March 12, 2015

 March 23, 2017

REVISION OF SECTIONS 105, 106, 412, 601 AND 709

CONFORMITY TO THE CONTRACT OF PORTLAND CEMENT CONCRETE PAVEMENT AND DOWEL BARS AND TIE BARS FOR JOINTS

**NOTICE**

This is a standard special provision that revises or modifies CDOT’s *Standard Specifications for Road and Bridge Construction.* It has gone through a formal review and approval process and has been issued by CDOT’s Project Development Branch with formal instructions for its use on CDOT construction projects. It is to be used as written without change. Do not use modified versions of this special provision on CDOT construction projects, and do not use this special provision on CDOT projects in a manner other than that specified in the instructions unless such use is first approved by CDOT’s Standards and Specifications Unit. The instructions for use on CDOT construction projects appear below.

Other agencies which use the *Standard Specifications for Road and Bridge Construction* to administer construction projects may use this special provision as appropriate and at their own risk.

**Instructions for use on CDOT construction projects:**

Use on all projects with Concrete Class E and Class P

The designer will place a note in the General Notes indicating whether the project will be accepted by flexural strength or compressive strength.

The Region Materials Engineer shall be consulted for assigning the acceptance criteria.

For rural projects the following criteria will be used for assigning acceptance criteria:

* Projects with greater than 5,000 sq. yds of PCCP will be accepted by flexural strength criteria.
* Projects with 5,000 or less sq. yds of PCCP will be accepted by compressive strength criteria
* If a rural project with greater than 5,000 sq. yds of PCCP consists of scattered repairs, or only intersection replacements, compressive strength criteria will be used for acceptance.

For metro area projects:

* Projects with more than 50,000 sq.yds. will be flexural strength.
* Project with less than 5,000 sq.yds. will be compressive strength
* Projects with 5,000 to 50,000 sq.yds could be either compressive or flexural. Consult the RME to determine acceptance method. Projects projected to have an on-site batch plant are encouraged to use flexural strength acceptance

Sections 105, 106, 412, 601 and 709 of the Standard Specifications are hereby revised for this project as follows:

Delete subsection 105.06 and replace with the following:

**105.06 Conformity to the Contract of Portland Cement Concrete Pavement.** Conformity to the Contract of all Portland Cement Concrete Pavement, Item 412, will be determined in accordance with the following:

When the Engineer finds that the materials furnished, the work performed, or the finished product does not conform with the Contract, or the Pay Factor (PF) for an element's process is less than 0.75 but that reasonably acceptable work has been produced, the Engineer will determine the extent of the work that will be accepted and remain in place. The Engineer will use a Contract Modification Order to document the justification for allowing the work to remain in place and the price adjustment that will be applied.

When the Engineer finds the materials furnished, work performed, or the finished product is not in conformity with the Contract, or the PF for an element's process is less than 0.75 and has resulted in an inferior or unsatisfactory product, the work or material shall be removed and replaced or otherwise corrected by and at the expense of the Contractor. When the PF for any process is 0.75 or greater, the finished quantity of work represented by the process will be accepted at the calculated pay factor.

Materials will be sampled and tested by the Contractor and the Department in accordance with subsection 106.06 and with procedures contained in the Department's Field Materials Manual. The approximate quantity represented by each sample will be as set forth in subsection 106.06, Tables 106-2 and 106-3. Additional samples may be selected and tested at the Engineer's discretion.

1. Incentive and Disincentive Payments (I/DP) will be made based on a statistical analysis that yields Pay Factors (PF) and Quality Levels (QL). The PF and QL will be made based on test results for the elements of compressive strength and pavement thickness (compressive strength criteria) or the elements of flexural strength and pavement thickness (flexural strength criteria). The Department will indicate in the plans whether compressive strength or flexural strength criteria will be used. If the acceptance criteria is not indicated, flexural strength criteria shall be used.

Incentive or Disincentive payment will not be made for thickness of concrete pavement furnished by the Contractor and placed by others.

When compressive strength criteria is indicated, then the QL will be calculated for the elements of compressive strength and pavement thickness on a process basis. When flexural strength criteria is indicated, then the QL will be calculated for the elements of flexural strength and pavement thickness on a process basis. A process will consist of the test results from a series of random samples. Test results determined to have sampling or testing errors will not be used. All materials produced will be assigned to a process. Changes in mix design, design pavement thickness, or a break of more than 120 working days between placements will create a new process. The following is provided to clarify changes in processes for each element:

1. Construction of mainline pavement, including the shoulders if placed with the mainline, is a single process for the compressive or flexural strength element, when the mix design does not change and there is not a break of more than 120 days between placements.
2. Construction of mainline pavement, including the shoulders if placed with the mainline, is a single process for the thickness element, when the planned thickness does not change and there is not a break of more than 120 days between placements.
3. Construction of ramps, acceleration and deceleration lanes and shoulders placed separately are considered separate processes.
4. Changes in paving equipment, changes in placement method, changes in hauling equipment, adjustments to mix designs that do not require a new mix design, changes in weather conditions, and changes in production rate shall not create a new process in the strength or thickness elements.

The Contractor and Engineer will determine element processes and what distinguishes them as processes during the pre-pave meetings prior to any concrete placement.

 (b) When it is necessary to represent material by one or two tests, each individual test shall have a PF computed in accordance with the following:

If the value of the test is at or above the lower tolerance limit, then PF = 1.000. If the value of the test is below the lower tolerance limit, then:

PF = 1.00 – [0.25(TL -T0)/V]

where: PF = pay factor.

 V = V factor from Tables 105-4 or 105-5.

 T0 = the individual test value.

 TL= lower tolerance limit.

 (c) The following procedures will be used to compute Incentive and Disincentive Payments (I/DP), quality levels (QL), and pay factors (PF) for processes represented by three or more tests:

1. Quality Level (QL) will be calculated according to CP-71.

2. Compute the PF for the process. When the process has been completed, the number of tests (Pn) it includes shall determine the formula to be used to compute the final pay factor in accordance with the following:

 A. For compressive strength and pavement thickness:

When 3 ≤ Pn ≤ 5

If QL ≥ 85, then PF = 1.00 + (QL ‑ 85)0.001333

If QL < 85, then PF = 1.00 + (QL ‑ 85)0.005208

When 6 ≤ Pn ≤ 9

If QL ≥ 90, then PF = 1.00 + (QL ‑ 90)0.002000

If QL < 90, then PF = 1.00 + (QL ‑ 90)0.005682

When 10 ≤ Pn ≤ 25

If QL ≥ 93, then PF = 1.00 + (QL ‑ 93)0.002857

If QL < 93, then PF = 1.00 + (QL ‑ 93)0.006098

When Pn ≥ 26

If QL ≥ 95, then PF = 1.00 + (QL ‑ 95)0.004000

If QL < 95, then PF = 1.00 + (QL ‑ 95)0.006757

B. For flexural strength:

When 3 ≤ Pn ≤ 5

If QL ≥ 85, then PF = 1.00 + (QL ‑ 85)0.002000

If QL < 85, then PF = 1.00 + (QL ‑ 85)0.005208

When 6 ≤ Pn ≤ 9

If QL ≥ 90, then PF = 1.00 + (QL ‑ 90)0.003000

If QL < 90, then PF = 1.00 + (QL ‑ 90)0.005682

When 10 ≤ Pn ≤ 25

If QL ≥ 93, then PF = 1.00 + (QL ‑ 93)0.004286

If QL < 93, then PF = 1.00 + (QL ‑ 93)0.006098

When Pn ≥ 26

If QL ≥ 95, then PF = 1.00 + (QL ‑ 95)0.006000

If QL < 95, then PF = 1.00 + (QL ‑ 95)0.006757

3. Compute the I/DP for the process:

I/DP = (PF‑1)(QR)(UP)

where: QR = Quantity Represented by the process.

 UP = Unit Price bid for the Item.

The total I/DP for an element shall be computed by accumulating the individual I/DP for each process of that element.

(d) As acceptance test results become available, they will be used to calculate accumulated QL and Incentive and Disincentive Payments (I/DP) for each element and for the item. The Contractor's test results and the accumulated calculations shall be made available to the Engineer upon request. The Engineer's test results and the calculations will be made available to the Contractor as early as reasonably practical. Numbers from the calculations shall be carried to significant figures and rounded according to AASHTO Standard Recommended Practice R-11, Rounding Method.

I/DP will be made to the Contractor in accordance with subsection 412.24(a). During production, interim I/DP will be computed for information only. The Pn will change as production continues and test results accumulate. The Pn at the time an I/DP is computed shall determine the formula to be used.

(e) The Contractor shall not have the option of accepting a price reduction or disincentive in lieu of producing specification material. Continued production of non‑specification material will not be permitted. Material which is obviously defective may be isolated and rejected without regard to sampling sequence or location within a process.

(f) When compressive strength is indicated, the Contractor may take cores at his own expense and in accordance with Colorado Procedure 65 to provide an alternative determination of strength to replace acceptance test results with a compressive strength less than 4,500 psi. The higher value of the 28 day compressive strength of acceptance cylinders or the corresponding core’s compressive strength will be used for I/DP.

When flexural strength is indicated, the Contractor may take cores at his own expense and in accordance with Colorado Procedure 65 to provide an alternative determination of strength to replace QC test results with a flexural strength less than 650 psi. The cores shall be obtained prior to 45 days after placement. The higher value of the 28 day flexural strength of QC beams or the corresponding core’s flexural strength will be used for I/DP.

**Table 105‑4**

**"V" FACTORS AND INCENTIVE PAYMENTS**

**COMPRESSIVE STRENGTH CRITERIA**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Element** | **V factor** | **Maximum Incentive Payment** | **Lower Tolerance Limit, TL** | **Plan Value** |
| Compressive Strength | 400 psi | 3.00 percent | 4,500 psi | 4,500 psi |
| Pavement Thickness | 0.4 inch | 2.00 percent | Plan Thickness-0.4 inch | Plan Thickness |

**Table 105‑5**

# "V" FACTORS AND INCENTIVE PAYMENTS

**FLEXURAL STRENGTH CRITERIA**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Element** | **V factor** | **Maximum Incentive Payment** | **Lower Tolerance Limit, TL** | **Plan Value** |
| Flexural Strength | 50 psi | 3.00% | 570 psi | 650 psi |
| Pavement Thickness | 0.4 inch | 2.00% | Plan Thickness-0.4" | Plan Thickness |

*Sand Equivalence*. If compressive strength criteria is indicated then the sand equivalence (SE) as determined by CP 37 will be considered acceptable when the running average of three consecutive tests is greater than 80 percent and no individual test result is less than 75 percent. When the running average of three consecutive SE tests falls below 80 percent or an individual SE test result falls below 75 percent, paving operations shall be suspended. The Contractor shall submit a written plan to correct the low SE test results to the Engineer for approval. The Contractor shall not continue paving operations until the Engineer approves the plan in writing and three SE test results from random samples in the stockpile are above 80 percent.

Delete subsection 106.06 and replace with the following:

**106.06 Sampling and Testing of Portland Cement Concrete Paving.** All Portland Cement Concrete Pavement, Item 412, shall be tested in accordance with the following quality control and acceptance testing procedures:

* + 1. *Quality Control Testing*. The Contractor shall be responsible for quality control testing of all elements listed in Table 106‑2 or 106-3. Quality control testing shall be performed at the expense of the Contractor. The Contractor shall develop a quality control plan (QCP) in accordance with the following:

Quality Control Plan. For each element listed in Tables 106-2 or 106-3, the QCP must provide adequate details to ensure that the Contractor will perform quality control. The Contractor shall submit the QCP to the Engineer at the preconstruction conference. The Contractor shall not start any work on the project until the Engineer has approved the QCP in writing.

* 1. Frequency of Tests or Measurements. The QCP shall indicate a random sampling frequency, which shall be equal to or more frequent than that shown in Table 106-2 or 106-3. The quality control tests shall be independent of acceptance tests.
	2. Test Result Chart. Each quality control test result, the appropriate area, volume, and the tolerance limits shall be plotted. The chart shall be posted daily at a location convenient for viewing by the Engineer.
	3. Quality Level Chart. The QL for each element in Table 106-2 or 106-3 shall be plotted. The QL shall be calculated in accordance with the procedure in CP 71 for Determining Quality Level. The QL shall be calculated on tests 1 through 3, then tests 1 through 4, then tests 1 through 5, then thereafter the last five consecutive test results. The area of material represented by the last test result shall correspond to the QL.
	4. F-test and t-test Charts. If flexural strength criteria is indicated, then the results of F-test and t-test analysis between the Department's verification tests of flexural strength and the Contractor's quality control tests of flexural strength shall be shown on charts. The F-test and t-test shall be calculated in accordance with standard statistical procedures using all verification tests and quality control tests completed to date. When a verification test is completed, the F-test and t-test calculations shall be redone. The area of material represented by the last test result shall correspond to the F-test and t-test. A warning value of 5 percent and an alert value of 1 percent shall be shown on each chart. The chart shall be posted daily at a location convenient for viewing by the Engineer.

Point of Sampling. The material for quality control testing shall be sampled by the Contractor using CP 61. The location where material samples will be taken shall be indicated in the QCP.

* + - 1. Testing Standards. The QCP shall indicate which testing standards will be followed. Acceptable standards are Colorado Procedures, AASHTO and ASTM. The order of precedence is Colorado Procedures, AASHTO procedures and then ASTM procedures.

The compressive strength test for quality control will be the average strength of two test cylinders cast in plastic molds from a single sample of concrete, cured under standard laboratory conditions, and tested three to seven days after molding.

* + - 1. Testing Supervisor Qualifications. The person in charge of and responsible for the quality control testing shall be identified in the QCP. This person shall be present on the project and possess one or more of the following qualifications:
			2. Registration as a Professional Engineer in the State of Colorado.
			3. Registration as an Engineer in Training in the State of Colorado with two years of paving experience.
			4. A Bachelor of Science in Civil Engineering or Civil Engineering Technology with three years of paving experience.
			5. National Institute for Certification in Engineering (NICET) certification at level III or higher in the subfields of Transportation Engineering Technology, Highway Materials, or Construction Materials Testing Engineering Technology, Concrete and four years of paving experience.
			6. Technician Qualifications. Technicians performing tests shall meet the requirements of Colorado Procedure 10.
			7. Testing Equipment. All of the testing equipment used to conduct quality control testing shall conform to the standards specified in the test procedures and be in good working order. If flexural strength criteria is indicated, then the Contractor shall provide the following equipment and supplies which will not be paid for separately but shall be included in the work:
	1. A separate, temperature controlled facility of at least 300 square feet usable space. This facility shall be used exclusively for the molding, storage and testing of concrete test specimens as required. This facility shall be provided in addition to other facilities required in Section 620. The storage facility shall have sufficient water storage capacity for curing all required test specimens. The storage facility shall provide separate storage tanks for each type of required testing. Each storage tank shall have a continuously recording thermometer and sufficient blank charts for the project. Temperatures of each storage tank shall be recorded for the duration of the project.
	2. A machine for testing flexural strength of concrete specimens. The machine shall be one of the following or an approved equal:
		1. Forney model number FHS-300 with a Co-Pilot digital monitor.
		2. Humboldt model number HCM-3000 with a iD Digital Indicator
		3. Gilson model number MC-400 with Pro Controller

Both the Contractor and the Engineer will use this machine for testing concrete specimens. The machine shall meet the requirements of AASHTO T 97 and T 22 and the following: The machine and the flexural strength assembly shall be of a rigid construction. The applied vertical load shall be uniformly distributed to the third points and uniformly across the width of the beam (transverse distribution). Uniform distribution of the load is defined as less than a 3 percent variation in the load between each of the nine strain gages placed in the middle third section of the tension face for loads from 1,000 to 10,000 pounds. Two firms that can evaluate and assess the ability of the machine to distribute the load evenly are KPFF Consulting Engineers, Chicago Illinois 847-859-7790 and Construction Testing Laboratories, Skokie Illinois 847-965-7500 . Other firms may be capable of evaluating and assessing the load distribution of the machine. The Engineer must approve the firm prior to assessing the machine. The machine shall be ready for use and certified two days before paving begins. After the machine has been certified and accepted by the Engineer it shall not be moved until all portland cement concrete paving and flexural strength acceptance tests have been completed. A weekly check of the planeness of all bearing surfaces on the flexural strength apparatus shall be made and recorded in the Contractor’s QC notebook for each week that flexural strength testing occurs. If the nominal maximum aggregate size of the mix is ¾ inches or less, then the Contractor shall also provide a separate flexural strength apparatus that is configured to test 4x4x14 inch beam specimens. Swapping flexural strength apparatuses will not require recertification of the test machine.

* 1. Beam molds for molding all test specimens required. Beam molds shall have a cross section of approximately 6 inches by 6 inches. All beam molds shall be checked by the Contractor prior to being placed in service and monthly. The checks of each beam mold shall be recorded in the Contractor’s QC notebook. This shall include all testing described in subsection 106.06. If the nominal maximum aggregate size of the mix is ¾ inches or less, then the Contractor shall also provide beam molds with a cross section of 4 inches by 4 inches and a minimum length of 14 inches.
1. Reporting and Record Keeping. The Contractor shall report the results of the tests to the Engineer in writing at least once per day.

The Contractor shall assemble a Quality Control (QC) notebook and update it daily. This notebook shall contain all worksheets, test results forms, test results charts and quality level charts for each of the elements listed in Table 106-2 or 106-3. The Contractor shall submit examples of worksheets, test result forms and test results charts in accordance with CP 12B as part of the Contractor's Quality Control Plan (QCP). The Contractor shall submit the QC notebook to the Engineer for review once a month on the date agreed to at the Pre-Construction Conference.

The QC notebook will be returned to the Contractor with a list of recognized deficiencies within two working days after submittal. Deficiencies may include, but are not limited to, the failure to submit the notebook on time or an absence of the required reports. For any month in which deficiencies are identified, the QC notebook will be submitted for review two weeks after the QC notebook is returned. Upon the second recognized deficiency the Engineer will notify the Contractor, and the pay estimate shall be withheld until the Contractor submits, in writing, a report detailing the cause for the recognized deficiency. The report shall include how the Contractor plans to resolve the deficiencies. Additional recognized deficiencies will result in a delay of the pay estimate until the Contractor has identified and resolved the deficiency along with revising and resubmitting his QCP to address these issues. Once the Engineer has reviewed and approved the revised QCP the estimate may be paid. Upon submittal of the QC notebook for the semi-final estimate, the QC notebook shall become the property of the Department. The Contractor shall make provisions such that the Engineer can inspect quality control work in progress, including QC notebook, sampling, testing, plants, and the Contractor's testing facilities at any time.

1. Optimized Gradation. The Contractor will be required to perform quality control testing of the combined aggregate gradation (CAG) when an Optimized Gradation (OG) is used for Class E or P Concrete. The combined aggregate gradation testing frequency shall be three per day. Test one shall be sampled and tested after full production begins but before production reaches 100 cubic yards. Test two shall be sampled and tested after four hours of continuous production or production reaches 1000 cubic yards, whichever comes first. Test three shall be sampled and tested after seven hours of continuous production or production reaches 1750 cubic yards, whichever comes first. The frequency shall be a minimum of one per day if production is less than 750 cubic yards.

The Department will perform one gradation each day that may be a split of one of the three daily QC samples. This data will not be used to determine acceptability of the material but as information only.

The Contractor’s gradation test data will be used to calculate the coarseness factor (CF) and workability factor (WF) and must plot within the workability box. No corrective action shall be required if the data falls within the workability box.

When the Contractor’s gradation test results and the CF and WF fall outside the workability box, the Contractor shall immediately make corrections to bring the aggregate gradation within the workability box and notify the Engineer. If two or more consecutive test results for any single day or two successive days are found to fall outside the workability box, the Contractor shall immediately suspend production and provide a written corrective plan to the Engineer for approval prior to resuming production.

Upon being allowed to resume production, the Contractor shall follow the daily sampling frequency. If the next two consecutive gradation tests indicate the CF and WF plot inside the workability box, the Contractor may continue production. If the first two aggregate samples do not have CF and WF that fall inside the workability box, production shall be suspended.

Prior to resuming production the Contractor shall be required to sample the individual aggregate stockpiles at two or more locations to determine the range of variability within each stockpile, make appropriate adjustments to the percentages for each aggregate component, and discharge and sample the combined aggregates. The combined aggregate gradation shall be tested to determine if the CF and WF fall inside the workability box. Production can resume if the CF and WF plot within the workability box. Production will continue to be suspended for additional evaluation of stockpiles and aggregate feed rates until gradation sampling and testing indicate the CF and WF fall inside the workability box.

All gradation test information during production shall be provided to the Engineer daily. The Contractor shall immediately report all gradation test data to the Engineer for evaluation during periods when production is suspended or upon resuming production. The Contractor will be notified in writing in all cases when production may resume or shall remain suspended.

* + 1. *Acceptance Testing.* Acceptance testing frequencies shall be in accordance with the Schedule (Quality Assurance) in the Department’s Field Materials Manual. Except for flexural strength, acceptance tests will be conducted by and at the expense of the Department. Acceptance sampling and testing procedures will be in accordance with the Department's Field Materials Manual with the following exceptions and inclusions:

A split sample from an acceptance test shall not be used for a quality control test. The Engineer will designate the location where samples are to be taken. Samples shall be taken by the Contractor in accordance with CP 61. The Engineer will be present during the sampling and take possession of all acceptance samples. Samples transported in different containers will be combined and mixed before molding specimens. All materials are subject to inspection and testing at all times.

Pavement thickness acceptance will be determined by cores.

The compressive strength test for acceptance will be the average compressive strength of three test cylinders cast in plastic molds from a single sample of concrete and cured under standard laboratory conditions prior to testing. If the compressive strength of any one specimen differs from the average by more than 10 percent, that specimen will be deleted and the average strength will be determined using the remaining two specimens. If the compressive strength of more than one specimen differs from the average by more than 10 percent the average strength will be determined using all three specimens. Each set of three cylinders will be tested at 28 days after molding.

Acceptance tests for flexural strength shall be the Contractor's quality control tests. The flexural strength tests shall be the average flexural strength of four test beams. The test beams shall be prepared according to AASHTO T 23. The flexural strength of each specimen shall be measured according to AASHTO T 97 with the following additional requirements: If the flexural strength of only one specimen differs from the average by more than 10 percent, that specimen shall be deleted and the average strength shall be determined using the remaining three specimens. If the flexural strength of more than one specimen differs from the average by more than 10 percent, the test value shall be the average of all four specimens. Each set of four beams shall be tested at 28 days after molding. If the nominal maximum aggregate size of the mix is ¾ inches or less, then the Contractor shall prepare three additional test beams using the 4x4x14 inch molds. The 4x4x14 inch specimens will be tested 28 days. The results of the 4x4x14 inch specimens will be for information only and will not be used to determine the acceptability of the concrete. Results of the 4x4x14 inch specimens will be reported to the Engineer with the corresponding acceptance test results. These additional specimens are being used to evaluate the validity of using smaller test specimens for acceptance.

* + 1. *Verification Testing.* Verification testing will be used only when flexural strength criteria is indicated and is the responsibility of the Department. The Department will determine the locations where samples or measurements are to be taken. The location of sampling shall be based on a stratified random procedure.

Verification sampling and testing procedures will be in accordance with Sections 105, 106, 412, the Schedule for Minimum Materials Sampling, Testing and Inspection in the Department's Field Materials Manual, and CP 13. Samples for verification testing shall be taken by the Contractor in accordance with CP 61 in the presence of the Engineer.

An analysis of test results will be performed after all test results are known using the t-test and F-test statistical methods with an alpha value set at 0.05. If either the above t-test and F-test analysis shows a significant difference, then the following items shall be checked: comparison of beam fracture locations and types, computations and flexural testing machine outputs, curing tank temperature charts, slump and air contents, plant batch tickets for major changes, review of sampling, molding, testing procedures, along with IAT check tests and any other investigations that may clarify the significant differences. If after a review of the data no reasons can be determined for the significant difference, the Department's test data shall be used for determining Quality Levels and Incentive or Disincentive according to the methods in this Section.

* + 1. *Check Testing.* The Contractor and the Engineer shall conduct a check testing program (CTP) prior to the placement of any concrete pavement. The check testing program will include a conference directed by the Region Materials Engineer, the Contractor's testers and the Department's testers concerning methods, procedures and equipment for compressive or flexural strength testing. Check testing shall be completed before any portland cement concrete pavement is placed. A set of three cylinders or four beams will be molded by both the Contractor and the Department's project testers from a split sample. The specimens will be sampled, molded and cured for seven days and tested for compressive or flexural strength according to the procedures of Section 106. The Department's Independent Assurance Tester will also mold, cure and test a set of three cylinders or four beams, but the Independent Assurance Test results will not be entered in the check testing analysis. If the results of the check tests do not meet the following criteria, then the check testing will be repeated until the following criteria are met:
1. The average of the Contractor's test results and the average of the Department's test results shall be within 10 percent of the average of all test results.
2. Each specimen test result shall be within 15 percent of the average of all test results.

When compressive strength criteria is indicated, a check test must also be conducted on the sand equivalent test. A set of 5 sand equivalents will be run by both the Contractor's and the Department's project tester, from a split sample. The average of the absolute differences between tests taken by the quality control personnel and the acceptance testing personnel will be compared to the acceptable limits shown in Table 13-1 of CP 13. The CTP will be continued until the acceptance and quality control test results are within the permissible ranges shown in Table 13-1 of CP 13.

During production, split samples of randomly selected acceptance tests will be compared to the permissible ranges shown in Table 13-1 of CP 13. The minimum frequency will be as shown in Table 106-3.

If production has been suspended and then resumed, the Engineer may order a CTP between tests taken by quality control and acceptance testing persons to assure the test results are within the permissible ranges shown in Table 13-1 of CP 13. Check test results shall not be included in quality control testing. The Region Materials Engineer shall be called upon to resolve differences if a CTP shows unresolved differences beyond the ranges shown in Table 13-1 of CP 13.

* + 1. *Independent Assurance Testing*. The sample for the IAT will be a split sample of the Contractor's quality control test. The Department's representative performing verification tests shall also use a split sample of the Contractor's quality control test and participate in the IAT. The IAT for flexural strength will be the average flexural strength of four test beams prepared according to the requirements of Section 106 and cured for seven days in the field before being transferred to the IAT lab. IAT specimens will be tested at 28 days.
		2. *Testing Schedule.* All samples used to determine Incentive or Disincentive payment by quality level formulas in accordance with Section 105, will be selected by a stratified random process.

**Table 106‑2
QC TESTING SCHEDULE ‑ ITEM 412
PORTLAND CEMENT CONCRETE
PAVEMENT, FLEXURAL STRENGTH CRITERIA**

| **Element** | **Minimum Testing Frequency****Contractor's Quality Control** |
| --- | --- |
| Aggregate Gradation and Sand Equivalent | For the first five days, minimum of 1/day, then 1/10,000 sq. yds. After 5 days, 1/40,000 sq. yds. |
| Slump | First three loads each day, then as needed for control. |
| Water Cement Ratio | First three loads each day, then 1/500 cu. yds. |
| Air Content and Yield | Minimum of 1/day, then 1/2,500 sq. yds. |
| Flexural Strength | Minimum of 1/day, then 1/2,500 sq. yds. |
| Compressive Strength | 1/10,000 sq. yds. |
| Pavement Thickness | In accordance with subsection 412.21. |
| Pull Test Joints | Minimum of six transverse and six longitudinal joint locations for the 1st 2500 linear feet, then three transverse and three longitudinal joints thereafter  |
| Load Transfer Dowel Bar Placement | In accordance with subsection 412.13 (b) 2 |
| Texture Depth | 1 per 528 linear feet in each lane and shoulder wider than 8 feet. |

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**Table 106‑3**

**QC TESTING SCHEDULE ‑ ITEM 412**

**PORTLAND CEMENT CONCRETE**

**PAVEMENT, COMPRESSIVE STRENGTH CRITERIA**

|  |  |
| --- | --- |
| **Element** | **Minimum Testing Frequency****Contractor's Quality Control** |
| Aggregate Gradation  | Minimum of 1/day, then 1/10,000 sq. yds. |
| Slump | First three loads each day, then as needed for control. |
| Compressive Strength, Air Content, Yield, and Sand Equivalent | Minimum of 1/day, then 1/2,500 sq. yds. |
| Pavement Thickness | In accordance with subsection 412.21. |
| Pull Test Joints | Minimum of six transverse and six longitudinal joint locations for the 1st 2500 linear feet, then three transverse and three longitudinal joints thereafter |
| Load Transfer Dowel Bar Placement | In accordance with subsection 412.13 (b) 2 |
| Texture Depth | 1 per 528 linear feet in each lane and shoulder wider than 8 feet. |
| Water Cement Ratio | First three loads each day, then 1/500 cu. yds. |

Subsection 412.10 shall include the following:

The Contractor shall provide a MIT-Scan-2 which is manufactured by MIT GmbH.

The Contractor shall ensure the MIT-Scan-2 is calibrated for the specific dowel bar size or load transfer device being placed, and is operating within the manufacturer’s tolerances. The Contractor shall also ensure that the operator of the MIT-Scan-2 is fully competent in the use of the device. The Contractor shall supply the serial number of the device to be utilized on the project.

In subsection, 412.13 (a) 3rd paragraph, delete the first sentence and replace with the following:

Holes with a diameter 1/4 inch greater than the bar diameter shall be drilled laterally into the hardened concrete slabs at one half the slab depth, 36 inches on center, 15 to 16 inches deep.

In subsection 412.13 (a), delete the 5th paragraph and replace with the following:

When tie bars are placed in plastic state concrete or drilled and epoxied into a construction joint, and if required by the Engineer, the Contractor shall demonstrate by testing at least 15 of the tie bars that the bar pullout resistance is at least 11,250 pounds with slippage of 1/16 inch or less. If two or more tie bars do not meet the required pullout resistance, then another 15 tie bars shall be tested. If any of the second 15 do not meet the required pullout resistance, then all remaining tie bars shall be tested. The Contractor shall perform additional pullout tests and take corrective action when and as directed. All steps taken to test bars, and to correct, repair or replace failed tie bars and the surrounding failed area shall be at the Contractor’s expense. Concrete strength shall have a compressive strength of at least 2500 psi before testing. ASTM E488 shall be used for performing pullout testing..

Delete subsection 412.13 (b) 1 and 412.13 (b) 2 and replace with the following:

*1. Longitudinal Weakened Plane Joints.* Epoxy coated deformed steel tie bars shall be inserted into the plastic state concrete after the auger. In the event the tie bars are placed behind the machine paving mold, vibration will be required during placement. Other methods of bar placement may be acceptable if the Contractor can demonstrate satisfactory performance of the alternate method. Proposals of alternate methods or additional costs associated with other methods shall be at the Contractor’s expense. Tie bars shall be placed according to a method approved by the Engineer. The Contractor shall use an MIT Scan-2 to evaluate the location of tie bars that cannot be visually inspected. Each longitudinal joint located within the dowel bar test locations described in subsection 412.13 (b) 2 that were not visually inspected shall be evaluated with the MIT Scan-2. The MIT Scan-2 shall be calibrated for the tie bar size placed. The tie bars shall be located within the middle third of the slab, and a minimum of ½ inch below the saw cut. Tie bars shall have a minimum embedment of 12 inches on each side of the joint. The weakened plane joint shall be made by sawing in hardened concrete in accordance with the plan details.

Tie bars that are cut during sawing operations shall be replaced at the contractor’s expense. Tie bars that are located less than 2 inches above the bottom of the slab shall be replaced at the contractor’s expense. Tie bars that are not embedded a minimum of 12 inches on each side of the joint shall be replaced. When the spacing between two in-place tie bars exceeds 40 inches but less than 72 inches, a tie bar will be installed halfway between the two tie bars, unless this installation location is within 12 inches of a transverse weakened plane joint. When the spacing between two in-place tie bars exceeds 72 inches, tie bars will be installed at an even spacing not to exceed 36 inches, but shall not be installed within 12 inches of a transverse weakened plane joint. The Contractor shall submit to the Engineer a method for replacing the tie bars. The Contractor shall not proceed to replace the tie bars until the method for replacement has been approved by the Engineer.

*2. Transverse Weakened Plane Joints.* When dowel bars are specified in the Contract, they shall be installed within the tolerances and of the size, grade, and spacing specified. Horizontal support wires or shipping braces shall be non-deformed bars or wires with a diameter less than or equal to 0.307 inches (gauge 0 wire). The number of horizontal support wires or shipping braces shall be limited to five per assembly. The horizontal support wires or shipping braces shall not be cut prior to concrete placement. The center of the dowel assembly or the insertion location shall be marked on both sides of the pavement slab for reference in sawing the joint. Dowel bars shall be furnished in a rigid welded assembly or placed by a dowel bar insertion (DBI) machine.

When a DBI is used, the Contractor shall submit details and specifications of the proposed slip-form paver and DBI to the Engineer a minimum of 14 calendar days prior to the Concrete Pavement Pre-Paving Conference. The Contractor shall detail his methodology for ensuring correct marking of dowel bar insertion points and correct sawing of the joints. The Contractor shall ensure that the slip-form paver is compatible with the DBI.

The rigid assembly shall be fabricated from number 1/0 wire or heavier with vertical support wires every 1 foot. Assembly shall be securely fastened to the subbase and constructed to firmly hold all the dowel bars at T/2 depth, parallel to each other and to the pavement grade and alignment.

See Standard Plan M-412-1 for schematic describing the measurement of each tolerance.

.A weighted-score system will be used to conduct a joint-by-joint evaluation of rotational misalignments of the dowel bars. The Joint Score is a measure of the combined effects of rotational misaligned dowel bars at a joint. A Joint Score is determined by summing the product of the weights (given in Table 412-1) and the number of bars in each misalignment category and adding 1. For example, if a joint has four misaligned bars in the 0.6 to 0.8 inch range, the joint score is 9; if a joint has one misaligned bar in the range 0.6 to 0.8 inch and one bar in the 1 to 1.5 inch range, the score is 8. A Joint Score of 10 is the critical level, above which the risk of joint locking is considered high.

**Table 412-1
WEIGHTING FACTORS USED TO DETERMINE JOINT SCORE**

|  |  |
| --- | --- |
| **Range of Rotational Misalignment** | **Weight** |
| < 0.6 in. | 0 |
| ≥ 0.6 in and < 0.8 in. | 2 |
| ≥ 0.8 in and < 1 in. | 4 |
| ≥ 1 in | 5 |

Individual Dowel Bar Rejection Criteria:

Rotational Alignment:

Any bar with a misalignment greater than 1.5 in.

Longitudinal (side) shift:

Any bar that is not embedded at least 6 inches on each side of the joint

Depth:

Any bar within the top 3 inches of the pavement or at a depth less than the saw-cut depth.

Any bar within the bottom 3 inches of the pavement

When rigid assemblies are used to install dowel bars and the bars are rejected for depth, the Contractor may core the pavement to verify the MIT Scan depth results.

Joint Rejection Criteria:

Any joint with a Joint Score greater than 10. An individual joint may be allowed if the two longitudinally adjacent joints each have a joint score less than or equal to 10

Any joint that does not have at least three acceptable dowel bars in each wheel path.

Corrective Measures: The following corrective measures will be allowed for the bars or joints that are rejected.

Rotational misalignment.

Saw-cut the misaligned bars. Joints with less than three un-cut bars in each wheel path will require the addition of dowel bars using an approved dowel bar retrofit method.

Longitudinal (side) Shift and missing bars.

Addition of dowel bars using an approved dowel bar retrofit method.

Depth.

Inadequate cover above the bar—Remove the bar and install a replacement bar using an approved dowel bar retrofit method*.*

Inadequate cover below the bar— Addition of dowel bars using an approved dowel bar retrofit method*.*

Retrofitted dowel bars shall not exceed the dowel bar rejection criteria.

In addition to the above procedures, the Contractor may propose removal and replacement of the affected slabs.

The Contractor shall submit his method of repair to the Engineer for approval.

The Contractor shall demonstrate his ability to place dowel bars in conformance with the specifications by placement of a test section.

The test section shall be a minimum of 300 feet in length. Upon completion of the test section, the Contractor shall shut down paving operations. During the shutdown period, the Contractor shall evaluate all joints in the test section using the MIT-Scan-2, analyze the results and submit the results to the Engineer. Paving operations shall not be restarted until the Engineer approves the test section results. The test section will be found acceptable if 85% of the dowel bars placed are found to be within the rejection criteria. All dowel bars exceeding the Rejection Criteria must be addressed using the above corrective measures. The Contractor may continue paving at his own risk before the test section evaluation is complete.

If the Project has less than 500 linear feet of pavement, the test section will not be required. If a Project does not have sections of continuous pavement greater than 45 linear feet, the test section will not be required.

Upon completion of the test section(s) and for each week of production, the Contractor shall prepare an electronic report generated using MagnoProof software and submit it to the Engineer at the start of each working week during production for the previous weeks work. All data shall be submitted in the manufacturer’s native file format, along with the calibration files.

The electronic report shall include the following:

1. Contract number, date, highway number and direction of traffic.
2. Joint number, lane number and station.
3. Bar number and x-location of dowel bar.
4. Horizontal and vertical misalignment of each bar in inches.
5. Overall misalignment of each bar in inches of each bar
6. Side shift of each bar in inches.
7. Depth to center of each bar in inches.
8. Joint Score
9. All measurements exceeding the rejection criteria shall be highlighted in red.

Due to potential magnetic interference from tie bars, dowel bars located within 15 inches of a tied joint shall not be included in the evaluation.

When the test section is found to be unacceptable, the Contractor shall perform corrective actions and place a second test section. If the second test section is found to be unacceptable, the Contractor shall pave no more than 500 feet per day until an acceptable test section has been achieved.

Once a test section is successfully completed, Dowel Bar Placement testing frequency shall be a minimum of one location per 1,250 linear feet of each continuous lane including climbing lanes, passing lanes, acceleration and deceleration lanes and ramps. Sections greater than 45 linear feet and less than 1,250 linear feet require a minimum one of test location. . Testing locations shall be determined by a random procedure so that each area has a randomly selected transverse joint location. At each location, five consecutive joints shall be tested.

Sections of continuous pavement constructed by the project less than 45 linear feet will not require Dowel Bar Placement Testing.

When any joint score is greater than10 or any one bar in a single joint exceeds the rejection criteria, joints shall be tested in each direction from the rejected joint, until two consecutive joints in each direction are found to be within the rejection criteria.

All delays or costs associated with equipment being rejected for use by the Engineer will not be paid for by the Department, and will be considered a Non-excusable Delay in accordance with subsection 108.08 (c) 2.

When concrete shoulders or widenings are constructed subsequent to the driving lanes, transverse weakened plane joints shall immediately be formed in the plastic concrete of these widenings to create an extension of the existing transverse joint. This tooled joint shall be formed in such a manner that it controls the cracking and shall be sawed and sealed in accordance with the above requirements.

In subsection 412.21, delete the first sentence in the sixth paragraph.

In subsection 601.02, delete Class E and P Concrete from Table 601-1 and replace with the following:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Concrete Class** | **Required Field Compressive Strength (psi)** | **Cementitious Material Content: Minimum or Range (lbs/yd3)** | **Air Content: % Range (Total)** | **Water /Cementitious** **Material Ratio: Maximum or Range** |
| **E** | 4500 at 28 days | 520 | 4 – 8 | 0.44 |
| **P** | 4500 at 28 days | 520 | 4 – 8 | 0.44 |

In subsection 601.02, delete the sixth and ninth paragraphs and replace with the following:

**Class E** concrete is used for fast track pavements needing early strength in order to open a pavement to service soon after placement. Class E concrete shall meet the requirements of Class P concrete. ASTM C150 Type III or ASTM C1157 Type HE cement may be used. Accelerating admixtures may be used.

**Class P** concrete is used in pavements. Additional requirements are: The Required Field Flexural Strength shall be 650 psi when flexural strength acceptance is specified. The laboratory trial mix shall produce a minimum average 28 day flexural strength 700 psi. Two aggregate gradation options are available:

1. *Standard Gradation (SG).* The concrete mix shall consist of a minimum 55 percent AASHTO M 43 size No. 357 or No. 467 coarse aggregate by weight of total aggregate. If all transverse joints are doweled, the concrete mix shall consist of a minimum 55 percent AASHTO M 43 sizes No. 57, No. 6, No. 67, No. 357, or No. 467 coarse aggregate by weight of total aggregate.
2. *Optimized Gradation (OG).* Aggregate proportions must be a result of an optimized combined aggregate gradation (CAG) developed by an approved mix design technique such as Shilstone or KU Mix. The amount of aggregate in the CAG passing the 19 mm (¾ inch) sieve and retained on the12.5 mm (½ inch) sieve shall be a minimum of 8 percent for the trial mix design. The coarseness factor (CF) and workability factor (WF) must plot within the workability box (ABCD) depicted graphically by the following 4 coordinate points:
3. Point A> (CF,WF) 72, 31
4. Point B> (CF,WF) 44.5, 35
5. Point C> (CF,WF) 44.5, 43.5
6. Point D> (CF,WF) 72, 40

Figure 601-1



CF = (S / T) x 100

Where:

S = Percent Cumulative Retained on 9.5 mm (3/8 inch) Sieve

T = Percent Cumulative retained on 2.36 mm (No. 8) Sieve

WF is the percent passing the 2.36 mm (No. 8) sieve. Increase workability factor by 2.5 percentage points for every 94 pounds per cubic yard of cementitious material used in excess of 564 pounds per cubic yard in the mix design. Decrease workability factor by 2.5 percentage points for every 94 pounds per cubic yard of cementitious material used below 564 pounds per cubic yard in the mix design. Do not adjust the workability factor if the amount of cementitious material is 564 pounds per cubic yard.

Delete Subsection 601.05 (7) and replace with the following:

(7) Class E and P concrete shall include AASHTO T97 (ASTM C78) Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading). When compressive strength is indicated, at least two specimens will be tested at 7 days and four specimens at 28 days. When flexural strength is indicated, at least two specimens will be tested at 3, 7 and 14 days and four specimens at 28 days.

When flexural strength is indicated, the mix design shall include AASHTO T198 (ASTM C496) Splitting Tensile Strength of Cylindrical Concrete Specimens. At least two specimens will be tested at 3, 7and 14 and 28 days. The splitting tensile strength specimens for each age shall be cast from the same trail batch as the same age flexural strength specimens. Multiple trial batches may be used. The Engineer will verify the correlation curve during production by casting and testing Splitting Tensile specimens. If the correlated flexural strength of the splitting tensile sample is not within 50 psi of the verification beam specimen’s flexural strength, a new correlation curve shall be required if low flexural strength specimen are to be evaluated.

Subsection 601.05 shall include the following in the second paragraph:

 (8) Class P concrete with an OG shall indicate the gradation proportions that results in a combined aggregate gradation corresponding to compliance within the specified CF and WF box and shall include the following charts used to perform aggregate gradation analysis:

1. Coarseness Factor
2. Workability Factor
3. 0.45 power
4. Combined gradation

Delete Subsection 601.06 (10) and (11) and replace with the following:

(10) Weights of fine and coarse aggregates or combined weight when an OG is pre-blended

(11) Moisture of fine and coarse aggregates or combined moisture when an OG is pre-blended

Subsection 601.06 (c) shall include the following:

Aggregates for Class P concrete using an OG, a combination of aggregates (stockpiled separately) shall be combined prior to the stationary charging drum to meet the approved CAG.

In subsection, 709.03, delete the first paragraph and replace with the following:

**709.03 Dowel Bars and Tie Bars.** Tie bars for longitudinal and transverse joints shall conform to AASHTO M 284 and shall be grade 60, epoxy-coated, and deformed. Bar size shall be as designated on the Standard Plan M-412-1.

Colorado Procedure 65-15a

# Standard Practice for

## EVALUATING LOW CONCRETE STRENGTH TEST RESULTS OF CONCRETE CYLINDERS

**1. SCOPE**

1.1 Field test procedures and strength test results for standard molded and cured cylinders and beams shall be evaluated separately for each class of concrete. Such evaluation shall be conducted to determine if tests have been conducted in accordance with the ASTM, AASHTO and/or approved CDOT procedures and specifications.

1.1.1 The evaluation process will include investigation to ensure that proper procedures were followed in the following areas:

-Molding

-Curing methods and temperatures

-Initial curing period

-Laboratory curing period

-Testing procedure

-Personnel qualifications

**NOTE: Contact the Central Laboratory at (303) 398-6543 at least 48 hours before coring so that additional instruction can be given.**

1.2 This practice is comprised of two methods. Method A for evaluation of low concrete compressive strength and Method B for the evaluation of low concrete flexural strength.

**2. EVALUATION**

2.1 Should cylinders or beams fall below the specified strength, a field investigation will be conducted as follows:

2.1.1 If test procedures outlined in Subsection 1.1 were not followed, results will be considered to be invalid and the tests shall be discarded. If cores are required, they will be at the expense of CDOT to replace acceptance cylinders and at the expense of the Contractor to replace QC beams.

2.1.2 The concrete supplier will furnish concrete batch tickets of the suspected low strength concrete for comparison against approved mix design.

2.1.3 Batch tickets will be checked to determine job site water addition.

2.1.4 Evaluation of the concrete in question will be made based on Subsections 2.1.1, 2.1.2 and 2.1.3.

**3. Section Deleted**

**4. CORING**

4.1 This procedure describes the method used to obtain and evaluate cores from in-place concrete. This will be performed in accordance with the latest revision of AASHTO T 24 (ASTM C 42), with the exception that immediately after removal from the structure, cores will be cured at a temperature between 60o - 80oF (15o - 27oC) and at a relative humidity below 60% for the first 24 hours.

4.2 Cores taken for the determination of strength shall be of a standard size and within appropriate tolerance.

**NOTE 1** Bits cut approximately 1/4" smaller than nominal OD (outside diameter). The 4 1/4" and 6 1/4" OD bits produce 4" and 6".

**5. APPARATUS**

5.1 The apparatus shall be as described in AASHTO T 24 (ASTM C 42).

**Method A Compressive Strength**

**6. PROCEDURE**

6.1 Within 45 days after placement, cores with a diameter at least 3 times the nominal maximum size of the coarse aggregate used in the concrete shall be obtained in accordance with AASHTO T 24 (ASTM C 42). The cores shall be conditioned in accordance with Subsection 4.1. The cores will then be tested for compressive strength between 24 and 48 hours after removal.

6.2 At least 3 representative cores shall be taken from the concrete represented by each out- of-specification cylinder set.

6.3 Coring location shall be in locations directed by the Engineer. .

6.4 Core holes shall be filled with low slump concrete or mortar.

6.5 If the compressive strength of any one core differs from the average by more than 10% that core will be discarded and the average will be determined using the compressive strengths of the remaining two cores. If more than one core’s compressive strength differs from the average by more than 10%, the average will be determined using all three cores.

6.6 Pay factors for strength of structural concrete shall be according to Table 601-3 of the CDOT Standard Specifications, and will be used to price reduce the cores or standard test cylinders, whichever are higher in strength. Pay factors for concrete pavement will be evaluated according to subsection 105.06 of the CDOT Standard Specifications.

6.7 The following examples are for structural concrete in accordance with Subsection 601.17 of the CDOT Standard Specifications:

**Example 1:**

Given: f 'c = 3000 psi

Concrete test cylinders averaged 2800 psi.

PSI

Core 1 2900

Core 2 2850

Core 3 2450

Average compressive strength of 3 cores = 2730 psi.

Find: Is the concrete in the structure adequate under CDOT specifications?

Solution:

Test Evaluation:

f 'c = 3000 psi

Average compressive strength of 3 cores - 2730 psi

Do any compressive strengths differ from the average by more than 10%?

10% of Average compressive strength = 273 psi

Core 1: 2900 - 2730 = 170 psi, < 273 therefore OK

Core 2: 2850 - 2730 = 120 psi, < 273 therefore OK

Core 3: 2730 - 2450 = 280 psi, > 273 therefore -discard core and re-compute average compressive strength using two remaining cores.

New average compressive strength = 2875 psi

Use Table 601-3 to compute appropriate price reduction based on 2875 psi, since core strengths were higher than the cylinders strengths.

**Example 2:**

Price Reduction of Concrete

In this example calculation, a certain project has a pay item for 720 cubic yards of Concrete Class D (bridge). The contractor bid $700 per cubic yards. To cover this quantity 8 sets of cylinders were molded and tested for compressive strength at 28 days. Some of the test results showed the concrete had less than the required 28-day compressive strength of 4500 psi. The project engineer has used all eight sets of cylinders to calculate the appropriate price reduction.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|   |   |   |   | Average  |
|   | Cylinder | Cylinder | Cylinder | Cylinder  |
| Test | Strength | Strength | Strength | Strength |
| Number | psi | psi | psi | Psi |
| 1 | 4510 | 4270 | 4580 | 4450 |
| 2 | 6200 | 6100 | 6250 | 6180 |
| 3 | 3800 | 4310 | 3840 | 3980 |
| 4 | 4210 | 4380 | 4060 | 4220 |
| 5 | 4040 | 3830 | 3790 | 3890 |
| 6 | 4130 | 4020 | 3930 | 4030 |
| 7 | 4710 | 4670 | 4790 | 4720 |
| 8 | 4960 | 5160 | 5200 | 5110 |

**TABLE 65-1**

 The average strength of three 28-day cylinders is used to determine the acceptability of concrete placed in a structure. The break results of test numbers 1, 3, 4, 5 & 6 are below the required 28-day strength of 4500 psi for bridge decks. According to Section 601.17(c) of the CDOT Standard Specification for Road and Bridge Construction “The concrete will be considered acceptable when the running average of three consecutive strength tests is equal to or greater than the specified strength and no single test falls below the specified strength by more than 3.5 MPa (500 psi).”

|  |  |  |  |
| --- | --- | --- | --- |
|   |  Average | Average  |   |
|   | Cylinder | of Three | Strength |
| Test | Strength | Consecutive | Below fc' |
| Number | psi | Tests (psi) | psi |
| 1 | 4450 | --- | --- |
| 2 | 6180 | --- | --- |
| 3 | 3980 | 4870 | 520 |
| 4 | 4220 | 4793 | 280 |
| 5 | 3890 | 4030 | 610 |
| 6 | 4030 | 4047 | 470 |
| 7 | 4720 | 4213 | --- |
| 8 | 5110 | 4620 | --- |

**TABLE 65-2**

 The table above shows that the running average of three consecutive tests fall below the required strength of 4500 psi, and the concrete placed will be price reduced according to the pay factors in Table 601-3 in Subsection 601.17. Test numbers 3, 4, 5, & 6 are represented in the low consecutive averages and will be price reduced. Test number 1 is considered acceptable and will not be price reduced because its running average with the next two tests is greater than the required strength, and it is not more than 500 psi below the required strength.

 To price reduce the low strength results you need to know the bid price for the concrete, and the quantity represented by each test. As stated above, the concrete was bid at $700.00 per cubic yard. The contractor placed 720 cubic yards of Concrete Class D (bridge). The 720 cubic yards are represented by 8 sets of cylinders. Therefore, on this project the Engineer determined that each test represents 90 cubic yards. This is only an example and the quantity represented per test shall be determined by the Project Engineer. The formula for price reduction is:



Where:

 PR = Price Reduction,

 P = Bid Price of Concrete,

 PF = Pay Factor from Table 601-3 of Subsection 601.17,

 CY = Cubic Yards represented by the test.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Average |  | Pay |  |
|  | Average | of Three | Strength | Factor |  |
| Test | Strength | Consecutive | Below fc' | Table | Price |
| Number | Psi | Tests (psi) | psi | 601-2E | Reduction |
| 1 | 4450 | --- | --- | --- | --- |
| 2 | 6180 | --- | --- | --- | --- |
| 3 | 3980 | 4870 | 520 | 0.65 | $22,050.00 |
| 4 | 4220 | 4793 | 280 | 0.92 | $ 5,040.00 |
| 5 | 3890 | 4030 | 610 | 0.54 | $28,980.00 |
| 6 | 4030 | 4047 | 470 | 0.75 | $15,750.00 |
| 7 | 4720 | 4213 | --- | --- | --- |
| 8 | 5110 | 4620 | --- | --- | --- |
|  |  | Total Price Reduction | $71,820.00 |

**TABLE 65-3**

 The Contractor has the option to obtain cores from the areas represented by tests 3, 4, 5 & 6 before the concrete is 45 days old. Coring will be in accordance to CP 65. In this case the contractor elected to obtain cores from the bridge deck. The following is a summary of the core break results:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  | Average |
|  | Core | Core | Core | Core |
| Test | Strength | Strength | Strength | Strength |
| Area | psi | psi | psi | psi |
| 3 | 4230 | 4010 | 4100 | 4110 |
| 4 | 4630 | 4570 | 4510 | 4570 |
| 5 | 3690 | 3740 | 3700 | 3710 |
| 6 | 4270 | 4510 | 4400 | 4390 |

**TABLE 65-4**

 The core strength results will replace the cylinder strength results if the core strengths are higher. In this case, cores from areas 3, 4 & 6 will replace the cylinder strength results for tests 3, 4 & 6. The following table shows the new price reductions:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Average | Average |  | Pay |  |
|  | Cylinder | Core | Strength | Factor |  |
| Test | Strength | Strength | Below fc' | Table | Price |
| Number | psi | psi | psi | 601-2E | Reduction |
| 1 | 4450 | --- | --- | --- | --- |
| 2 | 6180 | --- | --- | --- | --- |
| 3 | 3980 | 4110 | 390 | 0.84 | $ 10,080.00 |
| 4 | 4220 | 4570 | --- | --- | --- |
| 5 | 3890 | 3710 | 610 | 0.54 | $28,980.00 |
| 6 | 4030 | 4390 | 110 | 0.96 | $ 2,520.00 |
| 7 | 4720 | --- | --- | --- | --- |
| 8 | 5110 | --- | --- | --- | --- |
|  |  | Total Adjusted Price Reduction | $41,580.00 |

**TABLE 65-5**

**Method B Flexural Strength**

**7. PROCEDURE**

7.1 Within 45 days after placement, cores of the same size as the splitting tensile cylinders used in the trial mix shall be obtained in accordance with AASHTO T 24 (ASTM C 42). The cores shall be conditioned in accordance with Subsection 4.1. The cores will then be tested for splitting tensile strength between 24 and 48 hours after removal.

7.2 At least 3 representative cores shall be taken from a single slab represented by each low flexural strength. A core containing rebar or dowel bars shall be discarded and a new core shall be taken.

7.3 Coring location shall be in locations directed by the Engineer. .

7.4 Core holes shall be filled with low slump concrete or mortar.

7.5 If the splitting tensile strength of any one core differs from the average by more than 10% that core will be discarded and the average will be determined using the splitting tensile of the remaining two cores. If more than one core’s splitting tensile strength differs from the average by more than 10%, the average will be determined using all three cores.

7.6 The flexural strength of the concrete will be determined by using a correlation of the concrete’s flexural strength to its splitting tensile strength.

7.6.1 Using the flexural strength and splitting tensile strengths from the concrete’s trial mix, for each age, plot the flexural strength on one axis and the splitting tensile strength on the second axis. Determine a linear equation relating the two strengths.

7.6.2 Using the average splitting tensile strength from a set of cores, and the equation in section 7.6.1, determine the corresponding flexural strength.

7.7 Pay factors for concrete pavement will be evaluated according to subsection 105.06 of the CDOT Standard Specifications.

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REVISION OF SECTIONS 105, 106, 412, 601 AND 709

CONFORMITY TO THE CONTRACT OF PORTLAND CEMENT CONCRETE PAVEMENT AND DOWEL BARS AND TIE BARS FOR JOINTS

**Example 3:**

The following example shows a plot of flexural strength and splitting tensile strength.

|  |  |  |
| --- | --- | --- |
| Age | Average Flexural Strength (psi) | Average Splitting Tensile Strength (psi) |
| 3 | 545 | 480 |
| 7 | 580 | 505 |
| 14 | 635 | 560 |
| 28 | 720 | 650 |

