Title 210 – National Engineering Handbook

Part 645 – Construction Inspection

Appendix E – Construction Tolerances

Amended March 2025

645APPE.0 Introduction

A. The following explanation of construction tolerances provides the quality assurance (QA) inspector with an overview of the tolerances accepted in the construction industry. Any tolerances given in a contract, either directly or by reference, take precedence over accepted tolerances. The QA inspector must consult with the project engineer on all questions about allowable tolerances.

B. All construction work has tolerances to allow for inherent variances in construction materials and workmanship skills. Many of these variances are an integral part of quality designs, which can be related to minimum required safety factors. Zero tolerance in construction is not feasible or necessary in the NRCS. Tolerance is the permissible range of variation in a dimension of an object, permissible variation of an object in some characteristic such as hardness, density, or size, or the permissible deviation from plan alignment, location, or grade.

C. Construction tolerances are a variation in dimension, construction limit, or physical characteristic of a material. They are a practical variation related to the function of the material or finished work and commonly accepted standards of the construction industry.

D. Tolerances range from a fraction of an inch to feet. There is, for example, a great deal of difference in the amount of acceptable tolerance in the invert of a cast-in-place conduit subject to cavitation velocities compared to overfill on an earthfill embankment. Experienced contractors know acceptable tolerances for various types of construction work and, unless advised otherwise, will expect permission to operate within these familiar tolerance limits.

E. The following excerpt from the "Handbook of Heavy Construction" emphasizes the importance and responsibility of tolerances:

   1. "The matter of job tolerances and good workmanship is a very important consideration in the inspection of construction work. The Resident Engineer must realize that weather, time, the construction methods and materials often control and even dictate the accuracy and quality of the completed job. Of course, some consideration should have been given to these items in the original preparation of the plans and specifications. Also, good specifications will stipulate some working tolerances, which will assist the Resident Engineer. However, appreciation of job tolerances becomes primarily the

problem of the Resident Engineer, who must decide and instruct his staff on the accuracy's to be expected of the Contractor on the various operations. This obviously requires experience and good judgment and should include such considerations as the function, stability, and appearance of the work; the limits of workability of the materials being used, the mechanical limitations of first-class construction equipment to be used, etc. Probably the most common cause for controversies on the matter of job tolerances results from a Contractor using poor construction equipment or unskilled labor with which the desired final work cannot be produced. This generally requires a positive stand by the Resident Engineer and insistence that the Contractor either improves his present operations or gets something better on the job."[1]

F. Some tolerances come from Title 210 National Engineering Handbook, Part 645 "Construction Inspection," Construction Specifications (CS), some from ASTM International's (ASTM) standards used for testing, and still others from common usage or accepted practice within the construction industry.

G. The following tolerances identify the more significant categories of work with cited references and descriptions. Specific tolerances must be established for each job prior to construction, but don't have to be documented on the construction drawings or specifications. The designer, project engineer, and QA inspector must all understand what tolerances are allowed.

H. When making computations based on measurements involving tolerances, the results will only be as precise as the measurement. Therefore, the numerical precision used must be compatible and consistent with the measurement. In computing test results, for instance, carrying numbers out to places beyond that required by the test procedure is time consuming, provides opportunities for making computational errors, and may imply accuracy that does not exist. The job requirements for accuracy determine the appropriate rounding rules to produce the correct significant digits in the computations.

645APPE.1 Excavation

A. Common excavation

1. Foundation – Cut at least to the grade designated on the drawings with stable side slopes no steeper than specified. Additional depth by steepening the planned slopes is not allowed unless specifically approved by the project engineer. Additional depth must be accomplished by widening the excavation to maintain the planned side slopes.

2. Channel excavation – The bottom grade must be at least to grade with 0.5 foot below grade allowed. Drainage channels can typically be more generous on

[1] Handbook of Heavy Construction by F. Stubbs and J Havers, Published 1971 by McGraw-Hill Companies ISBN 10: 0070272786

the over excavation due to initial siltation in the completed channel. Side slopes plus or minus 0.2 foot if humps or pockets are blended in.

3. Waterways and diversions – These require a closer tolerance to control velocity and erosion. Plus or minus 0.2 foot in the bottom grade is allowable if ponding does not occur. Side slopes plus or minus 0.2 foot if humps or pockets are blended in.
4. Principal spillway trench – Bottom grade must be close to that specified. A tolerance, usually plus or minus 0.10 foot, is sufficient to lay the pipe to grade without excessive shimming, adjusting, or excavation to get the full cradle or bedding section under the pipe. The principal spillway pipe must be placed within plus or minus 0.05 foot of grade without any unspecified grade reversals.
5. Auxiliary spillways – The control or level section must be to plus or minus 0.10 foot. The inlet section is not critical, and plus or minus 0.30 foot will have little effect on function. The outlet channel must have the grade maintained lengthwise throughout the cross section to a tolerance of plus 0.10 foot and minus 0.20 foot. However, it is important that this section not vary significantly from plus or minus 0.10 foot from one side of the outlet channel to the other side.

B. Rock excavation

1. Foundation – Rock surface conformity is more important than final line and grade. A tolerance of plus 0.5 foot to minus 1.0 foot is reasonable in most rock. Dental concrete is a common aid to gain surface conformity.
2. Principal spillway trench and similar structure foundations – Closer tolerances due to a structure require plus 0.10 foot to minus 0.5 foot. To maintain grade, follow with dental concrete for minor adjustments and regular concrete for a pipe subcradle or working pad.
3. Auxiliary spillway – The tolerance for the level control section must be close, about plus 0.10 foot and minus 0.15 foot. If using a concrete sill or a control crest, the tolerance in the level section can be plus or minus 0.05 foot. The inlet channel can be plus 0.5 foot to minus 1.5 foot. The outlet must be plus 0.20 foot to minus 0.50 foot lengthwise and plus or minus 0.20 foot from one side to the other side of any given cross section.

645APPE.2 Earthfill

A. Finished Fill Slopes

1. Uniformity of grade from top to bottom and across slope is primarily for appearance and aesthetic considerations. Gradual changes of plus or minus 0.3 foot from plan line and grade are considered acceptable if overall appearance is acceptable.

B. Top of Fills

1. Dams, dikes, levees, etc., must be completed to specified grade. Tolerance of plus 0.10 foot is acceptable.

645APPE.3 Concrete

A. Formwork

1. References

   a. American Concrete Institute (ACI), Publication SP-4, "Formwork for Concrete"
   a. ACI 347 "Guide to Formwork for Concrete"
   b. ACI 117 "Specifications for Tolerances for Concrete Construction and Materials"

2. Cross-sectional dimensions of columns and beams and the thickness of slabs and walls:

   a. Minus ¼ inch to plus ½ inch.

3. Irrigation canal linings:

   a. Departure from profile grade plus or minus one inch. Departure from established alignment:
      (1) On tangents, plus or minus 2 inches.
      (2) On curves, plus or minus 4 inches.
   b. Thickness of lining:
      (1) Lining thickness six inches or less:
         (a) Plus 1 inch.
         (b) Minus 0 inch.
      (2) Lining thickness more than 6 inches:
         (a) 10 percent of specified thickness provided the average thickness is maintained throughout.

4. Monolithic culverts and siphons

   a. Departure from established alignment plus or minus 1 inch.
   b. Departure from established profile grade plus or minus 1 inch.
   c. Variation in thickness:
      (1) Minus the greater of 2½ percent or ¼ inch.
      (2) Plus the greater of 5 percent or ½ inch.

B. Concrete Surfaces

1. Reference: U.S. Bureau of Reclamation Concrete Manual

2. F2 and U2 surfaces – When different surface finishes are desired, use appropriate tolerances:

   a. F2 – Formed surfaces, measured from 5-foot template.
   b. Depressions: Gradual irregularity plus or minus ½ inch.
   c. U2 – Unformed surfaces, measured from 10-foot template. All surfaces plus or minus ¼ inch.

C. Concrete Cover or Protection on Rebars

1. Reference: Concrete Reinforcing Steel Institute (CRSI) “Placing Reinforcing Bars.”
2. Minus ¼ inch to plus ½ inch while meeting steel placement tolerances.

D. Steel Placement

1. Reference: CSRI
2. Cutting to length plus or minus 1 inch.
3. Hooked bars length out to out of hook plus or minus 1/2 inch for #7 or smaller bars plus or minus 1 inch for bars larger than #7.
4. Truss bars overall length plus or minus ½ inch for #7 or smaller bars plus or minus 1 inch for bars larger than #7.
5. Tension bars in beams or walls (distance from extreme compression fiber to the position shown on the drawings) plus or minus 3/8 inch for #8 or smaller bars and plus or minus ½ inch for bars larger than #8 bars.
6. Lap and splice location – Plus or minus 1 inch. Minimum 12-inch splice length.
7. Spacing – Minimum distance between bars plus or minus ¼ inch. In uniform spacing (from theoretical location), plus or minus 2 inches.
8. Minimum cover – Tolerance from minimum cover specified or shown on the drawings minus 3/8 inch for #8 or smaller bars and minus ½ inch for bars larger than #8 bars.

E. Concrete Materials

1. Reference: CS-31 and CS-32
2. Cement – Batch weight within plus or minus 1 percent.
3. Aggregate – Batch weights within plus or minus 2 percent.
4. Additives (liquid) – Metered measure plus or minus 1 ounce.
5. Water – Do not exceed maximum gallons established in the design mix.

F. Concrete Mixing

1. References:
   a. CS-31
   b. ACI 304 “Guide for Measuring, Mixing, Transporting, and Placing Concrete”
2. Mixing time – Under normal conditions, maximum time is 1 ½ hours from the time water is introduced to the aggregates. The tolerance cannot be quantified, but this is an area where good technical judgment must be used. If placement is going well, materials look good, material temperature is still less than 85° F, and most of the load is placed, time can be extended. If material is 85° F or

higher, placement not going well, load only partially placed, do not extend the permissible time of 1 ½ hours.

3. Mixing revolutions are related to time, and the same technical judgment must be applied. Revolutions become especially critical in hot weather. Establish procedures early in the job to see that mixing revolutions are maintained as specified.
4. **Note**: The tolerances cited are an incomplete listing of those contained in the references. References used are industry standards and may be used in establishing tolerances for specific work.

645APPE.4 Material Testing

A. References: Contract drawings and specifications with appropriate ASTM specifications or standards.

B. Concrete Testing

1. References:
    a. Contract drawings
    b. CS-31 and CS-32
    c. Appropriate ASTM standards
    d. ACI standards
2. Slump testing – Within the specified slump range, the slump must be within plus or minus ¼ inch (ASTM C143). Some judgment may be used here especially on the low side of the range. The dry side is controlled to get a workable mix that can be placed in a tight or crowded form area. If placement is not difficult, low slump may be acceptable providing all other factors are met. Making a judgment on the high side involves the consideration of the portion of the load tested, total water content in the mix, temperature, consistency, and the appearance of the concrete. Since high slump often results in low test strength, all slumps at the high side of the slump range must be judged with caution.
3. Air Content
    a. References: ASTM C231 and ASTM C173
4. Air range is specified and measured to the nearest 1 percent. Judgment may be used on the low side depending on the actual location of the concrete with respect to exposure. Entrained air improves the durability of concrete subject to freeze/thaw. Structures that are embedded in soil are not subject to freeze thaw. At least 4 percent air content is required for good durability. The high side must never be violated and approached with extreme caution. High air content will reduce strength significantly. If air is running consistently below the range specified, a new design mix must be required.

5. Compressive strength specimens – Test cylinders or cores must be made and handled in accordance with ASTM C31 or C42. Tolerances and ranges in these specifications must be adhered to and adequately documented.

C. Soil Testing

1. References:

   a. CS-23
   b. Appropriate ASTM standards

2. For standard density and moisture content reference tests, ASTM D698 (Proctor Curve), the test must be reported to:

   a. Moisture plus or minus 0.1 percent.
   b. Density plus or minus 0.1 pound per cubic foot.

3. For field For field density and moisture testing the tests must be reported to: Moisture plus or minus 0.1 percent.

   a. Density plus or minus 0.5 pound per cubic foot.

4. Field density can be obtained from ASTM D1556, D6938, D8167, or D2937. These methods are respectively: sand cone, nuclear gauge, low-activity nuclear gauge, and drive cylinder.

5. Field moisture can be obtained from ASTM D2216, D6938, D4959, D4944, or D4643. These methods are respectively: laboratory oven, nuclear gauge, direct heating, calcium carbide moisture gauge or microwave oven.

6. For the determination of percent compaction round off to the nearest 1 percent.

7. For the determination of specified moisture content round off to the nearest 0.5 percent.

D. Filter and Drain Materials

1. References:

   a. CS-24
   b. ASTM C136

2. Percent passing sieve size:

   a. Fines (No. 200 sieve), plus 0.5 percent.
   b. Other sizes, plus or minus 2 percent.

645APPE.5 Summary

A. The tolerances described in this appendix are those considered more common in construction activities. In each case, the tolerances intend to maintain the integrity, quality, and function of the material or work involved. All tolerances must be discussed during the preconstruction conferences and documented in the construction records.