembly .... ±½ in. [±13 mm]

m_2 = Tipping and flushness of bearing assembly .... ±⅛ in. [±3 mm]

o = Location of sleeves cast in stems, in both horiz. and vertical planes .. ±1 in. [±25 mm]

p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of member .... ±12 in. [±300 mm]

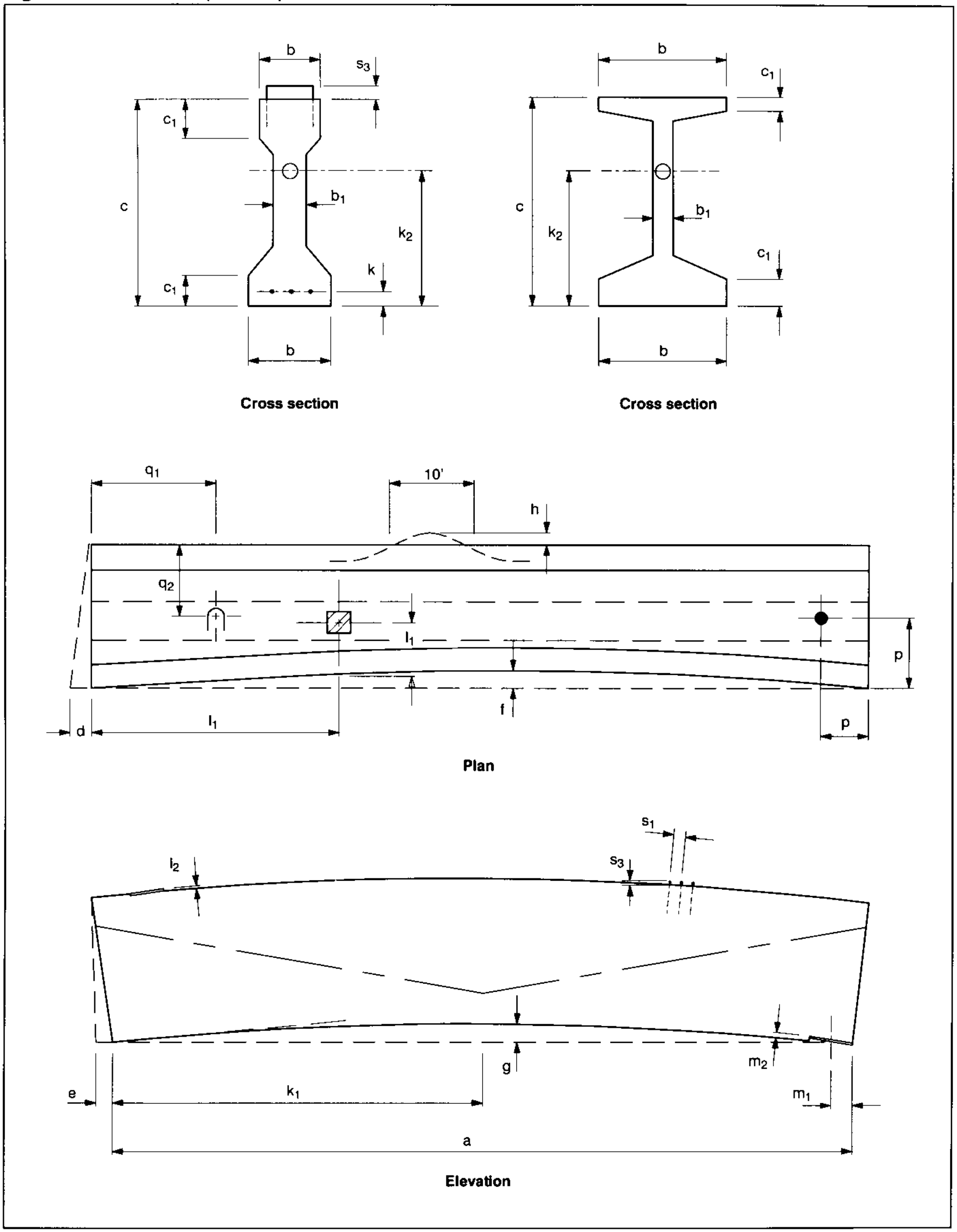
q_2 = Location of handling device transverse to length of member .... ±½ in. [±13 mm]

s_1 = Longitudinal spacing of stirrups .... ±2 in. [±50 mm]

s_2 = Longitudinal spacing of stirrups within distance "c" from member ends
.... ±1 in. [±25 mm]

s_3 = Stirrup projection from beam surface .... +¼ in., −½ in. [+6 mm, −13 mm]

Fig. 10.10.1 I Beams (Girders) or Bulb Tee Girders



10.10 I Beams (Girders) or Bulb Tee Girders

a = Length .... ±¼ in. per 25 ft. length, ±1 in. maximum [±6 mm per 7.5 m length, ±25 mm maximum]

b = Width (overall) .... +⅜ in., −¼ in. [10 mm, −6 mm]

b_1 = Web width .... +⅜ in., −¼ in. [+10 mm, −6 mm]

c = Depth (overall) .... +½ in., −¼ in. [+13 mm, −6 mm]

c_1 = Flange depth .... ±¼ in. [±6 mm]

d = Variation from specified plan end squareness or skew .... ±⅛ in. per 12 in. width, ±½ in. maximum [±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew .... ±3/16 in. per 12 in. depth, ±1 in. maximum [±5 mm per 300 mm, ±25 mm maximum]

f = Sweep .... ⅛ in. per 10 ft. length [3 mm per 3 m length]

g = Camber variation from design camber .... ±⅛ in. per 10 ft. [±3 mm per 3 m]
.... ½ in. [13 mm] maximum up to 80 ft. [24 m] length
.... 1 in. [25 mm] maximum for length greater than 80 ft. [24 m]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand*
Individual .... ±¼ in. [±6 mm]
Bundled .... ±½ in. [±13 mm]

k_1 = Location of harp points for harped strands from design location ... ±20 in. [±510 mm]

k_2 = Location of post-tensioning duct .... ±¼ in. [±6 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

m_1 = Location of bearing assembly .... ±⅝ in. [±16 mm]

m_2 = Tipping and flushness of bearing assembly .... ±⅛ in. [±3 mm]

p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

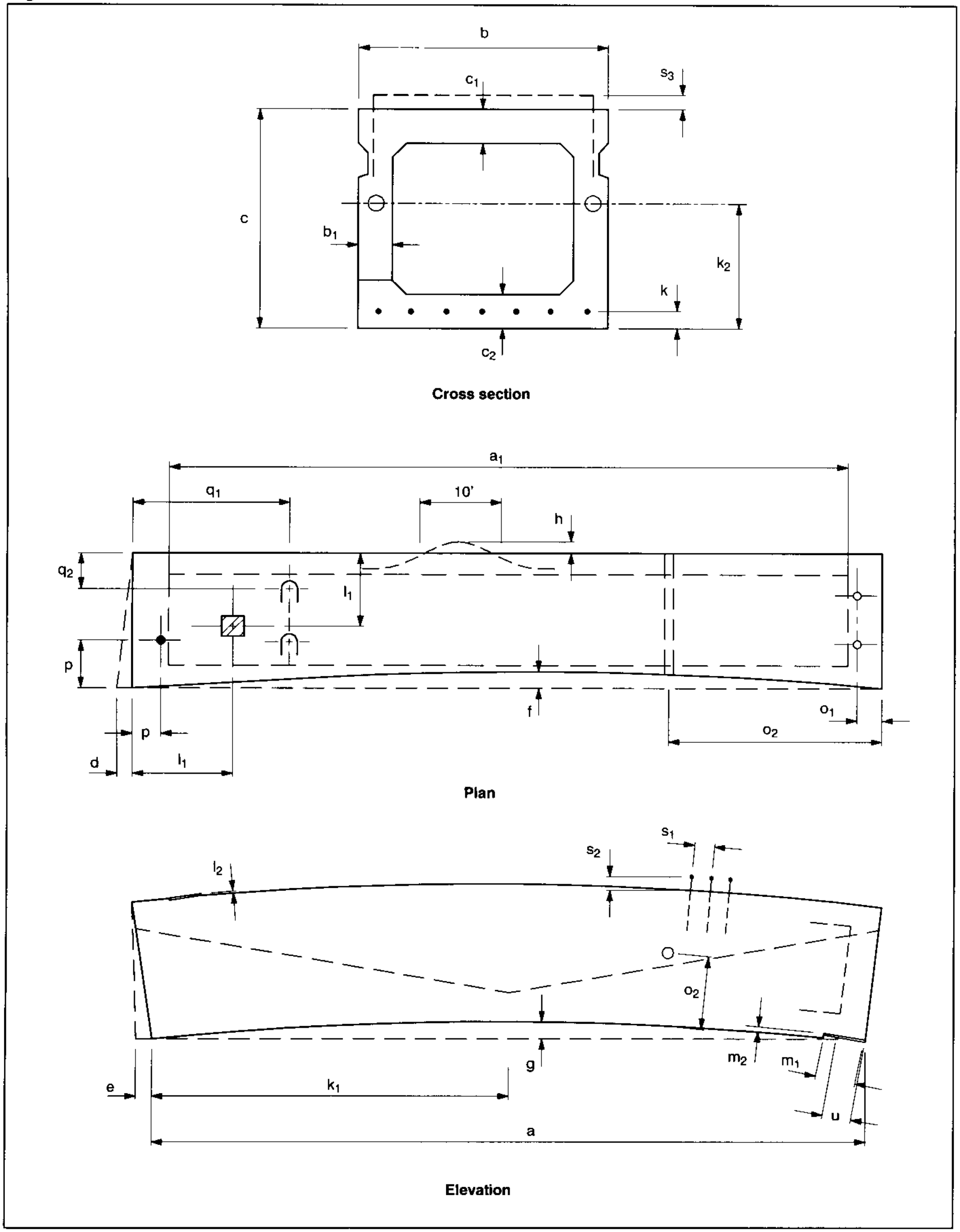
s_1 = Longitudinal spacing of stirrups .... ±2 in. [±50 mm]

s_2 = Longitudinal spacing of stirrups within dist. "c" from member ends ... ±1 in. [±25 mm]

s_3 = Stirrup projection from beam surface .... ±¼ in., −½ in. [±6 mm, −13 mm]

* The location of harped strand at the end of the beam may be controlled to ±½ in. [±13 mm] providing that calculations show that such a variation will not result in unacceptable stresses at any design load condition.

Fig. 10.11.1 Box Beams



10.11 Box Beams

a = Length .... ±¾ in. [±19 mm]

a_1 = Length of void form .... +1 in., −6 in. [+25 mm, −150 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Web width .... ±⅜ in. [±10 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Top flange depth .... ±½ in. [±13 mm]

c_2 = Bottom flange depth .... +½ in., −⅛ in. [+13 mm, −3 mm]

d = Variation from specified plan end squareness or skew .... ±⅛ in. per 12 in. width, ±½ in. maximum [±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew .... ±½ in. [±13 mm]

f = Sweep, for member length:
Up to 40 ft. [12 m] .... ±¼ in. [±6 mm]
40 to 60 ft. [12 to 18 m] .... ±⅜ in. [±10 mm]
Greater than 60 ft. [18 m] .... ±½ in. [±13 mm]

g = Camber variation from design camber .... ±⅛ in. per 10 ft., ±½ in. maximum [±3 mm per 3 m, ±13 mm maximum]

g_1 = Differential camber between adjacent members of the same design .... ¼ in. per 10 ft., ¾ in. maximum [6 mm per 3 m, 19 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand (individual and bundled)* .... ±¼ in. [±6 mm]

k_1 = Location of harp points for harped strands from design location .... ±20 in. [±510 mm]

k_2 = Location of post-tensioning duct .... ±¼ in. [±6 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

m_1 = Location of bearing assembly .... ±⅝ in. [±16 mm]

m_2 = Tipping and flushness of beam seat bearing surface .... ±⅛ in. [±3 mm]

o_1 = Location of sleeve at connection to support .... ±⅝ in. [±16 mm]

o_2 = Location of tie-rod sleeve (horizontal) .... ±½ in. [±13 mm]
Vertical .... ±⅜ in. [±10 mm]

p = Location of inserts for structural connections .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

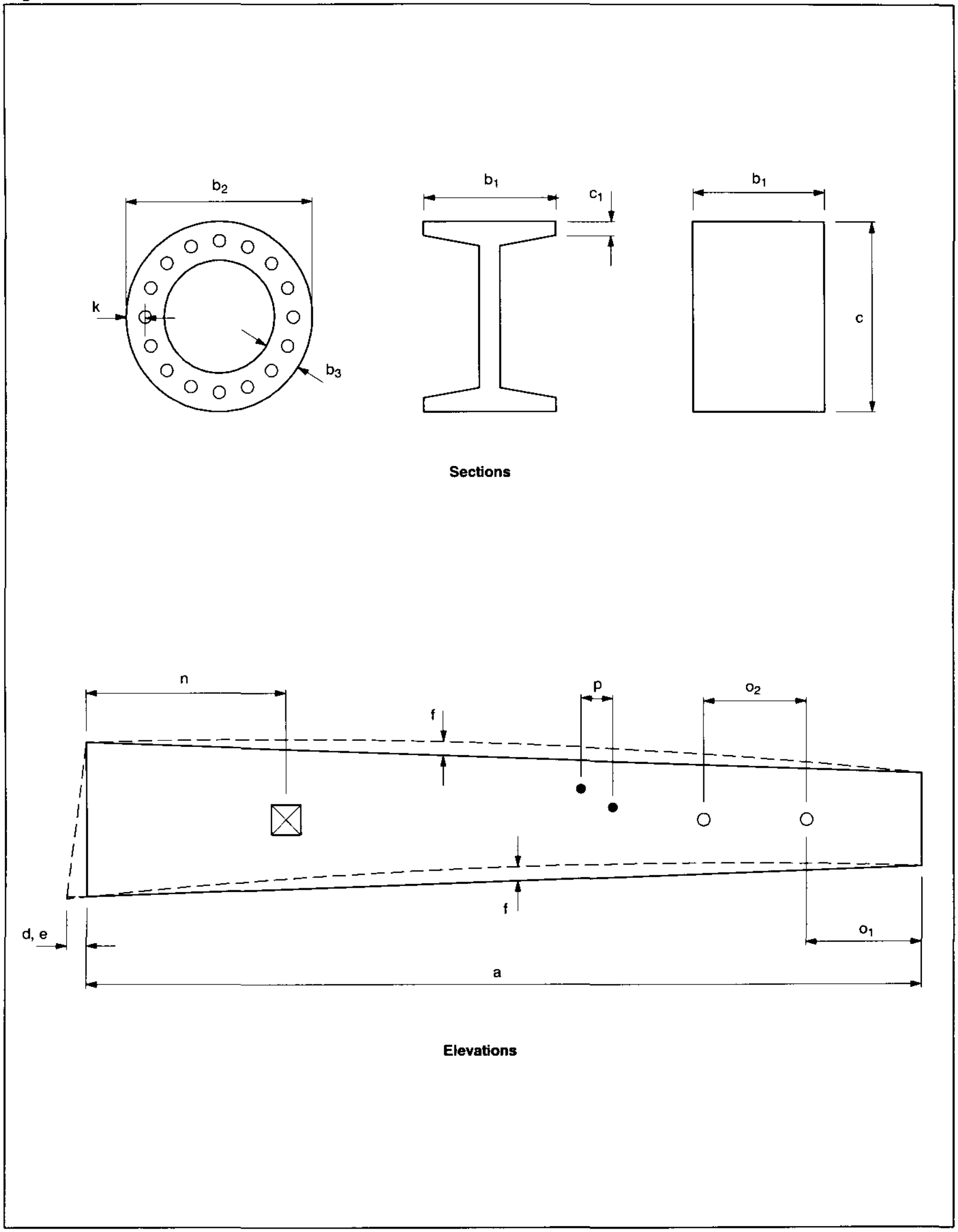
s_1 = Longitudinal spacing of stirrups .... ±1 in. [±25 mm]

s_2 = Stirrup projection from beam surface .... +¼ in., −½ in. [+6 mm, −13 mm]

u = Location of void relative to design center location .... ±½ in. [±13 mm]
From end of beam .... +3 in., −1 in. [675 mm, −25 mm]

* The location of harped strand at the end of the beam may be controlled to ±½ in. [±13 mm] if calculations show that the variation will not result in unacceptable stress at any design load.

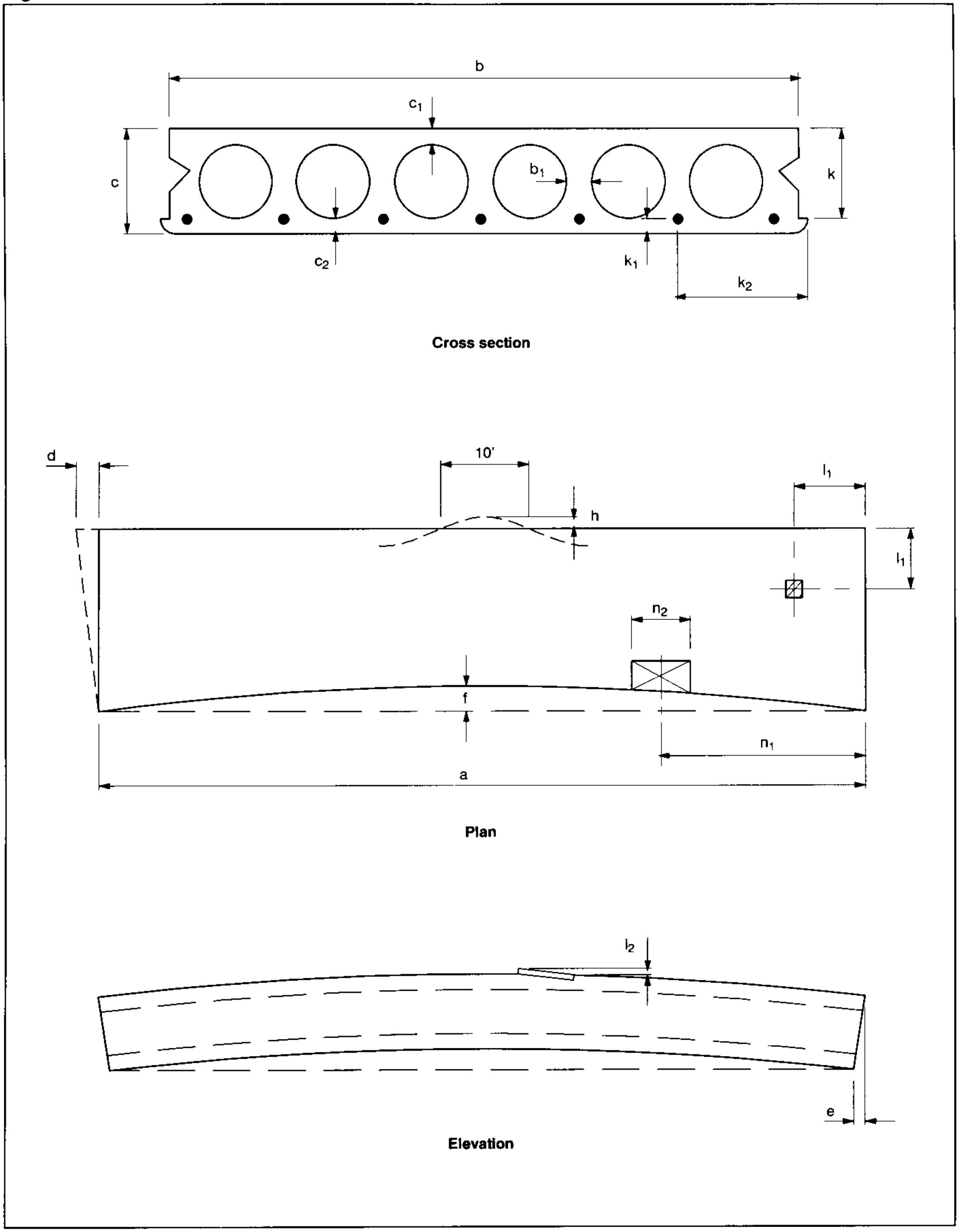
Fig. 10.12.1 Poles



10.12 Poles

a	=	Length	±⅛ in. per 10 ft. or ±2 in., whichever is greater [±3 mm per 3 m or ±50 mm, whichever is greater]
b_1	=	Width, static cast poles	
		Less than 24 in. [600 mm] width	±⅜ in. [±10 mm]
		24 to 36 in. [600 to 900 mm] width	±½ in. [±13 mm]
		Greater than 36 in. [900 mm] width	±⅝ in. [±16 mm]
b_2	=	Diameter, spun poles	±¼ in. [±6 mm]
b_3	=	Wall thickness	±¼ in. [±6 mm] or +20, −10 percent of nominal thickness, whichever is greater
c	=	Depth, static cast poles:	
		Less than 24 in. [600 mm] width	±⅜ in. [±10 mm]
		24 to 36 in. [600 to 900 mm] width	±½ in. [±13 mm]
		Greater than 36 in. [900 mm] width	±⅝ in. [±16 mm]
c_1	=	Flange thickness	±¼ in. [±6 mm]
d	=	Variation from specified plan end squareness or skew	
		Top	±¼ in. [±6 mm]
		Bottom	±1 in. [±25 mm]
e	=	Variation From Specified Elevation End Squareness or Skew	
		Top	±¼ in. [±6 mm]
		Bottom	±1 in. [±25 mm]
f	=	Sweep	±¼ in. per 10 ft. or ±½ in., whichever is greater [±6 mm per 3 m or ±13 mm, whichever is greater]
k	=	Location of strand	±¼ in. [±6 mm]
n	=	Location of blockout	±1 in. [±25 mm]
o_1	=	Location of sleeve	±1 in. [±25 mm]
o_2	=	Location of sleeve for matching hardware pattern	±⅛ in. [+3 mm]
p	=	Location of insert for matching hardware pattern	±⅛ in. [+3 mm]
x	=	Weight	±8 percent of nominal weight

Fig. 10.13.1 Hollow-core Slabs



10.13 Hollow-core Slabs

a = Length .... ±½ in. [±13 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Web width:
The total web width defined by the sum of the actual measured values of "b_1" shall not be less than 85 percent of the sum of the nominal web widths "$b_{1,\ nominal}$"

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Top flange depth:
Top flange area defined by the actual measured values of average "c_1" x "b" shall not be less than 85 percent of the nominal area calculated by "$c_{1,\ nominal}$" x "$b_{\ nominal}$"

c_2 = Bottom flange depth:
Bottom flange area defined by the actual measured values of average "c_2" x "b" shall not be less than 85 percent of the nominal area calculated by "$c_{2,\ nominal}$" x "$b_{\ nominal}$"

d = Variation from specified plan end squareness or skew .... ±½ in. [±13 mm]

e = Variation from specified elevation end squareness or skew
.... ±⅛ in. per 12 in., ±½ in. maximum
[±3 mm per 300 mm, ±13 mm maximum]

f = Sweep .... ±⅜ in. [±10 mm]

g = Applications requiring close control of differential camber between adjacent members should be discussed with the producer to determine applicable tolerances.

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Center of gravity (CG) of strand group .... ±¼ in. [±6 mm]

k_1 = Location of strand perpendicular to plane of panel .... ±½ in. [±13 mm]
Minimum cover .... ¾ in. [19 mm]

k_2 = Location of strand parallel to plane of panel .... ±¾ in. [±19 mm]
Minimum cover .... ¾ in. [19 mm]

l_1 = Location of embedment* .... ±2 in. [±50 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

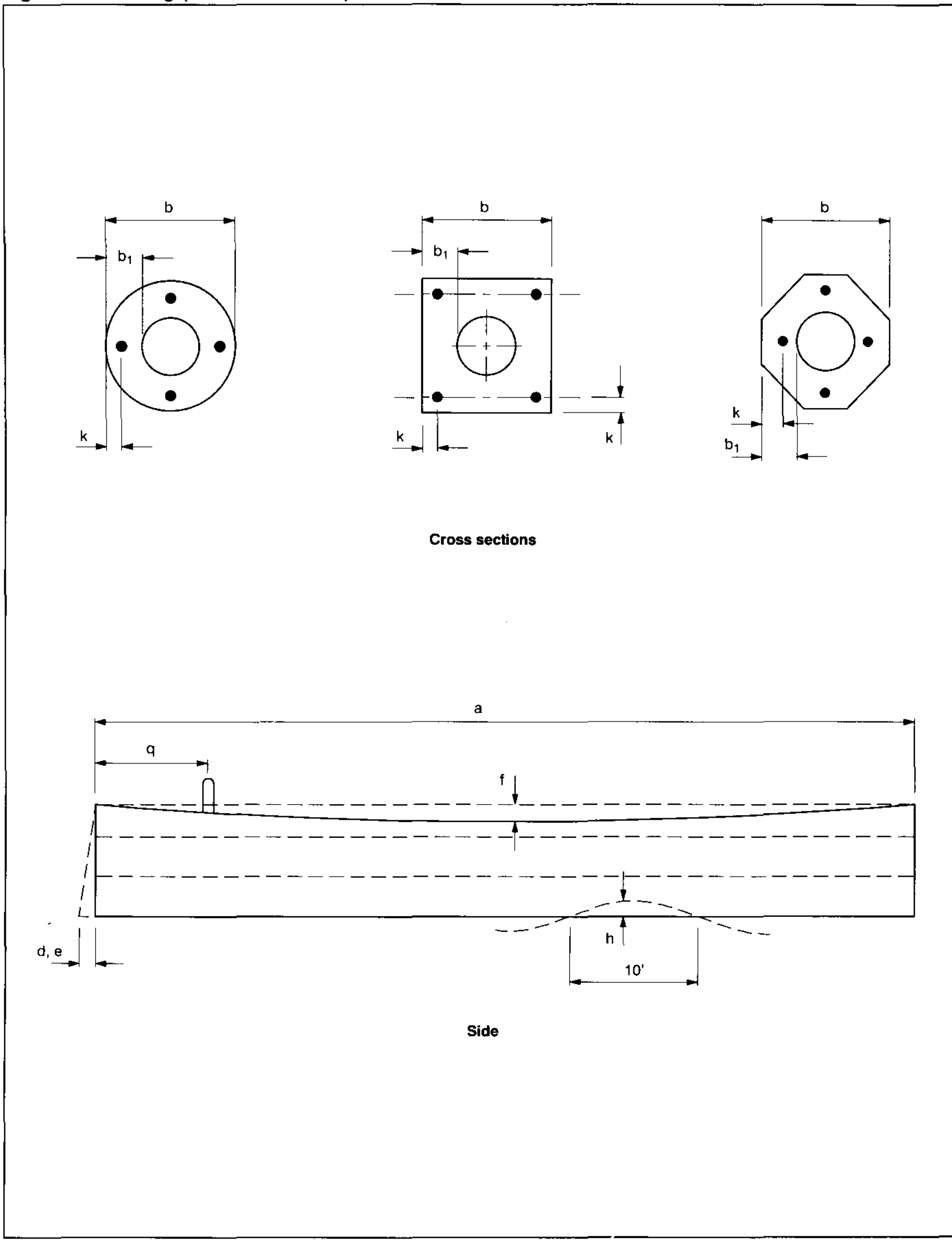
n_1 = Location of blockout .... ±2 in. [±50 mm]

n_2 = Size of blockouts .... ±½ in. [±13 mm]

x = Weight:
Actual measured value shall not exceed 110 percent of the nominal published unit weight used in the design.

* Some hollow-core production systems do not permit the incorporation of embedments. Contact local producers for suitable alternate details if embedments are not practical.

Fig. 10.14.1   Piling (Hollow and Solid)



10.14 Piling (Hollow and Solid)

a = Length* .... ±1 in. [±25 mm]

b = Width or diameter .... ±⅜ in. [±10 mm]

b_1 = Wall Thickness .... +½ in., −¼ in. [+13 mm, −6 mm]

c = Depth .... ±⅜ in. [±10 mm]

d = Variation from specified plan end squareness or skew
.... ±¼ in. per 12 in., ±½ in. maximum
[±6 mm per 300 mm, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew
.... ±¼ in. per 12 in., ±½ in. maximum
[±3 mm per 300 mm, ±13 mm maximum]

f = Sweep .... ±⅛ in. per 10 ft. [±3 mm per 3 m]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand .... ±¼ in. [±6 mm]

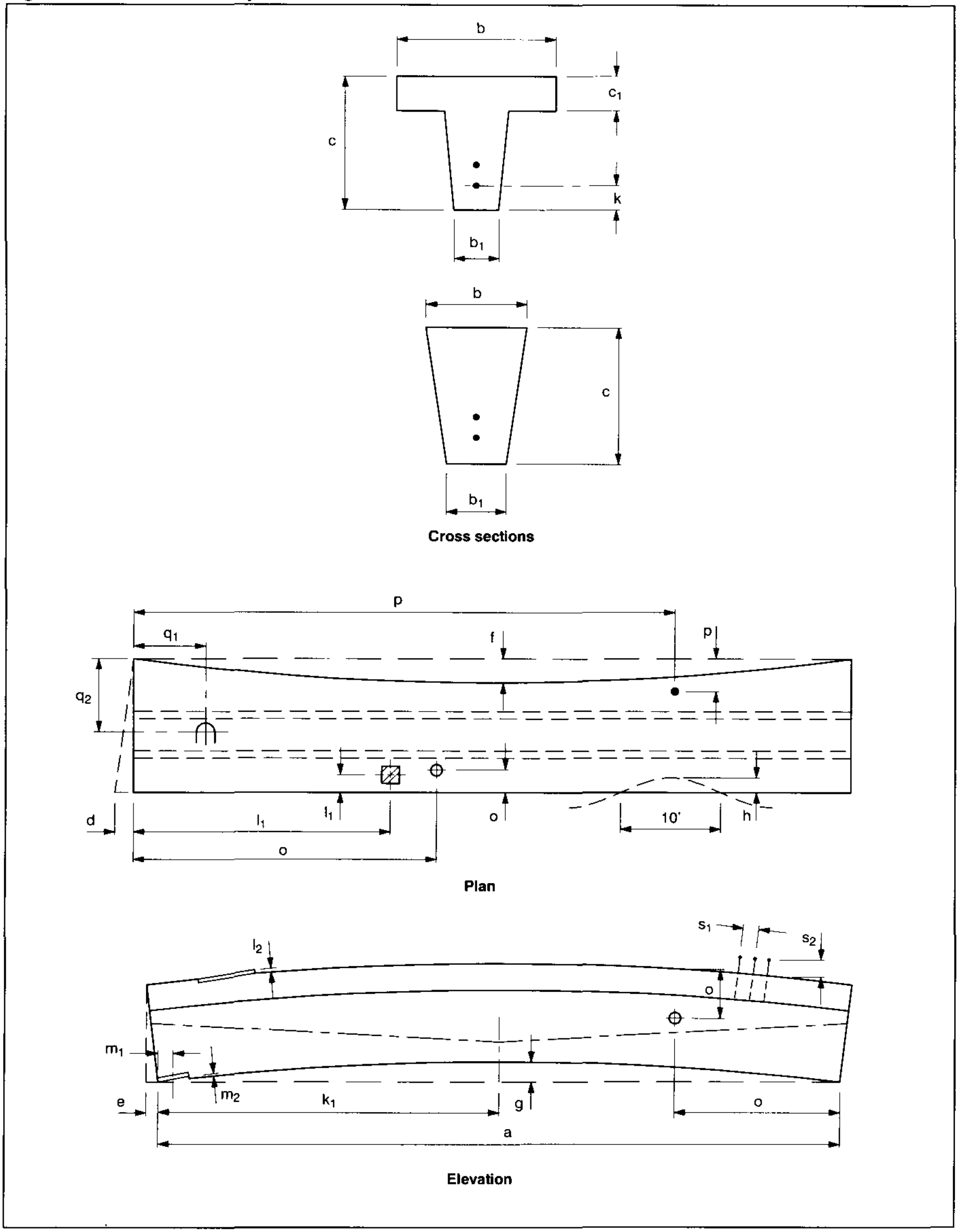
q = Location of handling device .... ±6 in. [±150 mm]

s = Longitudinal spacing of stirrups or spiral reinforcement .... ±¾ in. [±19 mm]

z = Location of driving tip .... ±½ in. [±13 mm]

* Controlling pile length to +6 in., −2 in. [+150 mm, −50 mm] is acceptable in most cases.

Fig. 10.15.1 Tee Joists/Keystone Joists



10.15 Tee Joists/Keystone Joists

a = Length .... ±1 in. [±25 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Stem width .... ±⅛ in. [±3 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Flange thickness .... +¼ in., −⅛ in. [+6 mm, −3 mm]

d = Variation from specified plan end squareness or skew .... ±¼ in. per 12 in. width, ±½ in. maximum [±6 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew .... ±¼ in. per 12 in. height, ±½ in. maximum [±6 mm per 300 mm height, ±13 mm maximum]

f = Sweep, for member length:
Up to 40 ft. [12 m] .... ±⅜ in. [±10 mm]
40 to 60 ft. [12 to 18 m] .... ±⅝ in. [±16 mm]
Greater than 60 ft. [18 m] .... ±¾ in. [±19 mm]

g = Camber variation from design camber .... ±¼ in. per 10 ft., ¾ in. maximum [±6 mm per 3 m, 19 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

k = Location of strand
Individual .... ±¼ in. [±6 mm]
Bundled .... ±½ in. [±13 mm]

k_1 = Location of harp points for harped strands from design location ... ±20 in [±510 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

m_1 = Location of bearing assembly .... ±½ in. [±13 mm]

m_2 = Tipping and flushness of bearing assembly .... ±⅛ in. [±3 mm]

o = Location of sleeves cast in stem, in both horiz. and vertical plane .... ±1 in. [±25 mm]

p = Location of insert for structural connections .... ±½ in. [±13 mm]

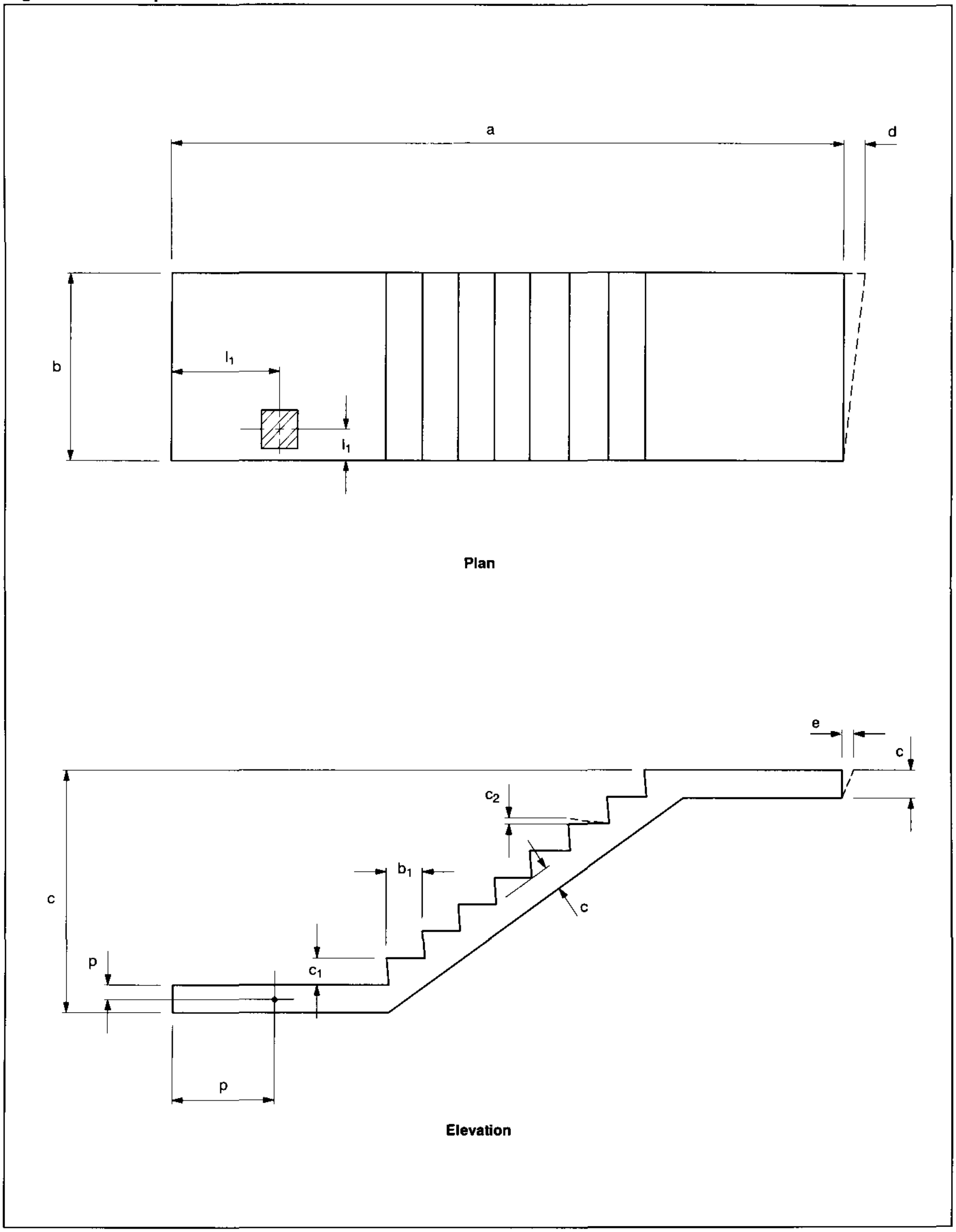
q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

s_1 = Longitudinal spacing of stirrups .... ±2 in. [±50 mm]

s_2 = Stirrup projection from beam surface .... +¼ in., −½ in. [+6 mm, −13 mm]

Fig. 10.16.1 Step Units



10.16 Step Units

a = Length .... ±½ in. [±13 mm]

b = Width (overall) .... ±⅜ in. [±10 mm]

b_1 = Individual tread width (not cumulative) .... ±¼ in. [±6 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Individual riser depth (not cumulative) .... ±3/16 in. [±5 mm]

c_2 = Riser variation from specified plane .... +⅛ in., −0 in. [+3 mm, −0 mm]

c_3 = Differential height between adjacent risers* .... ±¼ in. [±6 mm]

d = Variation from specified plan end squareness or skew .... ±⅛ in. per 12 in. width, ±½ in. maximum [±3 mm per 300 mm width, ±13 mm maximum]

e = Variation from specified elevation end squareness or skew .... ±¼ in. [±6 mm]

j = Warp .... ±¼ in. [±6 mm]

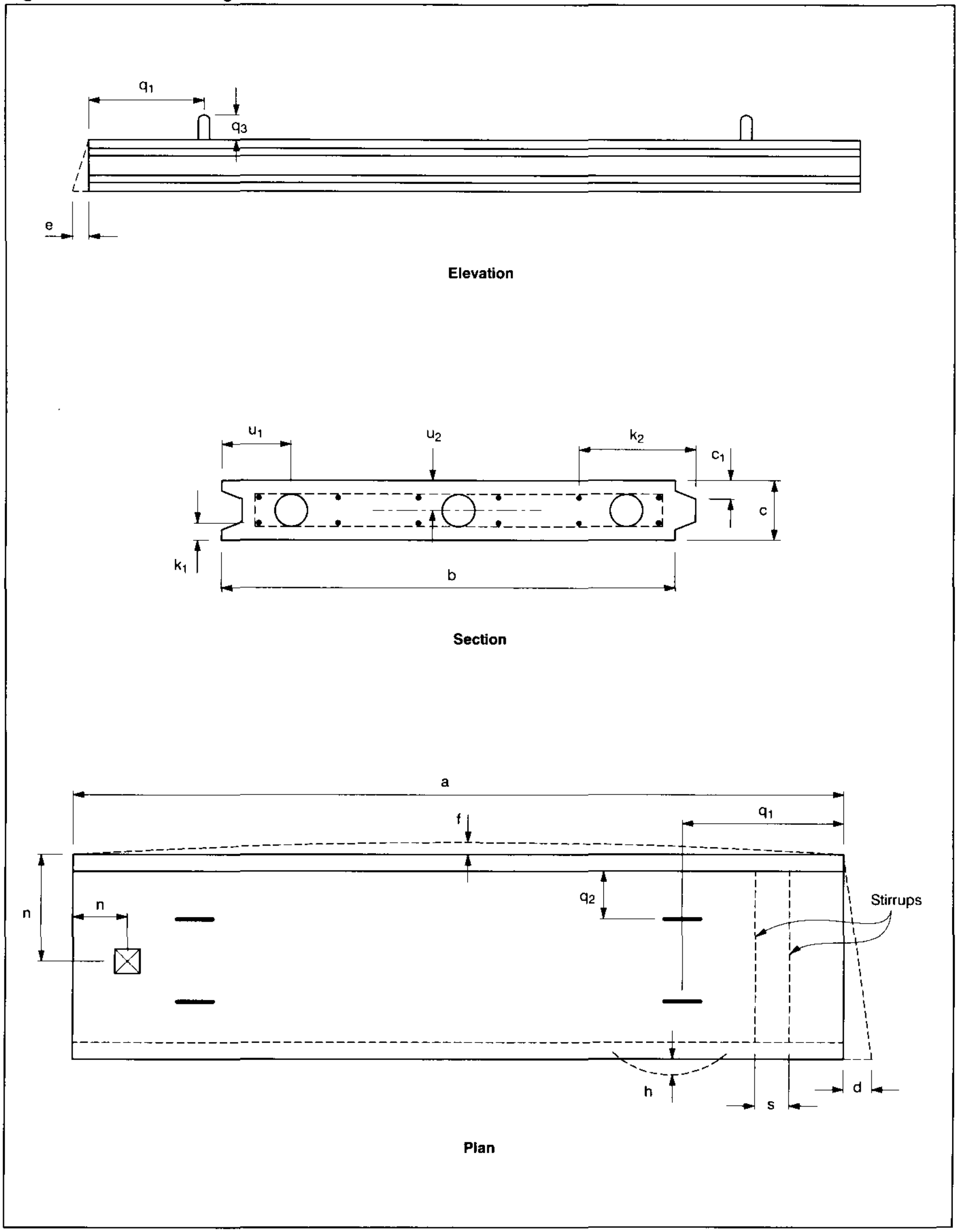
l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±⅛ in. [±3 mm]

p = Location of inserts for structural connections .... ±⅜ in. [±10 mm]

* Local building codes may restrict the maximum height differential between risers. The building code shall govern.

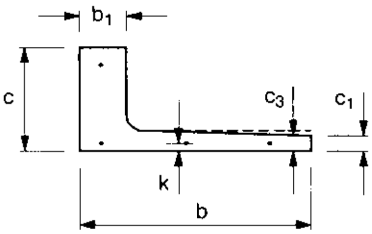
Fig. 10.17.1 Sheet Piling



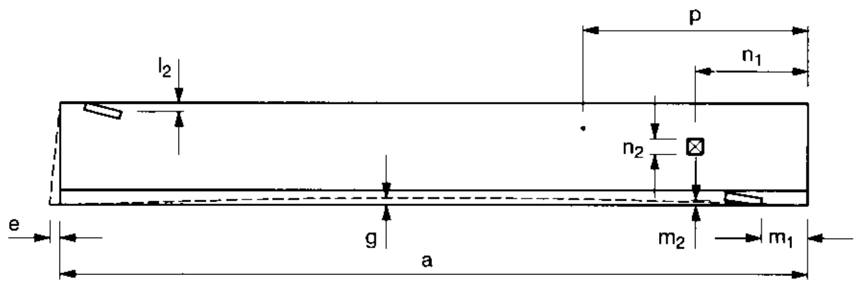
10.17 Sheet Piling

a	=	Length	±1 in. [±25 mm]
b	=	Width	±3/8 in. [±10 mm]
c	=	Depth	±1/4 in. [±6 mm]
c_1	=	Flange depth	±1/2 in. [±13 mm]
d	=	Variation from specified plan end squareness or skew	±1/4 in. per 10 ft., ±1/2 in. maximum [±6 mm per 3 m, ±13 mm maximum]
e	=	Variation from specified plan end squareness or skew	±1/4 in. [±6 mm]
f	=	Sweep	±1/8 in. per 10 ft. [±3 mm per 3 m]
h	=	Local smoothness of any surface	1/4 in. in 10 ft. [6 mm in 3 m]
k_1	=	Location of strand perpendicular to plane of panel	±1/4 in. [±6 mm]
k_2	=	Location of strand parallel to plane of panel	±1 in. [±25 mm]
n	=	Location of blockout	±1 in. [±25 mm]
q_1	=	Location of handling device parallel to length of member	±6 in. [±150 mm]
q_2	=	Location of handling device transverse to length of member	±1/2 in. [±13 mm]
q_3	=	Projection of handling device	±1/2 in. [±13 mm]
s	=	Longitudinal spacing of stirrups	±3/4 in. [±19 mm]
u_1	=	Transverse location of voids	±1/2 in. [±13 mm]
u_2	=	Vertical location of voids	±1/4 in. [±6 mm]
u_3	=	Longitudinal location of voids	±1/2 in. [±13 mm]

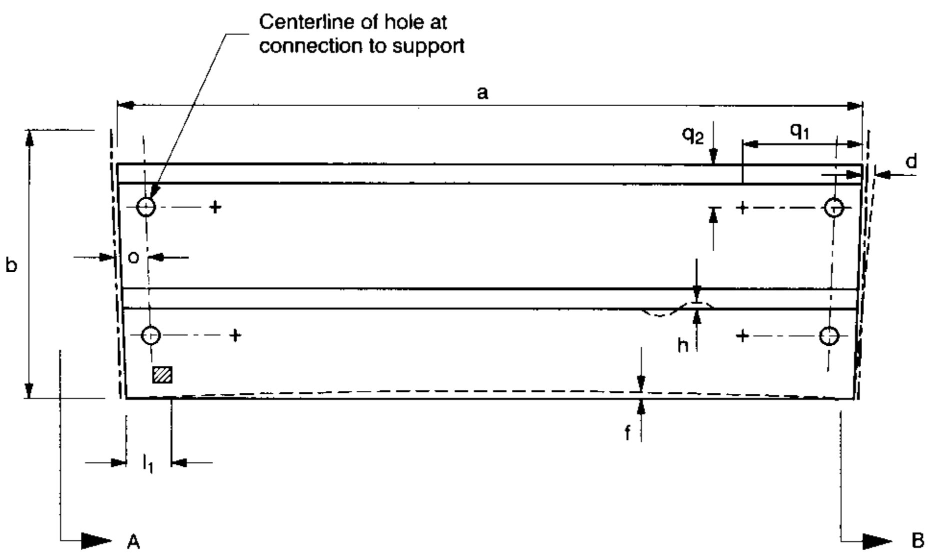
Fig. 10.18.1 Stadium Riser



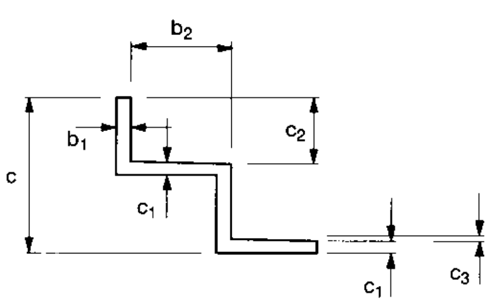
Single riser section



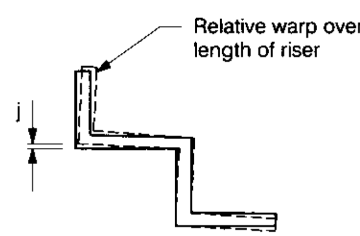
Elevation



Plan



Multi-riser section A



Multi-riser section B

10.18 Stadium Riser

a = Length .... ±½ in. [±13 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

b_1 = Stem width .... ±⅛ in. [±3 mm]

b_2 = Individual tread width (not cumulative) .... ±⅛ in. [±3 mm]

c = Depth (overall) .... ±¼ in. [±6 mm]

c_1 = Flange thickness .... +¼ in., −⅛ in. [+6 mm, −3 mm]

c_2 = Individual riser depth (not cumulative) .... ±⅛ in. [±3 mm]

c_3 = Riser variation from specified plane .... +⅛ in., −0 in. [+3 mm, −0 mm]

d = Variation from specified plan end squareness or skew .... ±⅛ in. per 12 in. width, ±¼ in. maximum [±3 mm per 300 mm width, ±6 mm maximum]

e = Variation from specified elevation end squareness or skew .... ±¼ in. per 12 in. height, ±½ in. maximum [±6 mm per 300 mm height, 13 mm maximum]

f = Sweep .... ±¼ in. per 40 ft. length, ±⅜ in. maximum [±6 mm per 12 m length, 10 mm maximum]

g = Camber variation from design camber .... ±¼ in. per 10 ft., ±½ in. maximum [±6 mm per 3 m, 13 mm maximum]

g_1 = Differential camber between adjacent units of the same design .... ¼ in. per 10 ft., ½ in. maximum [6 mm per 3 m, 13 mm maximum]

h = Local smoothness of any surface .... ¼ in. in 10 ft. [6 mm in 3 m]

j = Warp .... ±¼ in. [±6 mm]

k = Location of strand .... ±¼ in. [±6 mm]

l_1 = Location of embedment .... ±1 in. [±25 mm]

l_2 = Tipping and flushness of embedment .... ±¼ in. [±6 mm]

m_1 = Location of bearing assembly .... ±½ in. [±13 mm]

m_2 = Tipping and flushness of bearing assembly .... ±⅛ in. [±3 mm]

n_1 = Location of blockout .... ±1 in. [±25 mm]

n_2 = Size of blockouts .... ±1 in. [±25 mm]

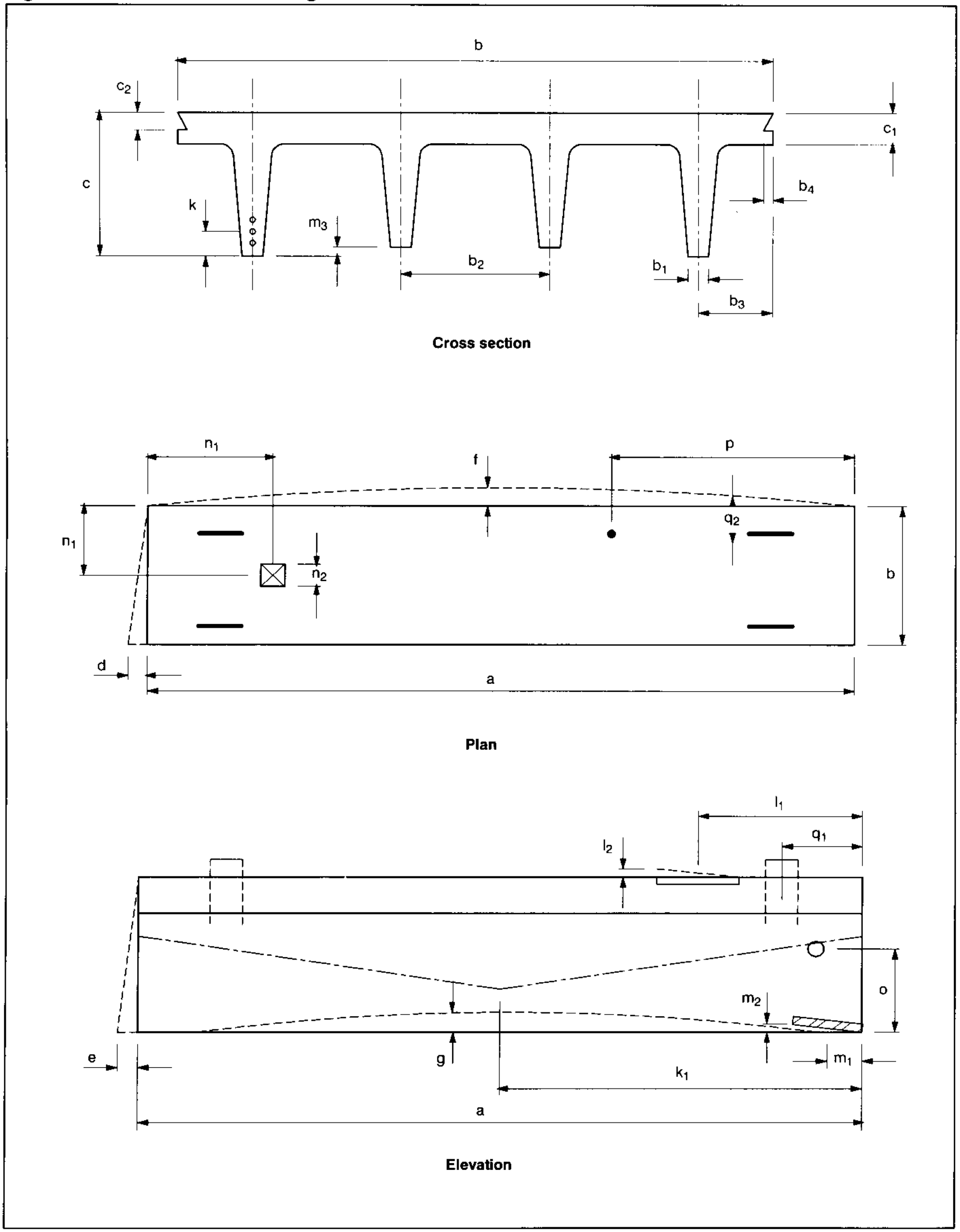
o = Location of sleeves at connection to support .... ±½ in. [±13 mm]

p = Location of inserts .... ±½ in. [±13 mm]

q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

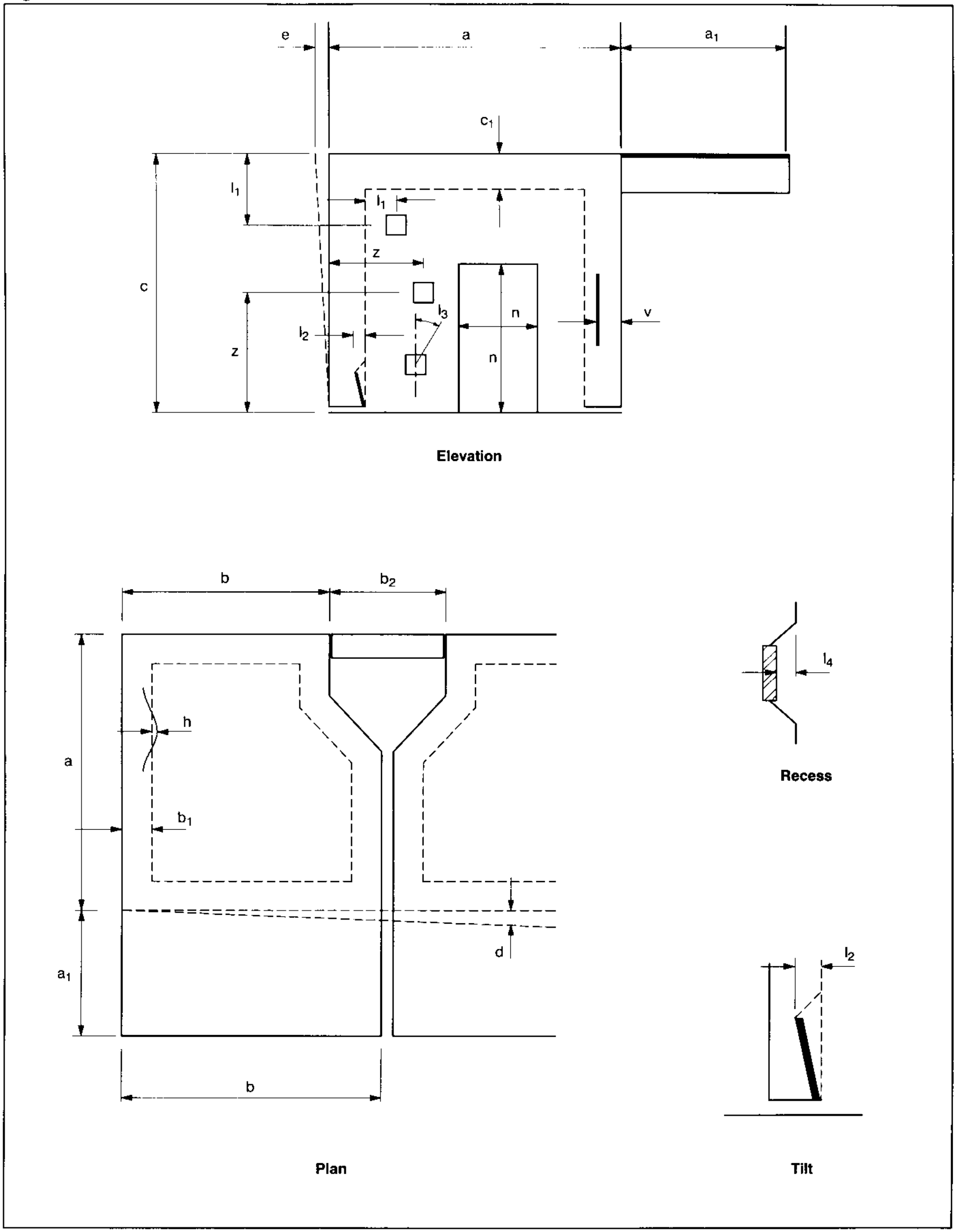
Fig. 10.19.1 Multi-Stemmed Bridge Units



10.19 Multi-Stemmed Bridge Units

a	=	Length	±¾ in. [±19 mm]
b	=	Width (overall)	±¼ in. [±6 mm]
b_1	=	Stem width	±¼ in. [±6 mm]
b_2	=	Distance between stems	±⅛ in. [±3 mm]
b_3	=	Stem to edge of top flange	±¼ in. [±6 mm]
b_4	=	Shear key width	±¼ in. [±6 mm]
c	=	Depth (overall)	±¼ in. [±6 mm]
c_1	=	Flange thickness	+¼ in., −⅛ in. [+6 mm, −3 mm]
c_2	=	Shear key depth	±¼ in. [±6 mm]
d	=	Variation from specified plan end squareness or skew	±¾ in. [±19 mm]
e	=	Variation from specified elevation end squareness or skew	±¾ in. [±19 mm]
f	=	Sweep, for member length:	
		Up to 40 ft. [12 m]	±¼ in. [±6 mm]
		40 to 60 ft. [12 to 18 m]	±⅜ in. [±10 mm]
		Greater than 60 ft. [18 m]	±½ in. [±13 mm]
g	=	Camber variation from design	±¼ in. per 10 ft., ±¾ in. maximum [±6 mm per 3 m, ±19 mm maximum]
g_1	=	Differential camber between adjacent units of the same design	¼ in. per 10 ft., ¾ in. maximum [6 mm per 3 m, 19 mm maximum]
k	=	Location of strand:	
		Individual	±¼ in. [±6 mm]
		Bundled	±½ in. [±13 mm]
k_1	=	Location of harp points for harped strands from design location	±6 in [±150 mm]
l_1	=	Location of embedment	±1 in. [±25 mm]
l_2	=	Tipping and flushness of embedment	±¼ in. [±6 mm]
m_1	=	Location of bearing assembly	±½ in. [±13 mm]
m_2	=	Tipping and flushness of bearing assembly	±⅛ in. [±3 mm]
m_3	=	Differential elevation of bearing surface between stems	±1⁄16 in. [±2 mm]
n_1	=	Location of blockout	±1 in. [±25 mm]
n_2	=	Size of blockouts	±1 in. [±25 mm]
o	=	Location of sleeves cast in stems, in both horizontal and vertical plane	±½ in. [±13 mm]
p	=	Location of inserts for structural connections	±½ in. [±13 mm]
q_1	=	Location of handling device parallel to length of member	±6 in. [±150 mm]
q_2	=	Handling device location transverse to member length	±1 in. [±25 mm]
s	=	Longitudinal spacing of stirrups	±1 in. [±25 mm]

Fig. 10.20.1 Modular Room Unit



10.20 Modular Room Unit

a = Length .... ±3/8 in. [±10 mm]

a_1 = Length of balcony extension .... ±1/4 in. [±6 mm]

b = Width (overall):
Single unit .... ±1/4 in. [±6 mm]
Multiple unit .... ±1/2 in. [±13 mm]

b_1 = Wall thickness .... +1/4 in., −0 in. [+6 mm, −0 mm]

b_2 = Width of closure panel between units .... +0 in., −1/2 in. [+0 mm, −13 mm]

c = Depth (overall) .... ±1/4 in. [±6 mm]

c_1 = Slab thickness .... ±1/4 in. [±6 mm]

d = Variation from specified plan end squareness or skew .... ±1/4 in. [±6 mm]

e = Variation from specified elevation end squareness or skew .... ±1/8 in. [±3 mm]

h = Local smoothness of any surface .... 1/4 in. in 10 ft. [6 mm in 3 m]

l_1 = Location of embedment .... ±1/2 in. [±13 mm]

l_2 = Tipping and flushness of embedment .... ±1/8 in. [±3 mm]

l_3 = Angular rotation of visible embedment or blockout .... 2 degrees
.... 1/4 in. [6 mm] maximum measured at perimeter of embedment or blockout

l_4 = Depth of recess to embedment .... +1/4 in., −1/8 in. [+6 mm, −3mm]

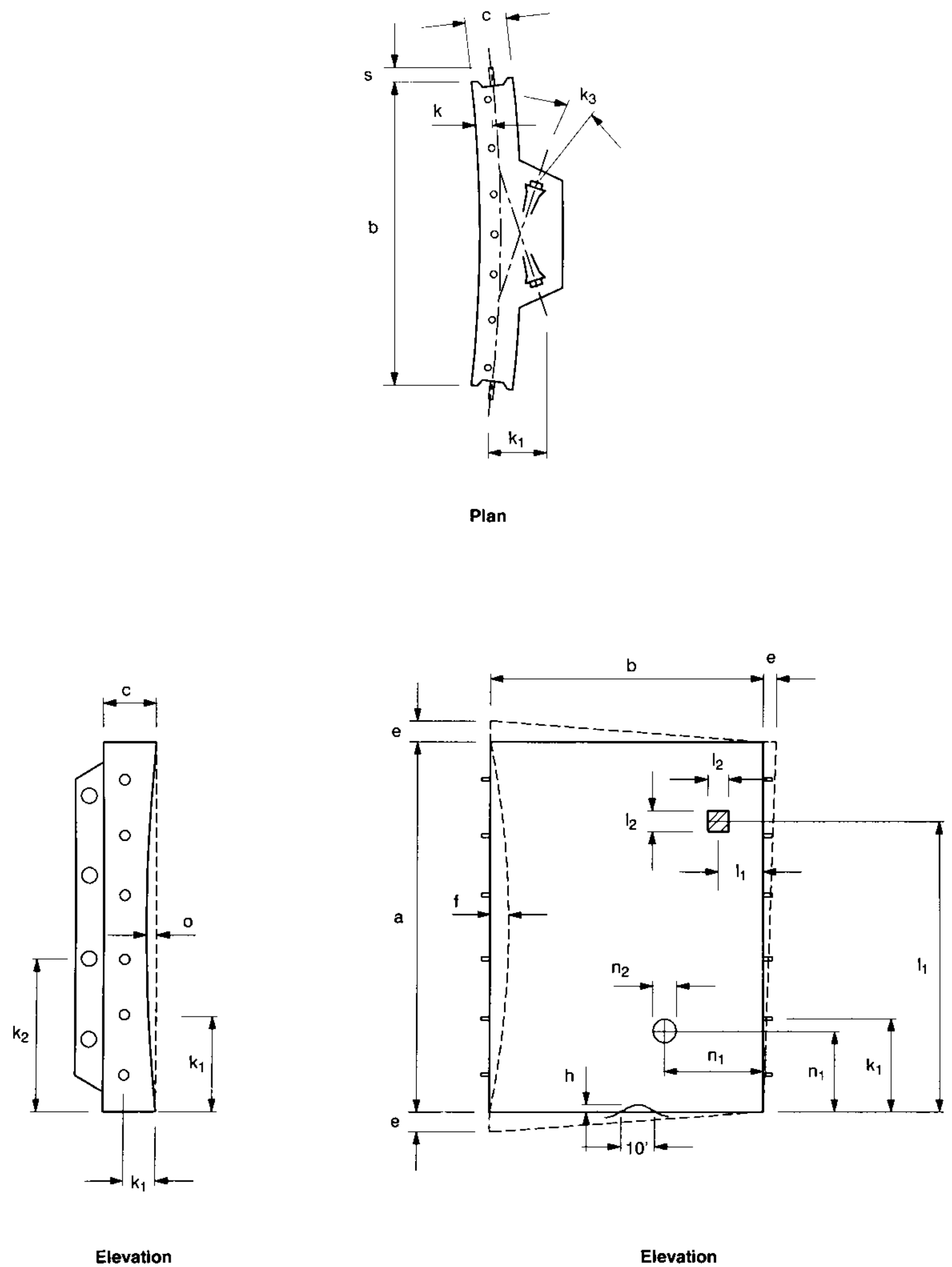
n = Size of blockout for door or window .... ±1/8 in. [±3 mm]

v = Cover over reinforcement .... ±1/4 in. [±6 mm]

z = Location of electrical boxes .... ±1 in. [±25 mm]

Note: Tolerances for project specific items, such as security hardware, mechanical/electrical/plumbing embedments, doors, and windows, should be included in the contract documents.

Fig. 10.21.1 Prestressed Concrete Panels for Storage Tanks



10.21 Prestressed Concrete Panels for Storage Tanks

a = Length .... ±¼ in. [±6 mm]

b = Width (overall) .... ±¼ in. [±6 mm]

c = Depth (overall) .... +¼ in., −⅛ in. [+6 mm, −0 mm]

e = Variation from specified elevation end squareness or skew .... ±⅛ in. per 72 in. length, ±¼ in. maximum [±3 mm per 1800 mm, 6 mm maximum]

f = Sweep .... ±⅜ in. [±10 mm]

h = Local smoothness:
Horizontal surface .... ⅛ in. in 10 ft. [3 mm in 3 m]
Vertical surface .... ¼ in. in 10 ft. [6 mm in 3 m]

i = Bow .... Length/360, ¾ in. [19 mm] maximum

i_1 = Differential bow between adjacent panels of the same design .... ⅜ in. [10 mm]

k = Location of strand .... ±¼ in. [±6 mm]

k_1 = Location of post-tensioning duct .... ±⅛ in. [±3 mm]

k_2 = Location of post-tensioning anchor .... ±¼ in. [±6 mm]

k_3 = Angular rotation of post-tensioning anchor from specified alignment .... ±5 degrees

l_1 = Location of embedment .... ±¾ in. [±19 mm]

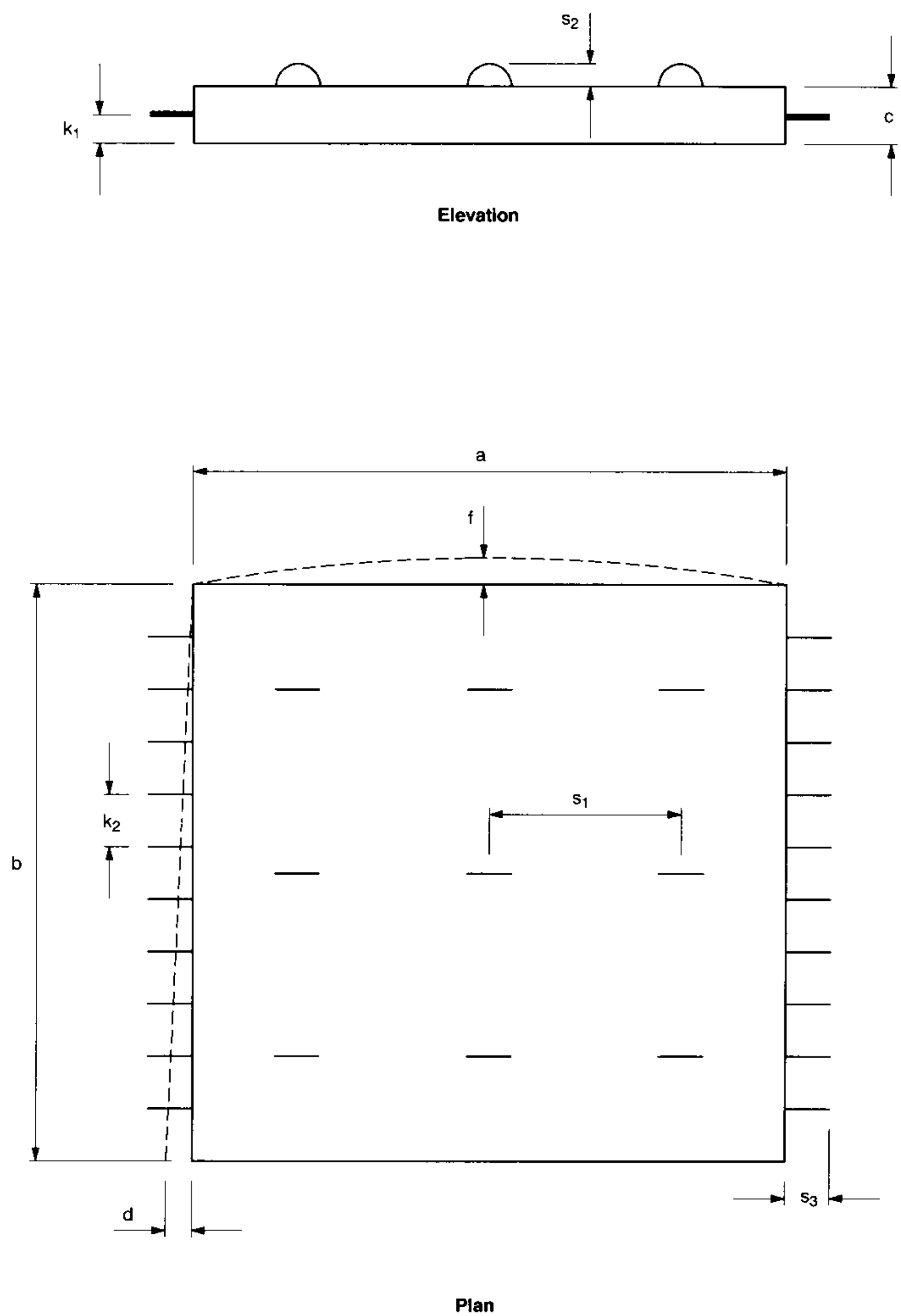
l_2 = Size of embedment .... ±⅛ in. [±3 mm]

n_1 = Location of blockout .... ±¾ in. [±19 mm]

n_2 = Size of blockouts .... ±¼ in. [±6 mm]

s = Projection of post-tensioning duct .... ±½ in. [±13 mm]

Fig. 10.22.1 Bridge Deck Units



10.22 Bridge Deck Units

a = Length .... ±¼ in. [±6 mm]

b = Width .... ±¼ in. [±6 mm]

c = Depth .... +¼ in., −⅛ in. [+6 mm, −3 mm]

d = Variation from specified plan end squareness or skew .... ±¼ in. [±6 mm]

f = Sweep .... ±⅛ in. [±3 mm]

k_1 = Location of strand perpendicular to plane of panel .... ±⅛ in. [±3 mm]

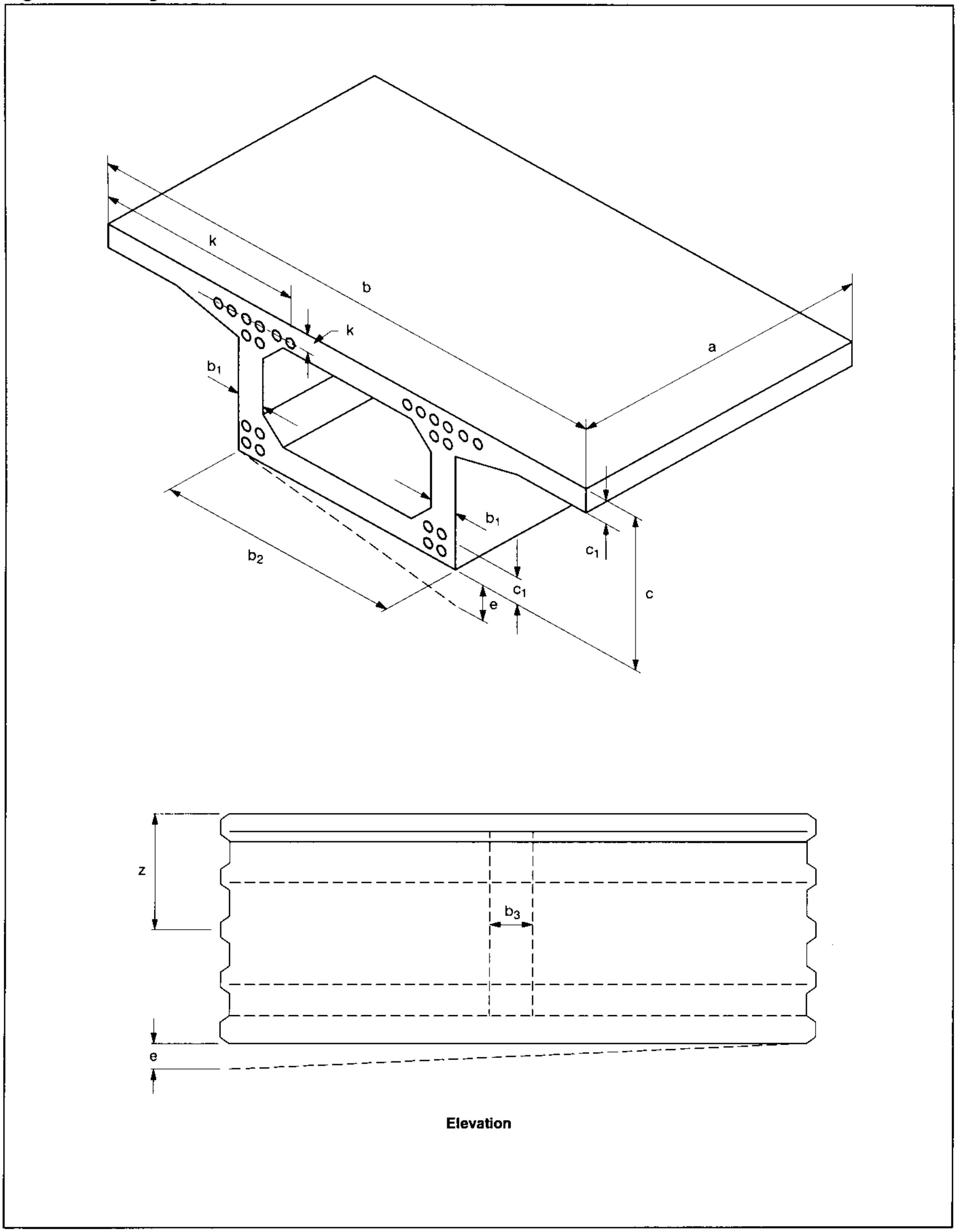
k_2 = Location of strand parallel to plane of panel .... ±¼ in. [±6 mm]

s_1 = Longitudinal spacing of stirrups .... ±1 in. [±25 mm]

s_2 = Stirrup projection from surface .... ±½ in. [±13 mm]

s_3 = Strand projection from end .... ±½ in. [±13 mm]

Fig. 10.23.1 Segmental Box Girder



10.23 Segmental Box Girder

a = Length .... ±1/8 in/ft. length, ±1 in. maximum [±10 mm/m length, 25 mm maximum]

b = Width (overall) .... ±1/16 in/ft. width, ±3/4 in. maximum [±5 mm/m length, ±19 mm maximum]

b_1 = Web width .... ±3/8 in [±10 mm]

b_2 = Bottom flange width .... 1/16 in/ft. width, ±1/2 in. maximum [±5 mm/m length, ±13 mm maximum]

b_3 = Diaphragm thickness .... ±1/2 in. [±13 mm]

c = Depth (overall) .... ±1/4 in. [±6 mm]

c_1 = Depth of top and bottom slab .... ±3/8 in. [±10 mm]

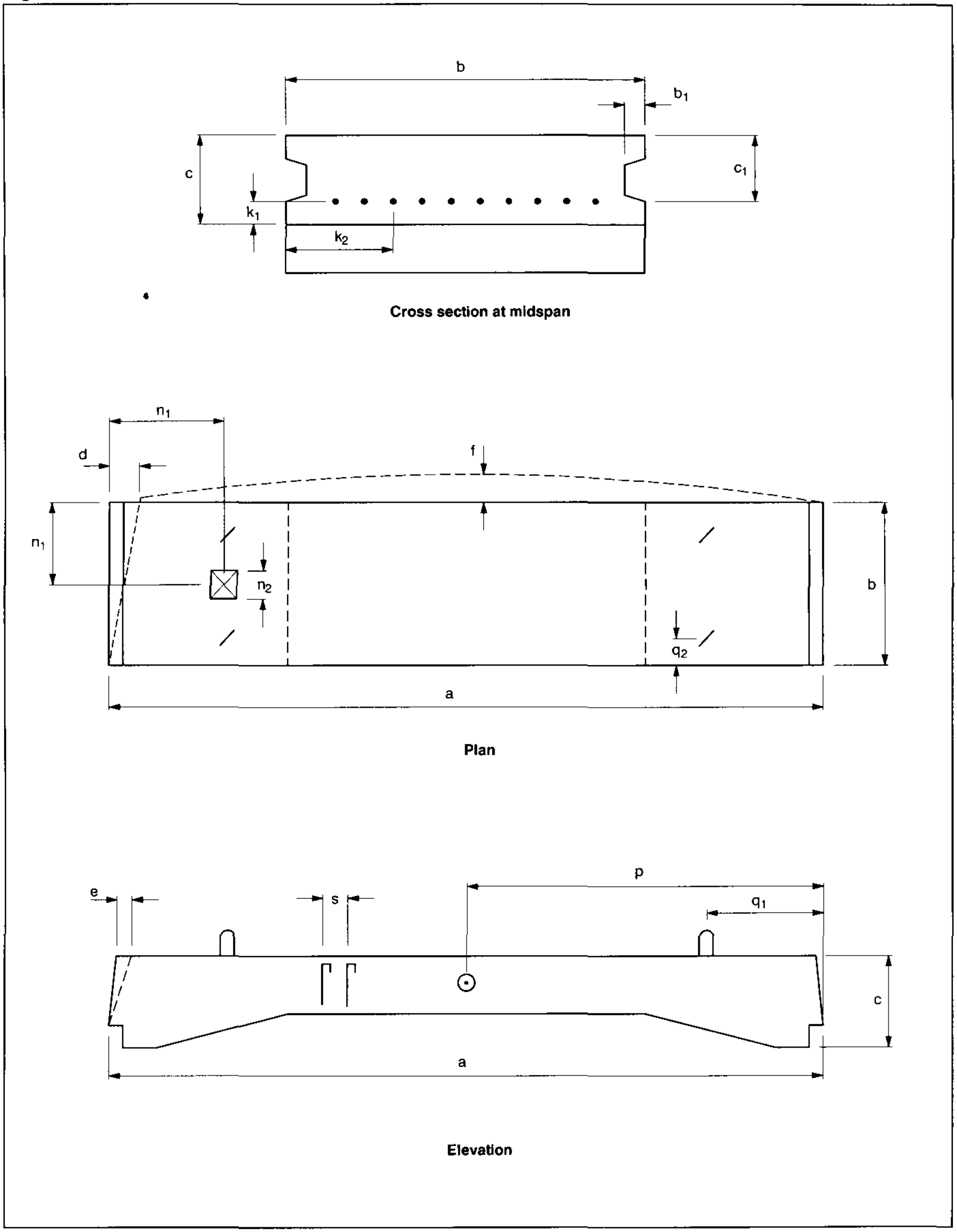
e = Grade of form edge and soffit (vertical curve and super-elevation) .... ±1/8 in. in 10 ft. [±3 mm in 3 m]

k = Location of post-tensioning duct .... ±1/8 in. [±3 mm]

z = Location of shear key .... ±1/4 in. [±6 mm]

Note: The above tolerances should be compared to the specific requirements of the project tolerance control plan and adjusted as necessary.

Fig. 10.24.1 Pier Deck Units



10.24 Pier Deck Units

a = Length .... ±½ in. [±13 mm]

b = Width .... ±¼ in. [±6 mm]

b_1 = Shear key width .... ±¼ in [±6 mm]

c = Depth .... ±¼ in. [±6 mm]

c_1 = Shear key depth .... ±¼ in. [±6 mm]

d = Variation from specified plan end squareness or skew .... ±½ in. [±13 mm]

e = Variation from specified elevation end squareness or skew .... ±½ in. [±13 mm]

f = Sweep .... ±⅛ in. per 10 ft. [±3 mm per 3 m]

g = Differential camber between adjacent
units of the same design .... ¼ in. per 10 ft. [6 mm per 3 m]

k_1 = Location of strand perpendicular to plane of panel .... ±¼ in. [±6 mm]

k_2 = Location of strand parallel to plane of panel .... ±1 in. [±25 mm]

n_1 = Location of blockout .... ±1 in. [±25 mm]

n_2 = Size of blockouts .... ±1 in. [±25 mm]

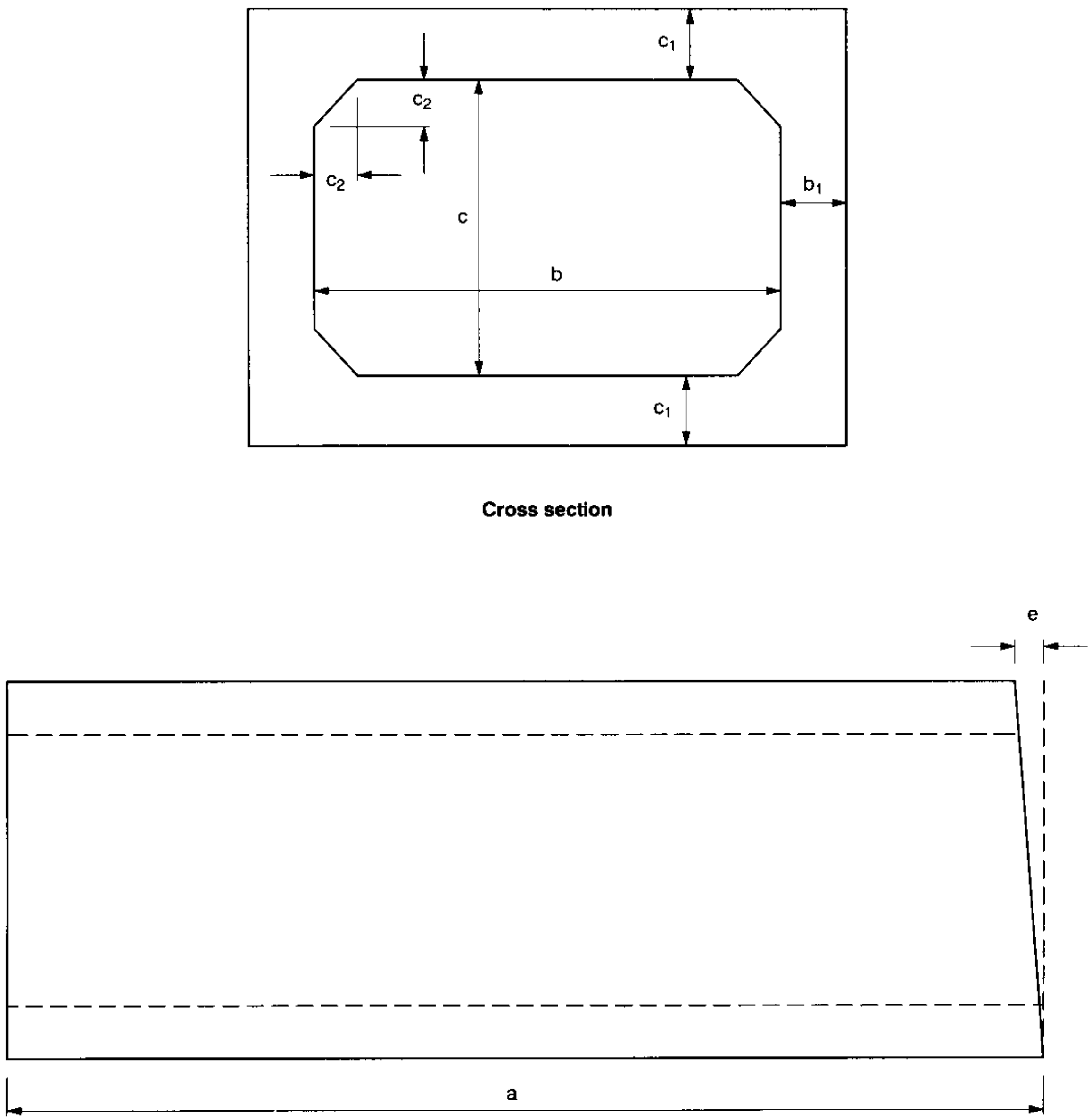
p = Location of inserts .... ±1 in. [±25 mm]

q_1 = Location of handling device parallel to length of member .... ±6 in. [±150 mm]

q_2 = Location of handling device transverse to length of member .... ±1 in. [±25 mm]

s = Longitudinal spacing of stirrups .... ±1 in. [±25 mm]

Fig. 10.25.1 Box Culvert



Cross section

Longitudinal Section

10.25 Box Culvert

a = Length .... $-\frac{1}{2}$,+1 in. [−13,+25 mm]

b = Span:
Less than 48 in. [1.2 m] .... ±$\frac{7}{16}$ in. [±10 mm]
48 in. [1.2 m] to 96 in. [2.4 m] .... ±$\frac{3}{4}$ in. [±19 mm]
Greater than 96 in. [2.4 m] .... ±1 in. [±25 mm]

b_1 = Thickness* of walls .... $-\frac{3}{16}$ in., +1 in. [−4.5 mm, +25 mm]
c = Rise
Less than 48 in. [1.2 m] .... ±$\frac{7}{16}$ in. [±10 mm]
48 in. [1.2 m] to 96 in. [2.4 m] .... ±$\frac{3}{4}$ in. [±19 mm]
Greater than 96 in. [2.4 m] .... ±1 in. [±25 mm]

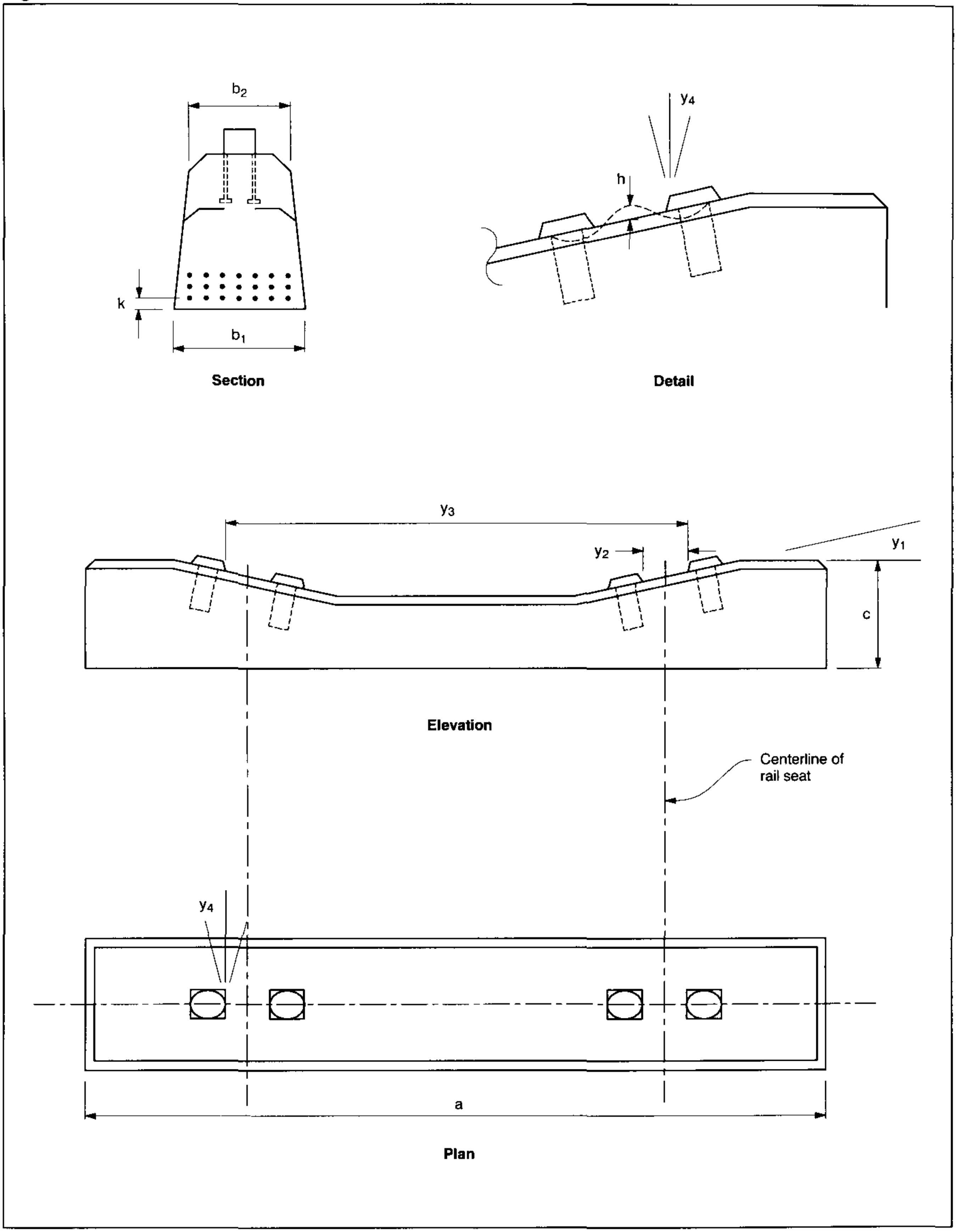
c_1 = Slab thickness .... $-\frac{3}{16}$, +1 in. [−4.5, + 25 mm]

c_2 = Haunch dimension .... ±$\frac{1}{4}$ in [±6 mm]

e = Variation in length of opposite surfaces:
Per 12 in [0.3 m] of internal span .... ±$\frac{1}{8}$ in. [±3 mm]
Maximum to 84 in. [2.1 m] span .... ±$\frac{5}{8}$ in. [±15 mm]
Maximum over 84 in. [2.1 m] span .... ±$\frac{3}{4}$ in. [±19 mm]

* Refer to ASTM C 850 and ASTM C 789 for reinforcement placement tolerances.

Fig. 10.26.1 Prestressed Concrete Railroad Ties



10.26 Prestressed Concrete Railroad Ties*

a = Length .... ±⅛ in. up to 108 in. length [±3 mm up to 2700 mm length]

b_1 = Width at bottom .... ±⅛ in. [±3 mm]

b_2 = Width at top .... ±⅛ in. [±3 mm]

c = Depth .... ±3⁄16 in. up to 10 in. depth [±5 mm up to 250 mm depth]

h = Local smoothness .... 1⁄32 in. over 6 sq. in. area of rail seat [1 mm over 3870 mm^2 area of rail seat]

k = Location of strand or wire .... ±⅛ in. [±3 mm]

y_1 = Rail seat slope .... ±5 degrees

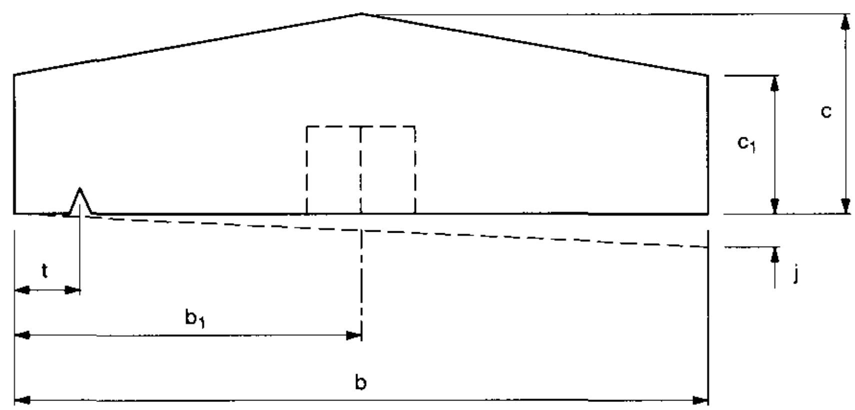
y_2 = Spacing between adjacent inserts for rail attachment .... +1⁄16 in., −0 in. up to 7 in. spacing [+2 mm, −0 mm up to 180 mm spacing]

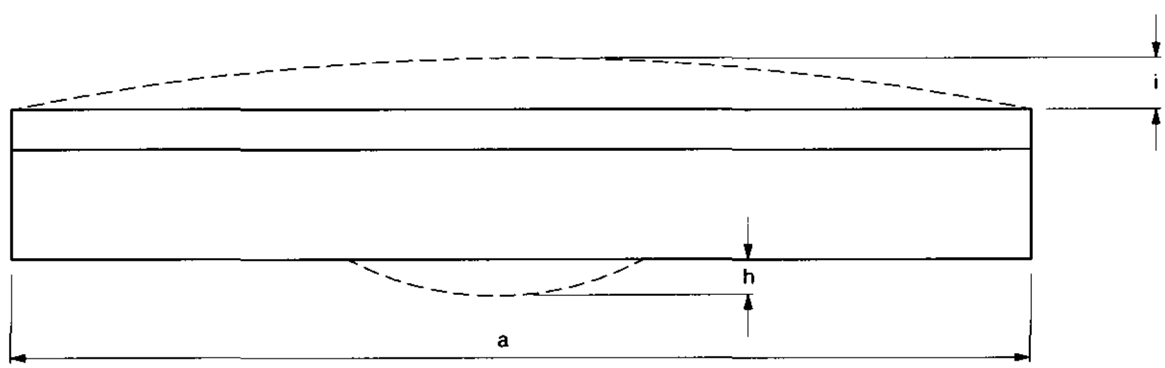
y_3 = Spacing between inserts for setting track gage .... ±0.08 in. up to 70 in. spacing [±2 mm up to 1800 mm spacing]

y_4 = Shoulder tilt, vertical or horizontal .... ±2 degrees

* Current tolerances as published by AREMA Committee No. 30 should be reviewed prior to production.

Fig. 10.27.1 Sills, Lintels, Copings, Cornices, Quoins and Medallions



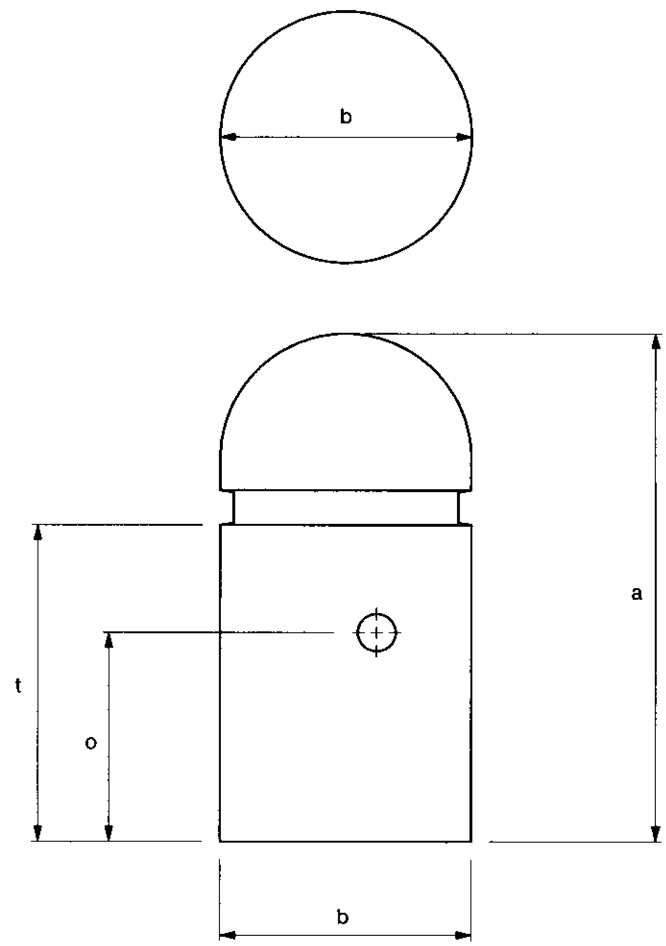


10.27 Sills, Lintels, Copings, Cornices, Quoins and Medallions

a	=	Length	±1/8 in. [±3 mm]
		Where one face will be installed in dead wall space of mortar joint	±1/4 in. [±6 mm]
b	=	Overall width of units*	±1/8 in. [±3 mm]
b_1	=	Location of inserts and appurtenances:	
		On formed surfaces	±1/8 in. [±3 mm]
		On unformed surfaces	±3/8 in. [±9 mm]
c	=	Overall height of units*	±1/8 in. [±3 mm]
c_1	=	Total thickness	±1/8 in. [±3 mm]
		Flange thickness	±1/8 in. [±3 mm]
		Where one face will be installed in dead wall space of mortar joint	±1/4 in. [±6 mm]
t	=	Size and location of rustications and architectural features	±1/16 in. [±1.5 mm]
h	=	Local smoothness	±1/8 in. per 5 ft.[±3 mm per 1.6 m]
i	=	Bowing	span/360, max, ±1/4 in. [6 mm]
j	=	Warping†	±1/16 in. per ft. [±1.5 mm per 0.3 m]

* Measured at face exposed to view
† Measured per foot of distance from nearest adjacent corner.

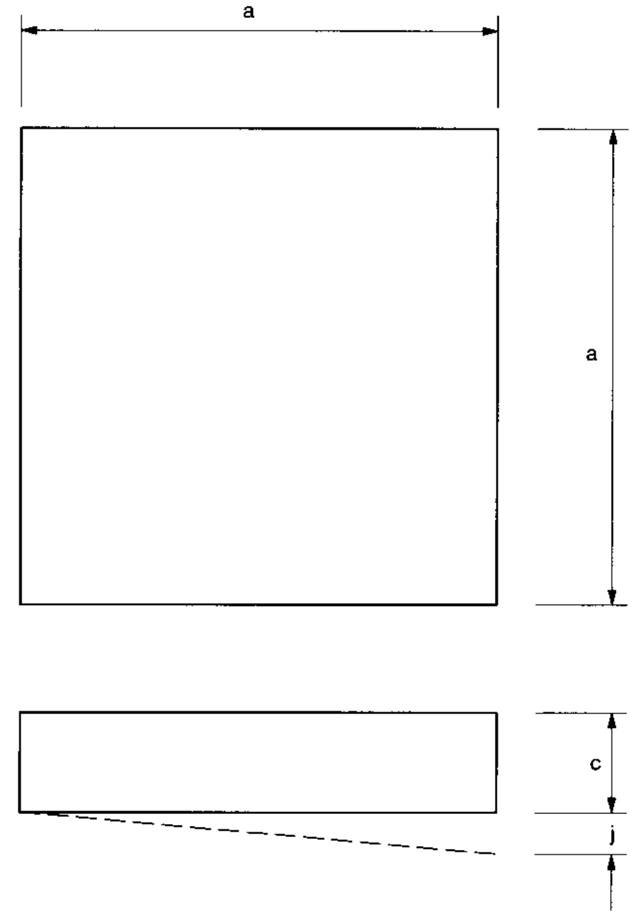
Fig. 10.28.1 Bollards, Benches and Planters



10.28 Bollards, Benches and Planters

a	=	Height or length	±¼ in. [±6 mm]
b	=	Width or diameter	±¼ in. [±6 mm]
o	=	Location of inserts and appurtenances:	
		Formed surfaces	±¼ in. [±6 mm]
		Unformed surfaces	±¼ in. [±6 mm]
t	=	Size/location of rustication/features	±¼ in. [±6 mm]

Fig. 10.29.1 Pavers



10.29 Pavers

a = Length or width .... ±$\frac{1}{16}$ in. [±1.5 mm]

c = Thickness .... ±$\frac{1}{16}$ in. [±1.5 mm]

j = Warping* .... ±$\frac{1}{32}$ in. [±0.75 mm]

* Measured per foot [0.3 m] of distance from nearest adjacent corner.

11.0 Erection Tolerances

The text below discusses the tolerance principles and considerations related to the erection and acceptable matching of precast and prestressed concrete members when they are used for the entire structure or in combination with other structural systems. It is important to understand the relationships of product, interfacing and erection tolerances, as all must be taken into account on each project to assure satisfactory panel and member installation. Erection tolerances are used in the planning of the erection activity to assure that the elements can be assembled to fit together as an integrated building structure.

It should be noted that in some instances project erection may be done by a company which may have no direct contractual relationship with the precast concrete member manufacturer. If this is the case, the party with contractual authority over the erector is responsible for assuring that the project erection tolerances are met by the erector.

Erection tolerances are determined by consideration of the characteristics of the building structure, and site erection conditions. They should be developed to achieve uniform joint widths and planar wall panel conditions. Important features include: individual member design, shape, thickness, composition of materials, and overall scale of the member being erected. The specified erection tolerances may affect the work of several different building trades and must be consistent with the tolerances as specified for those trades.

To understand the importance of erection tolerances specified, the function of the precast concrete components should be considered when specifying erection tolerances. For example, members which are covered by finish materials may not need the close tolerances required for those that are exposed to view. Members used for an industrial building may not require tolerances as restrictive as those used for a visually sensitive commercial or residential application.

One way to foster collaboration with regard to dimensional control is for those responsible for erection to participate with plant quality control personnel in the development of the member dimensional inspection plan. By doing this, the plant quality control personnel will understand the product tolerances which are critical to the successful erection of the project.

It is recommended that the producer review proposed tolerances with the architect/engineer and erectors prior to agreeing to the final project tolerances. If a producer encounters project specifications in which no mention is made of the tolerance to be controlled in a structure to which the precast concrete components are being connected, steps should be taken to develop an overall project tolerance system as a first priority before any precast members are cast. It is in the interest of all concerned that the architect/engineer and the party or parties responsible for the tolerances of the interfacing structure agree in writing to the overall project tolerance system.

In general, the more restrictive the erection tolerances, the higher the cost of erection will be. For example, combining liberal product tolerances with restrictive erection tolerances may place a significant cost burden on the erection phase of the project. This can negate any cost or time saving the designer expected to achieve by specifying less stringent product tolerances.

11.1 Recommended Erection Tolerances

The recommended erection tolerance values are those to which the member primary control surfaces are to be set. It is the position dimensions of the primary erection control surfaces which should be controlled during erection. The remaining position dimensions of the member features and secondary control surfaces of the member will be the result of the combination of the erection tolerances given here and the appropriate product tolerances given in Article 10.0. Also see Article 14.0 for a discussion of clearances.

Erection tolerances shall control the individual precast members as they are located and placed in the assembled structure. The primary control surfaces or features on the precast members shall be erected to be in conformance with the established erection and interfacing tolerances. Clearances are generally allowed to vary so that the primary control surface can be set within tolerance. Product tolerances shall not be additive to the primary surface erection tolerances.

Secondary control surfaces which are positioned from the primary control surfaces by the product tolerances are usually not directly positioned during the erection process but are controlled by the product tolerances. Thus, if the primary control surfaces are within erection and interfacing tolerances, and the secondary surfaces are within product tolerances, the member should be erected within tolerance. The result is that the tolerance limit for secondary surface may be the sum of the product and erection tolerances. To ensure trouble-free installation, the product tolerances, generally, must not exceed the erection tolerances. An example is the elevation of a second story corbel on a multi-story column whose first story corbel is selected as the primary elevation control surface.

Because erection and product tolerances for some features of a precast concrete member may be additive, the erection drawings should clearly define the primary erection control surfaces. If both primary and secondary control surfaces are critical, provisions for adjustment should be included. The accumulated tolerance limits may be required to be accommodated in the interface clearance. Surface and feature control requirements should be clearly outlines in the plans and specifications.

Final erection tolerances should be verified and agreed upon before erection commences and, if different from those given in this document, stated in writing and noted on the project erection drawings. As-built precast erection tolerances are often largely determined by the actual alignment and dimensional accuracy of the building foundation and frame (in those circumstances where the building frame is constructed from some material other than precast concrete). The general contractor is usually the party responsible for the plumbness, level, and alignment tolerances of the foundation and the structural frame, including the location of all bearing surfaces and anchorage points for the precast concrete members.

Project specifications should be checked by the producer to assure that tolerances have been specified for the site construction work which are compatible with the requirement to erect precast on the building frame. If discrepancies are discovered, they should be brought to the attention of the architect/engineer and resolved as early in the project as possible and in every instance prior to the start of precast production. The producer may collaborate with the architect/engineer to provide special details to accommodate the more liberal tolerances that may be associated with these site construction features. To protect the project cost and schedule by minimizing erection problems, the dimensions and locations of in-place structures should be checked prior to starting precast erection.

11.2 Erection Tolerance Groups

The erection tolerances are given in three groups:

1. Precast member to precast member
2. Precast member to cast-in-place concrete or masonry
3. Precast member to steel construction

Because erection is both equipment and site dependent, there may be good reason for the producer and erector to work with the architect/engineer to considerably vary some of the recommended tolerances to account for unique project conditions. This variation could involve modification of both specified product tolerances and specified erection tolerances.

Windows between open shape members where they will intersect a joint between members is an example which requires interface erection tolerances. A similar condition often occurs where panels are interspersed with glass or metal curtain wall elements. Close tolerances are often required between the mullion and the glass or curtain wall. This condition demands additional tolerance flexibility that may be provided by special consideration of the tolerance adjustment aspects of corner details.

Many of the erection tolerances address the tolerance on bearing length. Since the bearing length tolerance may have an effect on erection safety and structural integrity of the completed structure, it deserves special attention both in member fabrication and in erection. Problems in meeting bearing area related tolerances should be brought to the attention of the architect/engineer.

The bearing length and the length of the end of the member over the support are often not the same, as shown in Fig. 11.2.1. Bearing length should be measured in the direction of the member span. Bearing width should be measured at 90 degrees to the direction of the member span. For precast to precast erection acceptable bearing tolerance conditions which are required for safe erection should be shown on the erection drawings. For precast to other materials erection acceptable bearing conditions must be shown in the contract documents.

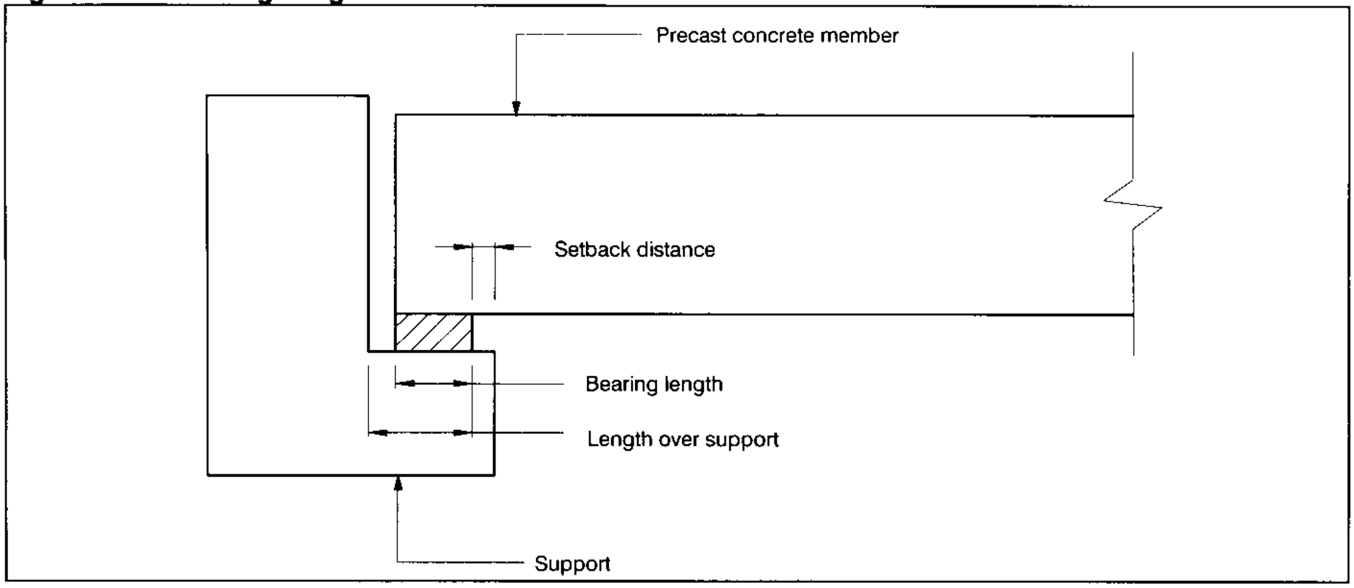
If for any reason a member cannot be erected as shown on the connection details, within the tolerances outlined in this document, the erector should notify the responsible party to check the structural adequacy of the resulting configuration.

For insulated wall panels where beams bear on the interior wythe of the panel, it may be practical to specify the beam length so that the tolerance can be taken up in the insulation. This is one method of avoiding bearing area deficiencies in this type of element.

11.3 Field Control of Erection Tolerances

Appropriate field procedures should be followed to ensure the erection of precast members within the limits of the project erection tolerances. The general contractor should establish (and maintain at convenient locations), control points, bench marks and lines in an undisturbed condition until final completion and acceptance of the project. Typically, panels are located in the center of their nominal (basic dimensional) location on the building. Panels may also need to be adjusted to accommodate erection and product tolerances and the locations of other adjacent materials while providing acceptable joint width.

Fig. 11.2.1 Bearing Length



Upon completion of panel alignment and before other trades interface any materials with the precast members the erector, in conjunction with the general contractor, should verify that the panels are erected within the specified tolerances.

No erected member should be left in an unsafe support condition. Any adjustments affecting structural performance, other than adjustments within the prescribed tolerances, should only be made after approval by the engineer of record.

11.4 Erection Tolerance Considerations for Segmental Precast Projects

An overall geometric control plan for the segmental project should be prepared. The plan should indicate in detail how the geometry control survey will be performed and the actions proposed to assure proper erection of the structure to the final grade shown on the design plans.

Contractors on segmental bridge projects are usually required to submit deflection and/or camber data for each stage of construction as required to construct the structure to its final grade. The procedure takes into account the effect of time dependent prestress losses and creep which will occur during the construction phase.

A geometric control plan should provide for regular monitoring of the superstructure deflections beginning with the addition of the first segment erected and concluding with the last segment erected.

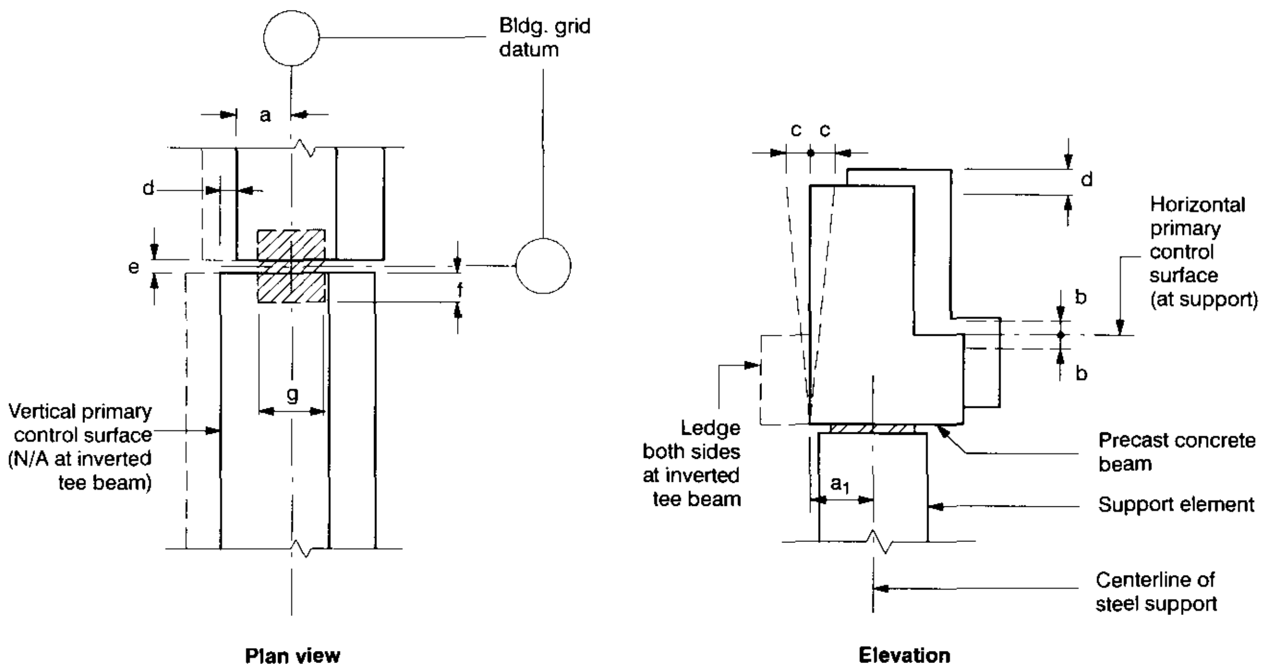
The control plan should also include the adjusting procedure to be used should the structure, as erected, deviate from the predicted alignment by more than a specified amount.

12.0 Erection Tolerance Listings

Erection tolerances for precast members are shown on the following pages.

These tolerances should be considered guidelines for the development of project specific tolerances for erection

Fig. 12.1.1 Beam Erection Tolerances



Precast element to: precast element, cast-in-place concrete, masonry, or structural steel

12.1 Beam Erection Tolerances

The primary control surfaces are usually as shown, although this needs to be confirmed on a job-by-job basis.

a = Plan location from building grid datum .... ±1 in. [±25 mm]

a_1 = Plan location from centerline of steel* .... ±1in. [±25 mm]

b = Bearing elevation† from nominal elevation at support:
Maximum low .... ½ in. [13 mm]
Maximum high .... ¼ in. [6 mm]

c = Maximum plumb variation over height of element:
Per 12 in. [300 mm] height .... ⅛ in. [3 mm]
Maximum at rectangular or L-beam .... ½ in. [13 mm]
Maximum at inverted tee beam .... ¾ in. [19 mm]

d = Maximum jog in alignment of matching edges:
Architectural exposed edges .... ¼ in. [6 mm]
Visually non-critical edges .... ½ in. [13 mm]

e = Joint width:
Architectural exposed joints .... ±¼ in. [±6 mm]
Hidden joints .... ±¾ in. [±19 mm]
Exposed structural joint not visually critical .... ±½ in. [13 mm]

f = Bearing length‡ (span direction) .... ±¾ in. [±19 mm]

g = Bearing width‡ .... ±½ in. [±13 mm]

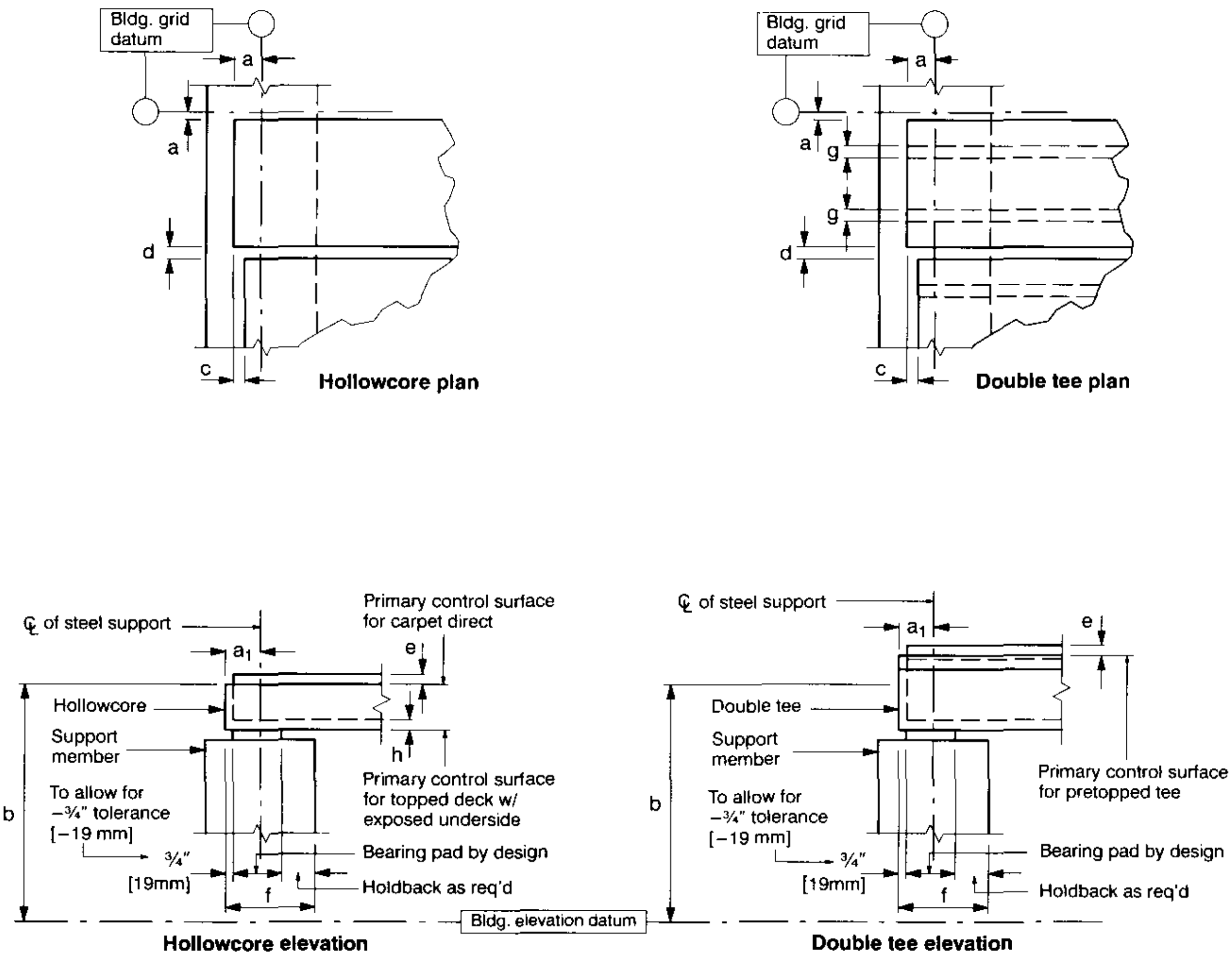
Note: When bearing pads are used at unarmored edges they should be set back a minimum of ½ in. [13 mm] from the face of the support or at least the chamfered dimension at chamfered edges.

* For precast elements on a steel frame, this tolerance takes precedence over tolerance on dimension "a".

† Or member top elevation where member is part of a frame without bearing ledges.

‡ This is a setting tolerance and should not be confused with structural performance requirements set by the architect/engineer. The nominal bearing dimensions and the allowable variations in the bearing length and width should be specified by the engineer and shown on the erection drawings.

Fig. 12.2.1 Floor and Roof Member Erection Tolerances



Precast element to: precast, cast-in-place concrete, masonry or structural steel support

12.2 Floor and Roof Member Erection Tolerances

The primary control surfaces are usually as shown. A majority of the time there is no designated vertical primary control surface, and in some scenarios there are no primary control surfaces at all. This needs to be determined on a job-by-job basis.

a = Plan location from building grid datum .... ±1 in. [±25 mm]

a_1 = Plan location from centerline of steel support* .... ±1 in. [±25 mm]

b = Top elevation from building elevation datum at member ends:
Covered with topping .... ±.¾. [±19 mm]
Pretopped tee/carpet direct hollow-core .... ±¼ in. [±6 mm]
Untopped roof .... ±¾ in. [±19 mm]

c = Maximum jog in alignment of matching edges
(both topped and untopped construction) .... 1 in. [25 mm]

d = Joint width:
0 to 40 ft. member .... ±½ in. [±13 mm]
41 to 60 ft. member .... ±¾ in. [±19 mm]
61 ft. plus member .... ±1 in. [±25 mm]

e = Differential top elevation as erected (for units of same design and length):
Field topped .... ¾ in. [19 mm]
Pretopped tees at driving lanes/carpet direct hollow-core .... ¼ in. [6 mm]
Untopped roof† .... ¾ in. [19 mm]

f = Bearing length‡ (span direction) .... ±¾ in. [±19 mm]

g = Bearing width‡ (n/a for hollow-core) .... ±½ in. [±13 mm]

h = Differential bottom elevation of
exposed hollow-core slabs§ .... ¼ in. [6 mm]

Note: When bearing pads are used at unarmored edges they should be set back a minimum of ½ in. [13 mm] from the face of the support or at least the chamfered dimension at chamfered edges.

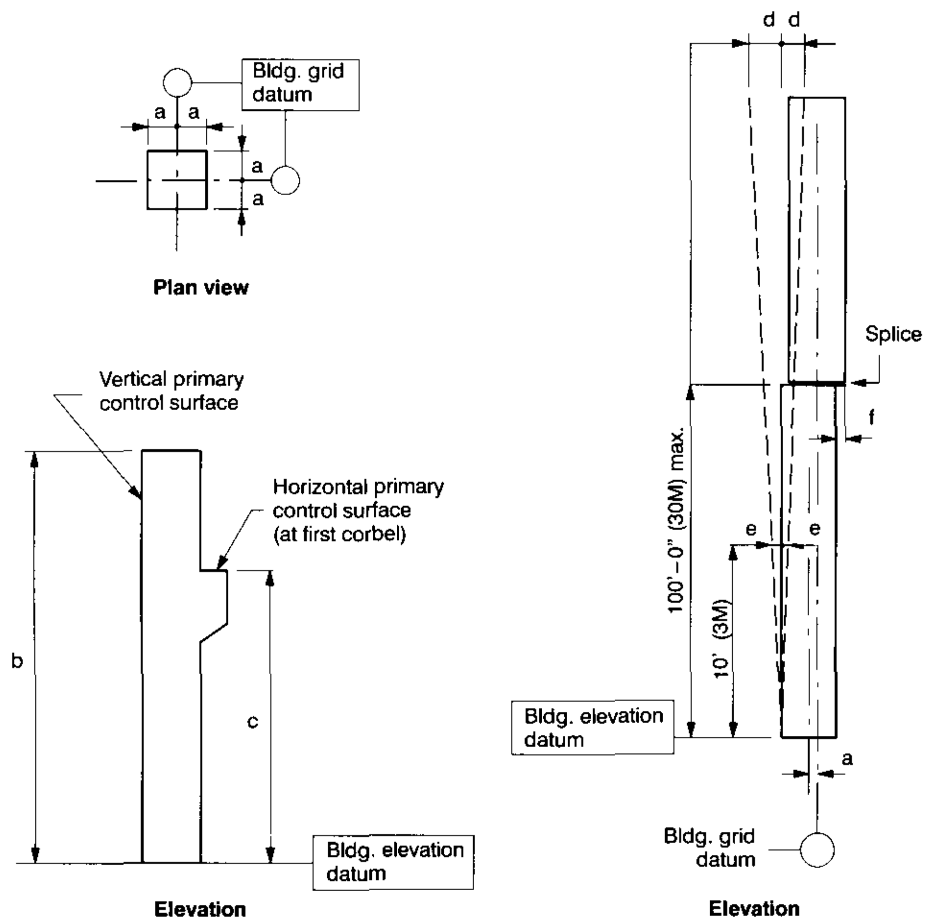
* For precast concrete erected on a steel frame building, this tolerance takes precedence over tolerance on dimension "a".

† It may be necessary to feather the edges to ±¼ in. [±6 mm] to properly apply some roof membranes.

‡ This is a setting tolerance and should not be confused with structural performance requirements set by the architect/ engineer. The nominal bearing dimensions and the allowable variations in the bearing length and width should be specified by the engineer and shown on the erection drawings.

§ Untopped installations will require a larger tolerance.

Fig. 12.3.1 Column Erection Tolerances



12.3 Column Erection Tolerances

The primary control surfaces are usually as shown, although this needs to be confirmed on a job-by-job basis.

a = Plan location from building grid datum:
Structural applications .... ±½ in. [±13mm]
Architectural applications .... ±⅜ in. [±9mm]

b = Top elevation from nominal top elevation:
Maximum low .... ½ in. [13 mm]
Maximum high .... ¼ in. [6 mm]

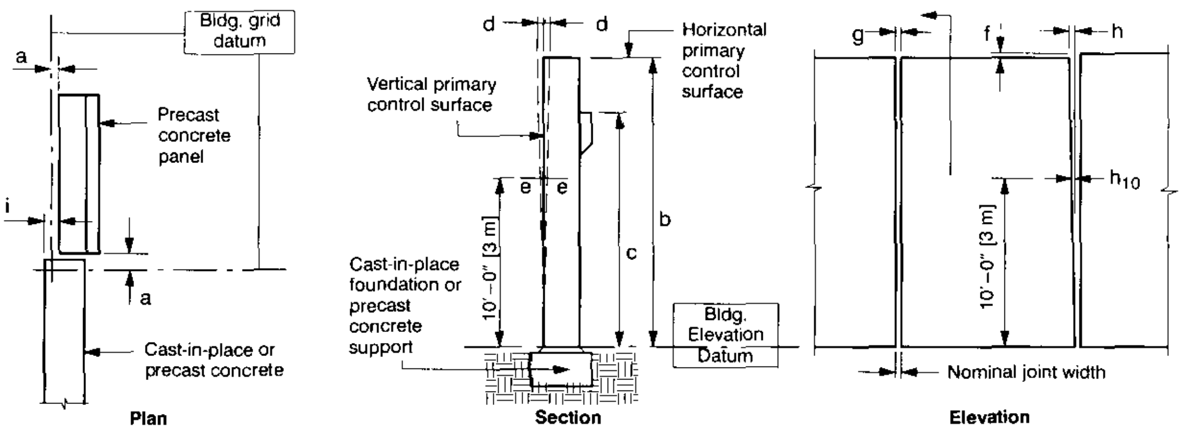
c = Bearing haunch elevation from nominal elevation:
Maximum low .... ½ in. [13 mm]
Maximum high .... ¼ in. [6 mm]

d = Maximum plumb variation over height of element (element in structure of maximum height of 100 ft. [30 m]) .... 1 in. [25 mm]

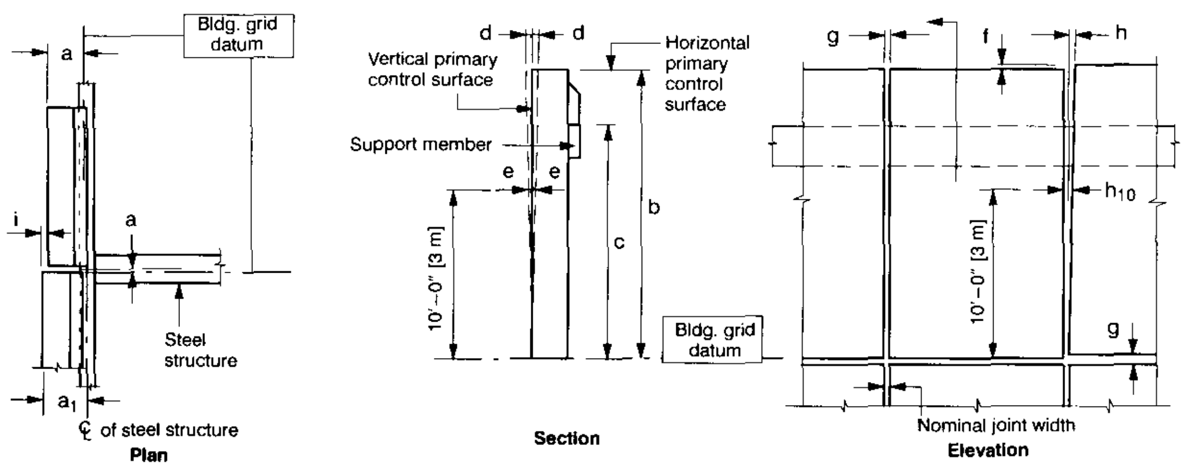
e = Plumb in any 10 ft. [3 m] of element height .... ¼ in. [6 mm]

f = Maximum jog in alignment of matching edges:
Architectural exposed edges .... ¼ in. [6 mm]
Visually non-critical edges .... ½ in. [13 mm]

Fig. 12.4.1 Structural Wall Panel Erection Tolerances



Precast element to precast or cast-in-place concrete or masonry



Precast element to structural steel

12.4 Structural Wall Panel Erection Tolerances

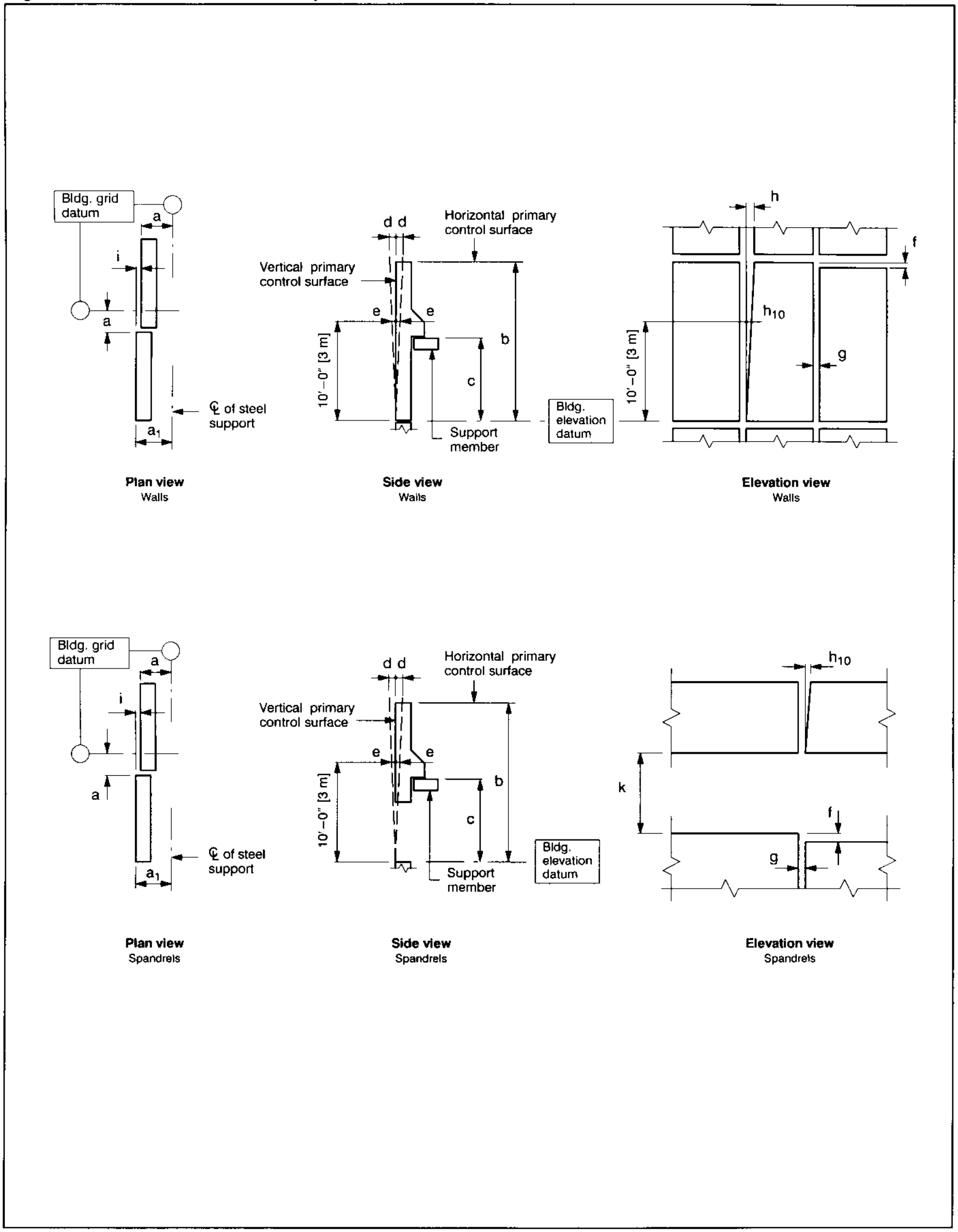
The primary control surfaces are usually as shown, although this needs to be confirmed on a job-by-job basis.

a	=	Plan location from building grid datum	±½ in. [±13 mm]
a_1	=	Plan location from centerline of steel support	±½ in. [±13 mm]
b	=	Top elevation from nominal top elevation:	
		Exposed individual panel	±½ in. [±13 mm]
		Non-exposed individual panel	±¾ in. [±19 mm]
		Exposed relative to adjacent panel	±½ in. [±19 mm]
		Non-exposed relative to adjacent panel	±¾ in. [±19 mm]
c	=	Support elevation from nominal elevation:	
		Maximum low	½ in. [13 mm]
		Maximum high	¼ in. [6 mm]
d	=	Maximum plumb variation over height of structure or over 100 ft. which ever is less*	1 in. [25 mm]
e	=	Plumb in any 10 ft. of element height	¼ in. [6 mm]
f	=	Maximum jog in alignment of matching edges.	½ in. [13 mm]
g	=	Joint width (governs over joint taper)	±⅜ in. [±9 mm]
h	=	Joint taper over length of panel	½ in. [13 mm]
h_{10}	=	Joint taper over 10 ft. length	⅜ in. [9 mm]
i	=	Maximum jog in alignment of matching faces:	
		Exposed to view	⅜ in. [9 mm]
		Non exposed to view	¾ in. [19 mm]
j	=	Differential bowing or camber as erected between adjacent members of the same design	½ in. [13 mm]†

* For precast buildings in excess of 100 ft. tall, tolerances "a" and "d" can increase at the rate of ⅛ in. [3 mm] per story to a maximum of 2 in. [50 mm].

† Refer to Article 8 for description of bowing tolerance.

Fig. 12.5.1 Architectural Walls/Spandrel Erection Tolerances



12.5 Architectural Walls/Spandrel Erection Tolerances

The primary control surfaces are usually as shown, although this needs to be confirmed on a job-by-job basis.

a = Plan location from building grid datum* .... ±½ in. [±13 mm]

a_1 = Plan location from centerline of steel support† .... ±½ in. [±13 mm]

b = Top elevation from nominal top elevation:
Exposed individual panel .... ±¼ in. [±6 mm]
Non-exposed individual panel .... ±½ in. [±13 mm]

c = Support elevation from nominal elevation:
Maximum low .... ½ in. [13 mm]
Maximum high .... ¼ in. [6 mm]

d = Maximum plumb variation over height of structure
or 100 ft. [30 m] whichever is less* .... 1 in. [25 mm]

e = Plumb in any 10 ft. [3 m] of element height .... ¼ in. [6mm]

f = Maximum jog in alignment of matching edges:
Exposed relative to adjacent panel .... ¼ in. [6 mm]
Non-exposed relative to adjacent panel .... ½ in. [13 mm]

g = Joint width (governs over joint taper) .... ±¼ in. [±6 mm]

h = Joint taper maximum .... ⅜ in. [9 mm]

h_{10} = Joint taper over 10 ft. [3 m] length .... ¼ in. [6 mm]

i = Maximum jog in alignment of matching faces .... ¼ in. [6 mm]

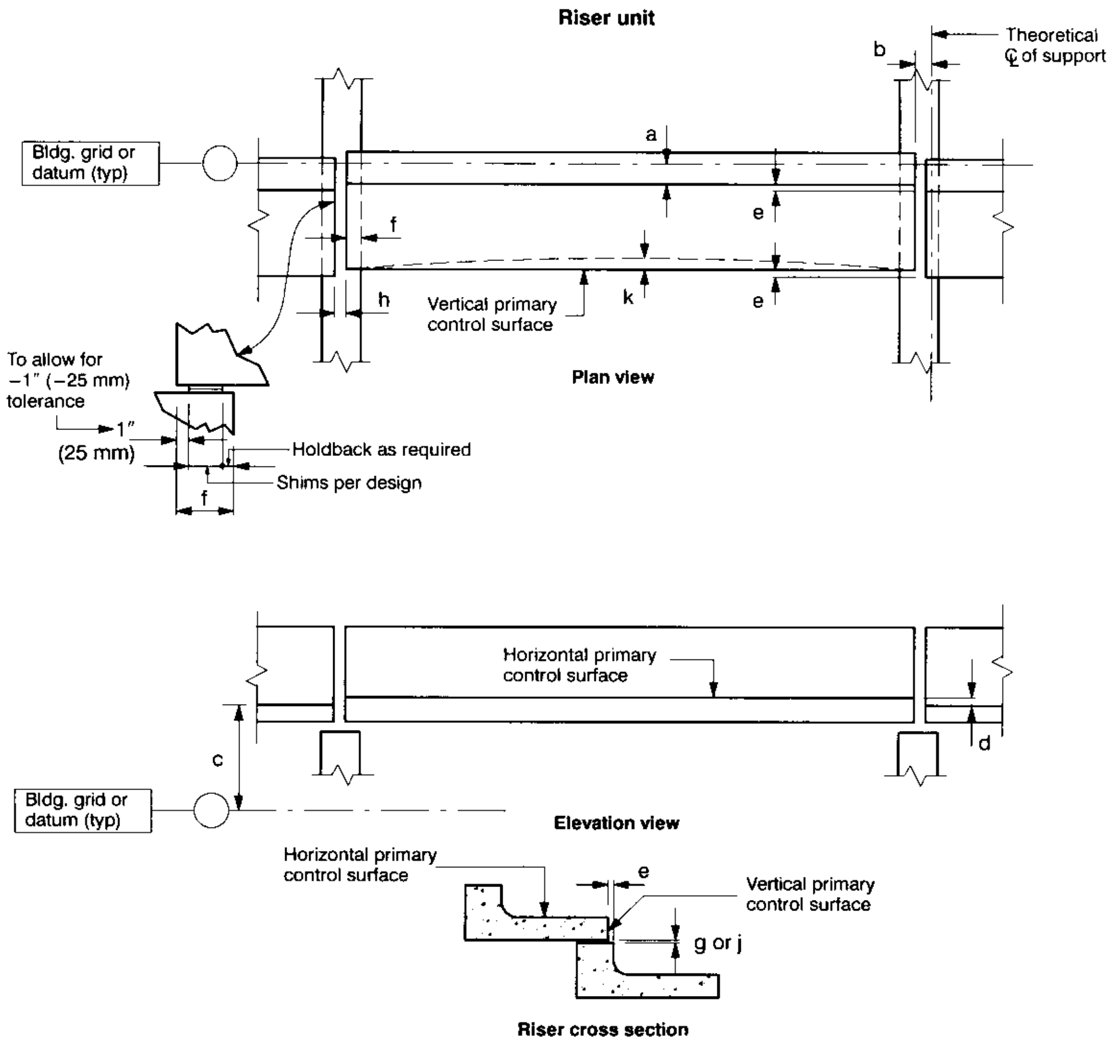
j = Differential bowing or camber as erected between
adjacent members of the same design .... ¼ in. [6 mm]

k = Opening height between spandrels .... ±¼ in. [±6 mm]

* For precast buildings in excess of 100 ft. tall, tolerances "a" and "d" can increase at the rate of ⅛ in. [3 mm] per story to a maximum of 2 in. [50 mm].

† For precast elements erected on a steel frame, this tolerance takes precedence over tolerance on dimension "a".

Fig. 12.6.1 Single and Double Stadium Riser Erection Tolerances



12.6 Stadium Riser Erection Tolerances

The primary control surfaces are usually as shown, although this is something that needs to be confirmed with the contractor on job-by-job basis.

a = Plan location from building grid line datum .... ±1 in. [±25 mm]

b = Plan location from theoretical centerline of support structure .... ±1 in. [±25 mm]

c = Top elevation from building elevation datum at members end. (This datum may be adjusted to accommodate existing field conditions.) .... ±½ in. [±13 mm]

d = Maximum jog in alignment of matching edges at the horizontal primary control surface .... ¼ in. [6 mm]

e = Maximum jog in alignment of matching edges at the vertical primary control surface .... ½ in. [13 mm]

f = Bearing in span direction .... −1 in. [−25 mm]

g = Joint width (horizontal) at end of piece (Joint width needs to be ¼ in. [6mm] minimum). .... ±½ in. [±13 mm]

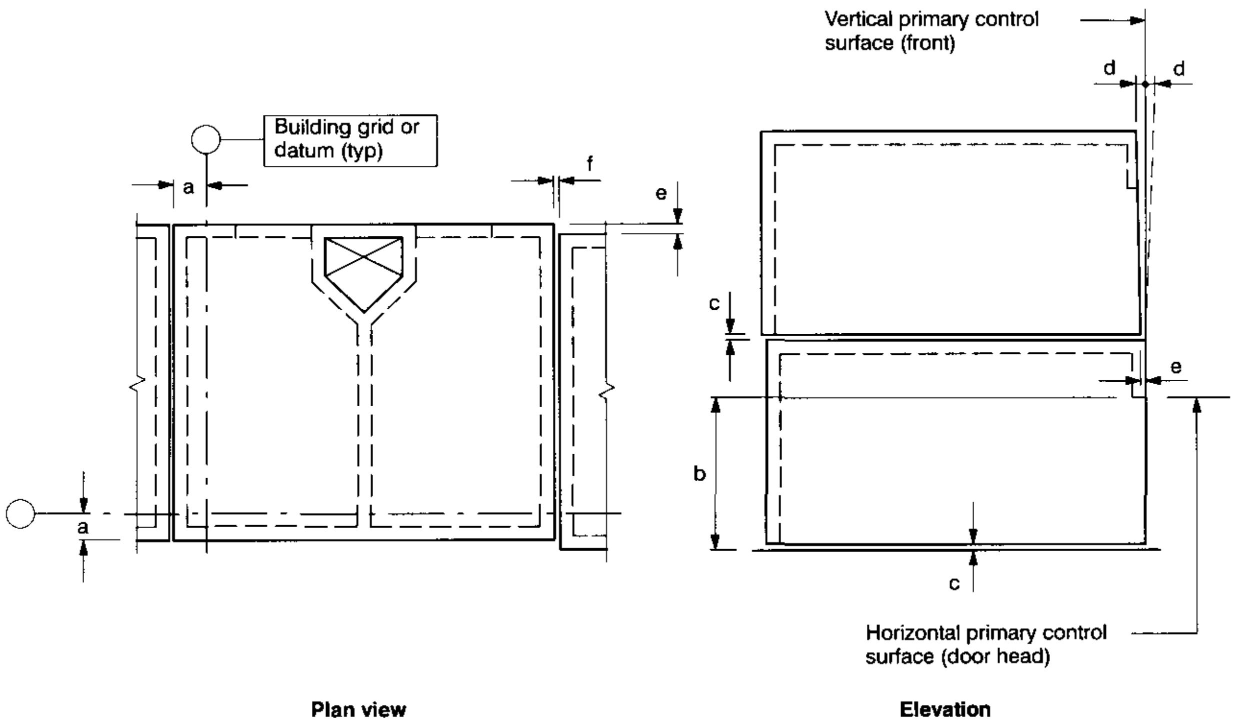
h = Joint width (Joint width needs to be ¼ in. [6 mm] minimum in either case)
90° angle .... ±½ in. [±13 mm]
Joint width at skewed ends .... ±⅝ in. [±16 mm]

j = Differential camber (at mid-span as erected) between adjacent members of the same design .... ±3/16 in. [±5 mm] per 10 ft. [3 m] of member length.

k = Differential sweep (at mid-span as erected) between adjacent members of the same design .... ±3/16 in. [±5 mm] per 10 ft. [3 m] of member length.

Note: Local building codes may require more restrictive riser height tolerances which could also affect product tolerance.

Fig. 12.7.1 Room Module Erection Tolerance



12.7 Room Module Erection Tolerance

The tolerances listed below are used at the primary control surfaces only, and only those tolerances that are applicable to that surface. Normally the primary control surfaces are the front face of the cell unit as the vertical primary control surface, and either the head of the door (as shown in Fig. 12.7.1), top of cell, or the bottom of balcony as the horizontal primary control surface. Note: on jobs where pre-topped balconies are cast as part of the cell unit, the horizontal primary control-surface may be the top surface of the balcony.

a = Plan location from building grid line datum .... ±½ in. [±13 mm]

b = Vertical control (at primary control surface) from a horizontal datum .... ±⅜ in. [±9 mm]

c = Actual grout joint .... ½ in. minimum [13 mm]

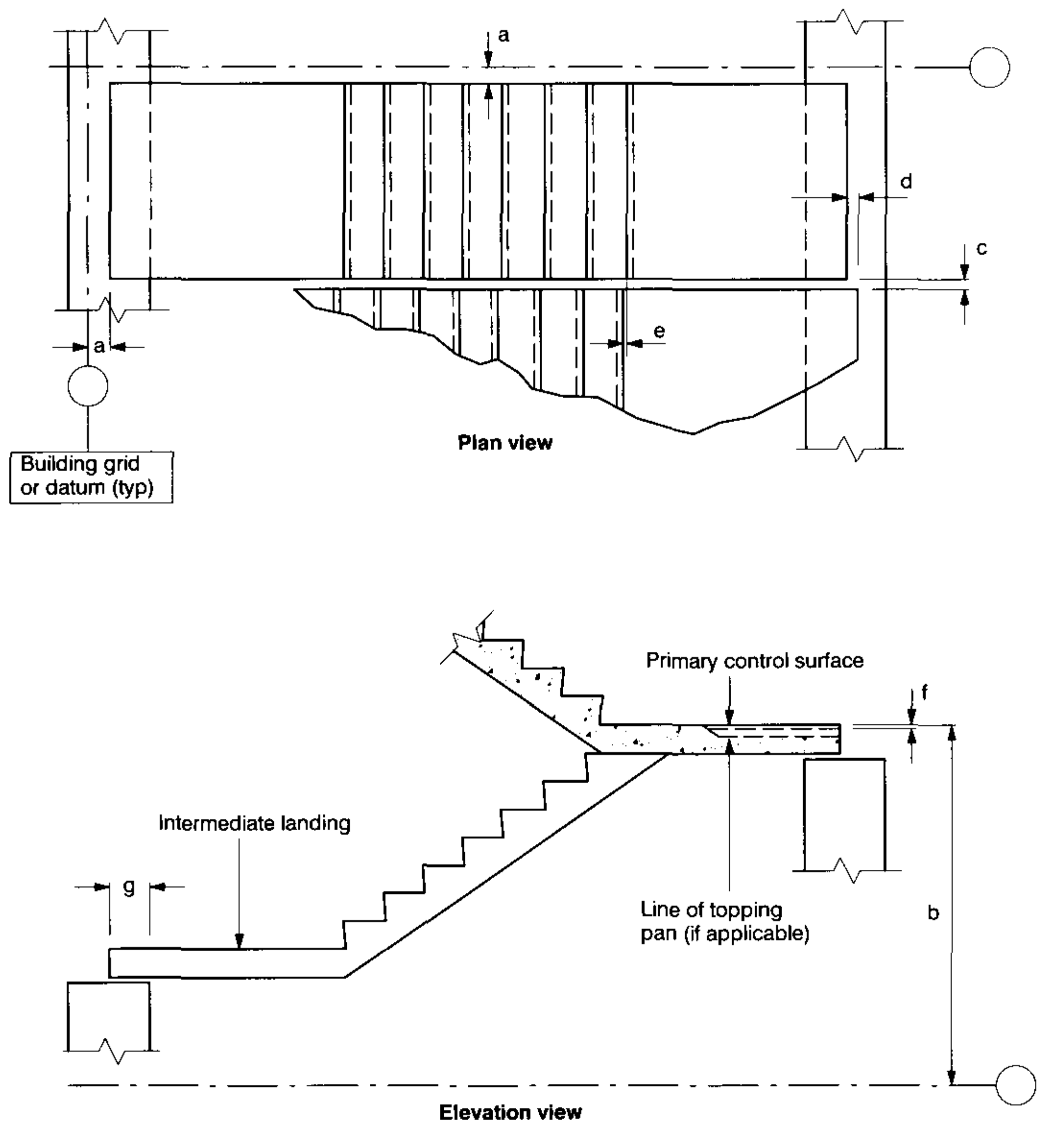
d = Plumb at element height .... ¼ in. [6 mm]

e = Maximum jog in alignment of matching edges .... ¼ in. [6 mm]

f = Vertical joint width .... ±⅜ in. [±9 mm]

g = Joint taper .... Not applicable

Fig. 12.8.1 Stair Unit Erection Tolerance



12.8 Stair Unit Erection Tolerance

The primary control surface for stair units is the top of landing at floor levels. Tolerances listed below are the same whether landings are monolithic or separate pieces.

a = Plan location from building grid line datum .... ±½ in. [±13mm]

b = Differential elevation as erected* .... ±⅜ in. [±9mm]

c = Joint width .... ±¾ in. [±19 mm]

d = Maximum jog in alignment of matching edges .... 1 in. [25 mm]

e = Maximum jog in alignment of stair tread nosings
(This tolerance overrides "d" if needed). .... ½ in. [13 mm]

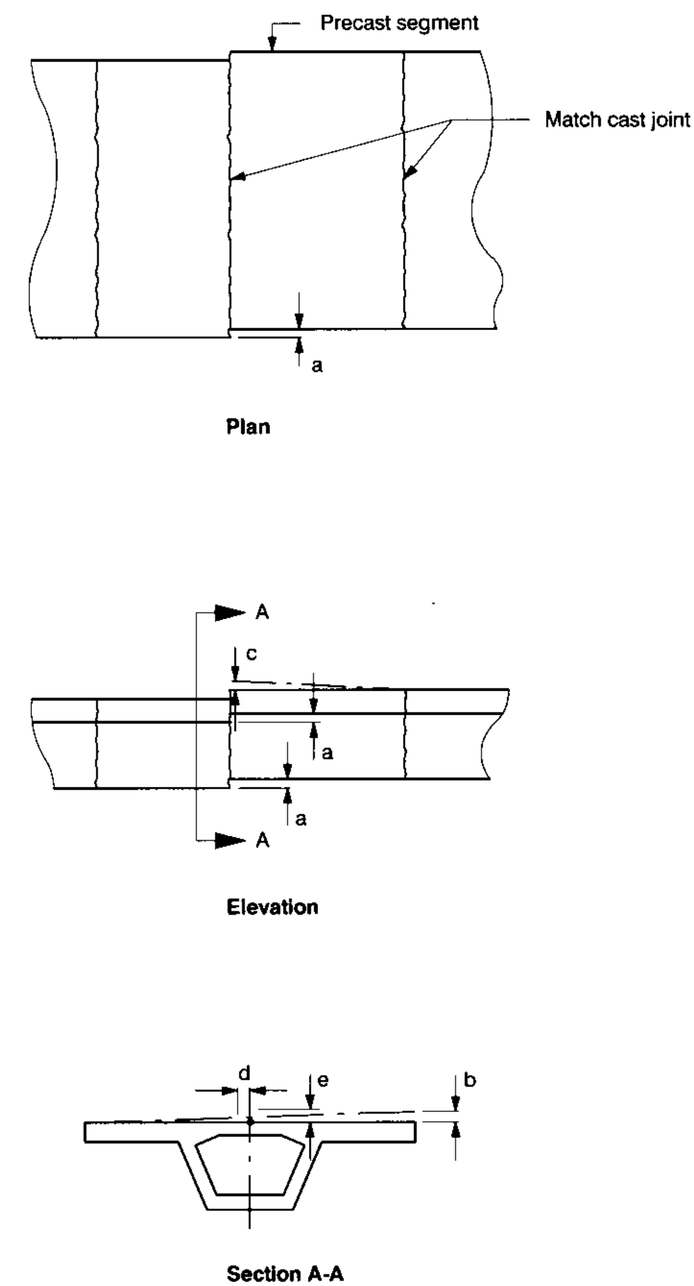
f = Maximum jog in alignment of matching edges
at the primary control surface* .... ⅜ in. [9 mm]

g = Bearing (in span direction) .... ±¾ in. [±19 mm]

Note: Local building codes may require more restrictive riser height tolerance which could also affect product tolerance.

* At stair units that have pre-topped precast landings, the maximum jog between stair units as well as from stair unit to finish floor can not exceed ¼ in. However, units which have landings that are topped have more leeway. This needs to be discussed and agreed upon with the general contractor.

Fig. 12.9.1 Segmental Bridge Element Erection Tolerance



12.9 Segmental Bridge Element Erection Tolerance

a = Maximum differential offset between outside faces of adjacent segments in the erected position .... 1/8 in. [3 mm]

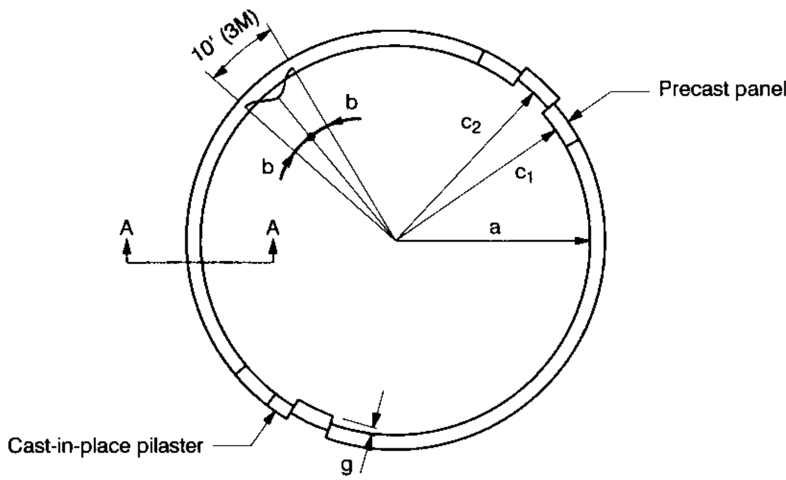
b = Deviation from the theoretical transverse cross slope of the roadway .... 0.001 radians measured curb to curb at any point along the span

c = Longitudinal angular deviation from the theoretical slope change between two successive segments .... not to exceed 0.003 radians

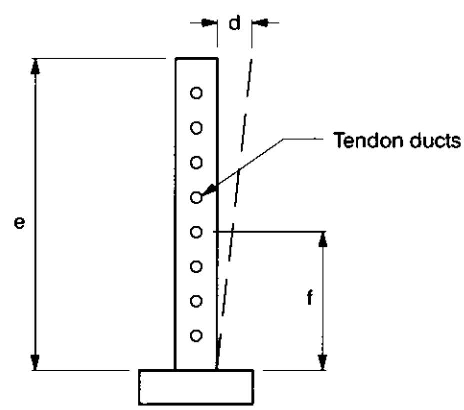
d = Deviation from horizontal centerline alignment as required by the plans and specifications .... ±1/8 in. [±3 mm]

e = Deviation from vertical centerline alignment as required by the plans and specifications .... ±1/8 in. [±3 mm]

Fig 12.10.1 Circular Storage Tank Erection Tolerances



Plan



Section A-A

12.10 Circular Storage Tank Erection Tolerances

a = Variation from the nominal tank radius ... ±½ in. per 50 ft. of radius [±13 mm / 15.2 m]
(Not to exceed ±1 in. [±25 mm])

b = Maximum variation of nominal tank radius
along any 10 ft. [3 m] of circumference .... ±⅜ in. [±10 mm]

c_1 = Radial dimension to panel edge adjacent to location c_2

c_2 = Radial dimension to panel edge adjacent to location c_1

$c_1 - c_2$ = Radial misalignment between adjoining
precast concrete panels .... not to exceed ⅜ in. [10 mm]

d = Plumb of walls .... ¼ in. per 10 ft. [6 mm per 3 m] of vertical height
(¾ in. [19 mm] maximum])

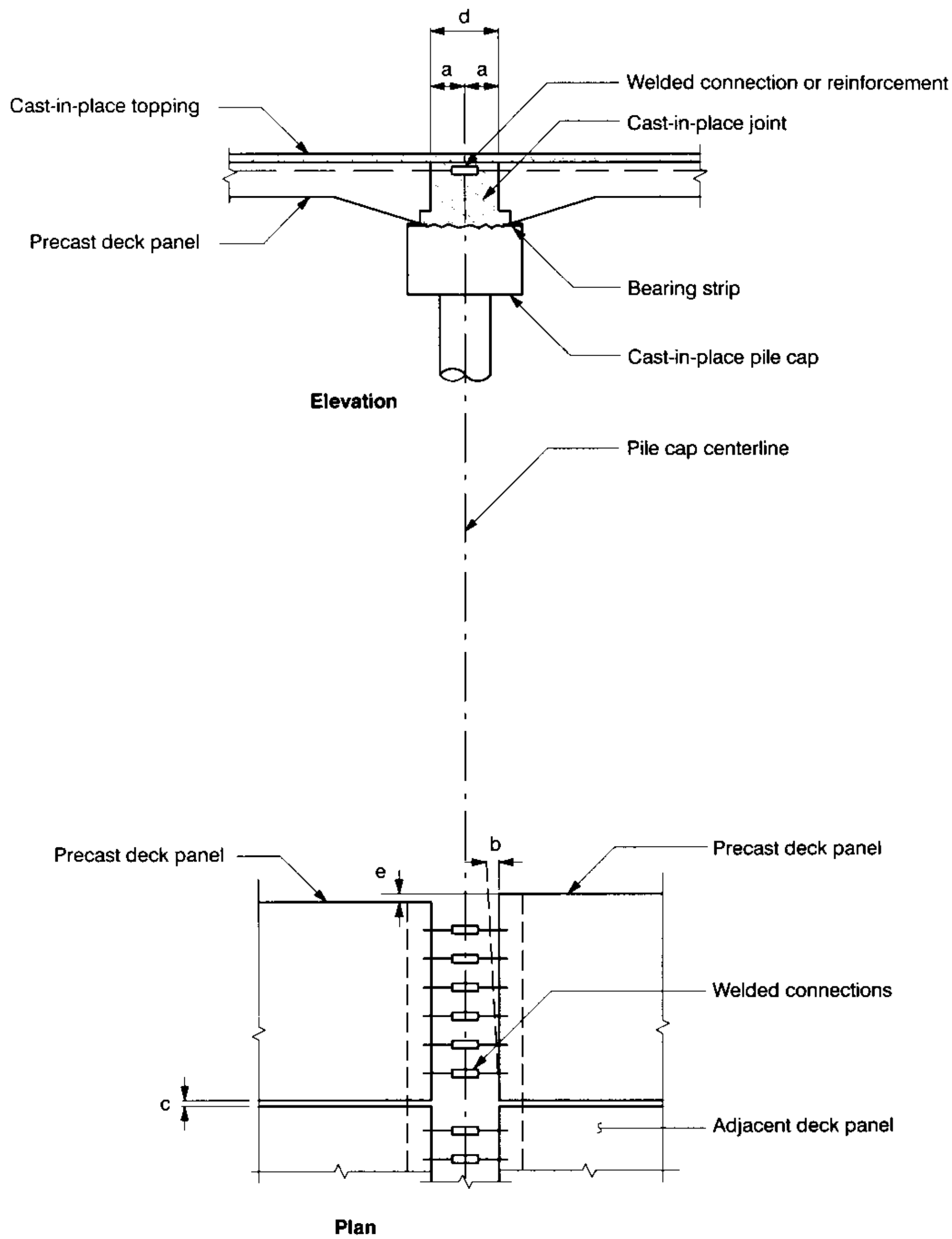
e = Height to top of wall panel .... ±½ in. [±13 mm]

f = Height to centerline of post-tensioning ducts
or embedded reinforcement to be welded .... ±¼ in. [±6 mm]

g = Step in face—interior surface .... ±¼ in. [±6 mm]*

* In applications which involve an internal surface wiper on the sides of the tank it may be required that this tolerance be made more stringent.

Fig 12.11.1 Pier Deck Erection Tolerances



12.11 Pier Deck Erection Tolerances

a = Variation in placement of end of panel relative to centerline of pile cap .... ±½ in. [±13 mm]

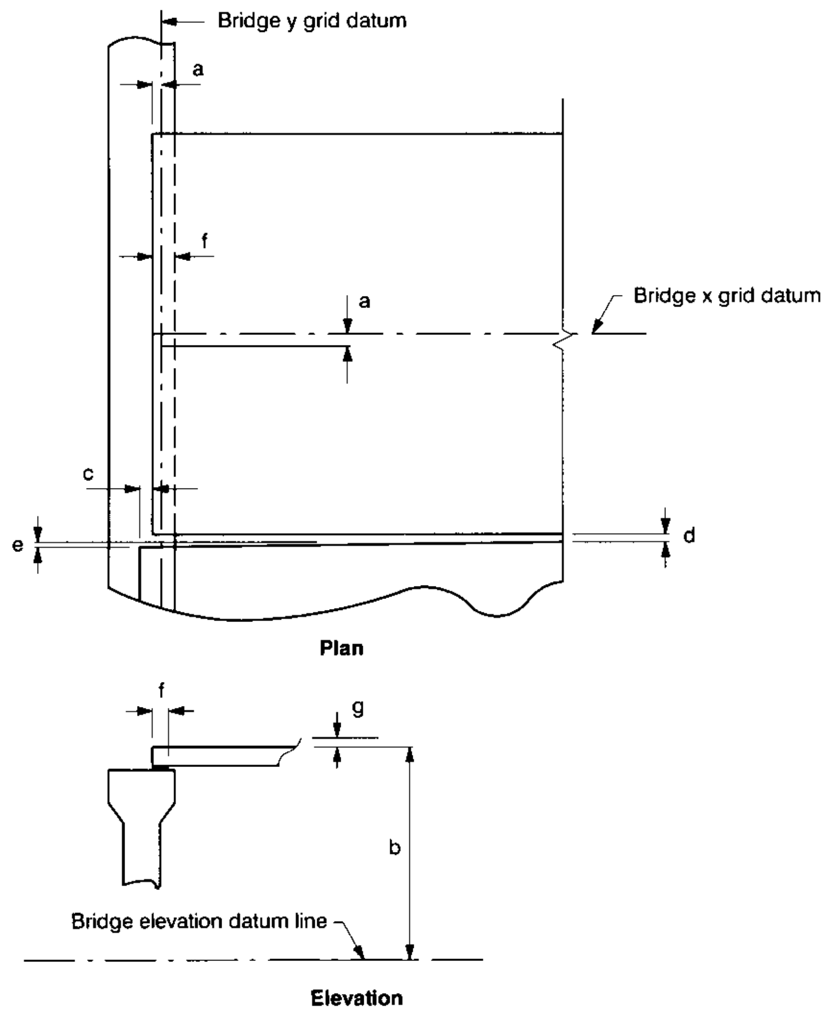
b = Variation of panel end from a line parallel to centerline of pier cap .... ±¼ in. [±6 mm]

c = Variation in width of panel to panel grout joint .... ±⅛ in. [±3 mm]

d = Variation in width of joint between panels .... ±1 in. [±25 mm]

e = Variation in alignment of adjacent panel edges .... ±⅛ in. [±3 mm]

Fig 12.12.1 Erection Tolerances for Bridge Deck Units



12.12 Erection Tolerances for Bridge Deck Units

a = Plan location from building datum .... ±1 in. [±25 mm]

b = Top surface elevation from nominal top surface elevation .... ±¾ in. [±19 mm]

c = Maximum jog in alignment of matching edges .... 1 in. [25 mm]

d = Joint width .... ±½ in. [±13 mm]

e = Joint taper .... ±¼ in. [±6 mm]

f = Bearing length in the span direction .... ±½ in. [±13 mm]

g = Differential elevation between adjacent panels .... ¾ in. [19 mm]

Note: These tolerances should be compared against those specified by the controlling bridge authority. If the specified project tolerances are more stringent than these, the specified tolerances shall govern the erection of the project.

13.0 Erection Tolerances for Mixed Building systems

A mixed building system is one which uses precast and prestressed concrete with other materials, usually cast-in-place concrete or structural steel. Mixed building systems subject erection tolerances to even more variables than do single system buildings. Each industry has its own specified erection tolerances which apply when its products are used exclusively. Because the industry standard tolerances for different materials are not necessarily compatible, it is in the interest of the producer and erector to verify the compatibility of each industry's erection tolerances with the precast tolerances. Compatibility of tolerances is achieved by connection design and/or by modification of standard tolerances of one or more of the involved building systems.

Note that any modification of standard tolerances on the non-precast portion of the work must be brought to the attention of the architect/engineer so the modifications can be coordinated throughout the project design and construction to assure that the modified tolerances are, in fact, achieved.

13.1 Connection Tolerances for Mixed Building Systems

Special attention should be given to assuring that the responsible project team member has appropriately considered the connection tolerance requirements when mixed building systems are involved. The manner in which precast concrete members are connected to each other or to members fabricated of other materials should be reviewed by the producer and erector in the context of the specified erection tolerances. The erector should review the design documents to assure it is practical to physically construct the connections.

For precast to precast erection acceptable bearing tolerance conditions which are required for safe erection should be shown on the erection drawings. For precast to other materials, erection acceptable bearing conditions must be shown in the contract documents.

If for any reason a member cannot be erected as shown on the connection details within the tolerances outlined in this document, the erector should notify the architect/engineer to check the structural adequacy of the resulting connection configuration and modify the connection if necessary. The connection design should be reviewed by the erector to assure that space has been provided so that adequate material, tools and equipment can be used to complete the connections. Verify that tools and equipment can be utilized in the intended manner under the most adverse combination of possible tolerances.

For a cast-in-place concrete frame the maximum tolerances that should be permitted, unless otherwise stated in the project specifications, are those given in the current revision of ACI 117 *Standard Tolerances for Concrete Construction and Materials*. The tolerances given in ACI 117 are quite optimistic for tall buildings when compared to the American Institute of Steel Construction tolerances and to as-built measurement of tolerances obtained from measurements of tall buildings.

Variations in height of floors in excess of the ACI 117 tolerances are more prevalent in cast-in-place construction than in other types of structures when compared to published tolerances for example in steel frame buildings. This will affect location or mating of the inserts in the precast panels with the cast-in connection devices.

The producer and erector should be aware that tolerances for cast-in-place structures may have to be increased even further beyond the values given in ACI 117 to account for local trade practices, the complexity of the structure, and climatic conditions which will exist at the time of construction. For these reasons local producers should collaborate with the architect/engineer early in the project providing their input on overall project tolerances.

14.0 Clearance Considerations in Product Manufacture

The entire building team should collaborate and cooperate throughout the project to allow the project to be satisfactorily built using practical tolerances and clearances. Clearance is the space provided between adjacent precast members and is one of the most important factors to consider in the planning for the erection. The clearance is jointly "owned" by all of the members of the building team. What this means is that the joint clearance is used to accommodate the product tolerances, the erection tolerances, and to allow adjustment for appearance.

Exposed joint clearance determination and configuration for architectural panels is an especially important consideration which should be reviewed by the producer and the erector in advance of production. If revisions are indicated the architect/engineer should be notified.

Tolerances in overall building width and length are normally accommodated in panel joints, making the overall building size tolerance and its relationship to building property lines important considerations in joint clearance design. In the architectural panel, the joint width must not only accommodate variations in the panel dimensions and the erection tolerances for the panel, must also provide both a good visual line and sufficient width to allow for effective sealing. Generally the larger the panel the wider the basic dimension of the joint should be in order to accommodate realistic tolerances in straightness of panel edge, in edge taper and in panel width.

When all factors are combined and considered, the minimum theoretical architectural panel joint width should not be less then ¾ in. [19 mm]. Joint widths specified as less than this amount should be discussed in detail with the project architect prior to start of production, as they may require more stringent special project tolerances to achieve the desired result.

The following items should be reviewed by the producer and erector in their project review to determine that appropriate clearance has been provided in the design.

14.1 Effects of Product Tolerances on Clearance Considerations

The product tolerance of the member or system (if it is an interfacing situation) and the possible maximum and minimum variations in the size of the member should be considered when reviewing the specified joint clearance for adequacy. If revisions to the design are indicated the architect/engineer should be notified.

When a project involves particular features sensitive to the cumulative effect of generally accepted tolerances on individual members, the producer's and erector's review should assure that the architect/engineer has provided for this effect by setting a cumulative allowance or by providing appropriate clearances where accumulated tolerances can be absorbed.

14.2 Effects of Member Type on Clearance Considerations

The type of member is partially accounted for when the product tolerances are considered. Those members exposed to view should be specifically reviewed with regard to clearance requirements. An exposed to view member requiring stringent erection tolerances generally requires more clearance for adjustments than does a non exposed member with a more liberal erection tolerance. Similarly, a corner member should have a large enough clearance provided, so it can be adjusted to line up with both of the adjacent panels.

In practice, members exposed to view are often specified with less clearance than non-exposed members. As previously noted, more stringent special project tolerances may be needed when narrow clearance joints are specified.

14.3 Effects of Member Size on Clearance Considerations

The effect of member size on thermal motions of the member should be considered in the review of the project clearances. Large members are more difficult to handle than smaller ones. A large member being erected by a crane requires more clearance than the small member that can be hand erected or adjusted.

14.4 Effects of Member Location on Clearance Considerations

The requirements for erecting the member in the structure should be considered in the review of the project clearances. With multistory members for example, floor members may be erected by lowering them from the top down between the previously erected vertical members. This process often requires a greater clearance for erection than does a roof member.

14.5 Effects of Member Movement on Clearance Considerations

The review of clearances should consider member movements caused by temperature expansion and contraction, creep, shrinkage, structural deflection and rotation. The clearance between vertical members and the adjacent horizontal members should allow for some movement in the horizontal member to prevent the vertical member from being pushed or pulled out of its original alignment. This is especially critical on exposed structures such as parking decks, where temperature ranges and the associated member movements are significant.

The effects of support member deflection on panel movement can effect the clearance specified between cladding panels that are supported by structural members.

14.6 Effects of Member Function on Clearance Considerations

The function of a member within the building should be considered in the review of the specified clearance. For example, allowances should be provided for end rotation of heavily loaded beams. Likewise a minimum amount of joint width is needed to assure the joint can be reliably sealed when the member must provide protection against the elements.

14.7 Effects of Erection Tolerances on Clearance Considerations

Of all the factors discussed above, product tolerances and member movement are the most significant variations to consider when reviewing project clearances. If the clearance provided is too small, erection may be slow and costly because of fit-up problems and the possible requirements for rework.

Reviews by the architect/engineer and producer should determine that the erection tolerances have been considered in the development of clearance specifications. The clearance necessary for erection of the members will depend on their geometric configuration, the dimensional accuracy of the building frame or other construction to which the members are connected and the limits of adjustment permitted by the connection details.

A rule of thumb is that at least 0.50 in. [13 mm] clearance be specified between panels and precast concrete panel support members with 1 in. [25 mm] preferred. A clearance of 1 in. [25 mm] is the minimum planned clearance between panels and cast-in-place concrete panel support members with 1.50 in. [38 mm] preferred.

For steel structures, 1 in. [25 mm] is the minimum clearance between the back of the panel and the surface of the fireproofing on the steel panel support members with 1.50 in. [38 mm] preferred. If there is no fireproofing required on the steel panel support members then 1 in. [25 mm] minimum clearance should be maintained. At least 1.50 in. [38 mm] of clearance between the back of the panel and the surface of the supporting steel beam should be specified in tall or irregular structures regardless of the structural framing materials.

The minimum clearance between column covers and columns should be 1.50 in. [38 mm], with 3 in. [76 mm] preferred because of the possibility of columns being out of plumb or a larger than nominal column dimension interfering with the completion of the column cover connections.

14.8 Procedure For Determination of Clearance

The following is a systematic approach for making a trial selection of a clearance value and then testing that selection to ensure that it will allow practical erection to occur. This type of systematic evaluation of all specified clearances will disclose potential problems or areas which will require special care in member production and/or erection.

Step 1

Determine the maximum size of the members involved (basic or nominal dimension plus additive tolerances). This should include not only the precast and prestressed members, but also other materials. This step includes evaluating the installation tolerances of the non-precast building systems and subsystems and the consequences of those tolerances on the precast member interface.

Step 2

Add to the maximum member size the minimum space required for member movement resulting from deflections, and thermal movements. Tolerances of systems installed by other trades are generally as defined in the standards of practice for those trades.

Step 3

Check to see if the selected clearance allows the member to be erected within the erection and interfacing tolerances, such as plumbness, face alignment, etc. If the member interfaces with other structural systems, such as steel frame or a cast-in-place concrete frame, check to see if the clearance provides for the erection and member tolerances of the interfacing system. Adjust the clearance as required to meet all of the needs. More clearance may be needed to accommodate interfacing with other systems which may have large tolerance variations.

Step 4

Check to see if the member can physically be erected with the clearance determined above. Consider the size and location of members in the structure and how connections will be made. Adjust the clearance as required. An understanding of the planned erection sequence is important in reviewing the appropriateness of specified clearances. For complex situations it is beneficial to involve the erector in this review.

Step 5

Review the clearance to see if increasing its dimensions will allow easier, more economical erection without adversely affecting aesthetics. Adjust the clearance as required. If adjusting the clearance as required to allow fit up still results in reasonable clearance widths, the design portion of the tolerance control plan for this element of the building is complete.

Step 6

Review structural considerations such as types of connections involved, sizes required, bearing area requirements, and other structural issues. Check structural adequacy. The structural requirements for bearing areas and connection eccentricities should be available as input to the review of the project tolerance plan.

Step 7

Check design to ensure adequacy in the event that minimum member size should occur. Adjust clearance as required for minimum bearing and other structural considerations.

Step 8

Select the final clearance which will satisfy all of the conditions considered.

14.9 Clearance Examples

A project tolerance plan incorporating all possible product tolerance variations, erection tolerance variations, setting of joint clearances, selection of tolerance accommodating connection details, and the variations in subsystem interface requirements is necessary for every project. One should not assume that by simply specifying that "PCI tolerances shall be used" that everything will work out. That "everything will work out" is something that needs to be verified by the development of the project tolerance plan. This is particularly true for complex projects or projects which are substantially different from those previously handled by the particular building team involved.

The following examples in Articles 14.10 through 14.12 demonstrate the thought process involved in forming a project tolerance plan. A judgment situation was created to emphasize that engineering judgment must be included as part of the clearance determination process. Therefore, the solution shown is not the only correct one for the situation described.

The project tolerance plan should not only include the specification of the project tolerances and details but should also provide the basis with which the construction team can verify the accomplishment of the tolerance objectives leading up to the erection effort.

14.10 Roof Member Clearance Example (Refer to Figure 14.10.1)

Given: A double-tee roof member bearing on ribbed wall panels.

Find: The minimum acceptable joint clearance. See Articles 10.3 and 10.6.

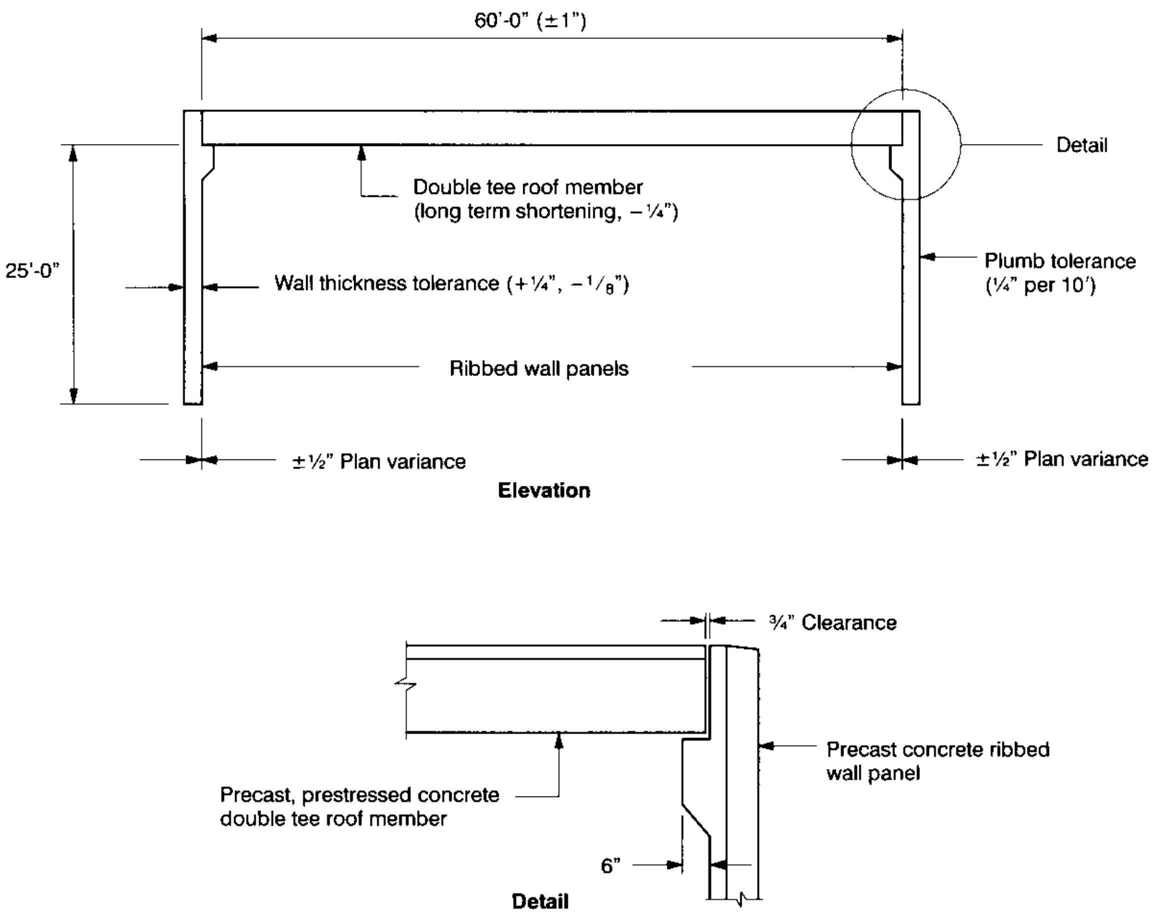
Length of member = 60 ft. [18 m] long
Length tolerance = ±1 in. [25 mm]
Wall member length to haunch = 25 ft. [7.6 m]
Max. plan variance = ±½ in. [±13 mm]
Plumb variation = ¼ in. per 10 ft. [6 mm per 3 m]
Haunch depth is 6 in. [152 mm] beyond the face of the panel.
Long term roof deflection is −¼ in. [−6 mm].

Procedure:

Step 1 – Determine maximum member sizes.

Maximum double tee length = +1 in. [+25 mm]
Maximum wall thickness = +¼ in. [+6 mm]
Initial clearance chosen = ¾ in [19 mm] each end

Fig. 14.10.1 Roof Member Clearance Determination (Example 14.10)



Step 2 – Evaluate effects of member movement

Required clearance adjustment as a result of member movement = none

Clearance chosen = ¾ in. [19 mm] (from Step 1)

The long term shrinkage and creep movement will increase the clearance, so this movement can be neglected in the initial clearance determination, although it must be considered structurally.

Step 3 – Evaluate effects of erection tolerances

If the wall panel is set inward toward the building interior ½ in. [13 mm] and erected plumb, the clearance should be increased by ½ in. [13 mm]. If the panel is erected out of plumb outward ½ in. [13 mm] no clearance adjustment is needed.

Clearance adjustment required to account for erection tolerances = none

Clearance chosen = ¾ in. [19 mm] (from Step 1)

Step 4 – Erection Considerations

If all members are fabricated perfectly, then the joint clearance is ¾ in. [19 mm] at either end of the double tee (1.5 in. total) [38 mm]. This is ample space for erection of this member. If all members are at maximum size variance, maximum inward plan variance, and maximum inward variance from plumb, the total clearance is zero. This situation is undesirable, as it would likely require some rework during erection. However, there is opportunity to directly measure the span length of the roof member and adjust the wall members upon erection.

Clearance chosen = ¾ in. [19 mm] (from step 1)

A judgment should be made as to the likelihood of maximum product tolerances all occurring in one location. If the likelihood is judged to be low, the ¾ in. [19 mm] clearance needs no adjustment, but, if the likelihood is high and the opportunity for adjustment upon erection is judged to be low, the tolerance system designer might increase the clearance to 1 in. [25 mm]. In this instance the likelihood has been judged to be low; therefore no adjustment has been made.

Step 5 Evaluate the economy of this clearance

In single-story construction, increasing the clearance beyond ¾ in. [19 mm] is not likely to speed up erection as long as product tolerances remain within allowed variances. No adjustment is required for economic considerations.

Step 6 Review structural considerations

Allowing a setback from the edge of the corbel, assuming in this instance to have be set by the engineer at 1.25 in. [32 mm] plus the clearance, the bearing is 4 in. [102 mm] and there should be sufficient space to allow expected member movement. The tolerance designer judges this to be acceptable from structural and architectural viewpoints and no adjustment to the clearance is required for structural considerations.

Step 7 Check for effects of minimum member sizes

Minimum double tee length = −1 in. [25 mm] [½ in. [13 mm] each end).
Refer to product tolerances Article 10.3 and 10.6
Minimum wall thickness = −⅛ in. [−3 mm]
Bearing haunch = no change
Clearance chosen = ¾ in. [19 mm] (from step 1)
The minimum bearing, of 4⅝ in. [117 mm], without setback is satisfactory in this instance.
Note : Wall plumbness is assumed to be at nominal (no variation from nominal) in this example.

Step 8 – Determine final clearance

Minimum clearance to be used = ¾ in. [19 mm]
This clearance satisfies all conditions considered.

Note: For simplicity in this example, beam end rotation, flange skew, and global skew tolerances have not been considered. In an actual situation, these factors should also be taken into account.

14.11 Bearing Wall Panel Joint Clearance Example (Refer to Figure 14.11.1)

Given: Bearing wall panel, 18 ft. [5.5 m] high erected on a cast-in-place concrete footing.
Find: The minimum acceptable clearance between the base of the wall panel and the top of the footing.

For simplicity, it is assumed that the plane of the top elevation of the wall panels will be set at exactly the basic elevation.
Minimum space for proper grouting beneath the wall panel is judged in this case to be ½ in. [13 mm].

Procedure:

Step 1 Determine maximum member sizes

Maximum panel height = +½ in. [+13 mm]
Highest footing top elevation = +½ in. [+13 mm]
Refer to Product Tolerances Article 10.3
Initial clearance chosen = 1.5 in. [37 mm]
This results in ½ in. [13 mm] clearance in the maximum member size condition.

Step 2 Evaluate effects of member movement

Bottom of member will be fixed once member is grouted. No adjustment is required for member movement.

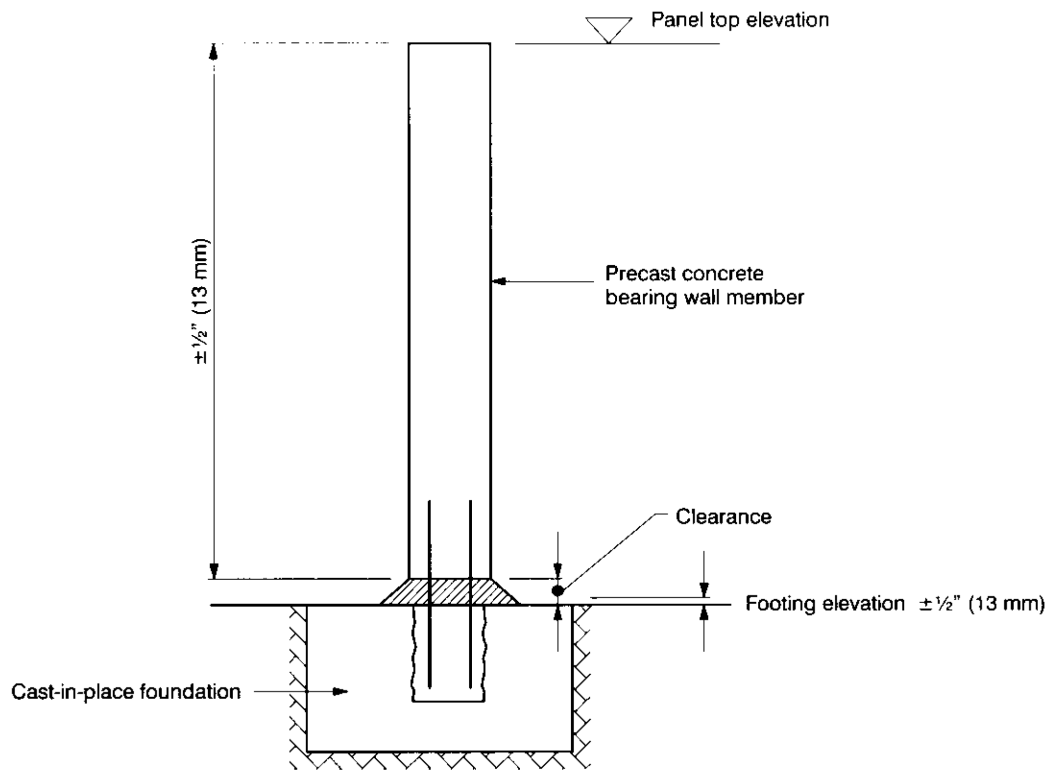
Step 3 Evaluate other erection tolerances

Plumb tolerance has minimal effect on the clearance at this location. In this example the top of the wall panel is assumed to be set at the nominal elevation.

Step 4 Erection considerations

Ease of erection is not influenced by the size of this clearance.

Fig. 14.11.1 Bearing Wall Clearance Determination (Example 14.11)



Step 5 Evaluate economic considerations

Varying the clearance above 1.5 in. [37 mm] will make the grouting operation more costly, as more grout will be required. The cost of the additional volume of grout required can be computed.

Step 6 Structural considerations

Clearance chosen = 1.5 in. [37 mm]
Minimum depth of grout bed = ½ in. [13 mm]
1.5 in. [37 mm] clearance is acceptable.

Step 7 Check effects of minimum member sizes.

Refer to Product Tolerances Article 10.3
Clearance determined (Step 6) = 1.5 in. [37 mm]
Minimum panel length = ½ in. [13 mm] short
Minimum footing elevation = ½ in. [13 mm] low
Maximum clearance calculated = 2½ in. [64 mm]

A judgment condition now exists. A 1.5 in. [38 mm] standard grout bed with a 2½ in. [64 mm] thick possible grout bed is expensive. As a general rule, for normal contracting conditions, it is desirable to provide at least 1½ in. [38 mm] of clearance for a detail such as this .

If special attention to detail in setting and finishing the tops of the footings is agreed upon with the contractors involved, one might reduce the nominal clearance to 1 in. [25 mm].

Step 8 – Determine final clearance

Minimum clearance used = 1 in. [25 mm]

The designer judges that with care to assure footings are set on the low side of their top elevation construction tolerance. This will likely satisfy all of the conditions considered and provide an economical connection.

Note: Alert contractor and erection crews to instances which may require isolated rework in order to provide minimum required grout space.

14.12 Cladding for High Rise Steel Frame Building Clearance Example (Refer to Figure 14.12.1)

Given: A thirty six story steel frame building is designed with precast concrete cladding. The steel structure is erected to tolerances per AISC. Assume that member movements have been calculated to be negligible. In this example, precast tolerance for variation in plan is specified as ±¼ in. [6 mm].

Find: Determine whether or not the panels can be erected plumb and determine the minimum acceptable clearance at the 36th story.

Procedure:

Step 1 – Product tolerance

Refer to product tolerances Article 10.1

Precast cladding thickness = +¼ in. [+6 mm] −⅛ in. [−3 mm]

Steel member width = +¼ in. [+6 mm] −3⁄16 in. [−4.5 mm]

Steel member sweep (varies) ±¼ in. [±6 mm] assumed.

Step 2 – Member movement effects

For simplicity, assume this can be neglected in this example.

Step 3 – Other erection tolerances

Maximum steel variation in plan = 2 in. [50 mm]

Minimum clearance = ¾ in. [19 mm]

This is the minimum clearance needed to complete the connection in the field.

Clearance chosen = 2¾ in. [70 mm]

Step 4 – Erection considerations

Adjustment required = none

Step 5 – Economic considerations

Clearance chosen = 2¾ in. [70 mm] (From Step 3)

Increasing clearance will not increase economy. No adjustment needs to be made for economic considerations.

Step 6 Structural considerations

Clearance chosen = 2¾ in. [70 mm] (From Step 3)

This results in an expensive cladding connection, but it is possible to construct. No adjustment required.

Step 7 Check minimum member sizes at 36th story.

Refer to product tolerances Article 10.3

Clearance chosen = 2¾ in. [70 mm] (Step 3)

Minimum cladding thickness = −⅛ in. [−3 mm]

Minimum steel beam width = −3⁄16 in. [−4.5 mm]

Steel support beam sweep = −¼ in. [−6 mm] (toward building interior)

Minimum size of steel variation in plan = −3 in. [−75 mm]

Clearances calculated = 6 5⁄16 in. [156 mm]

2¾ + ⅛ + 3⁄16 + ¼ + 3 = 6 5⁄16 in.

When the minimum condition exists, the resulting clearance of 6 5⁄16 in. [156 mm] produces a connection judged by the designer to be too costly for the precast concrete cladding on this project. In addition it produces a high torsional force on the supporting structural steel that must be considered in the design of any horizontal steel supporting members.

Step 8 – Determine final clearance

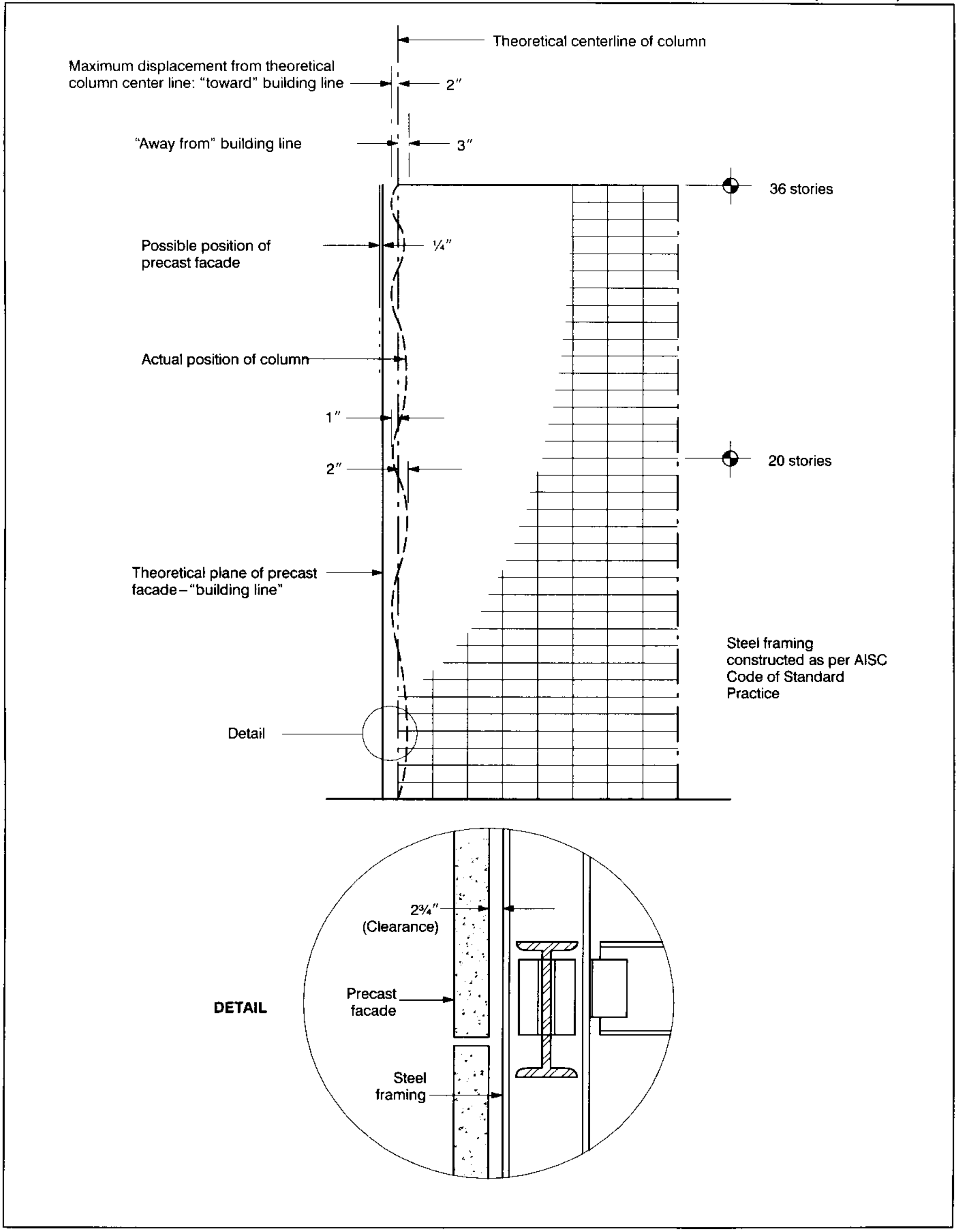
Minimum clearance used = 2¾ in. [70 mm]

The 6 5⁄16 in. [156 mm] clearance is judged not practical, although the 2¾ in. [70 mm] minimum initial clearance is still needed for erection. Therefore the initially specified erection tolerances need to be adjusted.

Either the precast cladding members should be allowed to follow the steel frame tolerances and be erected out of the standard plumb tolerances for precast panels or the steel frame erection tolerances need to be made more stringent. The likely most economical and recommended solution will be for the precast cladding members to follow the steel frame as the variation in plumb in a building of this height will not be noticeable.

Another solution which has proven to be both practical and economical in some instances is to specify the more stringent AISC elevator column erection tolerances for steel columns in the building facade which will receive the precast cladding panels. This type of solution should be agreed to as part of the design and specification process.

Fig. 14.12.1 Determinate of cladding connection tolerances—high rise steel frame (Example 14.12)



15.0 Interfacing Tolerances

The purpose of this section is to help the designer and producer deal with the problem of designing for interface tolerances. As with product and erection tolerances, the party to be responsible for assuring that interfacing tolerances are appropriately accounted for in the project tolerance plan should be agreed to in writing at the start of the project.

A comprehensive discussion of interfacing tolerances is presented and a number of typical details and examples are given as illustrations. With interfacing tolerances, it is important to note that the tolerances associated with the system to be interfaced may be very dependent on the specific system (e.g. window system) ultimately procured for the project. The fact that the specific systems to be interfaced with may not be known until late in the project make this issue one which is very important to deal with to assure a successful installation.

Unusual requirements or allowances for interfacing should be in the contract documents. It is in the interest of all parties on the project team to identify and take steps to accommodate unusual interfacing tolerance requirements as soon as they are identified.

Accommodation of interfacing tolerances may involve contractual changes, if the interface requirements are not initially defined in the contract, or if these requirements change as result of procurement decisions made after the precast contract has been finalized.

In practice the interfacing requirements may not be in the contract documents. It should be noted that building systems and hardware are often specified and procured by a company which may not have a contractual relationship with the precast member manufacturer. If this is the case, the party with the necessary contractual authority is responsible for assuring that the project interfacing tolerance requirements are appropriately coordinated and met.

For example, windows fabricated by Company A may have a quite different interface tolerance requirement than windows fabricated by Company B. On fast track projects the fact that the precast fabrication takes place early in the project may drive the installation and tolerance requirements of the interfacing systems and may influence subsystem procurement choices. If material or component substitutions are made for any reason after the initial design is complete, the interfacing design should be reviewed by the producer as well as by the architect/engineer for the new system tolerance requirements to assure compatibility of tolerances.

Where matching of the different materials is dependent on work executed at the construction site, interface tolerances should also be related to erection tolerances. Where the execution of the interface is independent of site work, tolerances should closely match the normal manufacturing tolerances for the materials to be joined plus an appropriate allowance (clearance) for differential volume changes between the materials.

Following is a partial checklist for the review of interfacing tolerance requirements. If revisions to clearances or tolerances are indicated, the architect/engineer should be notified.

15.1 Structural Requirements

a. The potential for introducing unintended structural loads from the precast into the interfacing subsystems should be evaluated. Does the behavior of the structure require that the interfacing system be isolated from primary or secondary structure loads?
b. Does the interface perform a structural function in the structure (e.g. load transfer)?
c. In the determination of erection tolerances attention should be given to expected deflections and/or rotations of structural members supporting precast concrete panels.
d. How are building motions, dimensional changes, and vibrations taken into account structurally, and how do they collectively affect interfacing tolerances?
e. If the deflection of the structural frame is sensitive to the location or eccentricity of the connection, limits on connection eccentricity should be given on the erection drawings. This is particularly important for heavy members bearing on light members, such as open web joists, or cantilevered structural members.
f. Consideration should be given to both initial deflections and to expected long term deflections caused by creep of the supporting structural members.
g. Allowances must be made when detailing connections of precast concrete panels to steel structures for effects of sway in tall, slender steel structures.

15.2 Volume Change

a. The potential for volume change effects in the precast or in the interfacing subsystem to introduce unintended loads into the interfacing sub systems should be evaluated.
b. Does the primary structure or the interfacing system undergo mutually incompatible volume changes that need to be considered? (e.g., openings for aluminum windows should allow clearance for the expected thermal expansion of the sash.

c. In tall buildings global movements of the building due to solar heating on one side and seasonal thermal expansions and contractions should be considered in the design of panel clearances and connections.

15.3 Exposure and Corrosion

a. Is the interface exposed to weather? If so, what dimensional requirements result from the need to provide protection from moisture and the elements?
b. How do the proposed precast concrete details enhance or detract from the ability of the structure to remain serviceable and durable over time? To assure the long term durability of precast members, it must be assured that tolerancing of interfacing subsystems do not provide a path for corrosion of metallic elements or contribute to unacceptable corrosion staining.

15.4 Waterproofing Requirements

a. Interfacing tolerances and clearances should be evaluated for the ability to properly support the installation of weatherproofing materials.
b. What are the waterproofing requirements of the roofing details, exterior penetrations, and drainage schemes. How do they apply to the interface between the precast concrete and the other materials?
c. A minimum clearance joint width is typically required to allow proper installation of waterproofing sealant systems. Manufacturer's recommendations for minimum joint width for the waterproofing sealant system to be used should be considered.
d. Cast in grooves, reglets, or lugs that are to receive glazing gaskets may require a higher level of precision than other aspects of panel construction in order to allow proper installation and function. Reference should be made to gasket manufacturers' tolerances on the groove width and surface smoothness necessary to obtain a proper moisture seal.

15.5 Drainage Requirements

a. Interfacing tolerances which have an effect on the proper draining of the roof or other features which could retain or pond water should be reviewed to assure that positive drainage is possible.
b. Where are the areas to be drained and how does the drainage requirement affect the interface between precast concrete and other materials?
c. What are the consequences of dimensional tolerance to the drainage system?

15.6 Architectural Requirements

a. Which portions of the structure exterior and interior are exposed to view? On projects where precast members have a primarily architectural/visual function architectural requirements may require special interfacing measures.
b. What are the architectural treatments proposed for the various interfaces? How do the treatments relate to interfacing tolerance requirements?
c. Tolerances for the planeness of concrete surfaces at the interface with glass or curtain wall face should be developed in conjunction with the curtain wall installation requirements.
d. The requirement to align architectural panels in three dimensions may result in special interfacing clearance requirements, even on the non-visible faces of the member.
e. It is important that the project design provides adequate clearance between the nominal face of the supporting structure and the back face of the attached concrete panel. Adequate space must be provided here to allow an efficient and economical erection operation.

15.7 Dimensional Considerations

a. How closely can the dimensions of the interfacing materials be controlled? It is important to note than unless specifically controlled during the construction process, the industry published tolerances for the installation of materials by other trades may or may not be met.
b. What are the dimensional considerations in relation to the proper function of the interfacing systems? If the precast installation has specific interface tolerance needs, it is important to communicate these to all levels of the project design team and follow up with the construction team. This communication should be through the party having contractual authority over the involved trades.
c. The following tolerances, in addition to ACI 117 requirements, should be specified for the cast-in-place concrete construction when precast concrete members are to be connected to cast-in-place structures. It should be noted that special measures and attention to detail are likely to be required to achieve these more stringent

than usual tolerances in the cast-in-place concrete construction. Following up to assure that the requested tolerances have actually been achieved has proven to be an important activity in assuring that the construction/precast erection activity proceeds smoothly.

1. Footings, caisson caps, and pile caps
aa. Variation of bearing surface for precast members from specified elevation:
±0.50 in. [±13 mm]

2. Piers, columns, and walls.
aa. Variation in plan from straight lines parallel to specified linear building lines: 0.025 in. per foot [2 mm per m] for adjacent members less than 20 feet [6 m] apart or any wall or bay length less than 20 feet [6 m].
0.50 in. [13 mm] maximum for adjacent members 20 feet [6 m] or more apart or any wall or bay length of 20 ft. [6 m] or more.
bb. Variation in elevation from lines parallel to specified grade lines:
0.025 in. per foot [2 mm per m] for adjacent members less than 20 ft. [6 m] apart or any wall or bay length less than 20 ft. [6 m].
0.50 in. [13 mm] maximum for adjacent members 20 feet [6 m] or more apart or any wall or bay length of 20 ft. [6 m] or more.

3. Anchor bolts
Special coordination with the cast-in-place concrete contractor and the use of erection bolt setting templates common to both the precast and cast-in-place construction effort will likely be required to achieve anchor bolt tolerances which will allow trouble free erection.
aa. Variations from specified location in plan: ±0.25 in. [±6 mm]
bb. Variation center to center of any two bolts within an anchor bolt group: ±0.125 in [±3 mm]
cc. Variations from specified elevation: ±0.50 in [±13 mm]
dd. Anchor bolt projection: − 0.25 in., +0.50 in. [−6 mm, +13 mm]
ee. Plumbness of anchor bolts: ±0.062 in. [±2 mm]

4. Tolerances for structural steel framing should be specified to conform with the American Institute of Steel Construction (AISC) "Code of Standard Practice for Steel Buildings and Bridges".

Particular attention is directed to the "Commentary" included with the AISC code. The commentary provides a detailed explanation of the specified steel erection tolerances.

15.8 Vibration Considerations

a. Does the mechanical subsystem have vibration considerations which must be accounted for in the interface between it and the precast concrete?
b. If vibrations result in deflections of members, contact between members as result of vibration should be avoided.

15.9 Fire-Rating Considerations

a. Does the need for fire resistance of the system impose any tolerance requirements on the nature of the interface such as maximum allowable gaps? Code requirements relating to fire ratings often require that gaps beyond a certain size be sealed in a fire proof manner.

15.10 Acoustical Considerations

a. Does the acoustic environment place any special requirements on the interface between precast concrete and interfacing systems? Clearance gaps can sometimes provide a route for unwanted transmission of sound from one room to another.

15.11 Economics

a. Does the chosen interface design alternative place any unusual or costly demands on either the precast or the interfacing system?
b. Has the most economical interfacing design alternative been used? In some cases the cost of accommodating a tolerance sensitive interfacing system may be a significant percentage of the total cost of the installed interfacing system.
c. Has the cost trade-off between in-plant work and field work been considered?

15.12 Manufacturing/Erection Considerations

a. Does the interfacing method consider practicalities of manufacturing? The manufacturing and erection work necessary to accommodate an interfacing tolerance should be objectively evaluated. Viable methods of attaining the required interfacing tolerances should be defined before the producer agrees to provide them.
b. Is the time required to manufacture the interface consistent with factory production?
c. Can the interfacing parts of the structure be erected together safely and economically?

16.0 Design Approach for Two Interfacing Tolerance Systems

Unless the design and construction team has a significant background of successful experience with a particular building system type, and the handling of all of the interfaces, the only way to assure the proposed approach to handling interfacing tolerances will be viable is to systematically and numerically review the proposed tolerances and interfacing requirements.

The following approach is one suggested method of organizing the task of systematically reviewing the interface specified between two tolerance systems. It is in the interest of the producer to confirm that someone on the project team is responsible for and has infact reviewed the project interface tolerances.

The nominal clearance dimensions shown on the erection drawings should be equal to the actual clearance required plus the outward tolerance permitted for the adjacent construction. The clearances should be evaluated on the assumption that the precast panel will be as far out of the nominal position as is allowed, in the direction which creates the requirement for the largest clearance. Special attention should be given to complex geometric interfaces. Drawing the interface to scale showing the possible local and global variations is one way to evaluate an interface situation.

Step 1 Review the interface between the two systems.

a. Has the architect/engineer graphically defined the interface to show its shape, location, and any split of contractual responsibility?
b. Has the architect/engineer shown the material furnished by the different contracting parties?

For example, one might indicate the precast panel furnished by the precaster, the window furnished and installed by the general contractor, and the sealant between the window and the precast concrete furnished and installed by the general contractor. On fast track projects it may be necessary for the window suppliers to measure the as-built window openings in the precast members prior to fabricating the windows.

Step 2 Review the functional requirements of each interfacing system.

Functional requirements which require close tolerances, such as justice facility locking mechanisms, require special attention. Often tolerance friendly interface details which can accommodate significant tolerance variations can be used to economically interface the precast members with interfacing subsystems which must be precisely installed to stringent tolerances in the completed structure.

Another example of functional requirements is the building drain line that must have a flow line slope which allows adequate drainage. This will place functional limits on where the line must penetrate members. Consider a tee beam that has harped prestressing strands in the stems, making the end areas of the beam potentially difficult locations to interface with the prestressing strands for the drain line penetrations.

Step 3 Review the dimensional tolerances of each interfacing system.

For example, determine from the manufacturer's specifications what the external tolerances on the specified prefabricated metal door jamb are. Determine from the precast/prestressed concrete product tolerances what the tolerance on a large panel door opening will be. For the door installation, determine what the floor surface tolerance requirement will be in the area of the door and its swing path.

Step 4 Review the operational clearance specified.

The most significant tolerance interface problems result when the members of the project team don't understand or are unaware of special operational requirements of interfacing subsystems. For example, determine the magnitude of operational clearances which are needed to align the specified door to function properly. Then, review the nominal dimensional choices to assure they include an allowance for necessary clearances.

Step 5 Review compatibility of the interface tolerances.

Interface tolerance incompatibility problems resolved in the design phase of the project do not become member fabrication problems or erection problems.

Starting with the least precise specified system, review the minimum and maximum tolerance conditions and compare the precast dimensions against the minimum and maximum dimensions of the interfacing system. If interferences result, notify the architect/engineer. For example, it is usually more economical to make a larger window opening to provide more clearance than to specify a prefabricated window system with either nonstandard sizes or tolerances more stringent than standard. It is important to understand how a close tolerance interface is adjusted upon installation and how much adjustment capability is required.

Step 6 Review procedures for compatibility.

Review assembly and installation procedures for the interfacing systems to assure compatibility. Review the installation procedure to assure that the preferred adjustments to accommodate the tolerances of the interfacing systems have been indicated. Review such items as minimum allowable bearing areas, minimum and maximum joint gaps, and other features which will vary in dimensions as a result of the interface tolerances.

Review that appropriate economic trade-off considerations such as in-plant work versus field work, and minor fit-up rework versus specification of tighter tolerances have been made. If project specifications are silent on the topic of interface tolerances, it is in the producer's interest to request that additional information be provided regarding interfacing tolerance requirements of specified subsystems.

Step 7 Review final project specifications

Review the final project specifications as they relate to interfacing. Be especially aware of changes which may be required as a result of possible subsystem substitutions made during the final bidding and procurement activities.

17.0 Defining the Characteristics of a Tolerance Interface

The following list of questions should be considered in the producer's review of the nature of the interface between the precast member and an interfacing system:

1. What specifically is to be interfaced?
2. How does the interface function?
3. Is there provision for adjustment upon installation? Some interfacing subsystems have adjustment capability within the subsystem. Others may have zero adjustment capability built in.
4. How much adjustment can occur without rework? It is important to understand who will be responsible for any tolerance related rework that may be required.
5. What are the consequences of an interface tolerance mismatch?
   a. rework requirements (labor and material)
   b. rejection limits (when a will a remake be required?)
6. What are the high material cost elements of the interface? It is important to understand who is responsible for the cost of materials and labor required to complete the different interfaces.
7. What are the high labor cost elements of the interface? This is especially important for field installed interfacing subsystems.
8. What are the normal tolerances associated with the system to be interfaced? Different types of systems may have substantially different interfacing requirements.
9. Are the system interface tolerances simple planar tolerances or are they more complex and three dimensional? For example, mechanical piping for on-site fabrication in primarily straight runs may have different interfacing tolerance requirements than do complex prefabricated mechanical piping systems which have bends occurring at penetration locations.
10. Do all of the different products of the type being interfaced with have the same interface tolerance requirements?
11. Does the designer of the precast system have control over all aspects of the interfaces involved? If not, what actions need to be taken to accommodate this fact?

If the answers to these questions indicate the need for revision to interfacing tolerances or details, the architect/engineer should be notified.

Listed below are some common characteristics and considerations which are typical of most systems:

17.1 Windows and Doors

a. No load transfer through window element
b. Compatible with air and moisture sealant system
c. Open/close characteristics (swing or slide). Windows that must open and close may have more stringent interface requirements than those which do not.
d. Compatibility with door locking mechanisms

17.2 Mechanical Equipment

a. Duct clearances for complex prefabricated duct work.
b. Large diameter prefabricated pipe clearance requirements.
c. Deflection clearance requirements for deflection associated with large-diameter piping and valves.
d. Expansion and contraction allowances for hot and cold piping. Large diameter piping with significant thermal differentials may be associated with significant forces if the piping is not appropriately isolated from the structure.
e. Vibration isolation/transfer considerations.
f. Acoustical shielding considerations.
g. Hazardous gas/fluids containment requirements. Hazardous materials applications may result in special gap sealing requirements unique to this type of installation.

17.3 Electrical Equipment

a. Coordination of multiple mating conduit runs.
b. Prefabricated cable trays that must align.
c. Embedded conduits and outlet boxes. Visible outlet boxes or switch boxes embedded in precast walls may require special angular alignment tolerances for visual reasons.
d. Corrosion considerations related to DC power.
e. Special insert placement requirements for electrical isolation and potential for adverse reaction with galvanized materials.
f. Location requirements for embedded grounding cables.
g. Shielding clearance for special "clean" electrical lines.

17.4 Elevators and Escalators

a. Elevator guide location requirements. Different manufacturers of elevators and escalators.

have specific interface tolerance requirements which may be different.

b. Electrical conduit location requirements.
c. Elevator door mechanism clearances. Floor slope tolerances at elevator door locations may require special consideration.
d. Special insert and control switch placement requirements.

17.5 Architectural Cladding

The three dimensional interface requirements of architectural cladding systems, especially at corners, locations of unique geometry, and areas of interface from one cladding type to another should be accounted for in the project tolerance plan.

a. Joint tolerances for the specified caulking system.
b. Flashing and reglet fit-up (Lining up reglets from panel to panel is very difficult and often costly. Surface-mounted flashing or field cut reglets should be considered.)
c. Expansion and contraction provisions for dissimilar materials.
d. Effects of differential thermal gradients.

17.6 Structural Steel and Miscellaneous Steel

The party with primary responsibility for interface coordination of structural steel shop drawings with precast concrete shop drawings should be defined in writing for the project.

a. Details to prevent rust staining of concrete.
b. Details to minimize potential for corrosion at field connections between steel and precast concrete.
c. Coordination of structural steel expansion/contraction provisions with those of the precast system.
d. Special provisions for weld plates or other attachment features for steel structures.
e. Consideration of thermal insulation and fire proofing requirements.

17.7 Masonry

The party with primary responsibility for interface coordination of masonry shop drawings with precast concrete shop drawings for the project should be defined in writing.

a. Coordination of masonry expansion/contraction provisions with those of the precast system.
b. Detailing to assure desired contact bearing between masonry and precast members.
c. Detailing to assure desired transfer (or isolation) of load between masonry shear wall and precast frame elements.

17.8 Roofing

The tolerance requirements for interfacing with unique roofing systems should be reviewed as part of the project tolerance plan.

a. Roof camber, both upon erection and long term, as it relates to roof drain placement.
b. Fit-up of prefabricated flashing.
c. Dimensional effects of increased deflections resulting from added material during re-roofing.
d. Coordination of structural control joint locations with roofing system expansion/contraction provisions.
e. Location of embedded HVAC unit supports.
f. Deflections due to live loads and added equipment dead loads.

17.9 Waterproofing

The party with primary responsibility for interface coordination of waterproofing details at the shop drawing stage should be defined in writing for the project.

a. Location and dimensions of flashing reglets.
b. Location and shape of window gasket grooves.
c. Coordination of waterproofing system requirements with structural system expansion provisions.
d. Special details around special penetrations.

17.10 Interior Finishes—Floors, Walls, and Ceilings

Different interior finishes require different levels of tolerance on substrata to which they are applied. Thus the interface tolerance requirements of the finish types specified for the project are a consideration to be addressed in the project tolerance plan.

a. Joints between plank members for direct carpet overlay.
b. Visual appearance of joints for exposed ceilings.
c. Fit-up details to assure acceptable appearance of interior corners.
d. Appearance of cast-in-place to precast concrete interfaces.

17.11 Interior Walls and Partitions

a. Clearance for prefabricated cabinetry and other prefabricated finish elements.
b. Interfacing of mating embedded conduit runs and switch boxes.
c. Effects of thermal bowing of wall panels.

The potential for thermal bowing to result in gaps between floors and walls should be evaluated.

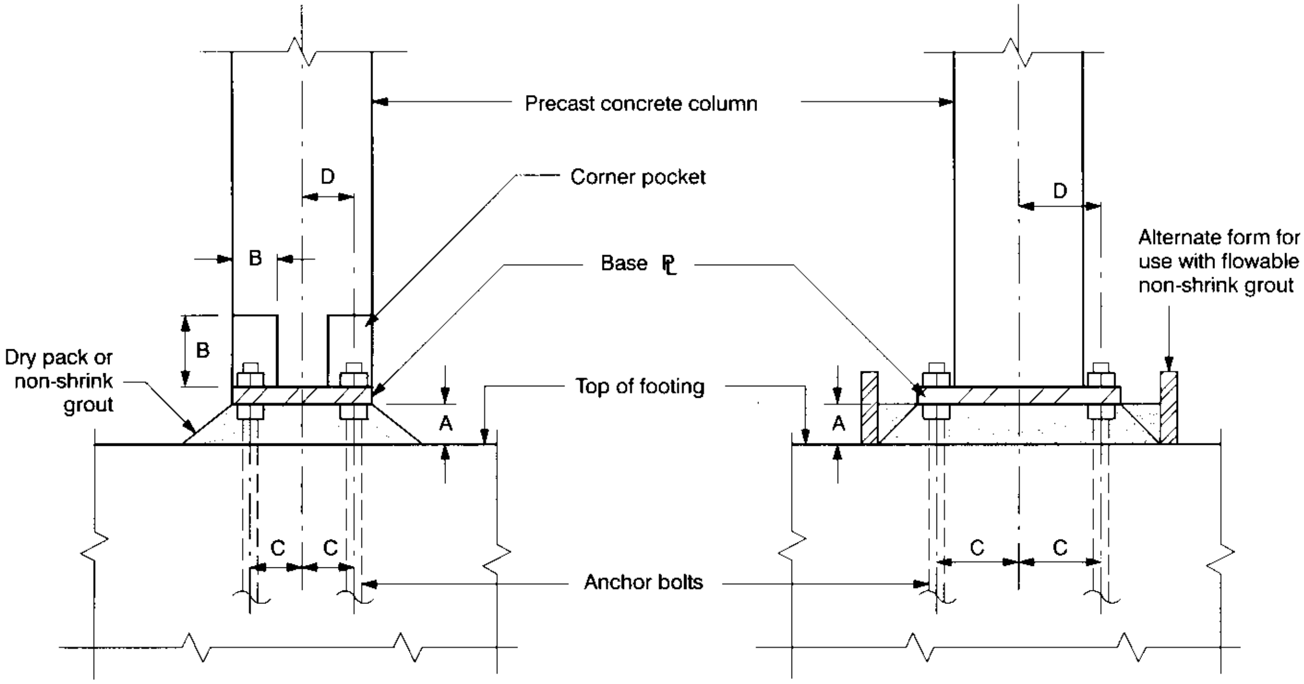
18.0 Typical Tolerance Related Details

The following pages illustrate assemblies and details often used in precast concrete structures. In some instances, precast to precast details are shown. However, many of the details are also applicable to interfacing with other materials.

Detailing suggestions are given with each assembly shown in this section. This section is primarily concerned with tolerance related considerations, therefore structural design and aesthetics, while of great importance, are not generally emphasized.

Note that in all details showing weld plates, anchors and auxiliary reinforcing are not shown to avoid confusion in the graphics. These elements, should be properly designed and included in the actual construction details as appropriate.

Fig 18.1.1 Detailing Suggestions for Column to Footing Connection Using Anchor Bolts



1. Provide clearance "A" to accommodate tolerances required as result of the combination of column length and footing elevation tolerances. This dimension is typically set to accommodate bottom leveling nuts and for proper tamping of dry pack grout.

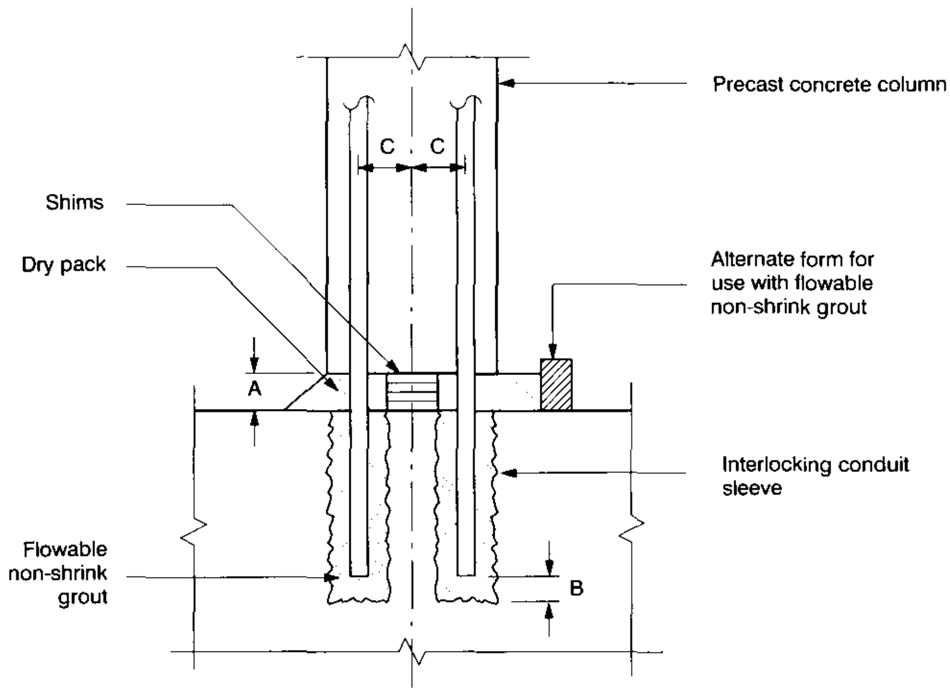
2. Provide pocket dimension "B" large enough for easy operation of a manual or power wrench to tighten anchor bolts to assure contact bearing with the base plate.

3. Control dimension "C" to acceptable levels of tolerance by using templates to set anchor bolts embedded in the footing.

4. Control dimension "D" by using a template which matches the footing anchor bolt template or by providing tighter tolerance on the location and size of the receiving holes in the base plate.

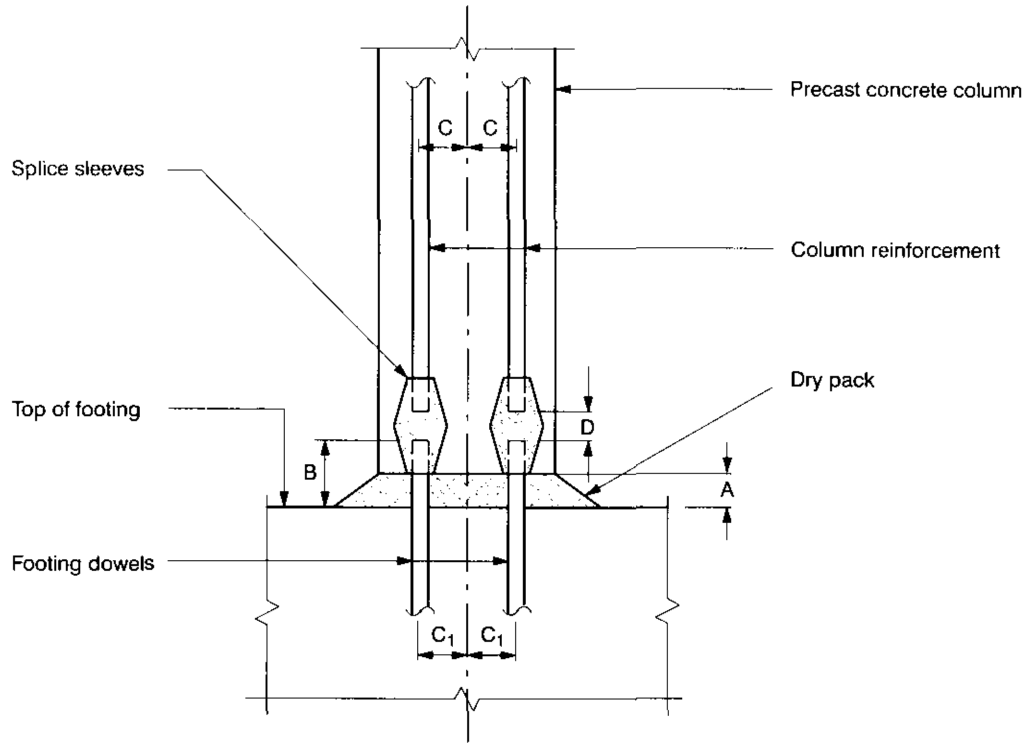
5. Check that minimum specified anchor bolt thread engagement has been achieved. If not, reconsider clearance "A" or increase anchor bolt length above top of footing.

Fig 18.2.1 Detailing Suggestions for Column to Footing Connection Using Footing Sleeves



1. Provide clearance "A" large enough to accommodate tolerances required as result of the combination of column length and footing elevation tolerances.
2. Provide sufficient minimum clearance (dimension "B") to accommodate proper flow of grout.
3. Control dimension "C" by using a template to control the placement of projecting column reinforcement to be embedded in the footing sleeves.
4. For the sleeves in the footing use oversized conduit or corrugated pipe at least two times the diameter of the reinforcing bar bundle to accommodate both the placement tolerances for the footing sleeves and the tolerance of projecting column reinforcing bars.

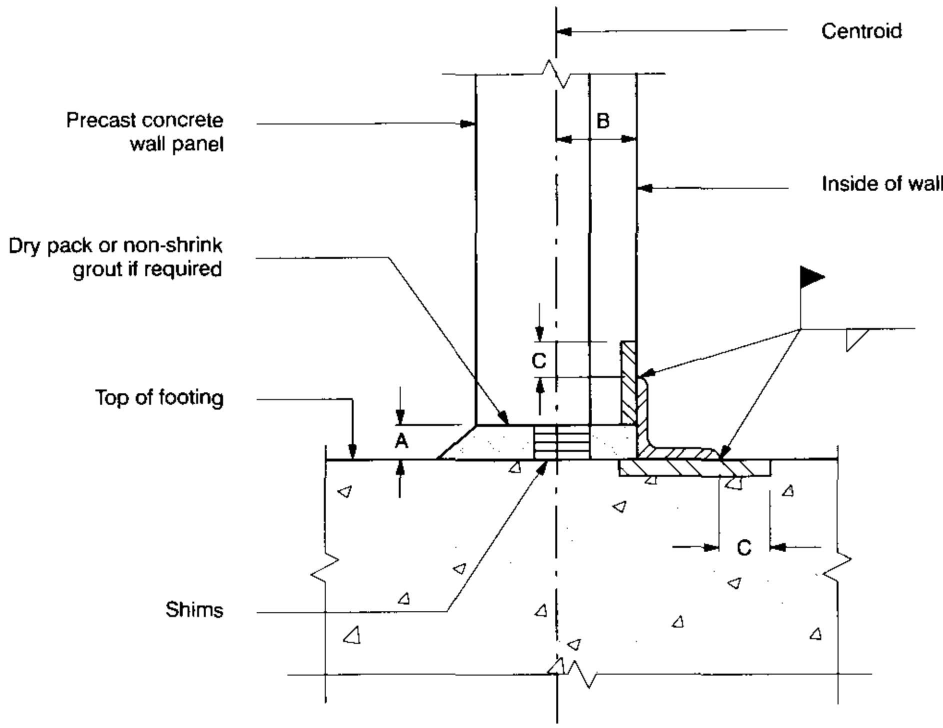
Fig 18.3.1 Detailing Suggestions for Column to Footing Connection Using Splice Sleeves



1. Use matching templates for the location of column reinforcement and splice sleeve placement within the footing to control critical dimensions "C" and "C_1" which should be identical.
2. Provide clearance "A" large enough to accommodate tolerances required as a result of the combination of column length and footing elevation tolerances. Also, this clearance must be adequate to allow access for the proper grouting of the reinforcing bar sleeves.
3. Consult manufacturer of reinforcing bar sleeves for proper dimensions "B" and "D" and for the tolerance on these dimensions.
4. Before executing splice sleeve assemblies always seek installation recommendations from the manufacturer of the reinforcing bar splice sleeve used.

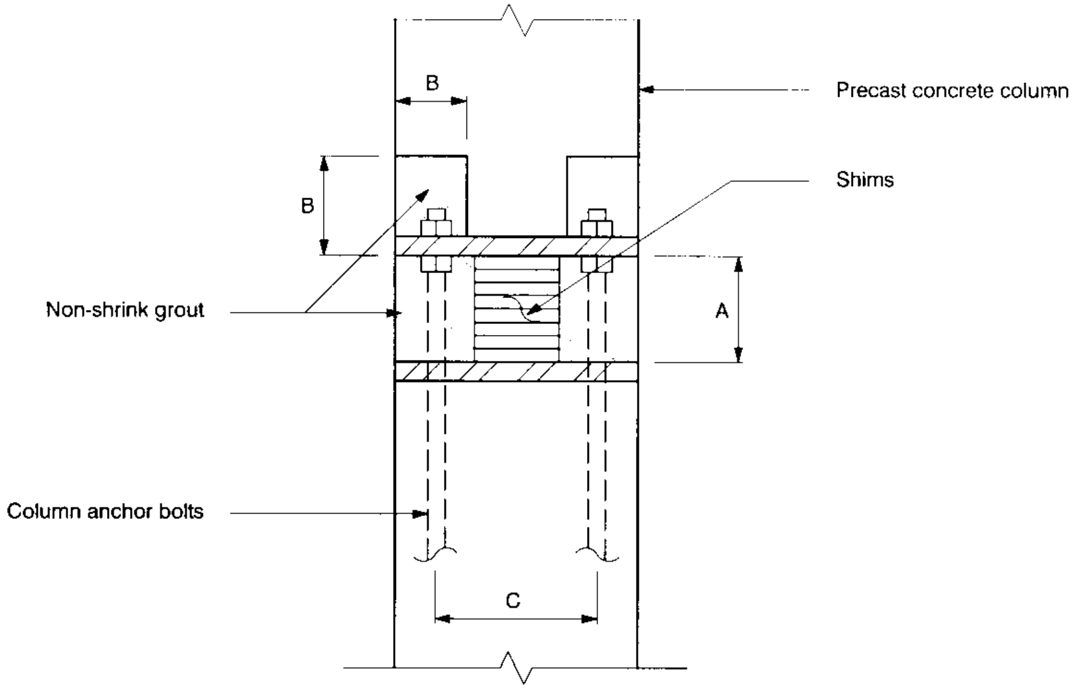
Note: Some producers have reported good success with splice sleeve connections where the sleeve portion of the connection is placed within the footing.

Fig 18.4.1 Detailing Suggestions for Wall Panel to Footing Connection



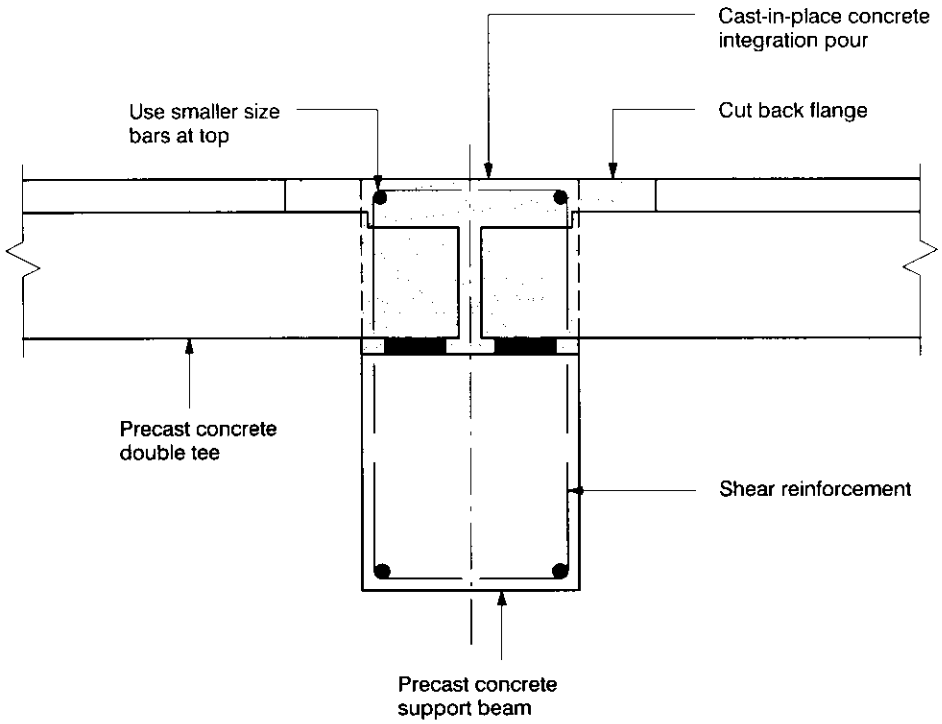
1. Provide clearance "A" to accommodate tolerances as result of the combination of panel length and footing elevation tolerances.
2. Locate erection shims under the the panel centroid (dimension "B") to allow adjustment of wall plumbness.
3. Provide a weld plate size in both wall panel and footing which gives adequate projection "C" to accommodate the tolerance required for plate placement and the combination of panel length and footing elevation tolerances.
4. Depending upon which is the most critical from aesthetic or functional points of view, use either the inside or the outside surface of the wall as an erection control surface. Do not use the wall centerline (centroid) as a control, since tolerances variations of wall depth cause it to be a less useful reference.

Fig 18.5.1 Detailing Suggestion for Column to Column Connection



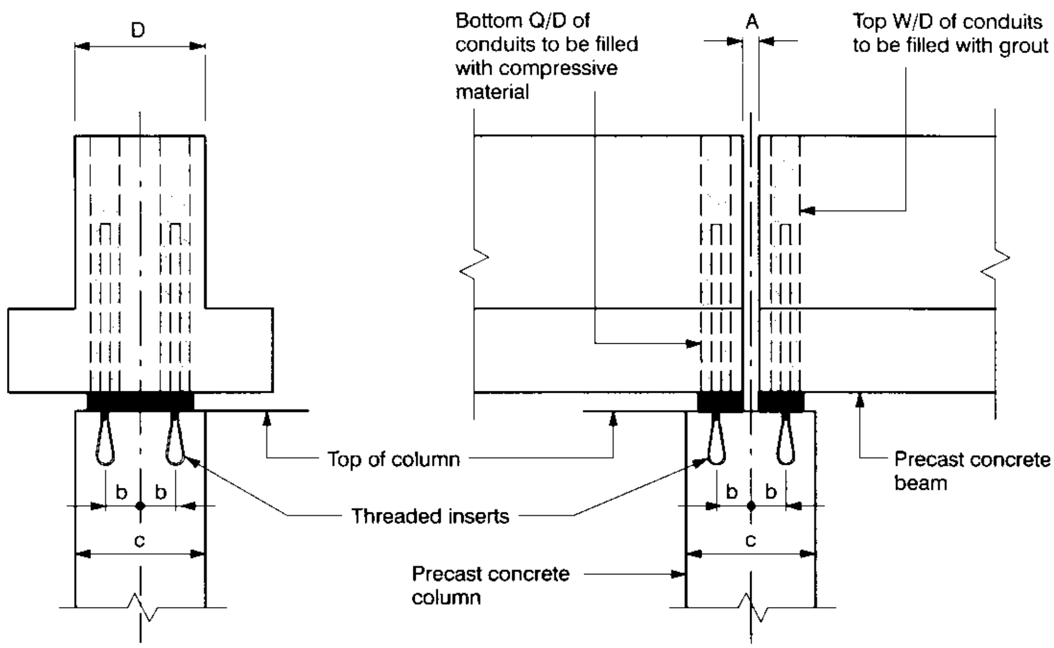
1. Provide adequate clearance "A" to accommodate the tolerances required for column length.
2. Provide pocket dimension "B" large enough for easy operation of manual or power wrench to tighten bolts.
3. Control dimension "C" by using template for setting anchor bolts in the lower column.
4. Use a grout thickness adequate to accommodate leveling nuts.

Fig 18.6.1 Detailing Suggestion for Composite Beam Supporting Double Tees



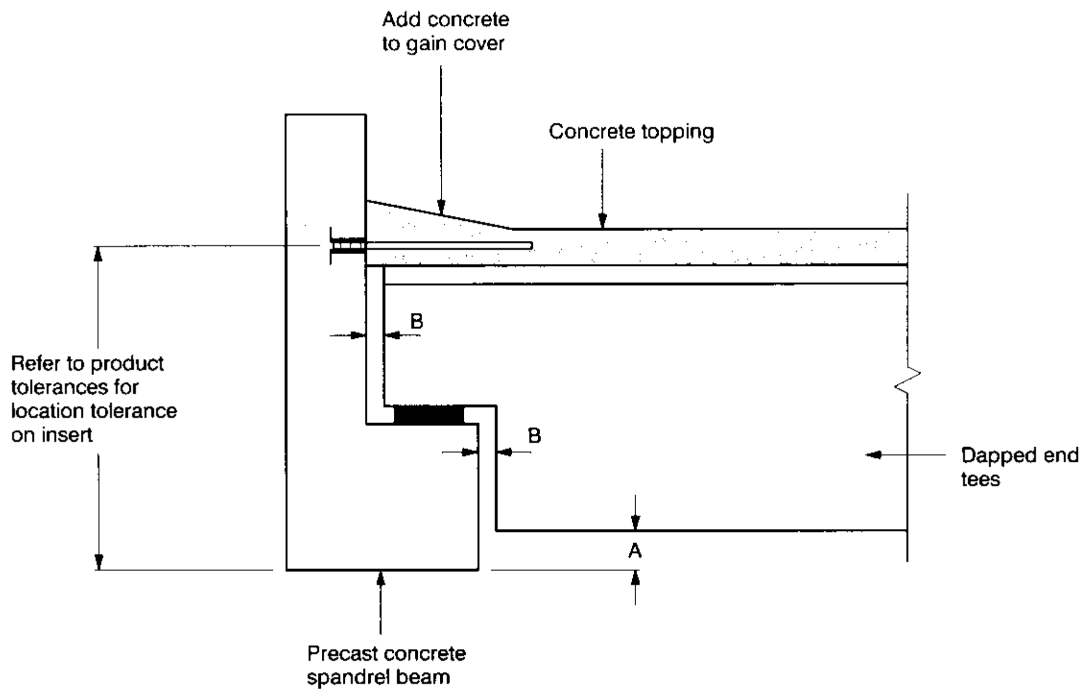
1. In order to avoid conflict between embedded shear reinforcement protruding from the support beam and tee stems, consider the layout of the double tee stems when determining the spacing of the beam shear reinforcement.
2. Provide adequate amount of cutback of the tee flange to allow forming of the composite portion of the beam while avoiding tight form tolerance requirements.
3. Use more small bars rather than fewer large bars as top steel, as these bars must often thread through the limited clearance between the tops of the tee stems and the horizontal portion of the embedded shear reinforcement extending from the support beam.

Fig 18.7.1 Detailing Suggestion for Beam to Column Connection



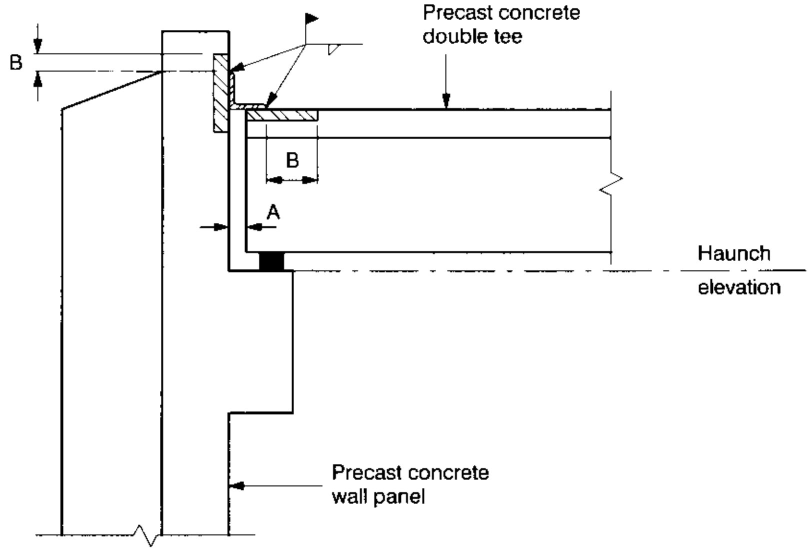
1. Use embedded conduits with oversized diameter to accommodate tolerances required for insert placement in the column.
2. Control dimension "B" by using a jig or template to position the inserts in the column.
3. Provide clearance "A" to accommodate the tolerances required for the combination of beam length and beam end squareness tolerances for both interfacing beams.
4. Prevent rotation of the beam due to unbalanced loads during erection.
5. To simplify erection, use top of column as a primary control surface. Vary grout pad thickness at the bottom of the column as required to accommodate tolerances in column length.

Fig 18.8.1 Detailing Suggestion for Exterior Spandrel Beam to Double Tee Connection



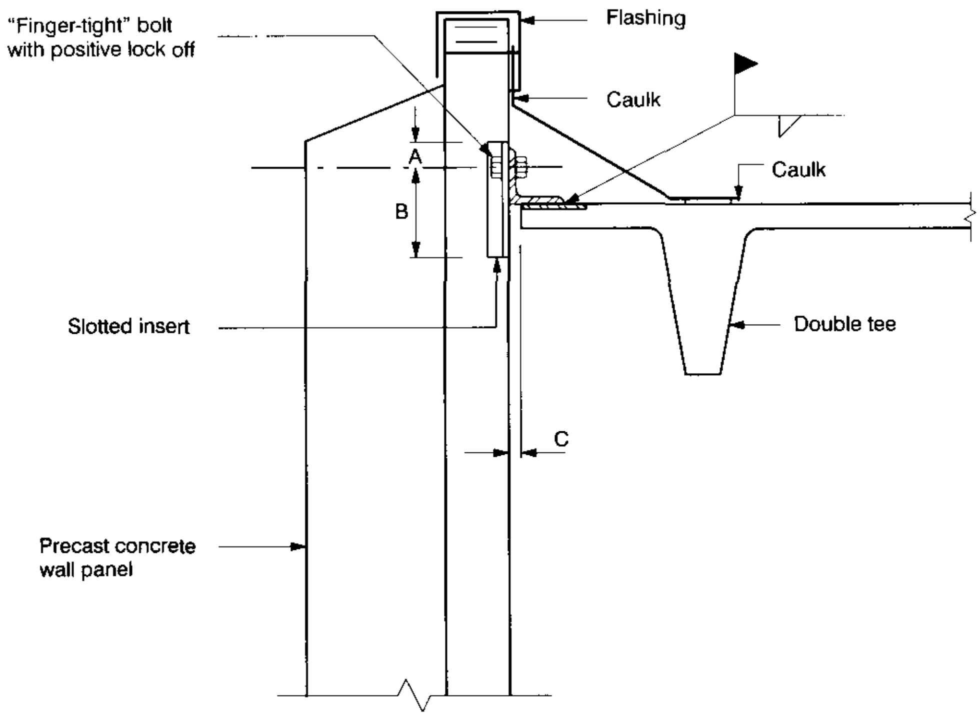
1. Allow adequate offset "A" in order to accommodate tolerances resulting from the combination of the beam depth and double tee bearing elevation tolerances. This is to ensure that the bottom of the tee stems will not be lower than the bottom of the spandrel beam. If this occurs, the random bottom line of the tee stems referenced from the soffit of the spandrel will create an unwanted visual effect when viewed from the exterior. A dimension "A" = 1 in. [25 mm] usually provides a satisfactory condition.
2. This same type of offset dimension "A" should be used when interfacing with a suspended ceiling.
3. Provide adequate clearance "B" to accommodate the combination of the following tolerances: beam length, beam end squareness in elevation and beam flange squareness in plan.
4. Consider locally thickening concrete topping adjacent to spandrel to accommodate insert placement tolerances and assure adequate concrete cover over bars threaded into insert in spandrel. This detail can also be beneficial to drainage in this area.

Fig 18.9.1 Detailing Suggestions for Load Bearing Wall Panel to Tee Connection



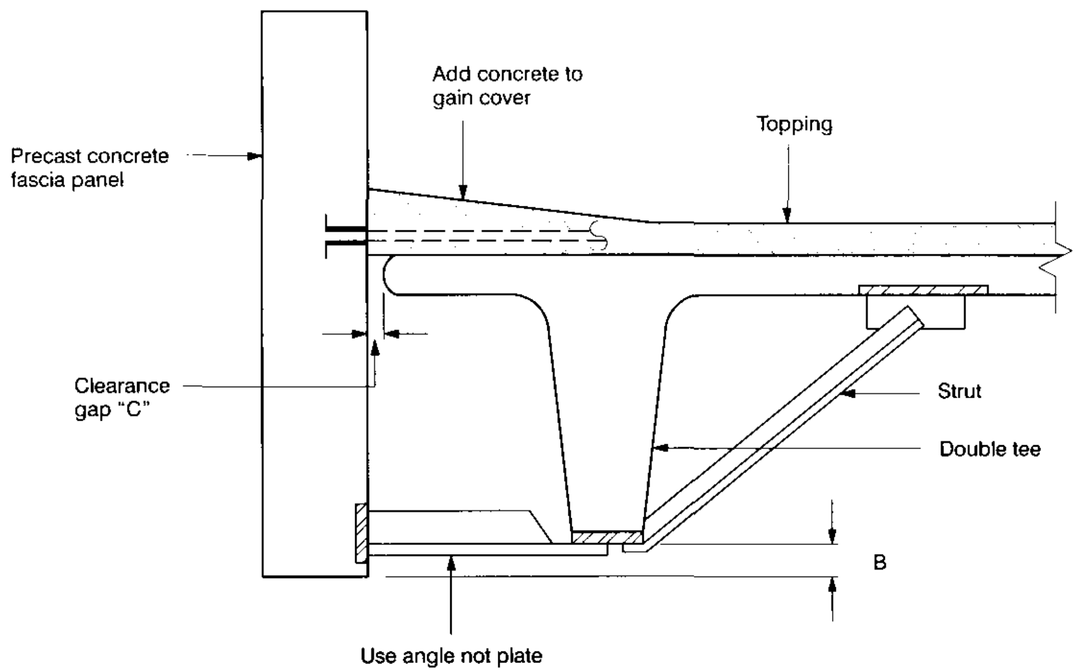
1. To create a visually pleasing line at the top of the panel and ease the erection of the roof elements, the haunch elevation of precast concrete wall panel should be set as a primary control surface. Tolerances for wall length and footing elevation should be absorbed at the panel bottom connection by varying the grout pad thickness.
2. Provide adequate clearance "A" to accommodate the following tolerances: beam length, beam end squareness in elevation and beam flange squareness in plan.
3. Provide weld plate in tee flange and in the wall panel of sufficient size to provide adequate projection "B" beyond the clip angle to accommodate tolerances in beam length, beam depth, and weld plate placement while allowing space for proper welding.

Fig 18.10.1 Wall Panel to Tee Flange Connection



1. Provide adequate insert slot clearance "A" to accommodate anticipated camber growth of tee, including the effects of camber tolerances.
2. Provide adequate insert slot clearance "B" to accommodate anticipated deflection of tee under load, long term sag and to accommodate differential elevations at the top of wall panels.
4. Do not tighten bolts connecting tee flange to wall panel more than "finger tight" per the AISC recommended practice, since tightening the bolts can result in overloading the connection when the double tee deflects.
5. Provide a positive lock-off of finger tight bolt from tee angle to slotted insert so that it will not work loose during the life of the structure. Provide adequate clearance gap "C" to accommodate combination of tee erection tolerances and local smoothness tolerance of the tee flange edge.

Fig. 18.11.1 Fascia Beam to Tee Connection



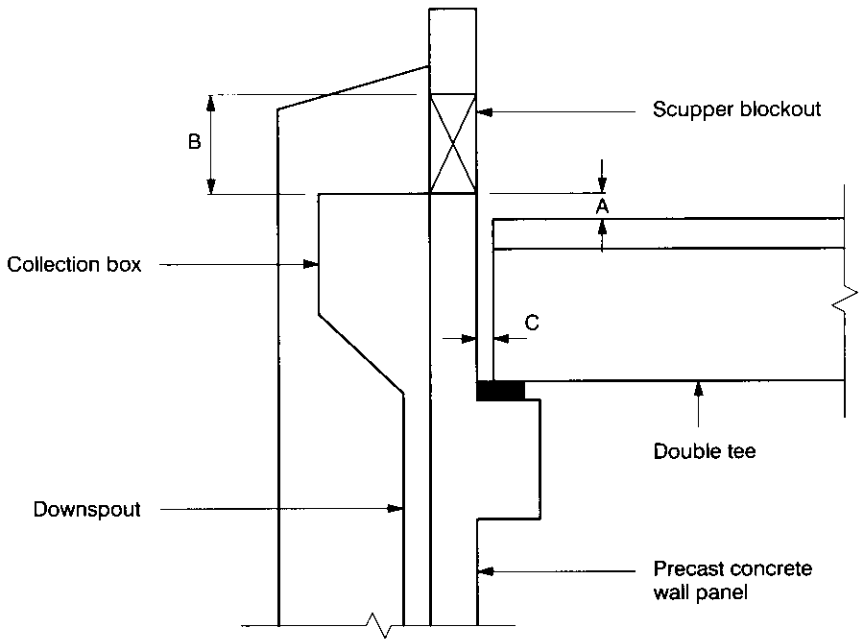
1. Consider locally thickening concrete topping adjacent to fascia panel to accommodate insert placement tolerances and assure concrete cover over bars threaded into insert in fascia panel. This detail can also be beneficial to drainage in this area.

2. Consider the camber of the the tee when determining the location of the inserts in the fascia panels. Consideration should be given to using a slotted connection here.

3. Provide adequate clearance gap "C" to accommodate combination of tee erection tolerances and local smoothness tolerance of flange edge.

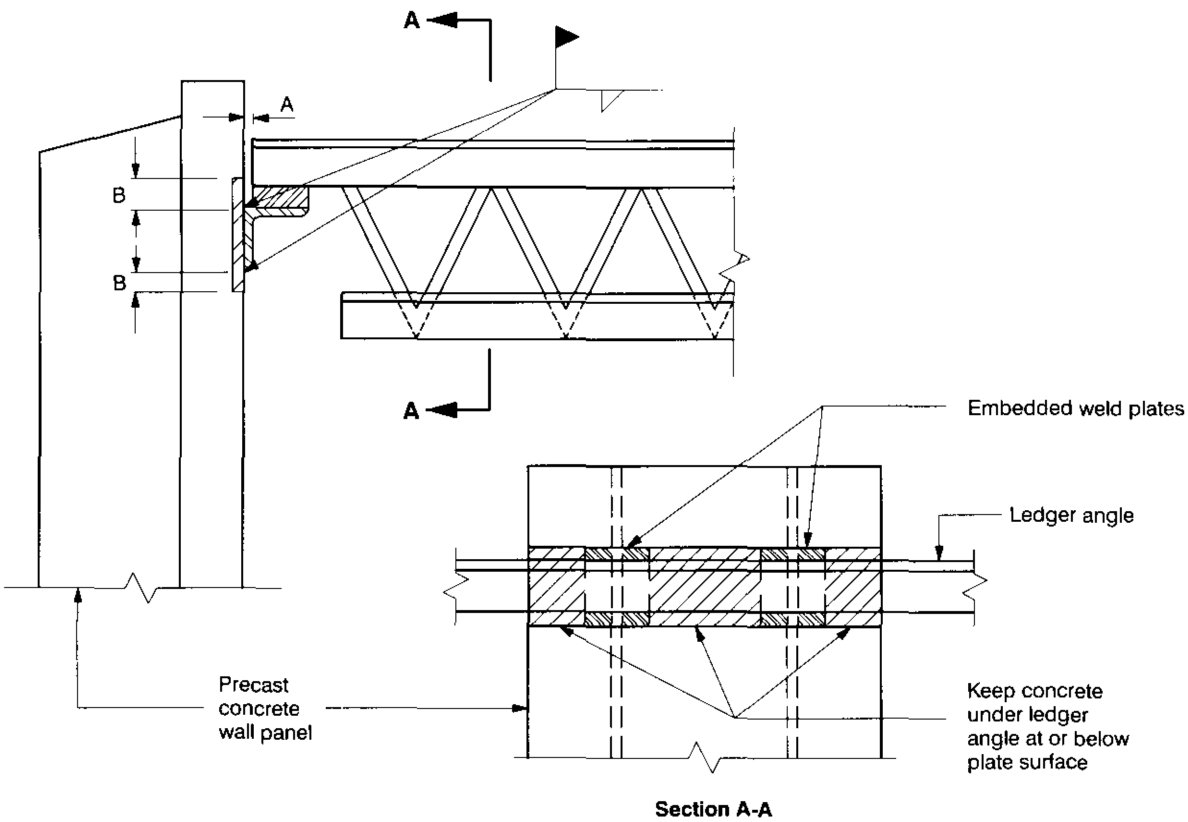
4. Allow offset "B" in order to accommodate tolerances resulting from the combination of the beam depth and double tee bearing elevation tolerances, and beam camber. This is to ensure that the bottom of the tee stems will not be lower than the bottom of the soffit of the fascia panel. If this occurs, the random bottom line of the tee stems referenced from the soffit of the facial panel will create an unwanted visual effect when viewed from the the exterior. A dimension "B" = 3 in. [75 mm] should be considered and checked for adequacy.

Fig. 18.12.1 Scupper Blockout in Wall Panels



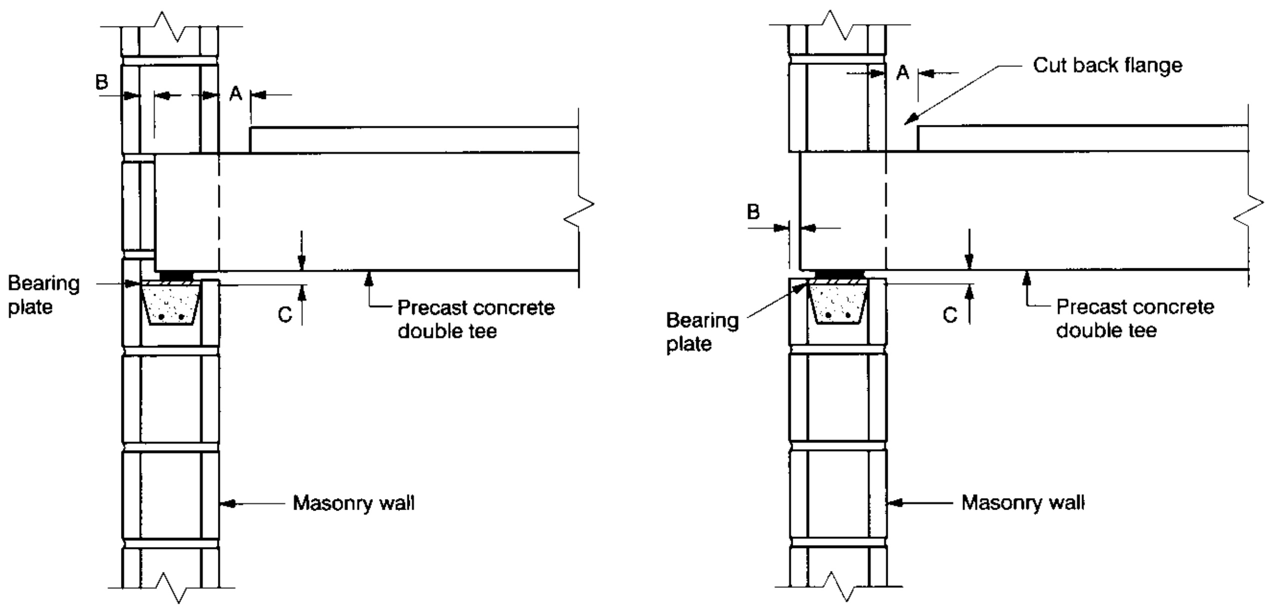
1. Provide clearance "A" to accommodate tolerances resulting from a combination of tee depth, insulation thickness, and roofing material thickness tolerances. When locating scuppers in wall panels oriented parallel to direction of beam span, consider the effects of beam deflection when determining scupper elevation.
2. Provide a scupper dimension of "B" 6 in. by 6 in. [150 mm by 150 mm] minimum to minimize the potential for plugging these openings.
3. Place scuppers away from panel joints to keep water from running into these areas.
4. Top of water collection box should be set at the same elevation or slightly lower than the bottom of the scupper to assure that tolerances allow positive drainage of the roof under all conditions.
5. Provide adequate clearance "C" to accommodate the following tolerances: beam length, beam end squareness in elevation and beam flange squareness in plan.

Fig. 18.13.1 Wall Panel to Bar Joist Connection



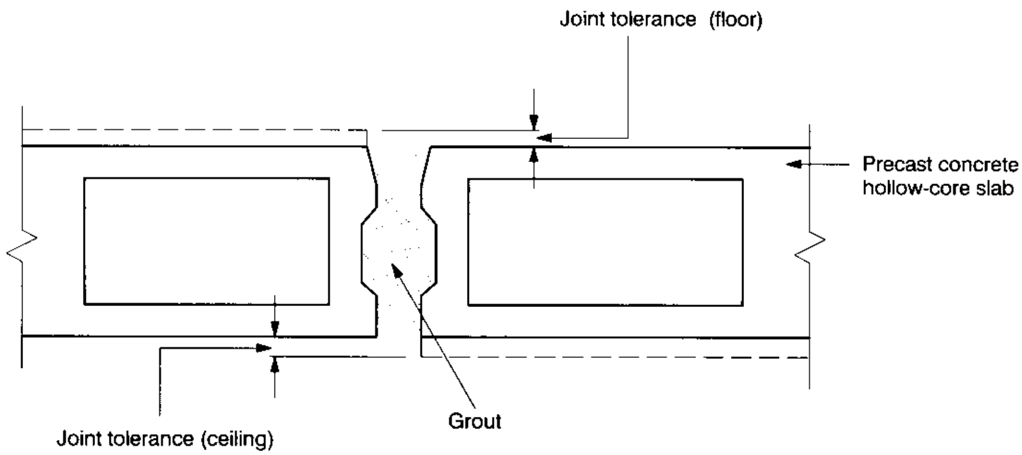
1. Provide adequate weld plates of sufficient size as needed to accommodate the combined effects of erection tolerances for the wall panel and embedded weld plate location and still provide adequate plate projection "B" to allow proper welding.
2. Provide adequate clearance "A" to accommodate the following tolerances: bar joist span and the panel plumbness erection tolerance and plan placement tolerance for the wall panel.
3. On the element production drawings, note that the concrete adjacent to the weld plates for the ledger angle (cross hatched area above) should be held to a tolerance of +0 in. to −¼ [−6 mm] relative to the surface plane of the embedded weld plates, to prevent interference problems when the continuous ledger angle is attached in the field. Alternatively, the embedment plate can be raised above the surface of the concrete.

Fig. 18.14.1 Masonry Wall to Tee Connection



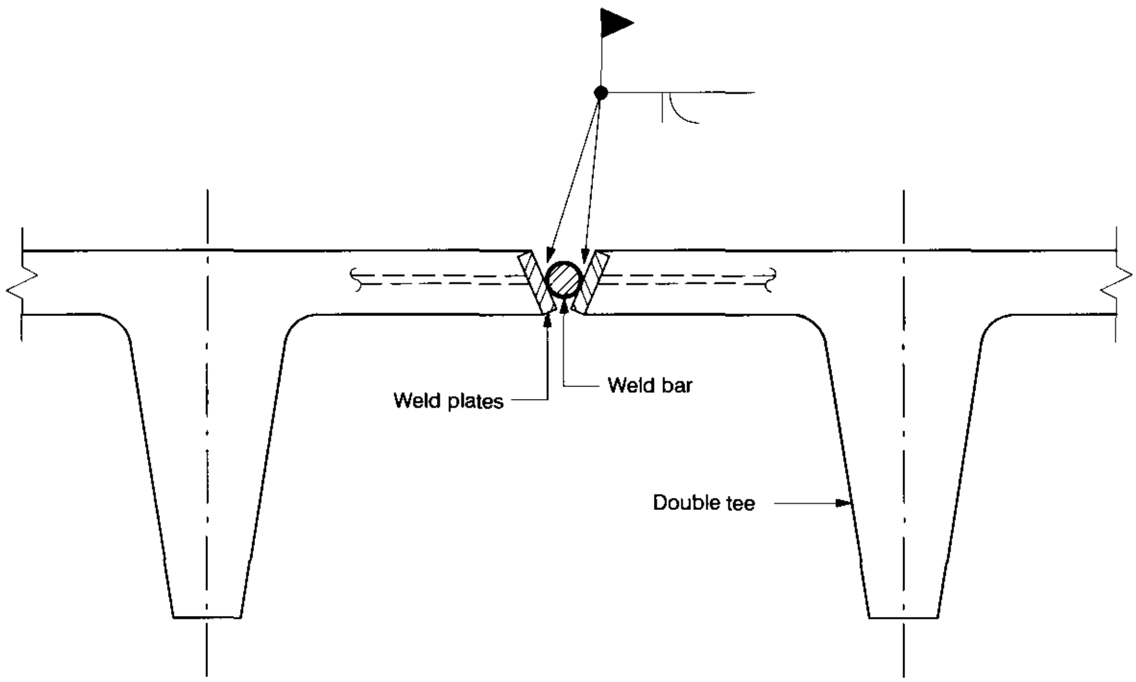
1. Provide adequate clearance "A" to accommodate tolerances required for the vertical alignment of masonry and tee length tolerance. Dimension "A" should be based on ease of erection, forming, and fire resistance considerations.
2. Set beam length such that there will always be a positive clearance or set back "B" from the face of the masonry wall when beam length, beam end skew, and masonry wall construction tolerances are considered.
3. Locate tee support bearing plates to assure that beam soffit does not contact masonry shell at "C" when the combined effects of all tolerances and beam deflection and end rotation under load are considered.

Fig 18.15.1 Typical Hollow-core Floor Joints



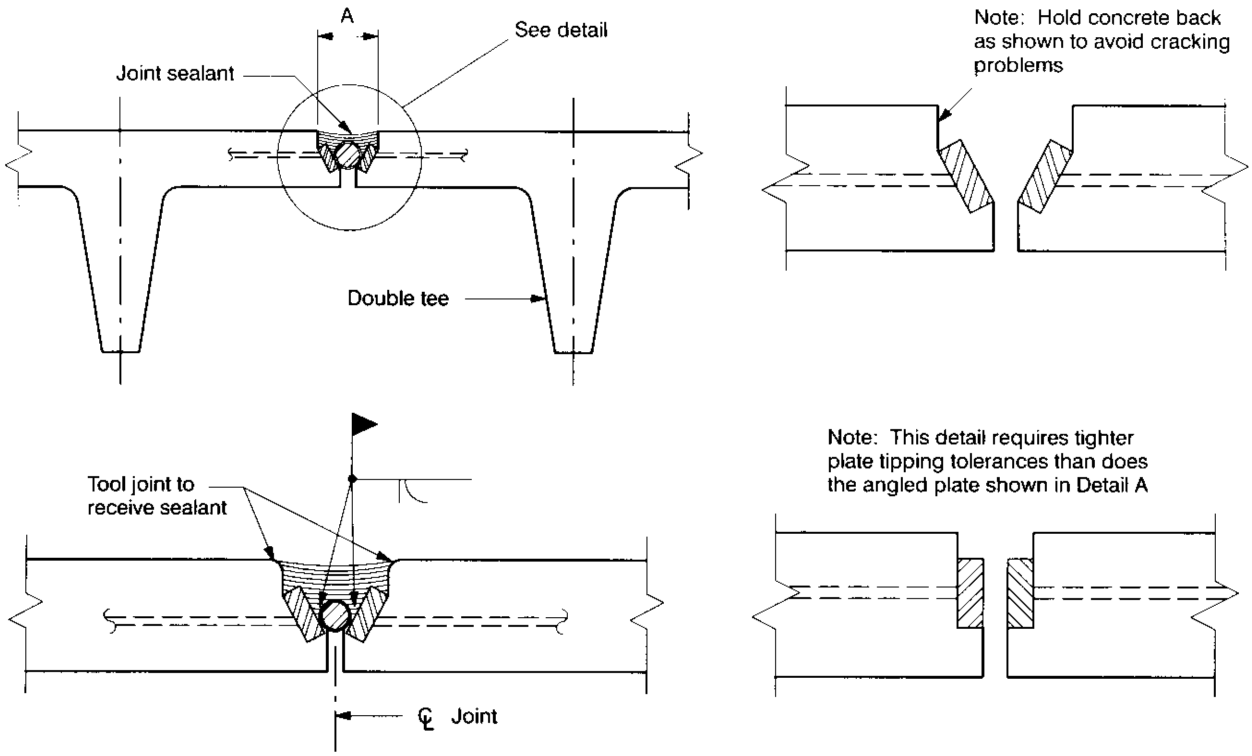
1. Use leveling devices to level the bottom edges of hollow core slabs at the joint location to minimize the effects of any differential camber when the ceiling is to be exposed or planned to receive direct acoustical treatment on the ceiling.
2. Do not release the leveling devices used to level the joints until the grout has attained adequate strength to hold the planks in the leveled position relative to one another.
3. Consider use of joint fairing materials for direct carpet applications.

Fig. 18.16.1 Tee Flange to Flange Connection



1. Provide flange connection weld plates at an angle as shown above to accommodate tolerances required for plate placement and allow the placement of a proper flare weld. Plate tipping tolerances are less critical for flange connector plates angled as shown compared to the more stringent tipping tolerances required for proper welding connector weld plates oriented with their surfaces parallel to the vertical centerline of the flange to flange joint (see Fig. 18.17.1, Detail B).
2. For the detail shown above use tipping tolerance for flange to flange weld plates of ±⅛ in. [±3 mm] in both directions.
3. Provide weld bar size that is larger than the nominal double tee joint to assure it fills the joint under the full range of expected tolerance variations.

Fig. 18.17.1 Typical Pretopped Double Tee Joints for Parking Structures



Detail A **Detail B**

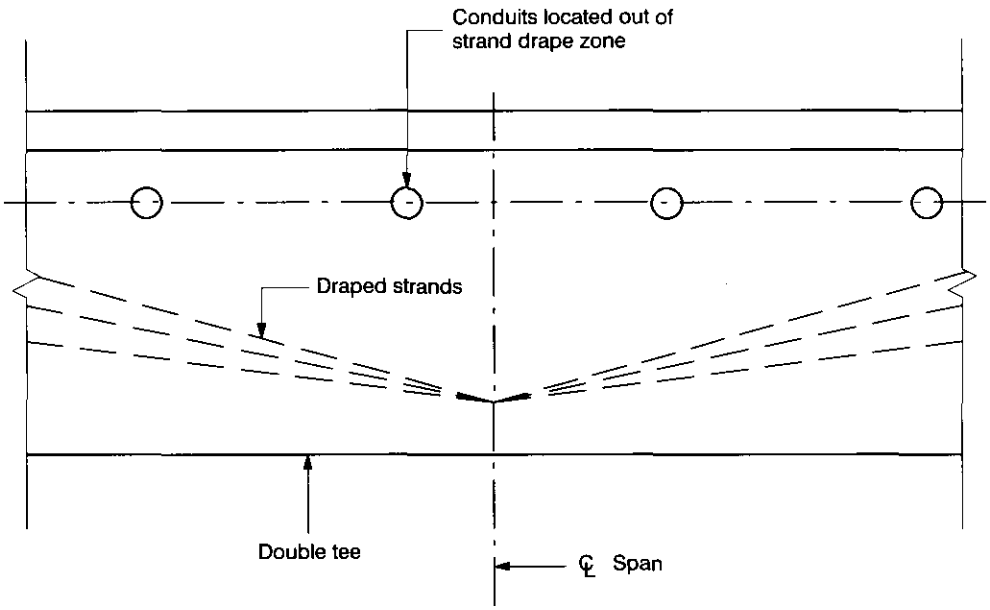
1. Tool edges of tee flange at weld plate locations as shown to assure that there is not a thin section of concrete directly above the weld plate that will be prone to cracking because of thermal expansion of the plate during welding. This can result in failure of the sealant system.

2. Tool edges of tees to provide the proper shape to the joint to accept the sealant specified for the project. Consult sealant manufacturer for recommendations when defining the edge tooling to produce the sealant cross section of the joint to be sealed.

3. Provide adequate clearance gap "A" to accommodate tee flange edge smoothness tolerances and still provide the minimum joint width necessary for proper sealing. Tolerance for alignment and smoothness of flange edges in pre-topped systems may require more stringent special project tolerances to accommodate some sealant systems. Consult sealant manufacturer recommendations for sealant joint geometric requirements and tolerances.

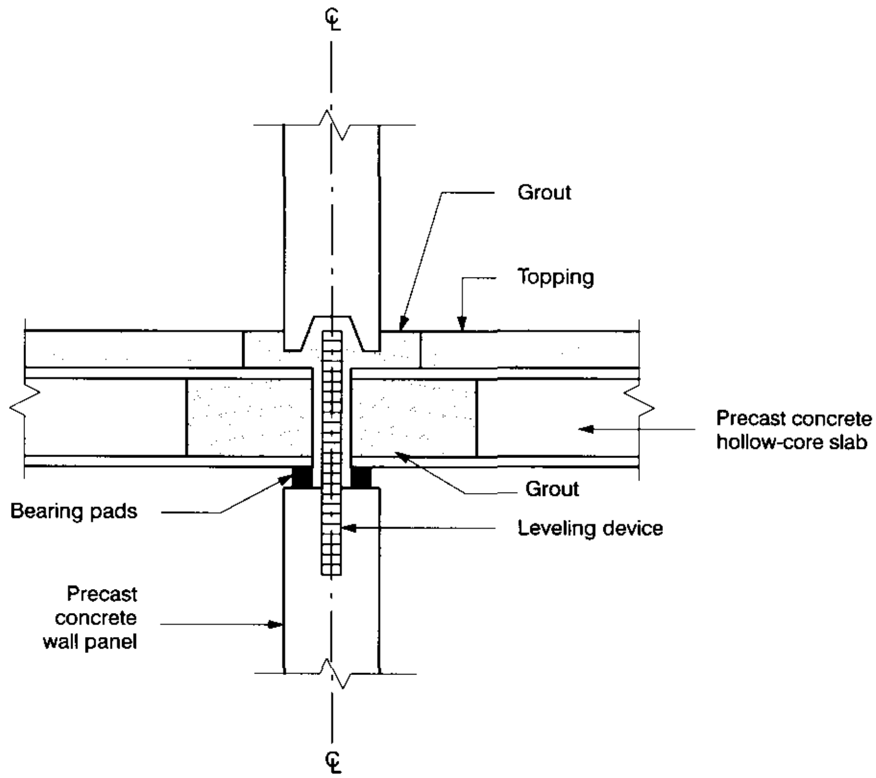
4. Do not weld flange connectors until the tees are adjusted in such a manner that acceptable matching of the tee flange top surfaces has been attained.

Fig. 18.18.1 Conduits Embedded in Double Tee Stems



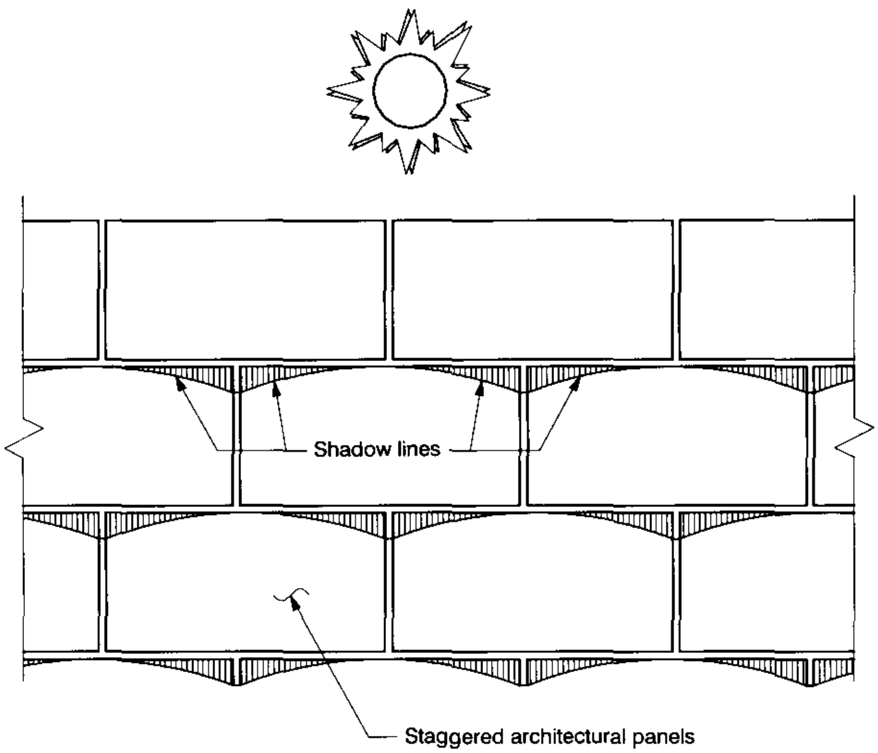
1. Locate embedded conduits above the level of the top strands or establish special project tolerances for lower conduit placement to accommodate the interface of the conduit with the draped strands.
2. Consider the tolerances associated with the placement of shear reinforcement when locating or setting location tolerances for conduits embedded in tee stems. If functionally acceptable, conduit tolerances should allow for relocation of embedded conduits by one conduit diameter plus one shear reinforcing bar diameter to avoid relocating shear steel to accommodate conduit placement.
3. Provide positive support to embedded conduits during casting to assure that placement tolerances are attained.
4. If conduit centerline alignment tolerances are important for embedded conduit in tee stems this should be specified as a special project tolerance.

Fig. 18.19.1 Typical Bearing Wall System Joint



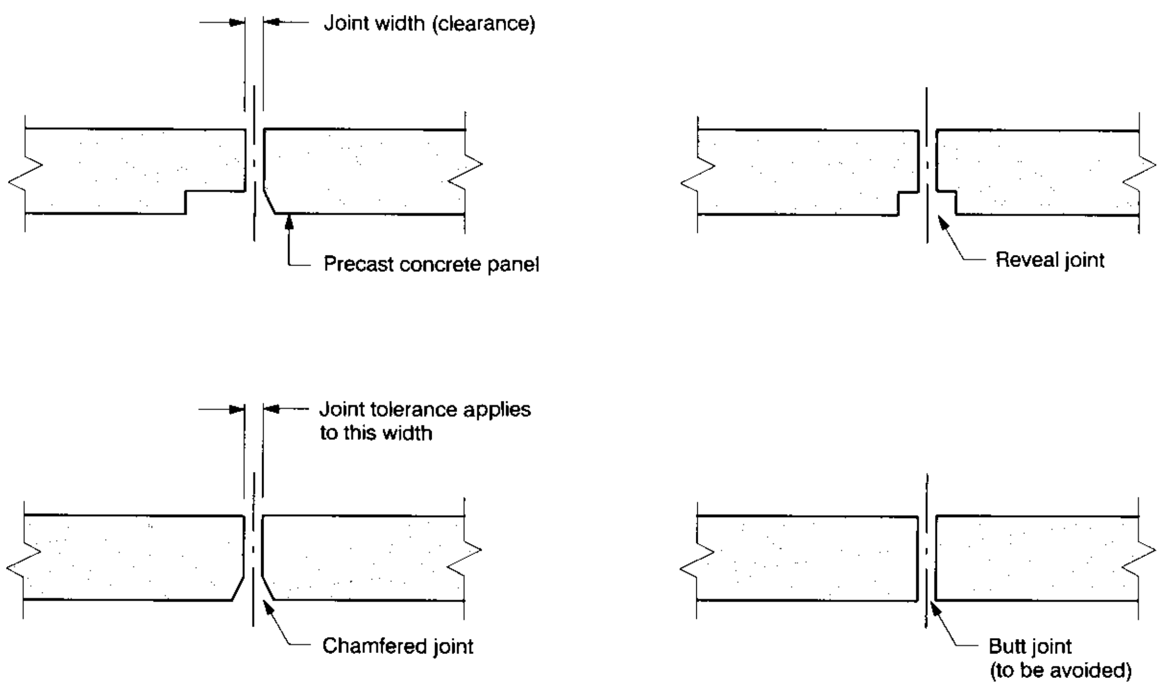
1. Require tighter tolerances than standard for the slab length due to the very small bearing width usually available in the panel framing system for such structures.
2. Provide leveling devices which allow adjustment for wall plumbness at each floor to assure that the tolerances required for vertical plumbness are not exceeded. The main reason for careful attention to wall plumbness tolerances is the availability of only a small bearing area.

Fig. 18.20.1 Staggered Architectural Wall Panels



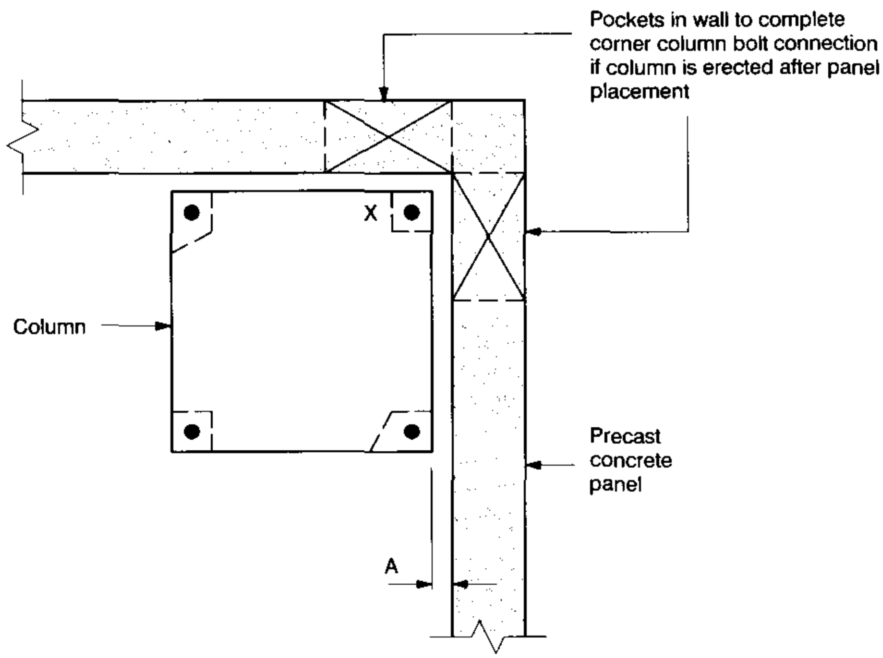
1. Check design of panels to assure that excessive thermal bowing will not be a problem. As shown in the drawing bowing of staggered panels can result in unwanted shadow lines at certain times of the day.
2. Consider joint configurations and joint tolerances to minimize unwanted shadow effects.

Fig. 18.21.1 Typical Architectural Panel Joints



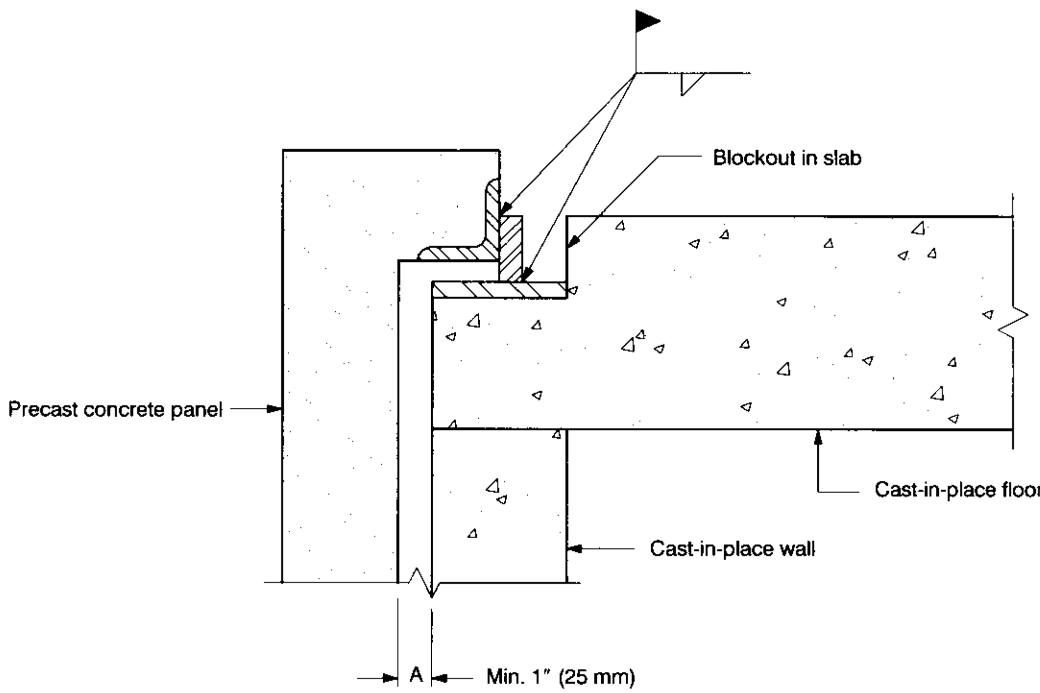
1. Specify either a chamfered or reveal joint, since these types of joints can accommodate the tolerance required for panel thickness and the shadows formed within these joints will minimize any adverse effects on the aesthetic appearance of the joint system.
2. As a general rule, the minimum design joint width should not be less than ¾ in. [19 mm]. When panel production and erection tolerances are applied to joints which are designed narrower than this, the joints may become too narrow to allow effective caulking.
3. Avoid the use of butt joints, as the tolerance variations in panel thickness may result in the formation of unwanted shadow lines directly over the panels rather than within the joint area. This may impair the aesthetic appearance of the panel assembly.

Fig. 18.22.1 Precast Column Near a Previously Constructed Wall Corner



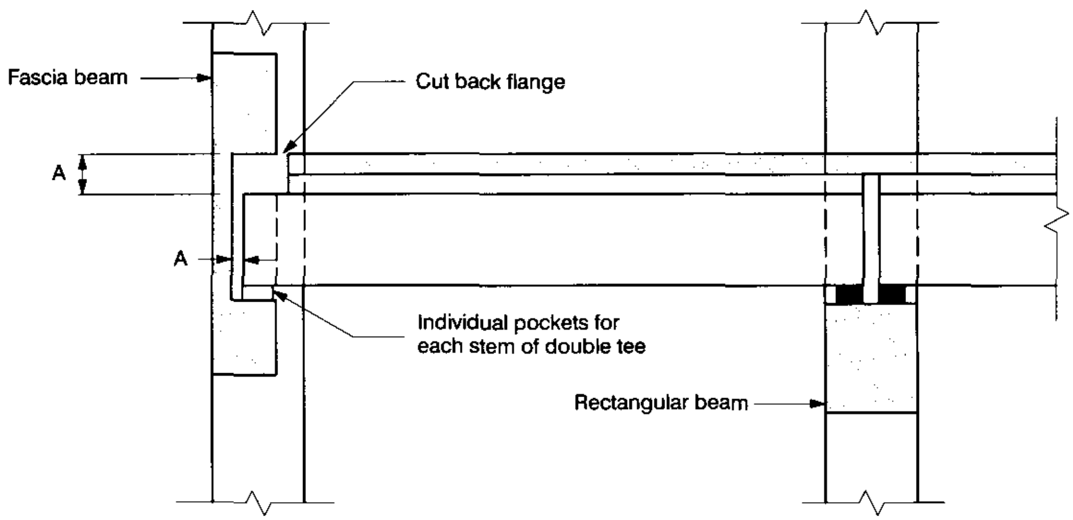
1. Provide pockets in the walls at either of the locations as shown above. Pockets should be sized and oriented to allow execution of bolted connections marked "X". Alternatively provide adequate clearance "A" to provide wrench access necessary to complete the connection at "X".
2. Unless adequate access is provided for bolt tightening, it is likely that the bolted connection "X" will not be completed.

Fig 18.23.1 Fascia Panel Connection to Cast-in-Place Slab



1. Provide a minimum of 1 in. [25 mm] clearance "A" to accommodate the tolerances from a combination of the panel thickness and the edge location of the cast-in-place slab and wall. If the minimum 1 in. [25 mm] clearance is used, care must be taken with dimensioning and detailing to assure that the cast-in-place and precast tolerances allow proper fit up without the requirement for rework.
2. Plan slab reinforcement location so that slab reinforcement is located away from the blockout location needed to complete the weld. Typically the reinforcing should be located adjacent to or below the bearing plate at this location.
3. Do not support the precast fascia panel at more than two points. If the panel is supported at more than two points the relative movement of the floor slab with respect to the panel may redistribute panel bearing loads in an adverse manner.

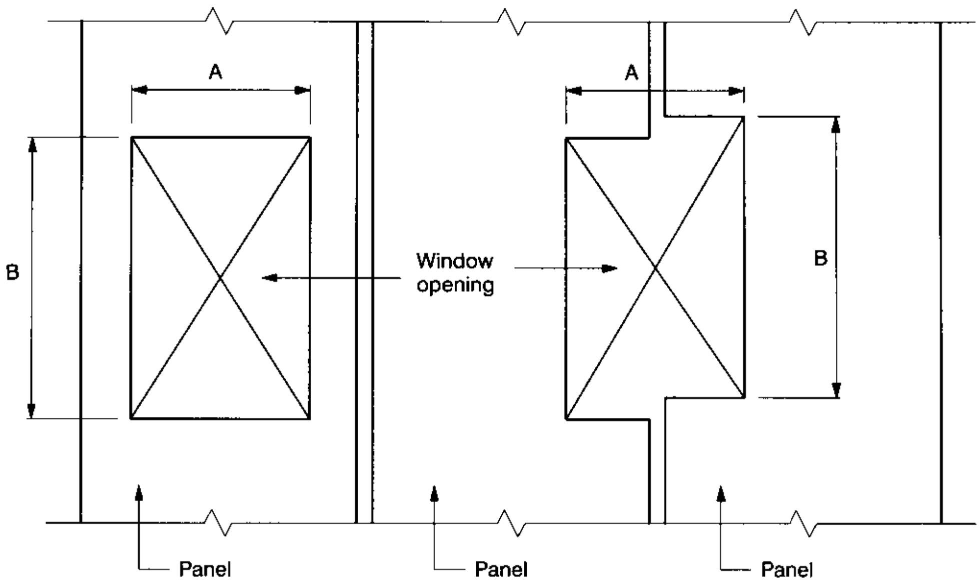
Fig. 18.24.1 Typical Fascia Beam to Tee Connection



1. Allow adequate clearance "A" at the fascia end of the double tee to assure that the tee stems can be easily slid into the pockets provided in the fascia beam.

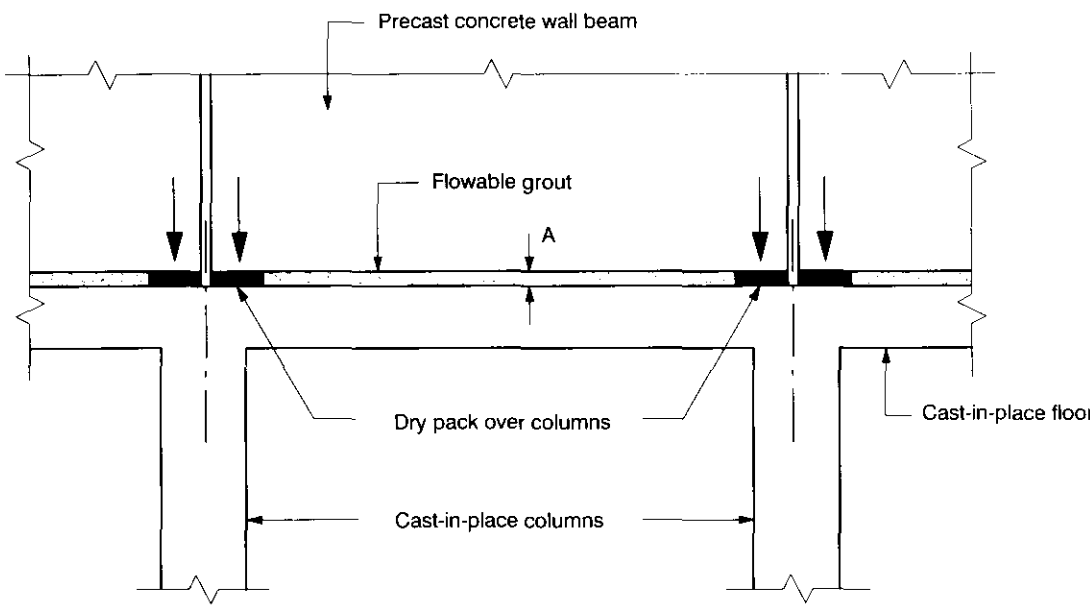
2. Provide a sufficiently wide cut back of the double tee flange to assure that the tee flanges have adequate clearance from the inside surface of the fascia beam. The clearance needs to be set sufficiently large so that the tee's flange does not contact the fascia beam when the tee is slid into the pockets at an angle as is required for erection. The maximum dimension of the cut back clearance should consider the requirements for erection, ease of forming for the cast-in-place floor, and fire resistance considerations.

Fig. 18.25.1 Window Openings in Wall Panels



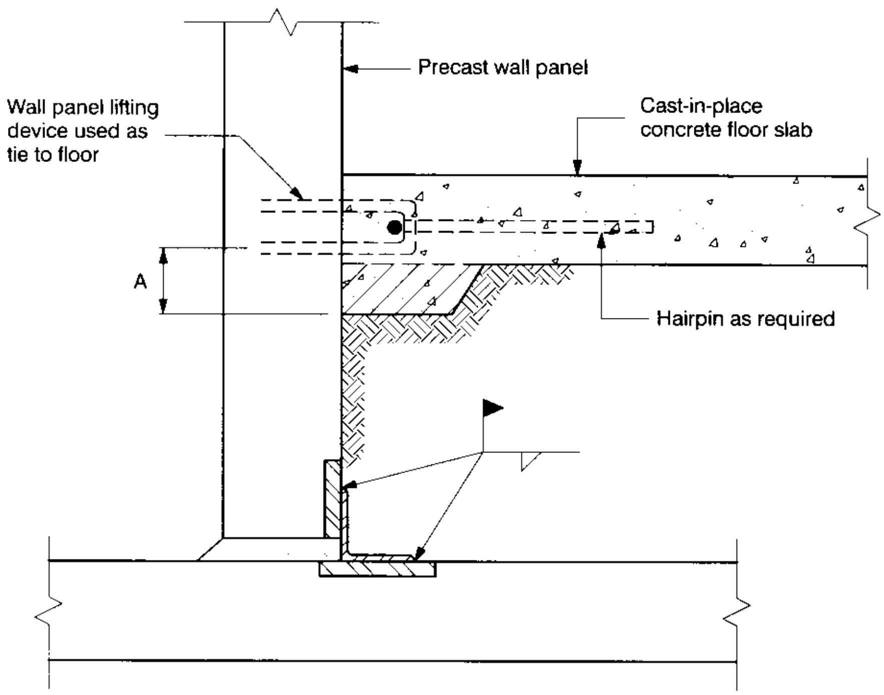
1. Consider the tolerance variations in window width and the minimum required caulking width between the window jambs and the wall panel to determine blockout dimension "A" and the tolerance on the "A" dimension.
2. Consider the tolerance variations in window height and the minimum required caulking width between the window heads and the wall panel to determine blockout dimension "B" and the tolerance on the "B" dimension.
3. Avoid locating window blockouts across a wall panel joint (see above). This introduces the erection tolerances for panel location and plumbness combined with the tolerance for panel width and joint width into the interfacing requirements for the window system. This is much more difficult to successfully execute than the window blockout which is wholly contained with a single panel.

Fig. 18.26.1 Precast Concrete Wall Beam to Column Connection



1. Provide adequate clearance "A" to accommodate cast-in-place concrete floor tolerance and assure that panel loads are transferred at column points only as shown above. This is necessary to avoid unintended loading of the floor slab and eccentric loading of the supporting columns.
2. Do not use flowable grout at panel load transfer points over the columns unless special provisions are made to assure complete grouting and positive load transfer.

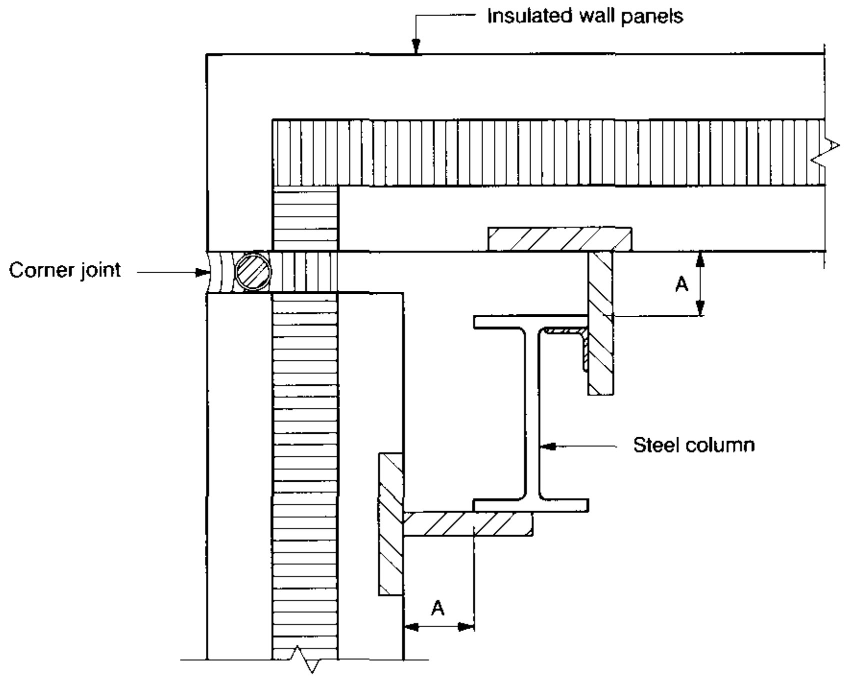
Fig. 18.27.1 Slab on Grade Connection to Precast Wall



1. When panel lifting device embedments are used as a tie to the floor, use a placement tolerance of ±½ in. [±13 mm] rather than the larger standard PCI tolerance given for embedded lifting devices when they are only used for lifting.

2. Use added concrete in the floor as shown by the crosshatched area to accommodate tolerances required to place lifting devices as well as to provide adequate concrete cover "A".

Fig. 18.28.1 Insulated Slender Wall Panels—Corner Detail



1. Consider the potential for opening of the corner joint as result of thermal bowing of these adjacent panels in different directions. Assure that any calculated joint opening does not exceed the motion capabilities of the specified joint sealant and joint sealant detail.

2. Provide a corner connection as shown above to resist thermal forces and prevent opening of the corner joint where the calculated panel joint movement exceeds the motion capability of the specified joint sealant detail.

3. Allow adequate clearance "A" between the columns and the inside face of the panels so that the tolerances required for the placement of the embedded hardware, tolerances for erection of the panels and the completion of the connection welding can be easily accommodated.

19.0 Examples of Tolerance Detailing Related Calculations

A detailed numerical approach to designing details for tolerances is illustrated here. Examples illustrating the consequences of certain tolerance conditions shown. These examples only address tolerance related issues and do not represent a complete consideration of all of the elements which must be considered in a comprehensive design of connections.

19.1 Clip Angle for Lateral Restraint

If all the dimensions of the connection are at their basic values as shown in Fig. 19.1.1(a) then:

P_u = 2 kips [8.9 kN]
e = 2.5 in. [62 mm]
F_y = 36 ksi [248 Mpa]
Angle length = 6 in. [152 mm]
Required angle thickness = ⅜ in. [9 mm]

However, a vertical slot, as shown in Fig. 19.1.1(b), is needed to allow for the following tolerances:

1. Panel erected 0.25 in. [6 mm] higher than nominal (see Article 12.0).
2. Insert is located 0.5 in. [13 mm] higher than nominal (see Article 10.0).
3. Beam (steel or cast-in-place concrete) is located ⅜ in. [9 mm] lower than nominal (reference AISC or ACI publications).

If this tolerance situation exists:

e = 2.5 in. + 0.25 in. + 0.38 in.
= 3.63 in. [92 mm]

Therefore, increase the size of the angel to:

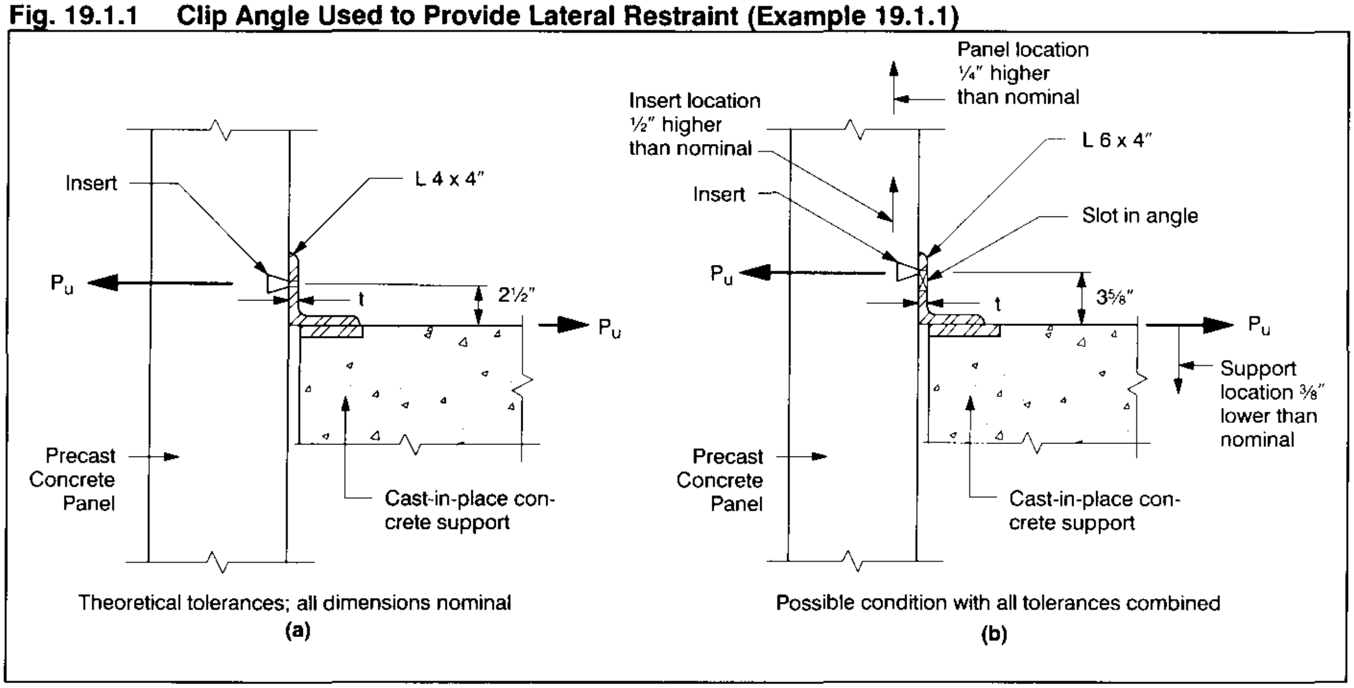
6 in. x 4 in. [152 mm x 102 mm]

Required angle thickness = 0.44 in. [11 mm], which represents a 45 percent increase in clip angle weight.

In the design of connections, one should not assume that all dimensions are the basic dimensions. Use judgement in establishing design parameters, balancing the cost impact of designing to accommodate the situation where all standard PCI and other interface tolerances accumulate in the most adverse manner rather than specifying tighter tolerances.

Depending on the circumstances, it may be more realistic to assume that the most probable tolerance condition for the connection design lies between the nominal dimension and the extreme worst case. If this assumption is made, the cost impact to the connection may be less. However, some field adjustments should be anticipated and the cost effect of these considered in the choice of design parameters for the connection.

Fig. 19.1.1 Clip Angle Used to Provide Lateral Restraint (Example 19.1.1)



19.2 Clip Angle Supporting a Precast Concrete Panel

In this case, the designer has determined that the line of load is desired to be at the center line of the supporting beam to avoid torsion in the beam. If all dimensions are basic or nominal as shown in Fig. 19.2.1(a), no torsion in the supporting beam results from the connection and the angle is designed with an eccentricity equal to 5 in. [126 mm].

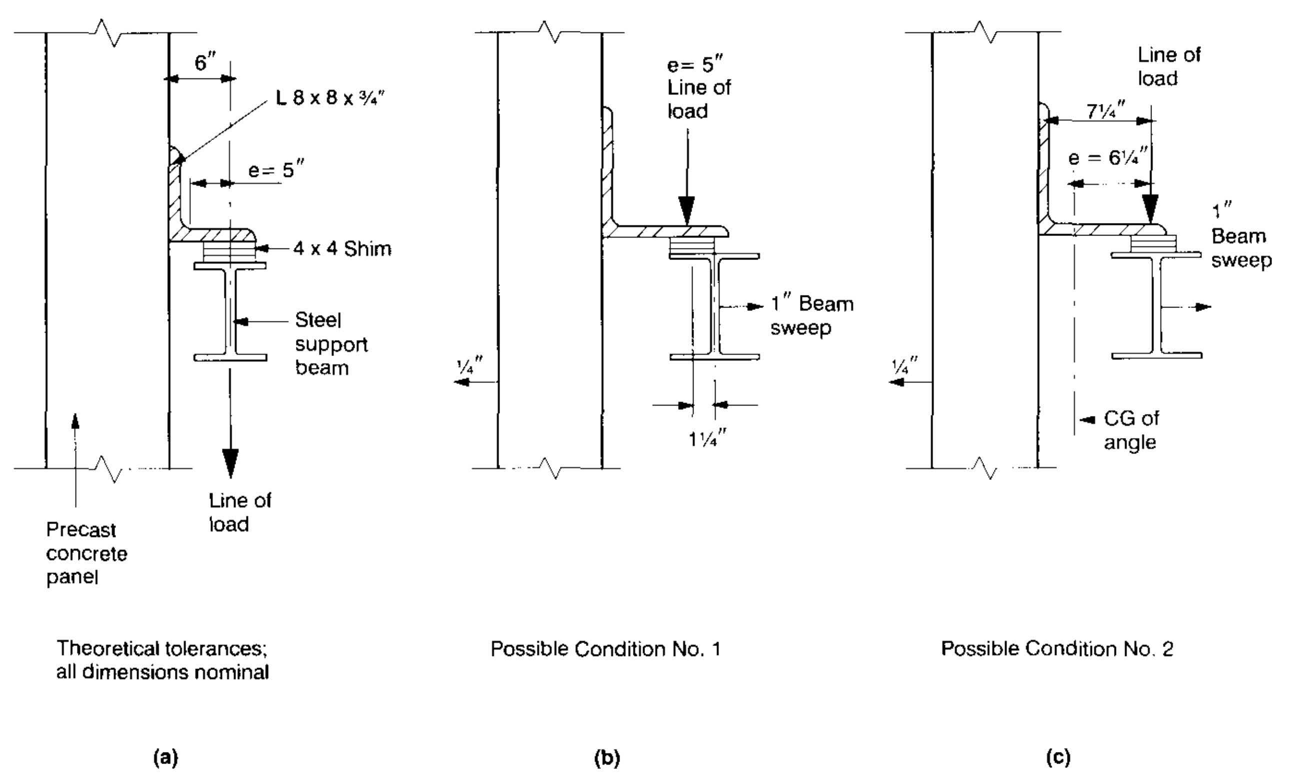
Possible Condition No. 1, shown in Fig. 19.2.1(b) may exist because the beam sweep tolerance is 1 in. [25 mm] away from the panel (AISC Code of Standard Practice) and the panel is located 0.25 in. [6 mm] away from its nominal position (see Article 12).

To keep the eccentric load of the angle at 5 in. [127 mm], the shims must be shifted toward the precast panels as shown. This results in torsion in the support beam, which may not be accounted for in its original design.

If Condition No. 2 shown in Fig. 19.2.1(c) exists, to keep from eccentrically loading the support beam, the eccentricity of the loading of the angle increases to 6.25 in. [159 mm]. This results in a requirement to increase the thickness of the support angle.

The conclusion is generally the same as example 19.1. It will likely be more economical to use a heavier angle and load the steel support beam though its centroid.

Fig. 19.2.1 Clip Angle Supporting a Precast Concrete Panel



19.3 Precast Corbel withSteel to Steel Bearing

If all of the dimensions are nominal as shown in Fig. 19.3.1(a), or if a favorable tolerance condition exists as shown in 19.3.1(c), a corbel designed for an eccentricity equal to 4½ in. [114 mm] would be adequate.

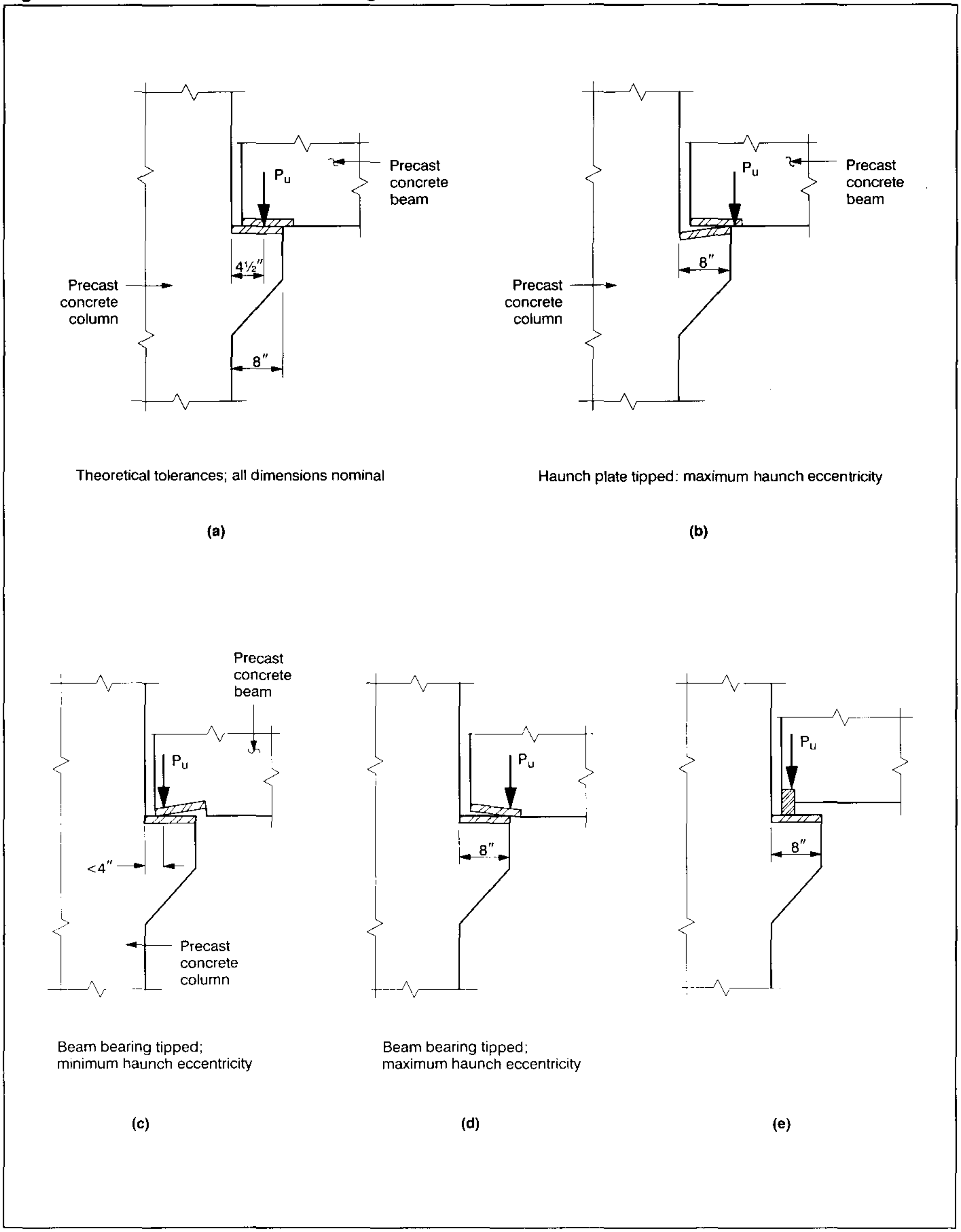
If the situation shown in Fig. 19.3.1(b) exists due to the slope of the haunch bearing (Reference Article 10), or if the situation shown in Fig. 19.3.1(d) exists due to tipping of the bearing plate, the corbel must be designed for an eccentricity of 8.0 in. [200 mm], an increase of 78 percent.

It is very unlikely that the nominal zero tolerance condition shown in Fig. 19.3.1(a) will occur and it is quite possible that the condition shown in Fig. 19.3.1(b) or (d) will occur. Therefore, the corbel should be designed for the most adverse configuration of tolerances.

It should be noted that corbels designed for ultimate loads will support beams experiencing ultimate deflections. This may result in a condition similar to that shown in Fig. 19.3.1(d). This will occur even when all of the feature dimensions of both the beam and the column haunch were originally at nominal values. The use of bearing pads is encouraged to ensure better load distribution.

The use of properly designed beam end armors as shown in Fig. 19.3.1(e) is another way of addressing this situation. The column haunch armor design must take into account the higher concentrated load associated with this detail. The joint must be detailed to assure that the unarmored concrete on the beam soffit does not bear on the haunch armor plate. This detail can be less tolerance critical than the detail shown in Fig. 19.3.1(a) through 19.3.1(d).

Fig 19.3.1 Precast Corbel with Bearing



19.4 Effects of Beam Camber

Prestressed floor and roof members usually exhibit camber as a result of eccentric prestress force. The camber is a function of the design of the product and since it is subject to product tolerances, may not be "built-in" to the desired levels.

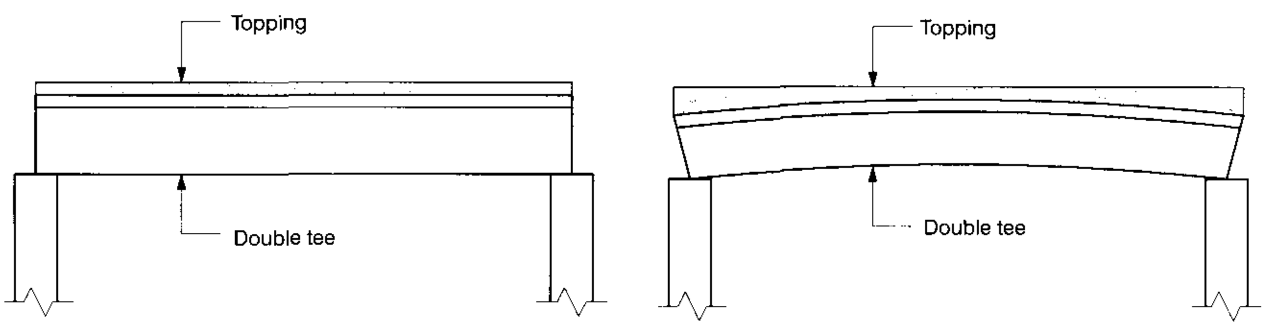
If the effect of camber is neglected, the situation shown in Fig. 19.4.1(a) may be the condition that the designer expects.

In actual fact, however, the real condition may resemble Fig. 19.4.1(b), where a long-span member may have several inches of camber. The floor topping in the example shown has been finished level, without regard to the cambered position of the beam finished surface.

The reduced topping thickness at the mid-span location may cause problems if not anticipated in design, or excess topping may be required if the design mid-span topping thickness is to be maintained and the top of the topping elevation is raised. This condition also leads to variations in topping dead load which may differ from design assumptions.

The dimensional effects of design camber, especially of long-span members, should be evaluated as part of the design process.

Fig. 19.4.1 Effect of Beam Camber



Expected condition neglecting camber

(a)

Possible result of beam camber

(b)

19.5 Effects of Camber Variation on Top Flange Connections

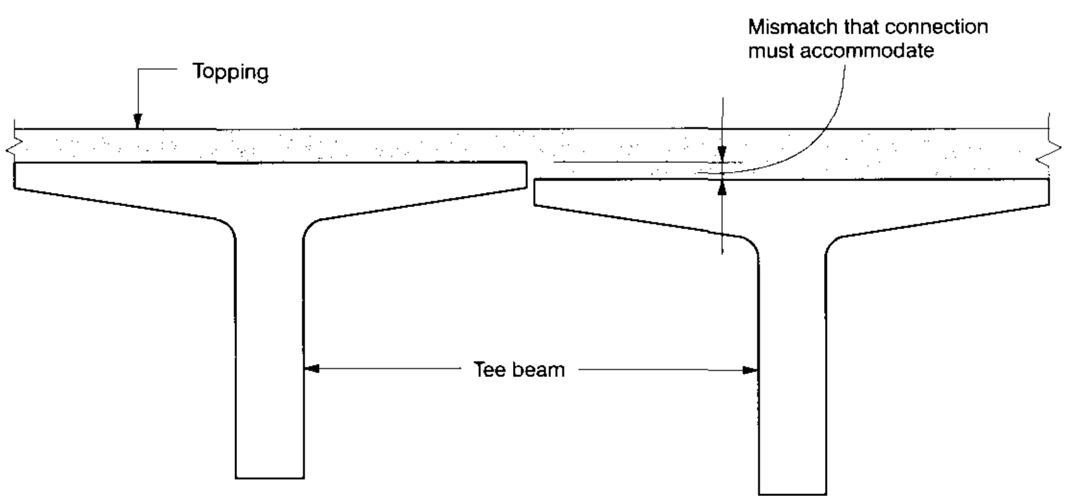
Camber variations between adjacent beam members can create significant dimensional discontinuities which may make the completion of important connections difficult.

In the section shown in Fig. 19.5.1, a step of 0.75 in. [19 mm] between the flanges is possible, even if both of the long span roof or floor members are within the differential camber tolerance.

Since welded diaphragm connections between members of this type are common, the designer should consider how the connections will be made under conditions of adverse combinations of product and erection tolerances. This condition can also lead to excessive topping on one member while the adjacent member may receive too little topping.

Specifications for erection should address the maximum allowable difference in adjacent member top elevations if this is a design consideration for either connection effectiveness or topping thickness.

Fig. 19.5.1 Effect of Camber Variation on Top Flange Connections



Beam Flange Joint Considerations

19.6 Deflection of Supporting Elements

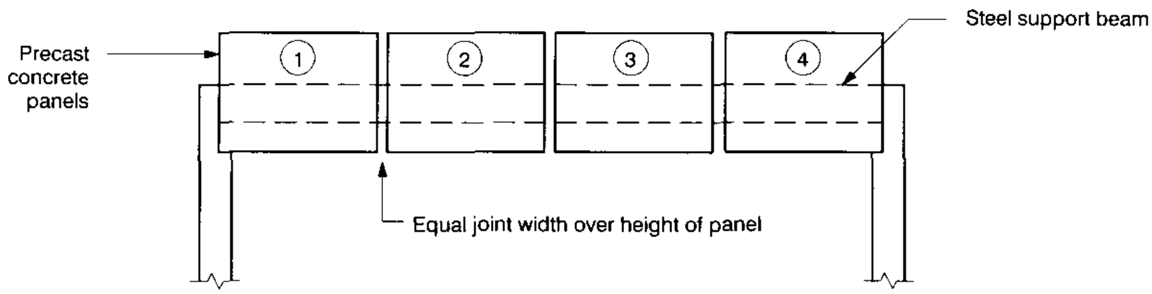
If support member deflection is neglected when a series of small architectural panels are supported on a long span beam, the designer may expect that the condition will be as shown in Fig. 19.6.1(a).

In actual fact, if the supporting beam is very flexible, the final condition may be as shown in Fig. 19.6.1(b). The support beam will deflect in increments as each panel is erected, resulting in an in-plane rotation of the panels previously erected. This rotation can result in variations in joint widths as illustrated in Fig. 19.6.1(b).

Loading from other sources may also cause deflection related problems. For example, if precast concrete is erected prior to floor slab construction, the weight of the floor may deflect the support beams and cause a problem similar to that shown in Fig. 19.6.1(b).

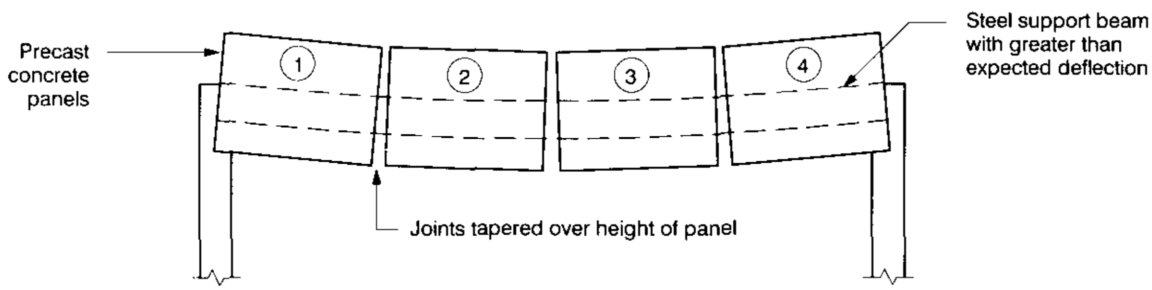
This effect can be avoided by either determining the beam intermediate and final deflections, and setting the precast concrete panels such that the final deflected condition of the support beam will bring them into alignment. Alteratively, adjustments can be made to the panels after they have all been erected.

Fig. 19.6.1 Deflection of Supporting Elements



Assumed condition neglecting support member deflection

(a)



Possible condition resulting from support member deflection

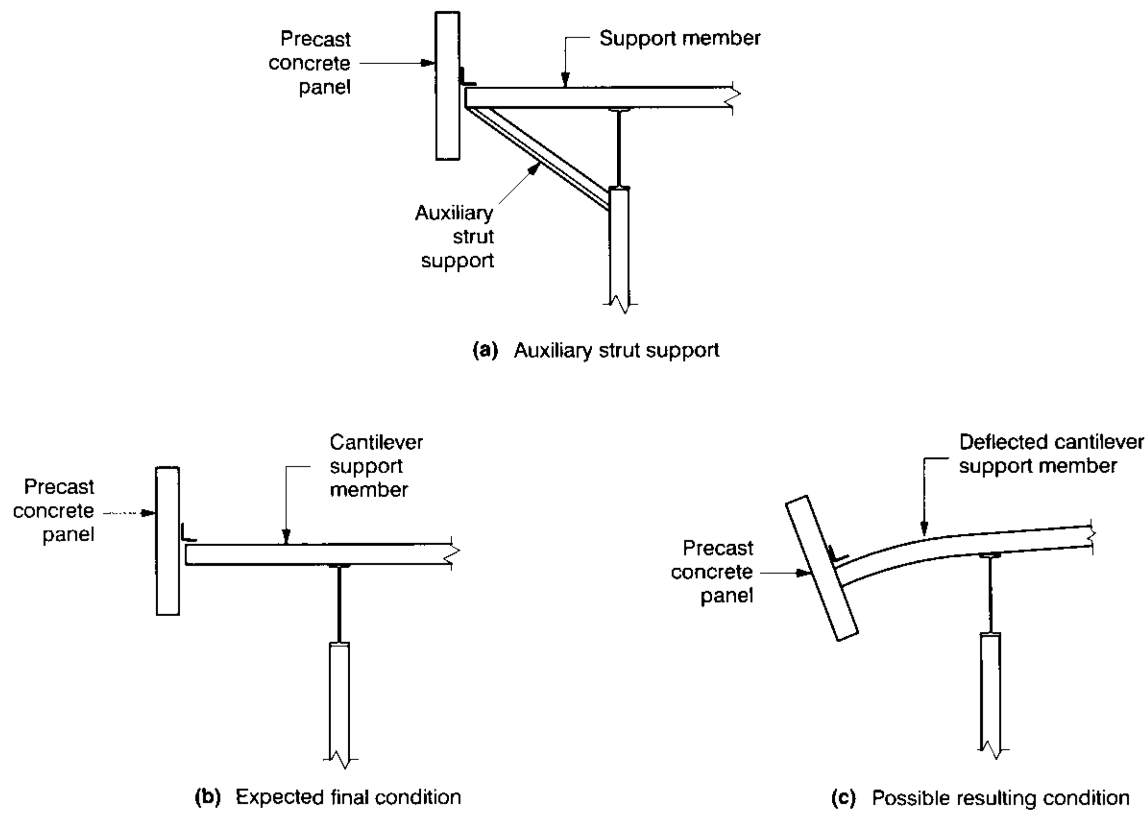
(b)

19.7 Panel Supported by a Cantilever

Panels supported by cantilever construction require extremely careful consideration because of the tendency of cantilevers to deflect and rotate significantly. Often, the best way to solve this problem is to use a support scheme that does not rely on cantilever action. Such a solution is shown in Fig. 19.7.1(a). If the detail shown in Fig. 19.7.1(b) is used, any deflection of the cantilever will not only result in vertical movement of the panel, but also in rotation as shown in Fig. 19.7.1(c).

Of particular note is the condition when panels supported on cantilever supports are adjacent to panels supported in a different manner. This may result in unwanted joint tapers and jogs in alignment. The possibility of increased deflection and rotation of the panel over time, resulting from creep off the supporting cantilever, must also be considered.

Fig. 19.7.1 Panel Supported by Cantilever



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Appendix A—Sample Specification Language

A.1 To Specify Tolerances for Architectural Precast Concrete

Element tolerances for architectural precast concrete members shall be per *Tolerances for Precast and Prestressed Concrete Construction, MNL 135–00,* by the Precast/Prestressed Concrete Institute, Article 10.1 and as amended with the special project tolerances listed below.

Specific project tolerance requirements which are different from those outlined in the above document are listed below:

Attach sketches as required.

A.2 To Specify Tolerances for Architectural Trim Units

Element tolerances for architectural concrete trim members shall be per *Tolerances for Precast and Prestressed Concrete Construction, MNL 135–00,* by the Precast/Prestressed Concrete Institute, Articles 10.29, 10.30 and 10.31 and as amended with the special project tolerances listed below.

Specific project tolerance requirements which are different from those outlined in the above document are listed below:

Attach sketches as required.

A.3 To Specify Tolerances for Structural Precast Concrete Elements

Element tolerances for structural concrete members shall be per the applicable element type as described in *Tolerances for Precast and Prestressed Concrete Construction, MNL 135–00,* by the Precast/Prestressed Concrete Institute, Article 10.0 with Articles 10.1, 10.29, 10.30 and 10.31 specifically deleted and as amended with the special project tolerances listed below.

Specific project tolerance requirements which are different from those outlined in the above document are listed below:

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Attach sketches as required.

A.4 To Specify Tolerances for Group CA/BA Structural Elements with Special Surface Finishes

Element tolerances for Group CA/BA structural concrete members shall be per the applicable element type as described in *Tolerances for Precast and Prestressed Concrete Construction, MNL 135–00,* by the Precast/Prestressed Concrete Institute, Article 10.0 with Articles 10.1, 10.29, 10.30 and 10.31 specifically deleted and as amended with the special project tolerances listed below.

Group CA/BA elements have specific project tolerance requirements on selected features which are different from those outlined in the above document are listed below. (Note that these products are <u>not</u> governed by the architectural tolerances listed in Article 10.1).

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Attach sketches as required.

A.5 To Specify Erection Tolerances for Architectural Precast Concrete Elements

Erection tolerances for architectural precast concrete members shall be per *Tolerances for Precast and Prestressed Concrete Construction, MNL 135–00,* by the Precast/Prestressed Concrete Institute, Article 12.5 and as amended with the special project tolerances listed below.

Specific project tolerance requirements which are different from those outlined in the above document are listed below:

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Attach sketches as required.

A.6 To Specify Erection Tolerances for Structural Precast Concrete Elements

Erection tolerances for structural precast concrete members shall be per *Tolerances for Precast and Prestressed Concrete Construction, MNL 135–00,* by the Precast/Prestressed Concrete Institute, Article 12.0 with Article 12.5 specifically deleted and as amended with the special project tolerances listed below.

Specific project tolerance requirements which are different from those outlined in the above document are listed below:

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Attach sketches as required.

A.7 To Specify Erection Tolerances for Group CA/BA Structural Precast Concrete Elements

Erection tolerances for Group CA/BA structural precast concrete members shall be per *Tolerances for Precast and Prestressed Concrete Construction, MNL 135–00,* by the Precast/Prestressed Concrete Institute, Article 12.0 with Article 12.5 specifically deleted and as amended with the special project tolerances listed below.

Group CA/BA elements have specific project tolerance requirements on selected features which are different from those outlined in the above document are listed below. (Note that these products are not governed by the architectural tolerances listed in Article 12.5).

Attach sketches as required.

Appendix B—Sample Contract Language – Responsibility for Project Tolerances

Project Tolerance Responsibilities for Project ____

The responsibility for the development of the project tolerance plan in the project lies with the following party:

_____ Owner
_____ Architect of Record
_____ Engineer of Record
_____ Precast Producer
_____ General Contract

This plan is to be reviewed and approved by the following party or parties:

_____ Owner
_____ Architect of Record
_____ Engineer of Record
_____ Precast Producer
_____ General Contract

The responsibility for tolerances on this project are further defined on the attached matrix title "Responsibility for Tolerances" which has been prepared specifically for this project.

Fig. B.1 Tolerance Responsibility

Project Activity	Owner	Architect/ Engineer	General Contractor	Precast Plant Management	Precast Plant Engineering	Precast Plant Quality Control	Erector Management	Erection Quality Control	Comments
Set Requirements									
Determine How to Satisfy Requirements									
Define Overall Project Tolerance Plan									
Specify Typical Product Tolerances									
Specify Typical Interface Tolerances									
Specify Typical Erection Tolerances									
Select Interface Tolerance Details									
Identify Special Project Tolerances									
Accept Project Tolerances									
Confirm Product Tolerances Achieved									
Confirm Erection Tolerances Achieved									
Confirm Interface Tolerances Achieved									

Legend: P = Prime Responsibility R/A = Review and Approval Authority I = Input Required From