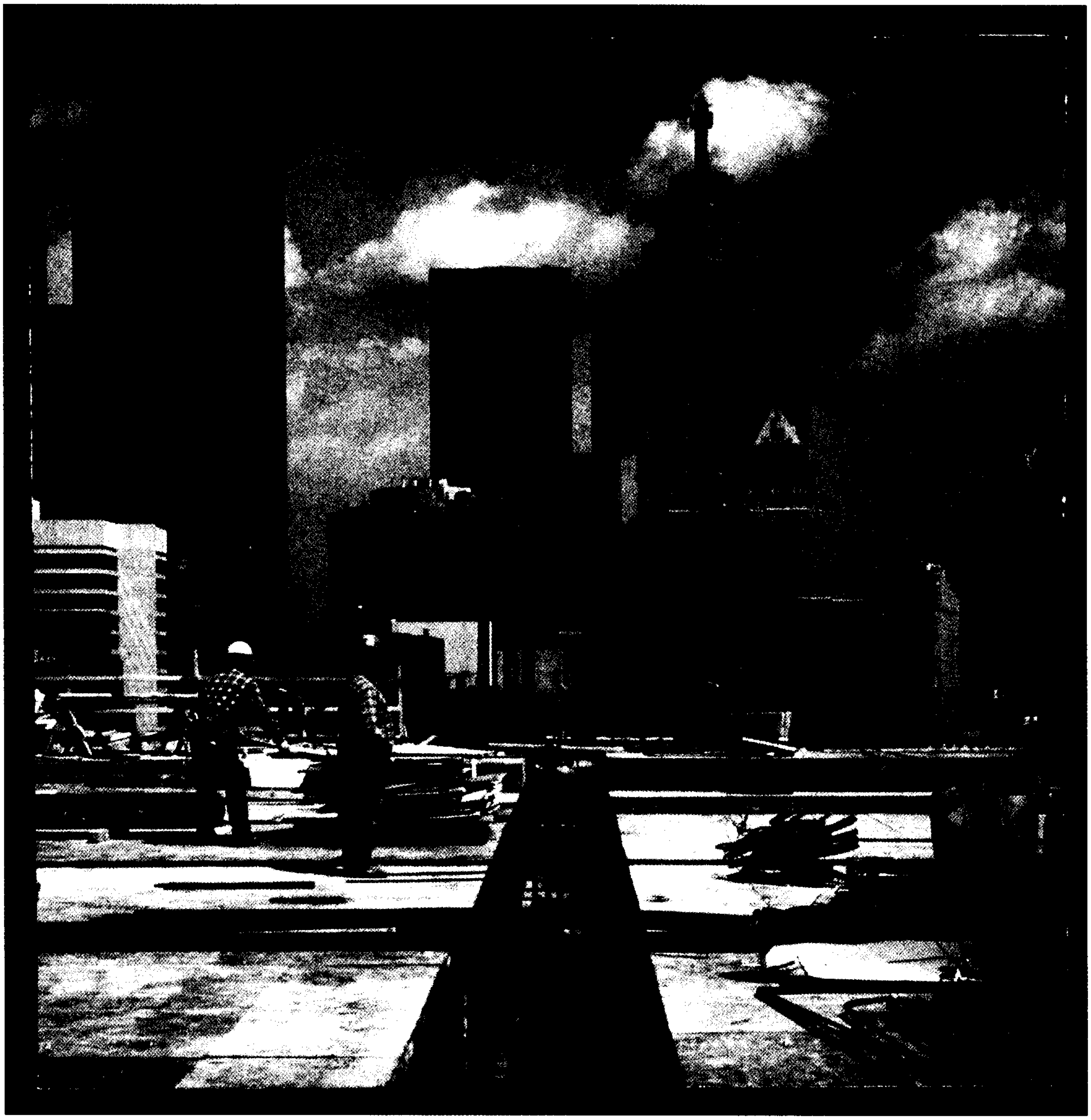
ELEVATED SLABS



Compilation 21

American Concrete Institute

Elevated Slabs

ACI Compilation 21

Contents

Preface

ACI Compilations combine material previously published in Institute periodicals to provide compact and ready reference on specific topics. The Material in a compilation does not necessarily represent the opinion of an ACI technical committee — only the opinions of the individual authors. However, the information presented here is considered to be a valuable resource for readers interested in the subject.

W. Thomas Scott
Chairman, ACI Committee 347
Formwork for Concrete

Hershell Gill
Chairman, ACI-ASCE Committee 421
Design of Reinforced Concrete Slabs

On the cover: A floor cycle of one month was achieved by contractors involved in the erection of a new addition to Toronto's skyline. The headquarters building for the Canadian Broadcasting Corp. is the first phase of a planned development that will later include twin commercial office towers of 28 and 50 stories and a residential tower with several retail levels.

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Point of View

Tolerance Conflicts and Omissions in Suspended Slab Construction

by Eldon Tipping

The goal of suspended slab construction is to produce deflected surfaces that are relatively flat, level, and at the proper elevation. Achieving this goal has presented its share of challenges to the designer and contractor over the years. This article discusses the effect of construction tolerances on conventionally reinforced cast-in-place concrete and concrete slabs on metal deck; post-tensioned and precast structures are not included.

The first section examines selected accepted tolerances for formwork elevation, reinforcing steel fabrication and placement, beam and slab thickness, and floor surface elevation. Tolerances for structural steel fabrication and erection are also addressed to illustrate the large degree to which tolerances for these different kinds of work can conflict with the stated goal.

The second section identifies and discusses tolerance areas that are commonly overlooked in contract documents. An awareness of these will allow the designer and specifier to address those conflicts and omissions as they deem appropriate.

Accepted tolerances and potential conflicts

The American Concrete Institute provides the accepted USA standard for tolerances in concrete construction. Its publication, "Standard Specifications for Tolerances for Concrete Construction and Materials (ACI 117-90),"[1] is intended to be used in its entirety by reference in project specifications.

Tolerances that affect cast-in-place concrete floor construction are those that address reinforcing steel (fabrication and placement), forms (elevation and level alignment), concrete cross-sectional dimensions, and concrete surface (elevation and level alignment). Fig. 1 shows major tolerances governing beam and slab construction.

ACI 117 contains a Specification Checklist that is not part of the standard, but is intended to assist the specifier in "properly choosing and specifying the necessary mandatory and optional requirements for the Project Specification." One admonition of the Checklist states: "Where a specific application uses multiply (sic) toleranced items that together yield a toleranced result, the specifier must analyze the tolerance envelope with respect to practical limits and design assumptions and specify its value where the standard tolerances (sic) values in this specification are inadequate or inappropriate."

The accepted USA standard for fabrication and erection of structural steel is the "Code of Standard Practice for Steel Buildings and Bridges,"[2] published by the American Institute of Steel Construction (AISC) in its *Manual of Steel Construction*. The most recent edition of this document was adopted effective September 1, 1986.

Tolerances that affect construction of concrete floors on metal deck are those that address structural steel (fabrication and erection), concrete cross-sectional dimensions, and concrete surface (elevation and level alignment). Tolerances for structural steel fabrication and erection are contained in the AISC Code (Fig. 2 and 3); the remaining tolerances are taken from ACI 117-90.

"Standard Mill Practice — General Information" in the AISC *Manual of Steel Construction* contains information pertaining to camber of structural steel beams (Fig. 4), and also contains the following statements about cambering of structural steel beams:

> Mill camber in beams of less depth than tabulated [in a table provided on page 1-167] should not be specified.
>
> Camber is measured at the mill and will not necessarily be present in the same amount in the section of beam as received due to release of stress induced during the cambering operation. In general, 75 percent of the specified camber is likely to remain.

When evaluating tolerances associated with cast-in-place concrete construction one must keep in mind the

POINT OF VIEW This article was selected for reader interest by the editors. However, the opinions expressed by the author are not necessarily those of the American Concrete Institute. The editors invite comments from our readers about the personal views given in this article.

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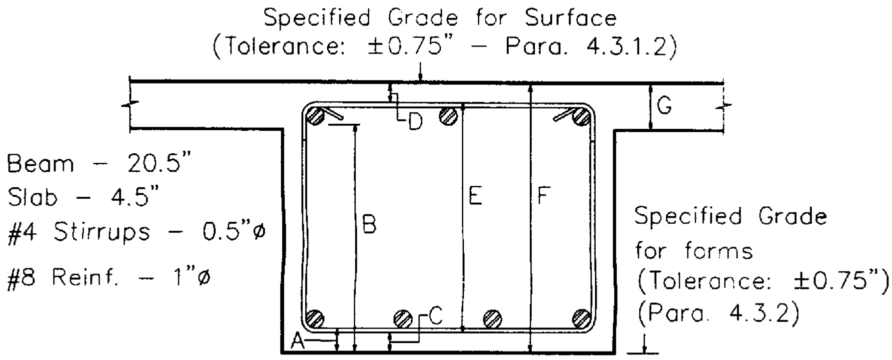
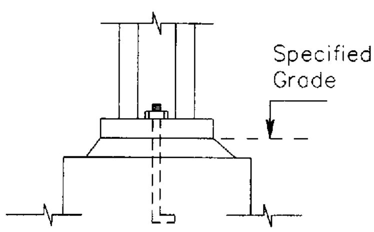


	Specified Dimension	Tolerance		Range		ACI 117
		Minus	Plus	Low End	High End	Para.
A	2.0"	.25"	.5"	1.75"	2.5"	2.2.3
B	17.5"	.5"	.5"	17.0"	18.0"	2.2.2
C	1.5"	.25"	–	1.25"	–	2.2.3
D	1.5"	.5"	–	1.0"	–	2.2.3
E	17.5"	.5"	.5"	17.0"	18.0"	2.1
F	20.5"	.375"	.5"	20.125"	21.0"	4.4
G	4.5"	.25"	.375"	4.25"	4.875"	4.4



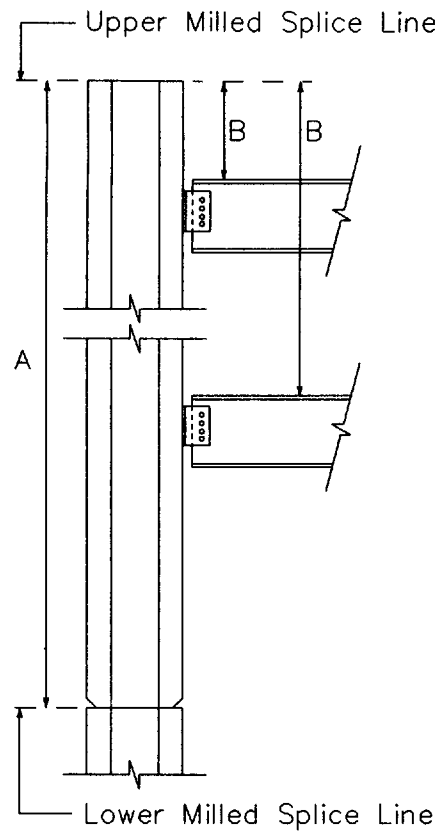
(AISC CODE OF STANDARD PRACTICE
–PARAGRAPH 7.6)

Elevation tolerance relative to established grade is ±0.125"

above: Fig. 1 — Major ACI tolerances governing beam and slab construction.

right: Fig. 2 — AISC elevation tolerance for column base plates.

left: Fig. 3 — AISC tolerances for column length and connection location.



(AISC CODE OF STANDARD PRACTICE)

ITEM	TOLERANCE	PARAGRAPH
A	±0.03125"	6.4.1
B	+0.1875" –0.3125"	7.11.3.2.(b)

admonition in Paragraph 1.2.3 of ACI 117 that tolerances are not cumulative.

Examples 1 and 2 below consider cast-in-place concrete construction and show the interaction of tolerances for reinforcing steel fabrication, clear distance (effective depth), concrete cover, and member thickness. Example 3 shows further inconsistencies that must be considered when one attempts to meld tolerance requirements from the structural steel industry with those for concrete construction.

The paragraph references in the three examples are from References 1, 2, and 3 as noted.

Example 1

Given: Beam with a specified depth of 20.50 in. and adjacent slab with a specified depth of 4.50 in. The void adjacent to the beam and below the slab is created by using a 16.00 in. deep prefabricated form. Beam stirrups are fabricated using #4 (0.50 in. diameter) bars. Beam top and bottom main reinforcement is #8 (1.00 in. diameter) bars.

Beam stirrups are fabricated with a vertical dimension 0.50 in. longer or shorter than specified.

Discussion:

- The envelope within which reinforcing steel, clear distance, and cover requirements must coexist is defined by the allowable variation in member thickness (Reference 1: 1.2.3 and 4.4.1). When the slab is formed by a void of constant depth that is supported at the same elevation as the beam bottom, distance from the slab surface to the beam bottom is limited by the allowable variation in the slab thickness from that specified (Reference 1: 4.4.1). In this instance that envelope, measured from the beam bottom, extends from 20.25 to 20.875 in. (a slab thickness of 4.25 to 4.875 in.).
- For stirrups with a length less than 12 ft, the tolerance for the vertical dimension is .50 in. The stirrup in this example conforms to tolerances for fabrication (Reference 1: 2.1).
- Prefabricated supports of the proper height are normally used to support bottom bars in beams. The vari-

ation of bottom bar clear distance to forms and concrete cover between the stirrups and formed surface from that specified is likely to be insignificant. The bottom reinforcing steel meets clear distance and minimum cover requirements (Reference 1: 2.2.2 and 2.2.3).

- Clear distance of beam top reinforcing steel is established by depth of supports and length of stirrups. Since cover at the beam bottom is nearly exact, the clear distance of the top steel to the forms will vary with the stirrup length from −0.50 to +0.50 in. This variation conforms to allowable tolerances (Reference 1: 2.2.2).
- For stirrups that are 0.50 in. too short (deep), the effective cover at the top of the beam could vary from 1.75 to 2.375 in. and meet the member thickness tolerance (Fig. 6). Construction of the floor surface at proper grade presents no problem, since the only restriction on cover for top steel is a 0.50 in. reduction of that specified (Reference 1: 2.2.3 and 4.4.1).
- For stirrups that are 0.50 in. too long (deep), concrete cover at the top of the beam could vary from 0.75 to 1.375 in. if member thickness were the only consideration. Any cover below 1.00 in., however, will violate the minimum cover requirements for top reinforcing steel (Reference 1: 2.2.3) so the actual allowable variation in concrete cover is from 1.00 to 1.375 in. The resulting member thickness will be from a minimum of 20.50 to a maximum of 20.875 in.; only use of the minimum allowable cover will result in a member thickness that matches specified thickness (Fig. 6).

Example 2

Given: *Beam and slab construction as stated in Example 1. Beam stirrups are fabricated with a vertical dimension 0.50 in. longer or shorter than specified.*

Form elevation varies from specified grade by as much as 0.75 in.

Discussion:

- The envelope within which the supported structure must fit prior to removal of shores is defined by planes that are 0.75 in. above specified grade for the slab and 0.75 in. below specified grade for the beam soffit (Reference 1: 4.3.1.2 and 4.3.2). It should be noted, however, that forms that are more than 0.25 in. higher than specified grade in any location will force the slab surface above specified grade at that location to maintain minimum thickness requirements for both beam and slab (Fig. 7).
- For stirrups that are 0.50 in. too short (deep), the effective cover at the top of the beam could vary from 1.75 to 2.375 in. and meet the member thickness tolerance. Construction of the floor surface at proper grade and meeting all tolerance requirements presents no problem, as long as the supporting forms are no more than 0.25 in. higher than specified grade or more than 0.625 in. below specified grade (Fig. 6 and 7).
- For stirrups that are 0.50 in. too long (deep), member thickness can vary from a minimum of 20.50 to a maximum depth of 20.875 in. If supporting forms are above specified grade, the surface must also be above specified grade or the end result will be a member that violates the minimum thickness requirements (Fig. 6 and 7).

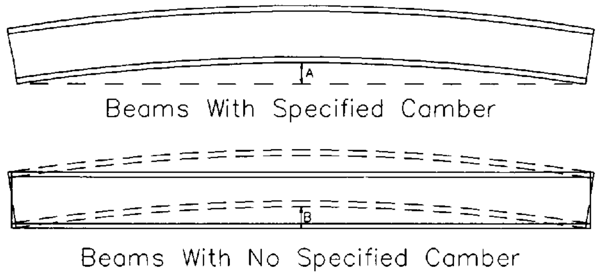
Example 3

Given: *Concrete slab with a total specified thickness of 6 in. supported by 3 in. deep composite metal decking supported in turn by a grid of structural steel beams and girders. The structural steel is cambered in some locations as much as 2 in. at midspan and is designed to support the weight of the wet concrete during placement (unshored construction).*

Top of structural steel (bottom of metal deck) is at the ideal elevation when beam-to-column connections are at specified grade and when the pre-placement midspan elevation of the steel is at specified grade plus the specified camber. In this example, top of steel elevations vary from the ideal elevation by as much as 1.00 in.

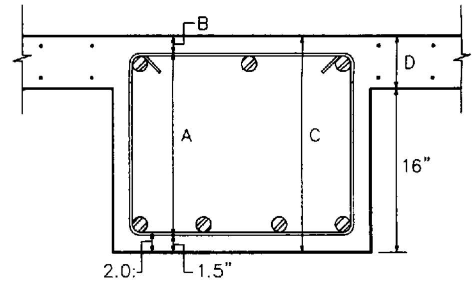
Discussion:

- When evaluating tolerance conformance within the framework of the AISC Code, the first factor that must be recognized by the specifier is that only base plates for column sections are tied to an established grade. All other tolerances are stated in terms relative to the fabricated member.
  - The elevation tolerance for column base plates is 0.125 in. (Fig. 2).
  - The length tolerance for each column section is 0.03125 in. (Fig. 3).
  - The working point for beams and girders framing into columns may be too high by 0.3125 in. or too low by 0.1825 in. from the desired location measured from the splice line of the column section (Fig. 3).
  - The top edge of adjustable curb angles and lintels are acceptable if they are within 0.375 in. of the proper distance from the upper milled splice point of the nearest column to which the steel beam is attached (Reference 2: 7.11.3.3).
  - There is no specified tolerance for items that are attached directly to steel beams and girders (Fig. 5), other than statements that variations in overall dimensions are acceptable if within the cumulative total permitted for rolling, fabricating and erection (Reference 2: 7.11.1 and 7.11.3.2.(c)).
- The tolerance for location of lintels, sills, etc., are not the same in the AISC Code and ACI 117 (References 2: 7.11.3.3; and 1: 4.3.2). The AISC Code references location relative to upper splice elevation of the nearest column; ACI 117 references tolerances to specified grade.
- Initial camber in structural steel beams and girders may not match that required by the drawings (Reference 3: p. 1-167).
- Mill camber should not be specified for steel beams that are 12 in. or less in depth, and those that are expected by the engineer to deflect less than ¾ in. under load of the concrete (Reference 3: p. 1-167).
- Beams, girders, and trusses with no specified camber may have a natural camber as a result of rolling or fabrication (Fig. 4). These elements are to be fabricated so that any such camber is upward (Reference 2: 6.4.4).
- Variations in supporting steel platform prior to concreting operations dictate that concrete be placed to a uniform thickness over steel beams to meet slab cross-sectional tolerances (Reference 1: 4.4.1).



(AISC STANDARD MILL PRACTICE)

ITEM	BEAM LENGTH	TOLERANCE	
		PLUS	MINUS
A	50' & Less	0.5"	0.0"
A	Over 50'	0.5" + 0.125"/10'	0.0"
B	All	0.125"/10'	0.0"



Beam – 20.5"
Slab – 4.5"

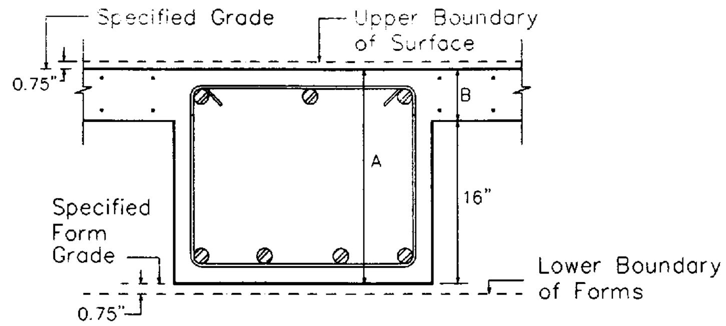
	17"	18"
A	17"	18"
B	1.75" to 2.375"	1.00" to 1.375"
C	20.25" to 20.875"	20.50" to 20.875"
D	4.25" to 4.875"	4.50" to 4.875"

above: Fig. 4 — AISC tolerances for camber of beams.

below: Fig. 5 — There is no specified tolerance for items attached directly to steel beams and girders.

above right: Fig. 6 — Dimensions for Example 1.

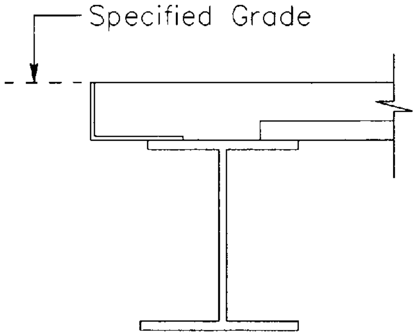
right: Fig. 7 — Dimensions for Example 2.



Required Top Surface Elevation (relative to specified grade)
When Stirrup Depth and Form Elevation Vary Within Tolerance Limits

Stirrup Depth	Form Elevation Relative to Specified Grade		
	−0.75"	0.0"	+0.75"
17"	−1.00" to −0.375"	−0.25" to +0.375"	+0.50" to +1.125"
17.5"	−1.00" to −0.375"	−0.25" to −0.375"	+0.50" to +1.125"
18"(b)	−0.75" to −0.375"	0.00" to −0.375"	+0.75" to +1.125"

(a) Given: Beam Depth 20.5" (−0.25" to +0.375")
Slab Thickness 4.5" (−0.25" to +0.375")
Assume all other tolerances are met.
(b) Beam depth and slab thickness cannot be less than specified if cover tolerance requirements are met.



• There is no tolerance on variation of the surface elevation, because the supporting steel framework is not supported during placement of concrete (Reference 1: 4.3.1.2).

Summary of tolerance conflicts

A number of accepted tolerance standards are in potential conflict with the goal of achieving deflected elevated surfaces that are flat, level, and at the proper elevation. The ability of the contractor to achieve this goal is directly affected by these tolerances.

• Example 1 illustrates the manner in which stirrups that are fabricated slightly longer than required by design documents can force the resulting concrete surface above that which might otherwise be necessary.

• Example 2 shows that form elevations that are too high can also force the resulting concrete surface to a level higher than indicated by the contract documents.

• Examples 1 and 2 illustrate that restrictions on cross-section thickness of slabs and beams can restrict the ability of the contractor to produce a surface profile that is at the specified elevation.

• Example 3 shows that failure to place controls on the elevation of the structural steel platform will result in a concrete surface that has essentially the same variations as the supporting structural steel platform.

• Example 3 also points out that concrete cross-section tolerances restrict the ability of the contractor to respond to out-of-level conditions that might exist in a structural steel platform.

Common tolerance omissions

A number of important tolerance areas have been overlooked by the industry and are often not considered by the designer during preparation of contract documents for suspended slab construction. These omissions do result in a lack of control over the ultimate quality produced by the contractor and can result in increased cost to the owner or eventual tenant.

Several of the overlooked tolerance issues are common to all suspended slab construction, regardless of the type floor framing employed by the designer. The following must be considered and addressed by the specifier if control over the quality of the final product is desired.

Acceptable surface quality near slab edges and at projections

Concrete finishing operations near columns and sleeves normally involve hand-held floats and trowels. Finishing on areas unobstructed by projections utilizes bull floats, highway straightedges, power floats and power trowels. There is a general recognition in the industry that surface quality near columns and sleeves can be substantially different from that achieved elsewhere. The current approach in our industry is to either ignore this probable variation in quality or to exclude these areas from evaluation.

The area near columns is almost invariably included in any grid survey used to establish variations in the floor surface. The result is that data that are not necessarily reflective of the overall floor quality can play a critical role in its evaluation. ASTM E1155,[4] which is used to evaluate surfaces using the F-Number system, specifically excludes slab areas within 2 ft of projections and slab edges.

Acceptable levelness of deflected slab surfaces

The complex interrelationship between construction of a floor system and the manner in which it deflects is recognized. One rationalization used for not addressing this issue is the fact that neither the contractor nor the engineer has complete control over the relative levelness of the deflected surface. Another is that application of a floor leveling material after construction has historically enabled the contractor to improve surface levelness sufficiently to meet the needs of the owner.

On the other hand, there are several arguments in favor of meeting this challenge. The cost of floor leveling with fill material is often high and its installation can disrupt completion of other scheduled work. Existing technology provides the means for rapid and economical identification of floor frame behavior during construction.[7] Components critical to construction of successful suspended slabs have been identified.[8] Procedures have been developed that allow the design/construction team to identify and to respond to local areas in which the floor surface does not deflect as originally anticipated by the engineer.[7]

The team approach to achieving levelness of the deflected surface has produced some exceptional results[5,6] with an added benefit of fostering team solutions to other challenges that arise during construction. Levelness of deflected surfaces need no longer be avoided by the specifier.

Elevation differences at columns during construction

On high rise projects differential shortening of columns is fairly common. Engineers often adjust column lengths to minimize the effect of anticipated shortening or the effects of building foundation settlement. The relative elevation of the floor surface at adjacent columns can change between the time a particular level is constructed and completion of construction. Consequently, it is important for the engineer to provide guidance and information to the contractor concerning relative elevation differences that should be observed at the time specific levels are constructed. This information gives the contractor a target against which he can evaluate his work during construction.

In structural steel construction, designers generally rely on the AISC Code to establish tolerance requirements for erection and fabrication of the structural steel. The incompatibility of ACI and AISC tolerances, however, dictates that the designer/ specifier take steps to resolve differences in the two documents.

One approach is to include in the contract documents provisions that establish elevation control over the erected structural steel. The specifier can establish the degree to which structural steel column splice points should conform to specified grade. This same approach can be applied to the elevation of beam-to-column connections. Finally, the specifier can establish an acceptable variation of closure angle elevations from specified grade prior to concreting.

Conclusion

Current methods of tolerancing suspended slab construction are inadequate and often internally inconsistent. If the contractor is to have the ability to produce deflected floors that are flat, level, and at the proper elevation, the specifier must consider alternatives to common tolerancing methods. Our industry needs to take a serious look at the variables involved and to make some decisions concerning approaches that will allow the designer and contractor to work together to produce the product desired by the owner.

References

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