1006 PORTLAND CEMENT CONCRETE

1006-1 General Requirements

This specification deals with Portland cement concrete. Included are component materials, design, mixing, transporting, and curing, as covered in the Standard Specifications. Placing and finishing concrete are covered by Specifications 401 and 601. Utility concrete is covered by Specification 922.

Refer to the Standard Specifications and *Materials Group Policy & Procedures Directives Manual* for additional information on Portland cement concrete inspection guidelines.

Good consistency control of concrete is of primary importance. It should be noted that other factors being equal, an increase in the water cement ratio of 0.4 gallon (1.5 liters) per sack of cement will result in an increase in slump of approximately 1 inch (2.5 millimeters) thereby causing a potential loss in compressive strength of about 100 pounds per square inch (700 kilopascals). Over-watered concrete also increases segregation and shrinkage. This is not to say that concrete having a very low slump should always be used. Good judgment must be exercised.

The concrete Inspector should be aware of the factors which affect the slump of a concrete mix. The following are some of those factors:

1. Variations in water content have a very pronounced effect on the slump. A change of 1% in the amount of free moisture in the fine, or 3% in the coarse aggregate can change the slump about 1/2 inch (12 millimeters).

2. A change of 1% in the amount of entrained air may alter the slump by approximately 1/2 inch (12 millimeters). An increase in air causes an increase in slump.

3. A fineness modulus of the sand is important because of its effect on the water demand of the mix. The finer the sand, the lower the F.M., the more water required for a given slump. The fineness modulus of sand is obtained by adding the cumulative percentages retained on the following standard sieves: 4, 8, 16, 30, 50, and 100 (metric sieves 4.75 mm, 2.36 mm, 1.18 mm, 600 □m, 300 □m, 150 □m). The total is then divided by 100.

Under these specifications, duties such as checking the stockpiles for moisture and adjustment of the mix are the Contractor's responsibility.

For simplicity, the inspection duties to be performed by ADOT personnel are separated into two categories: plant and site inspection. Documentation of inspection is necessary and will be made as follows:

1. The number of random checks to be made is at the discretion of the individual Resident Engineer or Project Supervisor. The number of random checks needed to document the acceptability of the aggregates will vary. In areas where testing has indicated a uniform product that meets specifications and which has been properly stockpiled to minimize segregation, the sampling guide minimum will probably be sufficient. In cases where testing has shown the material to be borderline or the stockpiles show segregation or excess moisture, extensive sampling may be required.

2. Frequent visits should be made to observe plant operations during the time material is being batched for the project. Although ADOT does not control the batching and mixing, it is important that project personnel assure all plant procedures are meeting standards. If problems are found they must be

discussed and resolved with all parties involved. The Contractor should be advised in writing the first time a discrepancy occurs.

When inspecting the plant some of the things to look for are:

1. Inspect/check the aggregates to see that there is no intermingling of aggregates from one stockpile or bin to another of a different gradation. Inspect for foreign material and contamination. If any of these conditions occur, you should stop production until the condition is corrected.

2. Inspect the aggregates for moisture content and inform the Contractor of your findings. Although we do not control the mix, every expedient shall be used to obtain and preserve uniform moisture content in the aggregates.

3. Inspect the cement storage. Inspect for caked cement that may be due to long storage time.

4. Inspect additive dispensing equipment. Agitation of these materials is not required by the Standard Specifications; however, it is believed to be necessary in all cases to assure that the original quality of the material is maintained. Agitation should be accomplished by the use of an air jet extending to the bottom of the container.

5. If concrete is being mixed in truck mixers, determine that mixers are in good condition and display on an approved inspection sticker in accordance with *Materials Group Policy & Procedures Directives Manual (PPD No. 7)*.

6. Verify that the mix designs submitted by the Contractor and approved by the Department is the correct design for the concrete strength (f'c) being used.

7. Check the batch ticket for correct information. The copy of the Contractor's or supplier's invoice (delivery ticket) provided for each load of concrete will be acceptable. Documentation of inspections will be made on the applicable invoice. It will not be necessary for ADOT Inspectors to fill out the concrete test report form for each load of concrete supplied. The minimum information to be shown on each invoice shall be the date, time batched, truck identification number, name or identification of the batch plant, name of the Contractor, name and location of the project, volume of the concrete, the number of revolutions the concrete has been mixed, the batch weights or mix design code number, the percent free moisture in the coarse and fine aggregates, the water withheld during batching, and any water added to the mix at the site. When samples for strength tests are taken, the concrete test report form will be completed by the ADOT Inspector and will accompany the cylinders to be tested.

8. Check the time cement is added to the batch to assure that the proper time has been recorded on the ticket. (90 minutes is the maximum time allowed for discharge.)

9. Make sure the revolution counter has been zeroed before mixing. Check mixing time and revolutions (at the plant). Document these on the delivery ticket, initial it, and return it to the driver.

10. All plant inspections and verifications must be well documented. All information, referring to a particular batch should be recorded (and initialed) on that batch ticket.

11. Any water added to a batch after the batching procedure will be measured and documented. (See placement site inspection requirements.) Measurement using a clean, calibrated sight glass is acceptable.

It is important that the complete plant operation be observed for addition of water other than in the batching operation. This is important to assure the maximum water/cement ratio is not exceeded.

The previously cited guidelines do not require full time inspection at the batch plant but it is advisable to have an Inspector watch the operation during the first day's production and on all-important major placements.

No concrete should be placed except in the presence of the concrete Inspector. Some of the duties of this Inspector are as follows:

1. Check the batch ticket to see if the correct concrete has been delivered. (See the Standard Specifications)

2. Observe the discharge of all concrete for acceptability (slump, air, segregation, etc.). If concrete slump is too low, it may have additional water incorporated, followed by additional mixing. Care should be exercised to be sure the problem of low slump is caused by low water. There may be other reasons for a low slump that water will only make worse. For example; sand too fine, or inadequate mixing.

3. Document any additional water added, mixing revolutions, temperature of concrete, and discharge times on the delivery ticket. The Contractor should not be permitted to move concrete down the chute with a vibrator since this segregates the concrete as it flows.

4. Document time each load is completed discharging.

5. Document where each load of concrete is placed, and how much of the load is placed there.

6. Take slump, air, and cylinder tests as specifications require, or as required to assure compliance of the concrete.

1006-2 Materials

1006-2.01 Hydraulic Cement

The Contractor is required to state the type and sources of cement when he submits his mix design.

Refer to the *Materials Policy and Procedures Directive Manual (PPD No. 13)* for certification and acceptance of hydraulic cements and fly ash.

1006-2.02 Water

The Contractor should identify the source when he or she submits his or her mix design. If the water is from a potable supply obtained from a public utility, no testing is required, however a memo stating this should be submitted to Materials Group. Water obtained from any other source shall be sampled and tested.

1006-2.03 Aggregate

(A) General Requirements

The production of aggregates meeting the specification requirements is the Contractor's responsibility but this does not mean that the Engineer may divorce himself from all involvement in this phase of the work.

During aggregate production, the Engineer will periodically observe the production methods, the sampling and testing, and stockpiling and handling to determine whether the methods used will result in acceptable products. If the Engineer finds any shortcomings or problems he should discuss these with the Contractor and document the details. The Engineer will not do production control testing; quality control is entirely the Contractor's responsibility.

Aggregates must be inspected during production to make certain that they do not become segregated through improper handling or stockpiling practices, and that they do not become contaminated. Allowing equipment with steel tracks to operate on stockpiles will tend to break edges of coarse aggregate. This material filters down through the voids and may cause the lower portions of the coarse aggregate stockpile to be out of grading specifications due to the self-contamination.

Uniformity of moisture contents is essential in the production of a concrete mix of uniform consistency. It is necessary to have uniform consistency, particularly in bridge decks, to avoid shrinkage and finishing problems. In slip form concrete pavement, it avoids edge slumping, shrinkage of the concrete, and finishing problems. Aggregate which comes directly from washing plants should remain in the stockpile long enough so that no free drainage is visible when the aggregate is transported to the mixer. Aggregate proposed for use in concrete pavement should not vary in moisture content more than 3% in any one work shift if good slump control is to be maintained.

An excess of moisture may collect in the bottom of a sand stockpile. The bottom 1 foot (0.3 meter) of a stockpile cannot be used, unless the aggregates are stockpiled on a paved surface. If the Contractor elects to reclaim the bottom of a stockpile, he will be required to do sufficient testing to be sure that the material conforms to the Standard Specifications; this may require much more testing than is needed when producing the aggregate originally.

The Contractor's sampling for moisture tests should be at intervals governed by existing conditions. If the moisture is known to be variable or if some event or production change affects the moisture, more frequent sampling may be called for. A reasonable frequency is one or two per day, if visual observation indicates little or no change.

1006-2.04 Admixtures

(A) General Requirements

The Contractor has the option of using admixtures for adjusting time of set, adding air, or for reducing water in the mix. If the admixtures have not been used with the aggregates or in the quantities proposed, the Contractor will have to test the admixtures using the proposed aggregates to determine the proper amounts to be used. Combining admixtures can result in undesirable effects that cannot be known without testing.

The mechanical dispensing devices used for admixtures must be accurate to within narrow limits so they need to be carefully checked to see that they operate properly. Some admixtures are used at rates as low as 2 or 3 fluid ounces per 100 pounds (59 or 89 milliliters per 46 kilograms) of cement, therefore, it can be seen that the dispensing equipment needs to be accurate. Accuracy checks are made by actual measurement of the material as it is dispensed.

Admixtures may be used prior to testing provided an acceptable Certificate of Compliance has been received. Refer to the sampling guide and current *Policy and Procedure Directive Manual (PPD No. 2)*.

(B) Air Entraining Admixtures

The Contractor must add air entrainment when it is called for, but the air content shall not exceed 7% and temperature must be documented.

1006-3 Design of Mixtures

1006-3.01 Design Criteria

Even though the following discussion is based on ADOT design procedures, the principles apply equally to designs by a Contractor or a private laboratory. ADOT design procedures are covered in greater detail in the *Material Testing Manual*. This Manual should be in every Construction Office.

1006-3.02 Design Procedures

Approval of Portland cement concrete mix designs is described in the *Materials Policy and Procedure Directives Manual (PPD No. 15)*.

Checking the mix design is essentially the responsibility of the Regional Laboratory; however, it is important that the project personnel are able to check mix designs and evaluate mix adjustments based on the design procedures. The concrete field Inspector should be able to perform the design calculations and to understand the relationships between the various design criteria.

After the Regional Laboratory has checked the mix design, a trial mix may be produced to check the mix design against actual field conditions.

If it is found that the "trial mix" does not give the correct slump and checking has shown that the water in the aggregates has been accurately accounted for and corrected in the field mix, then it may be necessary to change the amount of water being used to obtain the specified slump.

Changes must remain within the specifications and mix design limits. If greater changes are needed, a new mix design will be required.

If it becomes necessary to increase water by more than 3 gallons per cubic yard (15 liters per cubic meter) over the design amount, the Regional and Central labs should be notified. Decreases in water are generally beneficial but if the decrease is substantial, the mix design should be checked.

1006-4 Concrete Production

1006-4.01 General Requirements

Portland cement concrete is strength specified and there are penalties against the Contractor if his product does not meet the strength requirements. Proper sampling, molding and curing of test cylinders is of the utmost importance. The specified procedures are to be followed without variation.

The anticipated strength is used by the designer to determine the strength characteristics of the structure. If the 28-day strength is below that specified or if the Contractor's 7-day strength indicates that the 28-day strength may be lower than the anticipated strength, then an immediate study should be made to see if there is any deficiency in the materials, proportioning, or procedure. Low strength is usually an indication that something is

not being done as it should be done and is an immediate signal for investigation. The District Office should be notified whenever low strength is detected. No adjustments for low strength should be made without District Office and Regional Lab approval.

The yield, as determined by form measurement, will normally be short from 3% to 5%. The reasons for this normal loss may be attributed to such things as spillage, loss of moisture and the fact that mixer truck cannot be completely discharged. Also, when concrete is placed in the forms, expansion of the forms accounts for part of the loss. The mix will not be adjusted to correct for actual yield variations based on form volumes.

Remember that the discussion in this section is only a guide for the Resident Engineer to enable him to judge whether the Contractor is controlling the mix using acceptable practices. The Resident Engineer is not to order any of the adjustments discussed in this section; control of the mix is wholly the Contractor's responsibility. If acceptable procedures are not followed, the Contractor should be so notified and the conditions documented.

1006-4.02 Proportioning

There will probably be minor adjustments needed due to one or more of the following causes:

1. Moisture content of aggregate being used.

2. Variation in air content.

3. Variation in slump.

All the variations can be corrected by field adjustments. However, judgment is needed to determine when to consult with the Region before allowing the Contractor to make adjustments. Major adjustments may require the Contractor to submit a new mix design.

The mix design is designed on the basis of an absolute volume of 27 cubic feet (0.765 cubic meters) and aggregates in the saturated surface dry (SSD) condition.

All equipment should be inspected to assure that all scales, dials, metering devices, etc. are graduated within allowable tolerances and accurate as outlined in the specifications.

(B) Water

It is extremely important that the amount of water being used in the mix be known at all times; therefore, the water tank or water meter should be the first piece of equipment to be calibrated. This can be done by drawing off water and measuring or weighing the amount for different settings of the gauge or meter. Water valves should be inspected to make certain there are no leaks into the mix.

(C) Aggregates

The amount of mixing water will probably have to be adjusted to allow for the moisture content variations as the stockpiles are used. It is preferable that stockpiles are kept in a SSD condition to minimize adjusting mixing water. The Contractor should make moisture determinations at least daily or as often as conditions require.

Scales for weighing cement and aggregate should be inspected for condition of working parts and knife edges. Hoppers should be inspected to make certain that there is no possibility of leakage and that each hopper empties completely. Make certain that the cement hopper is equipped with one or more suitable vibrators as required by the Standard Specifications.

Batching scales must be checked and certified by the Department of Weights and Measures before any production begins. Certified 50 pound (22.680 kilogram) weights furnished by the Contractor or supplier should be available at all times for checking these scales. To check scales using these weights, use the DWM approved procedure. If the scales are not accurate within the limits of the specifications, they should not be used until repaired or adjusted. The scales should be balanced several times each shift and should be retested when deemed necessary by the Engineer

(D) Admixtures

It should be noted that the Standard Specifications require that any admixture added shall be added by means of mechanical dispensing equipment. The Inspector should examine and test the dispensing equipment to see that it functions properly and that the amount of admixture can be accurately measured and also that the amount of admixture used can be readily adjusted.

The mix design will show the amount of air entraining agent estimated to be required to give the specified air content. It must be realized, however, that the effectiveness of air entraining agents may be changed by the effectiveness of the mixing of the concrete. The mixing action of the particular mixer employed may have an effect on the amount of air entrained. The amount of air entrained by a large batch mixer or a transit mixer might be much greater or less than the amount obtained by a somewhat smaller mixer.

The amount of air entrained is also variable with the temperature of the mix. The effectiveness of the air-entraining agent is ordinarily decreased with higher temperatures or increased with lower temperatures. It can be seen that the amount of air entraining agent required in the field might be entirely different from the originally recommended amount.

After one or two tests have been made to determine the amount of air entrained, it will often be found necessary to increase or decrease the amount of air entraining agent used on future batches. After the correct amount is once determined, the same amount will usually continue to be satisfactory unless there is considerable temperature change or some other variation which might affect the results.

If it is noted during construction that a high or a low air content has been obtained, one or two check tests should be made immediately. If these check tests confirm the original result then adjustments should be made in the amount of air entraining agent used. (Air meters sometimes get out of adjustment. To assure that results are correct, the air meter should be calibrated prior to each day's use.)

There is one other factor which sometimes affects the quantity of air entraining agents required. Some of these agents have a tendency to settle or separate in the drum. Agitation of these materials is not required by the Standard Specifications, however, it is believed to be necessary in all cases to assure that the original quality of the material is maintained. The Engineer should therefore require such agitation at lease once daily when the material is being used.

1006-4.03 Mixing

(A) General Requirements

Because the Contractor is responsible for the concrete does not mean that the Resident Engineer is unable to reject material that is obviously improperly batched. Likewise, if batching equipment is malfunctioning, the Engineer has the authority to refuse the product. All information regarding improper batching or malfunctions of equipment must be carefully documented by the Engineer.

In order to assure that the Contractor will be able to control concrete production, the Resident Engineer will have to inspect the batching and mixing equipment for proper operation including checking the weighing devices in actual operation.

Checking will begin with the stockpiled aggregates to see that the stockpiles do not become segregated and that intermingling of stockpiles does not occur. Adequate bulkheads or pile separation will prevent mixing as the piles are built and when material is removed. Spillover in batching bins is fairly common when the bins are loaded with an end loader. It is not unusual to find good stockpile control but poor control in the bins. While the Engineer cannot direct changes in the Contractor's operation, they do have the authority to refuse to accept material that is produced when the equipment is not functioning properly. Whenever material is rejected because of faulty processing, it is important to be sure of what the mechanical problem is, what the effect on the final product is, and to carefully document all the details. It goes without saying that every effort should be made to induce the Contractor to operate efficiently without getting into the position of having to reject the material being produced.

(B) Mixing in a Stationary Mixer

After the field mix has been determined by the Contractor, the weights of each size of aggregate, cement, water, air entraining agent, and admixtures, if any, are usually given to the operator for posting on the scales. Any subsequent change in the weights due to a change in the proportions or a change in the free moisture content, should be posted, by the Contractor, on the scale and copies provided to the operator. Each change should be noted in the Inspector's records, with each one being dated including the time.

It is often useful to prepare a chart showing batch weight adjustments for changes in aggregate moisture content. The Inspector can make a quick check of the changes needed to be made by the Contractor to allow for variations in the moisture content.

Batching plants can be classified into three categories: manual, semi-automatic, and automatic. All three types are permitted under the Standard Specifications. The operator controls all the functions necessary to complete the weighing and dumping on the manual plant. This type of plant is subject to human error in every operation so it should be inspected carefully by the Inspector. A semiautomatic plant is governed by controls that are actuated in a certain sequence to complete the batching cycle. An automatic plant has the complete batching cycle set in motion by a control button, which may be located remotely from the plant. Automatic plants are seldom encountered except at commercial concrete plants and large paving plants.

Dial scales or a load cell providing a digital printed readout is required for weighing all hydraulic cement.

(C) Mixing in Truck Mixers

A large percentage of the concrete placed in structures is mixed by truck mixers. This equipment is not usually permitted for mixing concrete for pavement principally because it cannot quickly discharge the low slump concrete which is required for pavement. (Tilt-up type mixers are an exception.) Truck mixers usually are satisfactory for structural concrete but require constant inspection of the operation. Instead of having one mixer and one operator to control, as in central mixed concrete, there may be a dozen or more truck mixers and operators, on a large job, where concrete is being mixed by truck mixers. Each truck mixer should be inspected occasionally for hardened concrete, worn blades, and water leaks. The Inspector must see that no mixer is loaded beyond its mixing capacity as indicated on the manufacturer's plate attached to the mixer. Weighing trucks before and after charging is an excellent check on the accuracy of the plant.
Where feasible, and when the equipment is adaptable, the sequence of weighing and discharging the aggregates, cement, and water from the batch plant should be such that a small amount of water enters the

mixer in advance of the other ingredients; then, followed by a blended "ribbon" of all the other ingredients, together with the remainder of the required water. Extensive research has proven conclusively that the "ribbon" method of charging a mixer contributes greatly to the uniformity of the concrete within any given batch. The transit mixers should be periodically inspected to confirm that the drums are free of water before being charged

The Standard Specifications require that each batch shall be mixed for not less than 70 and no more than 100 revolutions, at mixing speed, except that the maximum may be increased upon approval of the Engineer. Any revolutions made beyond the 100 specified as maximum are required to be at agitation speed.

Specification 1006-4.03(A) permits mixing at the plant site or at the delivery site. This specification has been interpreted to mean that mixing may also be performed while the truck mixer is enroute between the plant and the delivery site. Remember the maximum time limit for mixing to begin.

If it is necessary to add water to the mix at the site, it is required that the mixer shall be turned a minimum of 30 revolutions at mixing speed before the concrete may be discharged. The amount of water added, and the additional mixing time (or revolutions) shall be recorded on the concrete delivery ticket and, where appropriate, on the test report. This additional mixing may be in excess of the maximum revolutions previously specified. Remember that if samples are taken, they should be taken after all the water has been added.

Regardless of the type of mixer, the mixer drum should be inspected for worn blades or hardened concrete, rate of rotation, and mixing time. Each mixer is required to have a nameplate attached showing capacity and recommended speed of operation.

If truck mixers are used they are to be inspected, and the inspection will be documented in compliance with the *Materials Policy and Procedures Directives Manual (PPD No. 7)*.

1006-6 Curing Concrete

Curing practices can significantly detract from, or enhance the long-term durability of concrete. Inspectors and concrete finishers usually don't pay close attention to curing practices and to concrete while it cures, but they should. Research has shown that the service life of concrete slabs, decks, pavements and walls is increased when proper curing procedures are followed. Given the high cost of replacing existing highway pavements and structures, the extra amount of time and effort spent on properly curing concrete in its first 7 to 10 days can save literally tens of thousands of dollars over time.

Wet curing for 7 days is the most preferred method of curing. Contractors prefer to use liquid membrane curing since it is much less labor intensive. However, if given a choice, wet curing should be preferred over curing membrane since the added water will promote hydration.

1006-7 Acceptance Sampling and Testing

1006-7.02 Sampling and Testing of Concrete

In all cases, a diligent effort should be made to keep the consistency of the concrete within the range of slump and/or air as specified. However, when an occasional batch of concrete is found to have a slump or air content in excess of the maximum specified, corrective action must be taken.

Field tests will be made in accordance with the requirements of AASHTO T-119 on the concrete as it is discharged to determine the consistency in slump. One additional slump test will be made on a concrete batch that has failed to fall within the required slump range on the first test, unless the Contractor elects to make

adjustments in the slump. If adjustments are made, the concrete batch will be tested twice after such adjustments. In either case, the average of the two tests for that batch shall be within the required slump range and no single test shall be less or greater than the required range by more than one inch. Concrete that does not conform to the above consistency requirements should be rejected.

High slump concrete which has been placed prior to obtaining slump test results is subject to adjustment in price or removal based on the 28-day compressive strength obtained. An additional set of cylinders should be made to represent the load or portion of a load of high slump concrete placed. The location of the concrete in the structure and the quantity represented by the extra cylinders must be recorded.

Proper fabrication, handling, and curing of the cylinders are extremely important. All personnel responsible for any of the tasks relating to cylinders should be thoroughly familiar with AASHTO T23, T119, T152, and all the latest revisions.

The relationship between the Contractor's and ADOT's testing programs should be discussed at the preconstruction conference and just prior to the beginning of concrete work. The Engineer should request that if the Contractor finds any fault with the ADOT sampling and testing procedures, he will be notified immediately. The Contractor should also be clearly informed that he will be promptly notified in writing of any shortcomings in his procedures.

It should be apparent that ADOT project personnel doing testing must perform the tests in exact conformity with the prescribed test method. The testing technique should be observed frequently and referee tests should be made often enough to assure that proper procedures are being followed.

Compressive strength is not the only measure of the quality of concrete. The compressive strength test does not measure actual field strength of concrete. Field curing procedures (Subsection 1006-6) are different than the test cylinder curing procedure. Field conditions, such as ambient temperature and relative humidity can vary, but test cylinders should be cured in a controlled environment.

Failure to meet the specified mix design criteria such as slump, air, mixing time, segregation, incorrect batching, unloading time, etc., may be sufficient reason for rejection regardless of any claim by the Contractor that the concrete is acceptable because it will meet the strength requirement.

Sampling of fresh concrete mix for testing purposes, fabricating cylinders, or beams shall be in accordance with the *Materials Testing Manual (Series 900 Appendix C)*.

Some Contractors and suppliers are doing independent concrete testing and are being observed by ADOT personnel. If the Contractor performs the test they should be observed and documented noting whether test procedures conform to ADOT procedures.

1006-7.03 Sampling Frequency for Cast-In-Place Concrete

The inspector should refer to Section 1007-7.03 of the Standard Specifications and the Acceptance Sampling Guide for Portland Cement Concrete in the *Materials Testing Manual (Series 900 Appendix C)* prior to testing and sampling concrete. Field tests vary for the class of concrete and the amount of concrete being placed.