



**GUIDELINES  
FOR  
REVIEWING CONCRETE MIX DESIGNS**  
*In Accordance with the 2010 CBC*

Prepared by

SEAONC Construction Quality Assurance Committee  
July 2013



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## **Guidelines for Reviewing Concrete Mix Designs In Accordance with the 2010 CBC**

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## **GUIDELINES FOR REVIEWING CONCRETE MIX DESIGNS In Accordance with the 2010 CBC**

### **Preface**

This document was developed by the Structural Engineers Association of Northern California (SEAONC) Construction Quality Assurance Committee. The purpose of this document is to serve as a resource to structural engineers in the review of concrete mix design submittals.

It should be emphasized that the suggestions, recommendations, and commentary discussed in this document are offered in an advisory capacity only and reflect the opinion solely of the authors. This document does not define a standard of practice.



## **GUIDELINES FOR REVIEWING CONCRETE MIX DESIGNS In Accordance with the 2010 CBC**

### **I. Introduction**

Concrete mix designs are submitted for review so that the reviewer can verify the contractor is interpreting the construction documents correctly. These guidelines were developed to assist the engineer reviewing concrete mix designs. The main body of the guidelines focuses on the process of reviewing the mix design. The appendices provide a discussion of performance issues and code requirements for concrete as well as a discussion of what typically is considered when writing the project specification sections for concrete, and examples of how these specifications are typically organized.

The user is encouraged to review the performance and code considerations discussed in this document during the development of construction documents. The discussion of specification issues in Appendix C could then be utilized by the user to ensure that the construction documents fully define the project requirements. Taking these proactive steps is encouraged with the hope that doing so will result in a smooth review process where the contractor is more likely to submit compliant designs and the reviewer is more likely to spend less time verifying the adequacy of the submitted mix designs.

These guidelines do not make recommendations regarding specific project decisions but instead provide information to assist in making the decisions.

If questions are raised during the review process the reviewer will find the appendices a useful source of background information that will either answer the questions or that will help him/her to understand the issues. These guidelines make no attempt to provide all the information that the reviewer will possibly need but are intended to help identify issues that are likely to be relevant for building projects. The American Concrete Institute (ACI) *Manual of Concrete Practice* is often a good place to start when more information is needed. The Portland Cement Association (PCA) publication *Design and Control of Concrete Mixtures* is also a useful reference.

### **II. Process**

At the start of the construction administration phase, it is a good idea to discuss the schedule for submission of concrete mix designs with the contractor in order to convey to him or her the importance of timely submittals so that there is adequate time for review and for the contractor to provide supplemental information needed in response to the review. Sometimes pre-construction meetings can help communicate the need to submit more complete submittals early.

The reviewer should have the project plans and specifications available for review. It is recommended that the reviewer also have available a copy of ACI 318 – *Building Code Requirements for Structural Concrete*, which includes the building code requirements for



concrete mixes. It is also helpful to have handy copies of the standards referenced in the project specifications and in ACI 318.

If mix designs are submitted for work specified by multiple design professionals (e.g., civil work) each design professional specifying concrete mixes should make it clear which mix designs they have reviewed. Notifying the prime design professional that some of the mix designs submitted are for work specified by other consultants can allow the other consultants to perform their review in parallel. Where multiple consultants are reviewing the same mix designs or are commenting on the same components coordination of comments can be beneficial.

Some project construction documents require the general contractor to stamp and sign each submittal to indicate that he/she has reviewed and coordinated the submittal with the other work. When this is a requirement, verify if this has been done and if not notify the design professional in responsible charge.

The first step of the review process is to verify that the submittal is complete and responsive. This can be accomplished by answering the following questions:

- Are the submittal requirements listed in Part 1 of the specifications complied with?
- Have all of the mix designs specified for the project been submitted?
- Is it clear which mix design applies to which concrete elements or class of concrete used on the project?

If the submittal is obviously incomplete the reviewer should consider returning it without further review. Alternately the reviewer could notify concerned parties so that the contractor can be given the opportunity to provide the missing information before the submittal needs to be returned, hopefully eliminating the need to require the resubmission of the submittal. When the missing information cannot be promptly provided it may be necessary to return the submittal with a request for the missing information in order to comply with the contract requirements for prompt processing of submittals.

If mix designs are not provided for all concrete that will be used on the project, the reviewer may choose to identify the mix designs that still need to be submitted.

The focus of a mix design review is on whether the mix design conforms to the requirements in the construction documents. This is because the building code states that the construction documents are to be used as the basis of code compliance and because they are assumed to reflect the owner's performance objectives. This does not mean that the reviewer ignores situations where the construction documents may conflict with the code or have other defects but if such a situation were to occur this typically would require that a revision to the documents be issued.

Traditionally the submittal would be reviewed in the following order:

- Mix design;



- Historical test data or trial batch test data;
- Mill reports for cementitious materials;
- Certifications and test results for concrete components.

During the mix design review some of the basic requirements that should be verified include:

- Concrete compressive strengths;
- Slump or slump flow;
- Water cementitious material ratio (w/cm);
- Type of cement;
- Coarse aggregate size and source if specified;
- Proportions of supplementary cementitious materials;
- Concrete density;
- Specified admixtures are used and prohibited admixtures are not used;
- Additional properties and material requirements in the specifications such as entrained air content, limitations on total chlorides, or other durability or exposure criteria.

When reviewing the historical data the reviewer should verify that enough tests have been provided to establish a standard deviation and the required average compressive strength. If a satisfactory strength history is not provided then laboratory trial batch data will be needed to substantiate the mix performance. Refer to Appendix D for a discussion of the process of verifying concrete strengths.

Appendix A contains sample submittal documents with annotations that help identify some of the items commonly addressed in the review along with information to help understand the contents of the document and provide help in reviewing the submittal. Appendix A not only addresses the mix design and strength test results but also data on the components of the mix design. Pertinent items are identified and discussed briefly with references to more in-depth discussion in the Appendices. The annotations do not necessarily identify all of the items that should be reviewed.

It is generally not necessary to check the detailed calculations on the mix design summary sheet or the historical test data. The data provided should be reviewed to see if anything appears unusual or suspicious. If specified parameters are not reported but can be easily computed the reviewer may decide to calculate them, thus eliminating the need to request a resubmittal. Examples would include the water/cementitious material ratio and the percent of slag cement, fly ash or other supplementary cementitious materials.

When test reports present the test data and then make an affirmative statement that the material complies with the specified standard as well as the appropriate supplemental properties it is typically not necessary to verify that the individual test values conform to the standard. When test data is provided but no statement is made regarding compliance with the specified standard caution should be exercised since occasionally suppliers will just submit the data when they know that the material does not conform to some aspect of the standard. When in doubt it may



be appropriate for the reviewer to request an affirmative statement as to compliance from the supplier.

If information is provided in the mix design submittal that is beyond what is required by the construction documents then it is normally not reviewed, although the reviewer may want to check with the prime design professional and the contractor prior to returning any submittals with un-reviewed information. In cases where alternative mix designs that were not specified are provided, the engineer has the prerogative to not review these submittals. The reviewer should note that the alternative mix designs were not reviewed.

If problems are found during the review it is often desirable to talk with the contractor or concrete supplier to either resolve the problem or to develop a strategy to resolve the problem if project protocols allow. All such communications should be coordinated with the prime design professional.

Upon completion of the mix design review the reviewer will typically affix the submittal stamp to each submittal and return the submittal according to the project requirements.

#### Focus of Review

The review of a concrete mix design should focus on three key issues:

1. Does the mix meet the performance requirements of the specifications with respect to strength and other characteristics such as shrinkage, permeability, w/cm ratio, etc.?
2. Is the historical or trial batch test data adequate to justify the strength?
3. Do the materials used comply with the project requirements as evidenced by test results, certifications, and product data?

#### Follow up

After the completion of the mix design review the accepted mix designs need to be provided to the concrete special inspector to verify the use of the required design mix per Item 5 of CBC Table 1704.4.

It is expected that the special inspector will use the mix number and other information on the mix design to verify that the concrete mix provided is the mix design that was reviewed.

#### Reviews to Modified Mixes

If a concrete mix design is modified after it has been reviewed the engineer will need to decide whether it needs to be re-reviewed and if so the extent of the review. If a mix design is modified, care should be exercised to verify exactly what was changed if an abbreviated review is contemplated.



### III. Limitations of Submittal Reviews

Mix design submittals and their reviews are limited in their ability to assure performance of the in place concrete. Some of the limitations include:

- In the months between the times the material is tested and when the concrete is batched there may be variations in the product.
- There is great flexibility in selecting the concrete mixes whose historical test results are used to establish the standard deviation.
- The batching, delivery, and testing of concrete are subject to variation.
- Curing and environmental conditions will impact rate of strength gain and ultimate concrete strength.



## **APPENDIX A**

### **ANNOTATED SAMPLE SUBMITTAL DOCUMENTS**

The following sample documents are representative of what is often submitted and as a result may not fully address all of the necessary information for a specific project. It should also be noted that there is no one standard format for presenting the information requested, thus the reviewer may have to study the document to understand what is and is not provided.

## CONCRETE MIX DESIGN

## Annotations:

1. Check the project name to verify that the mix design is intended for use on this project.
2. It should be clear which elements in the project this mix design will be used for. If it is unclear where the mix design will be used the reviewer can request clarification before returning the submittal or return the submittal with a request for clarification.
3. Verify that the concrete compressive strength equals or exceeds the specified value. (Ref. Appendix C Section B.1)\*
4. Verify that the design slump does not exceed the specified value. If tolerances are listed in the submittal verify that they comply with the construction documents. (Ref. Appendix C Section B.4)
5. Verify the air content (air content as a percentage of concrete volume) if limits are specified. (Ref. Appendix C Section B.11)\*
6. Verify that the water cementitious materials ratio (w/cm) does not exceed specified value. The w/cm in this example equals  $283 / (446 + 118)$ , which is the weight of water divided by weight of cementitious materials. The water cement ratio is no longer used. (Ref. Appendix C Section B.5)\*
7. Verify that the types of cementitious materials comply with the specifications. (Ref. Appendix C Sections B.6 and C.2)\* In this example it is unclear what type of fly ash the mix design was based on so clarification should be requested.
8. Verify that the nominal maximum coarse aggregate size complies with the specified limits and the values in the submitted aggregate test report. (Ref. Appendix C Section B.3)
9. Verify that the admixtures used are consistent with the project specifications and matches the submitted admixture data. (Ref. Appendix C Section B.12)\*
10. Verify that the unit weight complies with the specifications. For light weight mixes verify dry weight or equilibrium density. (Ref. Appendix C Section B.2)
11. Verify that the percentage of supplemental cementitious materials (SCMs) is consistent with minimum and maximum percentages specified. This is calculated as the weight of the SCMs divided by the weight of the cementitious materials:  $118 / (118 + 446) = 20.9\%$ . (Ref. Appendix C Sections B.6 and C.2)
12. Aggregate weights are based on saturated surface dry condition (SSD), which implies that at batching the water added will depend on the actual moisture content of the aggregates.

## Notes:

If limits on total chloride content are specified check chloride content against the limits. Note that chlorides are not reported for this mix design. (Ref. Appendix C Section B.9)

\*If the contractor was given exposure category classifications and then expected to sort out the mix properties it may be necessary to verify that the properties comply with the requirements in Chapter 4 of ACI 318 in addition to the values specified in the construction documents.



**CONCRETE MIX DESIGN**  
**Excellent Ready Mix Company**

Project: Microapsoft Solutions **1**  
 Location: San Jose, CA  
 Use: Grade Beams **2**

Date: 10/14/2010  
 Mix Design No.: 604000  
 Design Strength: **3** 4000 psi @ 28-days  
 Design Slump: **4** 4" ± 1"  
 Design Air Content: **5** 1.50  
 W/CM **6** 0.50

Material Description	Designed		Percent Used	Specific Gravity	Absolute Volume (Cu. Ft.)
	S.S.D. Weights	Units			
<b>7</b> Performance Type II/V	446	Lbs		3.15	2.269
Cholla Fly Ash , 21% <b>11</b>	118	Lbs		2.30	0.822
Water	283	Lbs		1.00	4.535
Air, entrapped	1.50	%			0.405
<b>8</b> Jones 1x4	1745	Lbs	56.5	2.62	10.674
Smith Sand	1346	Lbs	43.5	2.60	8.296
<b>TOTAL</b>	<b>3940</b>				<b>27.001</b> Cubic Feet
<b>Admixtures</b>					
WRDA 64	22.6	oz/yd	4.0	oz/cwt <b>9</b>	
Design Unit Weight	145.9	pcf <b>10</b>			

## FIELD STRENGTH TEST RECORD

## Annotations:

1. ACI 318 Chapter 5 requires concrete to be proportioned on the basis of field experience (often “historical test data” or “field strength test record”), trial mixtures (often “trial batches”) or both. The field strength test record can be used to determine a standard deviation for a batch plant (which is then used to determine the “required average compressive strength” – see below), and to demonstrate that the mix will produce concrete with the required average compressive strength. The “required average compressive strength”  $f'_{cr}$  is always greater than the specified strength in order to limit the probability that strength tests during construction will fall below the specified strength. It is either a function of the standard deviation determined from a field strength test record (ACI 318, §5.3.2.1), or determined more conservatively on the basis of specified compressive strength in accordance with ACI 318 Table 5.3.2.2.
2. This field strength test record shows 30 test results for the actual mix proposed. If results from a similar mix are submitted (for example, when data from the actual mix are not available) the record should identify those mixes. See Appendix D for a discussion of the ACI procedures for documenting concrete mix proportions on the basis of compressive strength.
3. ACI 318, §5.3.1 now requires that the test record be no more than 12 months old.
4. 30 consecutive tests or two groups of consecutive tests totaling at least 30 tests are always acceptable per ACI 318, §5.3.1.1 for determining the standard deviation. Test records of no less than 15 tests can also be used, although the standard deviation must be factored upward per ACI 318 Table 5.3.1.2, thus increasing the required average compressive strength. For documenting the actual mix proportions, the test record may include as few as 10 tests (ACI 318, §5.3.3.1).
5. A strength test is the average of two cylinder breaks when 6 by 12 in. cylinders are used and three when 4 by 8 in. cylinders are used. The test record submitted may not include the results of the individual breaks.
6. As there are 30 tests in this record, the modification factor (see Note 4 above) to be applied to the standard deviation is 1.
7. The average compressive strength and the standard deviation are the key pieces of data derived from the test record.
8. The standard deviation,  $s_s$ , calculated from the strength test record is then used in the two formulae (See Note 9 below) from ACI 318, Table 5.3.2.1 to determine  $f'_{cr}$ . The larger value is used.
9. The formulae for concrete with a specified compressive strength less than or equal to 5,000 psi are shown and applied. The modification factor (MF) is taken as 1 as discussed above. The average compressive strength of the test record is found to be greater than the calculated required average strength  $f'_{cr}$ . Thus, the mix has been appropriately qualified and documented with respect to compressive strength.
10. The data in these columns are of interest only with respect to documenting the strength test data but are not required for the mix design review. Many field strength test records will not include this information.
11. The data in these columns present interesting information for the contractor or ready-mix supplier, but are not required for the mix design review.



**1** FIELD STRENGTH TEST RECORD

**2** Mix Number: **Substantiating Data**  
604000  
6.0 sk., W/CM=0.50

Lab No.	Ticket #	Date Cast	Compressive Strength (psi)						Cast Data				28 Day Moving Avg (3)
			7-Days	28-Day	28-Day	Ave. 28-	7 Day / 28 Day	56-Days	Slump	Conc Temp	Air Temp	Unit Wt.	
		<b>3</b>											
PM 3934	586474	11/23/2009	2839	4560	4680	4620	61%		4 1/2	60			
PM 4042	587056	1/12/2010	3550	5180	5560	5370	66%		4 1/2	57			
PM 4043	587068	1/12/2010	3220	4800	5240	5020	64%		4 1/4	64		5003	Tests 30 <b>4</b>
PM 4068	587166	1/26/2010	4110	5660	5440	5550	74%		4 1/4	55		5313	Modification Factor
PM 4069	587170	1/26/2010	3900	5370	5010	5190	75%		5	56		5253	1 <b>6</b>
PM 4075	587225	1/29/2010	3530	4820	5040	4930	72%		4 3/4	65		5223	Average Compressive Strength
PM 4166	587711	3/1/2010	3380	4810	4680	4750	71%		4 1/2	61		4957	7 day 3422
PM 4182	587787	3/4/2010	3380	5190	5390	5290	64%		4 1/4	69		4990	28 day 4869 <b>7</b>
PM 4199	587858	3/10/2010	3760	4870	5030	4950	76%		3 3/4	57		4997	Standard Deviation
PM 4157	587669	2/26/2010	3280	4900	4890	4900	67%		4 1/4	63		5047	7 day 468
PM 4267	588224	3/30/2010	3300	5090	5160	5130	64%		4 1/4	71		4993	28 day 403 <b>8</b>
PM 4340	588556	4/21/2010	4330	5440	5360	5400	80%		4 1/2	66		5143	
PM 4400	588887	5/12/2010	3390	4530	4450	4490	76%		4	70		5007	
PM 4433	589064	5/24/2010	3290	4330	4180	4260	77%		5	71		4717	
PM 4444	589134	5/27/2010	3530	4340	4620	4480	79%		5 3/4	70		4410	
PM 4464	589180	6/2/2010	3390	4480	4740	4610	74%		4 1/4	71		4450	
PM 4465	589189	6/3/2010	3300	4630	4490	4560	72%		4 3/4	70		4550	
PM 4479	589250	6/7/2010	3860	5300	5240	5270	73%		4	73		4813	7 day 468
PM 4480	589264	6/7/2010	4040	5530	5370	5450	74%		4	74		5093	28 day 403 <b>8</b>
PM 4481	589275	6/7/2010	3590	4910	5010	4960	72%			74		5227	
PM 4499	589403	6/11/2010	3130	3940	4060	4000	78%		4	69		4803	
PM 4576	589994	7/8/2010	3640	4740	4980	4860	75%		3 1/2	65		4607	
PM 4595	590093	7/15/2010	4040	5250	5150	5200	78%		3 1/4	75		4687	
PM 4665	590630	8/10/2010	3310	4920	4820	4870	68%		3 1/2	65		4977	
PM 4958	592229	11/1/2010	3090	4060	4100	4080	76%		3	77		4717	
PM 4885	591819	10/21/2010	3610	4610	4770	4690	77%		4 1/2	68		4547	
PM 4905	591949	10/29/2010	2510	5340	5200	5270	48%		4 3/4	70		4680	
PM 4913	591963	11/1/2010	2020	4720	4720	4720	43%		5	70		4893	
PM 4945	592127	11/5/2010	3110	4490	4310	4400	71%		5 1/4	75		4797	
PM 5320	593869	2/16/2011	3230	4810	4780	4800	67%		3 1/2	68		4640	

**10**      **10**      **10**      **5**      **11**      **10**      **10**      **11**

$f'_c = 4000 \text{ psi}$

$f'_{cr} = f'_c + 2.33s_s \text{ (MF)} - 500 \text{ psi} = 4439 \text{ psi} \leq 4869 \text{ psi} \quad \text{Ok}$

**9**  $f'_{cr} = f'_c + 1.34s_s \text{ (MF)} = 4540 \text{ psi} \leq 4869 \text{ psi} \quad \text{Ok}$



## TRIAL MIXTURE TESTING

## Annotations:

1. ACI 318 Chapter 5 requires concrete to be proportioned on the basis of field experience (often “historical test data” or “field strength test record”), trial mixtures (often “trial batches”) or both. Trial mixtures can be used alone or along with a field strength test record to establish the standard deviation for a batch plant. Although not shown here, the trial mixture test report should also include the mixture proportions and the test results for each of the trial mixtures.
2. Earlier editions of ACI 318 required trial mixtures to include three different water-cementitious material ratios (w/cm) selected to encompass the required compressive strength. In order to account for the more common use of supplemental cementitious materials, ACI 318-08 Section 5.3.3.2 no longer requires tests based solely on variations in water-cementitious material ratio and no longer specifies three mixtures. Trial mixtures are now required to simply include a “range of proportions.” However, the three-point curves shown here are still commonly used as part of the justification for qualifying a mix based on trial mixtures or, when accepted by the design professional, as the justification for accepting a mix based on ACI 318 Section 5.4.
3. The 28-day curve is the curve used to qualify the mix proportions with respect to compressive strength. This curve shows the best fit for three data points from trial mixtures with w/cm ratios of 0.38, 0.46, and 0.60.
4. The “required average compressive strength”  $f'_{cr}$  is either a function of the standard deviation determined from a field strength test record (ACI 318, §5.3.2.1) or determined more conservatively on the basis of specified compressive strength in accordance with ACI 318 Table 5.3.2.2. Although the three point curve shown here is intended to represent Excellent Ready Mix Company’s Mix 604000, for which we have already seen a field strength test record including a calculation of the standard deviation, here it is assumed that no such record is available and the required average strength is 5,200 psi in accordance with ACI 318 Table 5.3.2.2.
5. The dotted lines show that in order to achieve 5,200 psi, the w/cm should be no greater than 0.52.

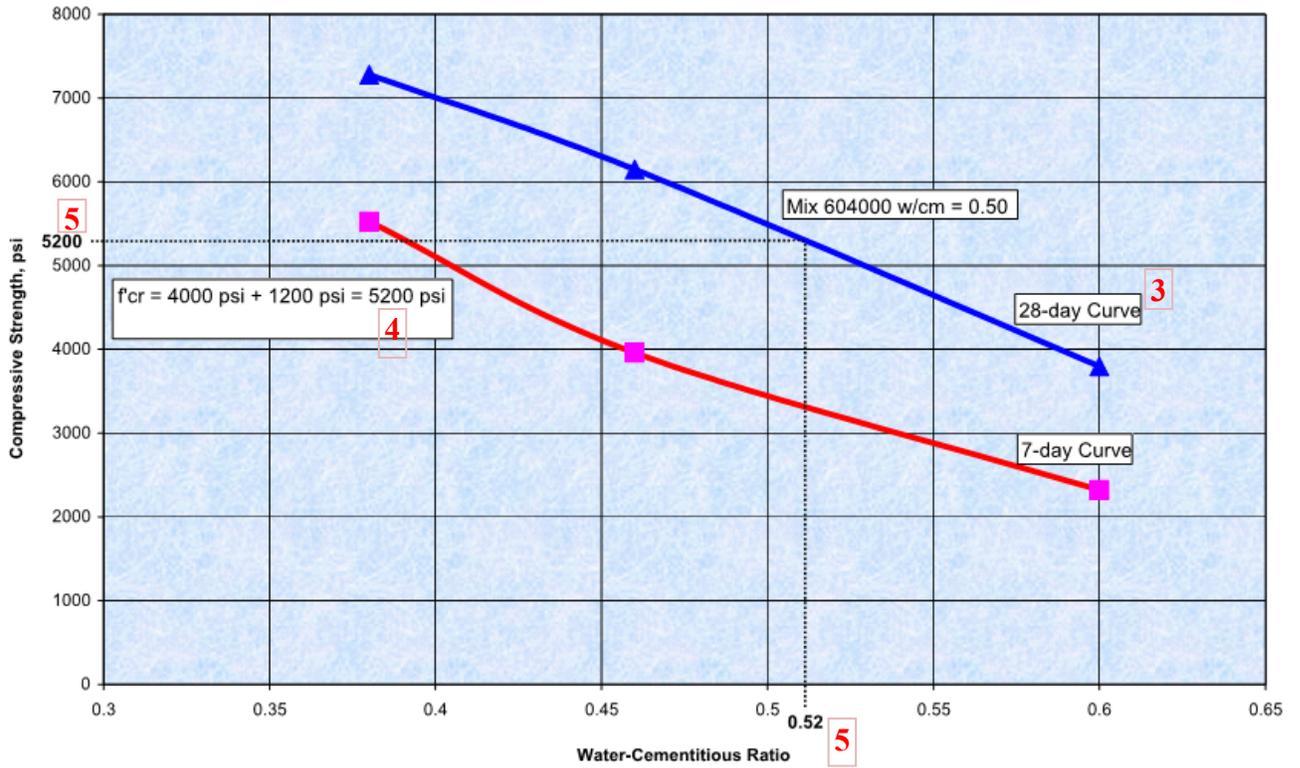
## Note:

Refer to Appendix D of these Guidelines for a more complete explanation of the ACI procedures for documenting concrete mix proportions on the basis of compressive strength.



1 TRIAL MIXTURE TESTING

2 Water-Cementitious Ratio vs. Compressive Strength  
4000 psi - 21% Fly Ash w/ Normal WRA  
Excellent Ready Mix Company





COARSE AGGREGATE CERTIFICATION/ TEST REPORT

Annotations:

1. Verify that the test report is reasonably current and in conformance with any time limits listed in the specifications. (Ref. Appendix C Section A.2)
2. Verify that the aggregate is same as the aggregate used in the mix design.
3. Verify that there is an affirmative statement that the material conforms to the standard listed in the specifications.
4. If the alkali-silica reactivity is not innocuous then check the specifications to see if any limits were placed on the ASR classification. There are several different tests for evaluating ASR potential and some individuals prefer to require certain tests. Verify the specified test(s) is referenced. (Ref. Appendix C Section B.8 and C.4)
5. Aggregate gradation need only be verified when the project specifications require specific gradation requirements.
6. If a cleanness requirement is included in the specifications, verify that the cleanness value exceeds the minimum value specified for the test. Caltrans Test Method 227 is the standard used in this example. (Ref. Appendix C Section C.4)

Note:

Verify that evidence is provided of conformance of other aggregate properties listed in the specifications besides what is noted above.



**1**  
February 31, 2012

**JONES ROCK**

421 Happy Valley Road  
Pleasantville, CA 99999  
Tel 555-123-4560

**2**  
Jones 1" x #4 Gravel

The Jones 1" x #4 concrete aggregate supplied by Jones Rock conforms to the requirements of Caltrans Standard Specification Section 90 and ASTM Specification C 33. **3** This aggregate is produced at the Jones Plant, Pleasantville, California, SMARA No. 99-01-9999. Concrete aggregate from this location has been used in concrete for more than 80 years with no known incidence of alkali reactivity or cement incompatibility. The typical physical properties of this aggregate are as follows:

Gradation:	<u>Percent Passing</u>		
	<u>Jones</u> <u>1" x #4</u>	<u>Caltrans</u> <u>Sect. 90</u>	<u>ASTM</u> <u>C 33</u>
<u>Sieve Size</u>			
37.5 mm (1½")	100	100	100
25.0 mm (1")	99	88 - 100	95 - 100
19.0 mm (¾")	87 (80)	65 - 95	-
12.5 mm (½")	36	-	25 - 60
9.50 mm (⅜")	9 (15)	0 - 30	-
4.75 mm (#4)	1	0 - 16	0 - 10
2.36 mm (#8)	1	0 - 6	0 - 5
75 µm (#200), C117	0	-	0 - 1
	(X-value)		
Specific Gravity, Bulk S.S.D.	2.62	-	-
Absorption, %, C 127	1.80	-	-
Cleanness Value, CT 227 <b>6</b>	80	75 min.	-
Clay & Friables, C 142	0.2%	-	2.0% max.
Lt. Wt. Particles, C 123	0.1%	-	0.5% max
Alkali Reactivity			
ASTM C 295	Innocuous		
ASTM C 289	Innocuous		
	} <b>4</b>		
Abrasion Loss, C 131	27.0%	45% max.	50% max.
Sodium Soundness, C 88	5.4%	10% max.	12% max.

Should you have questions regarding this aggregate material, please do not hesitate to call your Sales Representative.

JONES ROCK

John Jones  
Quality Control Manager

These data have been developed on the basis of information and tests of materials submitted to this laboratory which are assumed to be representative of the materials to be used. All test have been made in compliance with current ASTM or applicable methods of testing.



FINE AGGREGATE TEST REPORT

Annotations:

1. Verify that the test report is reasonably current and in conformance with any time limits listed in the specifications. (Ref. Appendix C Section A.2)
2. The sand source should agree with the sand listed in the mix design.
3. Verify that there is an affirmative statement that the material conforms to the standard listed in the specifications or verify that listed values comply with the allowed ranges for the standard.
4. If the alkali-silica reactivity is not innocuous check then the specifications to see if any limits were placed on the ASR classification. There are several different tests for evaluating ASR potential and some individuals prefer to require certain tests. Verify that the specified test(s) is referenced. (Ref. Appendix C Sections B.8 and C.3)
5. Aggregate gradation need only be verified when the project specifications require specific gradation requirements.
6. If a sand equivalent requirement is included in the specifications, verify that the sand equivalent value exceeds the minimum value specified for the test. Caltrans Test Method 217 is the standard used in this example. (Ref. Appendix C Section C.3)

Note:

Verify that evidence is provided of conformance of other aggregate properties listed in the specifications besides what is listed above.



**1**  
February 31, 2012

**Smith Sand Company**

666 Peacefull View Lane  
Lively, CA 99989  
Tel 555-987-6543

**2**  
**SMITH TOP SAND**

The Smith Concrete Sand supplied by Smith Sand Company is produced at the Lively, California plant, SMARA No. 99-00-9876. Concrete aggregates from this plant have been used in concrete for more than sixty years with no known incidence of alkali reactivity or cement incompatibility. The typical physical properties of the aggregate are as follows.

Gradation:	Percent Passing		ASTM C 33 <b>3</b>
	Smith Conc. Sand	Caltrans Spec. Sec. 90	
Sieve Size			
9.50 mm (3/8")	100	100	100
4.75 mm (#4)	99	95 – 100	95-100
2.36 mm (#8)	83	65 – 95	80-100
1.18 mm (#16)	57 (58)	48 – 68	50-85
600 µm (#30)	36 (38)	29 – 47	25-60
300 µm (#50)	18 (22)	16 – 28	5-30
150 µm (#100)	6	2 – 12	0-10
75 µm (#200), C 117	1.9	0 – 8	
	(X-value)		
Fineness Modulus	3.01	-	-
Specific Gravity, Bulk S.S.D.	2.60	-	-
Absorption, %, C 128	1.90	-	-
Sand Equivalent, CT 217 <b>6</b>	83	75	75
Light Pieces, %, C 123	0.1	-	-
Clay Lumps and Friable Particles, %, C 142	0.30		3% Max
Organic Impurities, C 40	Clear	S	S
Sod. Sulfate Sound., %, C88	5.0	10% Max.	10% Max.
Alkali Reactivity			
ASTM C 295	Innocuous		
ASTM C 289	Innocuous } <b>4</b>		

Should you have questions regarding this aggregate material, please do not hesitate to call your Sales Representative.

Sincerely,

SMITH SAND COMPANY

John Smith  
Quality Control Manager

These data have been developed on the basis of information and tests of materials submitted to this laboratory which are assumed to be representative of the materials to be used. All test have been made in compliance with current ASTM or applicable methods of testing.



CEMENT MILL CERTIFICATION/TEST RECORD

Annotations:

1. Verify that the test report is reasonably current so that it would be representative of current product. (Ref. Appendix C Section A.2)
2. Verify that the listed standard matches the standard listed in the specifications.
3. Verify that the reported cement type conforms to the project specifications and agrees with the type listed in the concrete mix design. (Ref. Appendix C Section C.1)
4. Comparison of the reported test values against the values defined in the ASTM standard is not normally done unless there is reason for concern.
5. This list shows all of the standards for cement that this test record conforms to. The data listed is only for ASTM C150. If ASTM C1157 cement was specified a different mill certificate indicating those specification limits would be provided.



**CEMENT  
COMPANY**

1234 Address Street  
City, State Zip  
Tel: (000) 123-4567  
Fax: (000) 890-1234

CEMENT MILL TEST REPORT

Cement Identified as: Date: 01/01/2011 ← 1  
 Plant: Cement Company  
 Location: City, State  
 Production Dates: Beginning 2 Month Day, Year  
 Ending Month Day, Year Reference No. 40702 M

STANDARD CHEMICAL REQUIREMENTS	ASTM C 150 SPECIFICATIONS	TYPE I	TYPE II <span style="border: 1px solid red; padding: 2px;">3</span>	TYPE V	TEST RESULTS
Silicon Dioxide (SiO <sub>2</sub> ), %	Minimum	....	....	....	20.1
Aluminum Oxide (Al <sub>2</sub> O <sub>3</sub> ), %	Maximum	....	6.0	....	<span style="border: 1px solid red; padding: 2px;">4</span> 3.7
Ferric Oxide (Fe <sub>2</sub> O <sub>3</sub> ), %	Maximum	....	6.0	....	3.6
Calcium Oxide (CaO), %	....	....	....	....	62.9
Magnesium Oxide (MgO), %	Maximum	6.0	6.0	6.0	4.7
Sulfur Trioxide (SO <sub>3</sub> ), %**	Maximum	3.0	3.0	2.3	2.7
Loss on Ignition (LOI), %	Maximum	3.0	3.0	3.0	1.9
Insoluble Residue, &	Maximum	0.75	0.75	0.75	0.28
Sodium Oxide (Na <sub>2</sub> O), %	....	....	....	....	0.22
Potassium Oxide (K <sub>2</sub> O), %	....	....	....	....	0.42
Equivalent Alkalis (Na <sub>2</sub> O+.658K <sub>2</sub> O), %	Maximum	0.60	0.60	0.90	0.50
CO <sub>2</sub> (%)	....	....	....	....	1.3
Limestone (%)	Maximum	5.0	5.0	5.0	3.0
CaCO <sub>3</sub> in Limestone	Minimum	70.0	70.0	70.0	97
Inorganic Process Addition (%)	Maximum	5.0	5.0	5.0	0.0
Tricalcium Silicate (C <sub>3</sub> S), %	....	....	....	....	59
Dicalcium Silicate (C <sub>2</sub> S), %	....	....	....	....	13
Tricalcium Aluminate (C <sub>3</sub> A), %	Maximum	....	8	5	4
Tetracalcium Aluminoferrite (C <sub>4</sub> AF), %	....	....	....	....	11
Heat Index (C <sub>3</sub> S + 4.75 C <sub>3</sub> A), %	....	....	100	....	77
(C <sub>4</sub> AF + 2C <sub>3</sub> A) or (C <sub>4</sub> AF + C <sub>3</sub> F), %	Maximum	....	....	25	18
<b>PHYSICAL REQUIREMENTS</b>					
Heat of Hydration (ASTM C 186) 7 days, kJ/kg (cal/g)	Informational data only Most recent value				327(78.1)
(ASTM C 204) Blaine Fineness, cm <sup>2</sup> /gm	Minimum	2600	2600	2600	3900
(ASTM C 430) -325 Mesh, %	....	....	....	....	96.5
(ASTM C 191) Time of Setting (Vicat)					
Initial Set, minutes	Minimum	45	45	45	116
Final Set, minutes	Maximum	375	375	375	213
(ASTM C 451) False set, %	Minimum	50	50	50	89
(ASTM C 185) Air Content, %	Maximum	12	12	12	5.5
(ASTM C 151) Autoclave Expansion, %	Maximum	0.80	0.80	0.80	0.13
(ASTM C 187) Normal Consistency, %	....	....	....	....	25.3
(ASTM C 1038) Expansion in Water %	Maximum	0.020	0.020	0.020	0.008
(ASTM C 109) Compressive Strength, psi (MPa)					
1 Day	....	....	....	....	2300(15.9)
3 Day	Minimum	1740(12.0)	1450(10.0)	1160(8.0)	4000(27.6)
7 Day	Minimum	2760(19.0)	2470(17.0)	2180(15.0)	4990(34.4)
28 day (strength from preceding month)	Minimum	....	....	3050(21.0)	6310(43.5)

\*\* The performance of CEMENT COMPANY Type II/V has proven to be improved with sulfur trioxide levels in excess of the 2.3% limit for Type V. Note D in ASTM C-150 allows for additional sulfate, provided expansion as measured by ASTM C-1038 does not exceed 0.020%.

CEMENT COMPANY hereby certifies that this cement meets or exceeds the chemical and physical specifications of:

By: \_\_\_\_\_  
 Quality Control Manager  
 CEMENT COMPANY - City Cement Plant  
 1234 Address Street, City, STATE ZIP

ASTM C-150-09 Type I, Type II, and Type V Low Alkali portland cements  
 ASTM C-1157-08a Type GU Hydraulic Cement ← 5  
 Caltrans, Section 90-2.01 Type II Modified and Type V



## FLY ASH CERTIFICATION/TEST RECORD

### Annotations:

1. Verify that the test report is reasonably current so that it would be representative of current product. (Ref. Appendix C Section A.2)
2. Verify that the listed standard matches the standard listed in the specifications and the concrete mix design submitted. If the specifications define constraints on the fly ash type verify that the reported fly ash type is acceptable.
3. Comparison of the reported test values against the acceptable values listed in the specification is not normally done unless there is reason for concern.

### Note:

If additional material requirements for fly ash are listed in the project specifications, such as loss on ignition, the submittal should be checked to verify that these requirements have been complied with.



*FLY ASH COMPANY*  
**ASTM C618 Testing of**

**Jim Bridger Fly Ash**

Sample Type: 3200-ton      Report Date: 01/01/2011 1

**Sample Date:**      **MM/DD – MM/DD/YY**      **MTRF ID**      **647JB**

**Sample ID:**      **BR-022-11-T**

Chemical Analysis		ASTM Limits		ASTM Test Method
		Class F	Class C	
Silicon Dioxide (SiO <sub>2</sub> )	60.48%			
Aluminum Oxide (Al <sub>2</sub> O <sub>3</sub> )	18.85%			
Iron Oxide (Fe <sub>2</sub> O <sub>3</sub> )	4.35%			
Sum of Constituents	83.68%	70.0% min	50.0% min	D4326
Sulfur Trioxide (SO <sub>3</sub> )	0.62%	5.0% max	5.0% max	D4326
Calcium Oxide (CaO)	5.68%			D4326
Moisture	0.05%	3.0% max	3.0% max	C311
Loss on Ignition	0.57%	6.0% max	6.0% max	C311
Total Alkalies, as Na <sub>2</sub> O	3.29%	5% max Caltrans		AASHTO T105
<b>Physical Analysis</b>				
Fineness, % retained on #325	21.20%	34% max	34% max	C311, C430
Strength Activity Index – 7 or 28 day requirement				C311, C109
7 day, % of control	86%	75% min	75% min	
28 day, % of control	89%	75% min	75% min	
Water Requirement, % control	95%	105% max	105% max	
Autoclave Soundness	0.03%	0.8% max	0.8% max	C311, C151
True Particle Density	2.36			

FLY ASH COMPANY certifies that pursuant to current ASTM C618 protocol for testing, the test data listed herein was generated by applicable ASTM methods and meets the requirements of ASTM C618 for Class F fly ash.

2

\_\_\_\_\_  
 First name Last name  
 MTRF Manager

**Materials Testing & Research Facility**  
 1234 Address Street  
 City, State ZIP  
 Tel: (000) 123-4567  
 Fax: (000) 890-1234  
[www.flyashcompanywebsite.com](http://www.flyashcompanywebsite.com)



## WATER REDUCING ADMIXTURE PRODUCT DATA

### Annotations:

1. Verify the admixture complies with the specification requirements and matches the admixture listed in the concrete mix design. If the admixture is specified by name in the project specifications verify that a named product is provided. If the admixture is specified only by the ASTM standard in the project specifications, verify that the standard listed here matches what is specified.

If the specifications make provisions for approved equals when the admixture was specified by name but a non-listed product was submitted the reviewer will need to consider whether to approve the product. When making the determination whether the product is an approved equal consideration should be given to the standards in the specifications as well as to properties of the listed admixtures that may not have been explicitly listed. (Ref. Appendix C section B.12)

2. Verify that the calcium chloride limitations as specified are satisfied. (Ref. Appendix C Section B.9)

### Note:

Strictly speaking the product literature is not a test report but the use of this literature in this form constitutes a promise that the product used will have the listed properties.

## ABC Concrete Products

ABC Concrete

### WRA 521

ASTM C494 Type A and D  
Water-reducing admixture **1**

#### Product Description

WRA 521 is a polymer based aqueous solution of complex organic compounds. WRA 521 is a ready-to-use low viscosity liquid which is factory pre-mixed in exact proportion to minimize handling, eliminate mistakes and guesswork. WRA 521 does not contain calcium chloride and weighs approximately 11 lbs./gal. **2**

#### Uses

WRA 521 produces a concrete with lower water content (typically 5 to 9% reduction), greater plasticity and higher strength. It is used in ready-mix plants, block and concrete product plants, in lightweight and prestressed work wherever concrete is produced.

WRA 521 also performs especially well in concrete containing fly ash and other pozzolans.

#### Finishability

The cement paste, or mortar, in WRA 521 admixed concrete has improved trowelability. The influence of WRA 521 on the finishability of lean mixes is particularly noticeable. Floating and troweling, by machine or hand imparts a smooth, close tolerance surface.

#### Addition Rates

The addition rate of WRA 521 is 4 to 7 fl. oz./100 lbs. of cement. Pretesting is required to determine the appropriate addition rate for Type A and Type D performance. Optimum addition depends on the other concrete mixture components, job conditions and desired performance characteristic.

#### Compatibility with Other Admixtures and Batch Sequencing

WRA 521 is compatible with most ABC admixtures as long as they are added separately to the concrete mix, usually through the water holding tank discharge line. In general, it is recommended that WRA 521 be added to the concrete mix near the end of the batch sequence for optimum performance.

#### Product Advantages

- Improves performance of concrete containing supplementary cementitious materials
- Consistent water reduction and set times
- Produces concrete that is more workable, easy to place and finish
- High compressive and flexural strength





## **DISCUSSIONS AND REFERENCES**

The following appendices discuss issues to be considered when developing project specifications as well as definitions and a list of documents referenced in these guidelines.



## APPENDIX B

### PERFORMANCE AND CODE CONSIDERATIONS FOR MIX DESIGNS

This appendix provides a summary of concrete performance and code issues that the engineer may consider when developing the construction documents.

#### A. Appearance

The appearance of concrete is affected by finishing practices, form materials, cementitious material types and amounts (i.e. such as white or grey cement, slag, fly ash and silica fume), the incorporation of color pigments, and curing practices. Aggregate color and uniformity may be a concern if the aggregate will be exposed.

Where appearance and uniformity of color is important the architect should be involved in editing the concrete specifications and these issues should be discussed at a pre-placement conference. The construction and approval of test panels may be required when specific appearances are desired. When consistency of finish is important consider requiring new test panels when changes are made to the source of materials.

The need to provide uniformity in materials should be made explicitly clear to the contractor.

When a test panel is required to verify appearance characteristics it supplements the mix design review submittal.

#### B. Workability and Placement

The concrete mix needs to be of a consistency such that it can be placed by the intended methods, properly consolidated to prevent voids and segregation, and provided with the desired finish. Placement is influenced by the form geometry, the amount and location of reinforcing steel, and the concrete properties such as aggregate size, aggregate gradation, and slump. The common strategy is to give the contractor sufficient control over the details of the mix design to ensure proper placement.

When the contractor is given the responsibility to proportion the concrete mix the engineer must make sure that he/she has not imposed constraints on the mix that create difficulties. Some potential constraints that could cause problems are large maximum aggregate sizes, maximum slumps that are too low, or not allowing the use of high range water-reducers (super plasticizers) or self-consolidating concrete.

The need to control concrete temperature in mass concrete or during hot and cold weather will often necessitate changes in the mix design. When temperature control is important the use of fly ash, ice or chilled water, and the type of cementitious material are often adjusted.

When the control of temperature is critical the contractor should be required to submit a placement and temperature control plan. Such plans may include provisions for heating or cooling the concrete, the incorporation of suitable amounts of supplementary cementitious materials, monitoring temperature differentials and protecting the concrete for extended periods of time. While there is considerable overlap between the temperature control plan and concrete mix designs, these guidelines do not offer additional guidance regarding the review of such plans.

Mix design weights of aggregate and water are reported based on aggregates in saturated surface dry condition (SSD) and thus at time of batching the weights must be adjusted for the actual aggregate moisture condition.

#### C. Durability

The durability requirements of Chapter 4 of ACI 318 may impose limitations on the types and amounts of cementitious materials, water-cementitious material ratio (w/cm), freeze-thaw resistance, and permeability or corrosion resistance.

#### D. Economic

Concrete mix proportioning decisions, like all design decisions, are strongly influenced by economic considerations. These economic concerns can include life cycle cost, initial cost and schedule, and the impact on liability exposure. There may be no one right answer and the appropriate decision will often be driven by project specific considerations.

A general strategy is to specify only what is needed, do not deviate from standard practice unless there is a real need, specify generically when possible, and focus on specifying performance objectives as opposed to specifying prescriptively. This strategy promotes competition by allowing the contractor to make use of his special expertise to control project costs.

#### E. Shrinkage

If concrete shrinkage is a concern, two common strategies are to require the concrete mix to meet specific shrinkage limits or to indirectly control the shrinkage by placing limits on the mix design and the materials used. Setting specific shrinkage limits is attractive but because of project time constraints and the lack of historical shrinkage data for many mix designs this is often not feasible. It is recommended that the specifier adopt one of the strategies and not use both approaches for the same concrete mix design.

When selecting the strategy to control drying shrinkage it is important to have realistic expectations regarding the impact of the expected shrinkage, cost, and schedule impact.

At times concrete drying shrinkage may not be a major concern depending on the building configuration or the amount of reinforcing steel used in the sections. Without restraint, concrete



can shrink without cracking and with enough reinforcing steel the cracks may be small enough that they will not create problems.

When evaluating the impact of drying shrinkage it is important to consider the sequence of construction and the rate of shrinkage. Shrinkage is not linear with respect to time and little shrinkage will occur in the first several weeks. Thus pour joints that cannot be left open for several months may not have a significant impact on reducing shrinkage cracking.

The point is that it may not be necessary to pay a premium for low shrinkage concrete if the building configuration does not provide restraint or if the reinforcing levels are high enough that crack sizes will be acceptably small.

When there are no shrinkage test results for the proposed concrete mix new tests would need to be performed. The time needed to perform the necessary tests may not be compatible with the project schedule. Thus this issue should be considered during design. This problem is aggravated by the tendency of contractors to not worry about concrete submittals until shortly before concrete is to be delivered to the job site, reducing the time available for testing.

When drying shrinkage limits are specified it is recommended to not also specify specific aggregate sources and other material properties to try to limit shrinkage since this would limit the supplier's options. The specifications should require that shrinkage test results be included with the mix design submittal.

Shrinkage testing should be performed upon laboratory trial batches. Specifying field shrinkage results are not appropriate because of the high variability of the initial curing conditions. In addition if higher than expected field shrinkage values are reported there are often no satisfactory options to correct the field conditions. ASTM C157 notes that the drying shrinkage test is intended as a laboratory test and that specimens cast in the field may exhibit up to twice the shrinkage of laboratory prepared specimens.

Concrete shrinkage is influenced by many factors with the major contributors being the volume of cement paste and amount of water, followed by aggregate properties. For common structural concrete mixes the contribution from the paste volume is relatively constant. The amount of water needed is primarily driven by the aggregate size, particle shape, aggregate characteristics and combined aggregate gradation. Other factors impacting the water demand for a mixture include supplementary cementitious materials and admixtures. Once the amounts of water and cementitious materials have been determined further reductions can be obtained by the use of low shrinkage aggregate and shrinkage reducing admixtures.

The mineralogical character of the aggregates (i.e. stiffness and adsorption) has a significant impact upon the total drying shrinkage. In a region where the aggregates have differing geologic characteristics there can be significant differences between aggregate sources.

The cost of out of market low shrinkage aggregates, specific aggregate sources, or the use of shrinkage reducing admixtures can be substantial and can significantly affect the economics of a



project. It is suggested that specifying a specific aggregate source be avoided unless the specifier has intimate knowledge of the materials, availability, and associated economics in the project area. Some of the historically low shrinkage aggregate sources may no longer be available or their characteristics may have changed because the aggregate from a specific pit may not have the same properties as the aggregate tested years ago. The fact that a particular concrete plant may not have access to specific aggregate sources may make it impractical or difficult to utilize a specific aggregate source.

Concrete shrinkage reducing admixtures reduce the effects of drying shrinkage by reducing the surface tension of the water in the concrete pores. The surface tension of the water in the concrete pores pulling the pores together is a significant factor in drying shrinkage.

#### F. Architectural Considerations

Increasingly concrete mix properties are driven by architectural considerations in addition to the physical properties discussed above. A common issue is the need to accommodate flooring or roofing materials.

The focus on flooring materials applied to concrete is driven by a heightened awareness of moisture transmission and the fact that currently available adhesives are not as effective as the products used in the past. In response to these concerns flooring manufacturers and others have imposed criteria on the w/cm ratio of the concrete mix. Thus it is important to consult with the architect to understand what these limits are. In addition to controlling the w/cm ratio the use of admixtures to reduce the flow of moisture through the concrete and the evaporation of moisture from the concrete may be considered.

In addition to structural or appearance considerations concrete admixtures have been developed that improve the electrical conductivity of concrete and others that cause air pollutants to precipitate out of the air.

#### G. Sustainability

Sustainability considerations are becoming more prominent in concrete construction. Some of the strategies that are used to reduce the environmental impacts and improve sustainability include:

- The use of the thermal mass of concrete to minimize temperature variations and thus the need to heat and cool the building.
- The use of exposed concrete as the building finish, thus eliminating the need to add other finish systems.
- The use of slag or white cement to improve reflectivity and reduce lighting requirements. Improved solar reflectance reduces the heat load and can help to mitigate heat island effects.



- The use of photocatalytic cement on exterior surfaces to remove nitrogen oxides and other atmospheric pollutants.
- Reducing the amount of cement to reduce the amount of carbon in the atmosphere generated by cement production.
- The use of slag, fly ash and other pozzolans to utilize what would otherwise be considered a waste product and to reduce the amount of cement required.
- Reusing crushed concrete or reclaimed aggregate as a portion of the aggregate in concrete mixes.

The California Green Building Standards Code (“CALGreen”) includes provisions that require evidence of percentage reduction in concrete usage, the use of supplementary cementitious materials, and the use of recycled concrete as aggregate. Reference CALGreen Sections A4.403.2, A4.405.3, A5.405.4, and A5.405.5.

Documenting conformance with CALGreen Section A4.403.2 can be difficult since it requires 20% or 25% reduction in cement usage. The question is how to measure this reduction in cement usage. One could show that 25% of the cementitious material was from fly ash or slag but this could be achieved by adding fly ash to the mix without reducing the amount of cement. The other option would be to compare the cement in the mix design to a comparable mix design without fly ash or slag but that would require the development of another mix design with historical test data to justify the design.



## APPENDIX C

### SPECIFICATIONS

#### Approaches to Specifying Concrete<sup>1</sup>

The approach to specifying concrete has evolved over the years. In the 1970's concrete was essentially composed of coarse aggregate, sand, cement, and water. In that era it was common for the engineer to specify the sources of aggregate, aggregate gradations, number of sacks of cement, and maximum slump in addition to the concrete strength.

The prescriptive approach to specifying concrete in the 1970's worked when the concrete strength did not exceed 4 ksi, the rebar congestion was low, concerns about environmental exposures were moderate, the carbon footprint of the concrete was not a concern, sources of materials were stable, and there was relatively little litigation when problems occurred.

In contrast to past practices is the current environment where concrete strength can exceed 10 ksi, high rebar congestion is common, greater attention is paid to durability and environmental exposures, energy and environmental concerns drive decisions, material sources are constantly changing, and where litigation is common. As a result of these current practices concrete specifications focus more on the desired end result, leaving it to the concrete supplier and contractor to develop the mix design and to worry about workability and placement issues.

In response to these pressures and the need to keep their prices down the National Ready Mixed Concrete Association (NRMCA) launched the P2P Initiative to promote a shift to performance-based concrete specifications. As a result of this initiative the Ready Mixed Concrete Research and Education Foundation has developed guidelines for the performance specification of concrete. This initiative is a work in progress.

Performance-based specification of concrete is attractive to engineers because while they know the desired performance characteristics most engineers do not have expertise with concrete mix design. In addition performance-based specifications result in the contractor being responsible for the cost of resolving the problem if the concrete does not meet the performance objectives. As a result these guidelines reflect a bias in favor of performance-based concrete specifications.

In an attempt to minimize the work in specifying concrete mix designs individuals will often state that the mix design should comply with the building code. The introduction of ACI 318 states that this practice is not desirable.

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<sup>1</sup> The intent of this appendix is to help the specifier identify mix design issues that are commonly addressed in concrete specifications. The specifier can then decide what issues are relevant for the current project. It is not the intent of this appendix to establish technical criteria that is appropriate for particular projects.



In response to the growing tendency to specify performance requirements ACI has produced ITG-8R-10 *Report on Performance Based Requirements for Concrete* to help engineers understand the issues.

## Organization of this Appendix

This appendix first discusses how construction specifications are structured and where the information will be located. This is followed by a discussion of the technical content normally addressed in the project specifications. This discussion of the technical content first discusses what is required to be in the submittal followed by specification provisions related to mix design properties and finally the specification provisions related to properties of the materials included in the mix design.

## Organization of Information

Construction documents include the drawings and the specifications. The drawings identify elements with respect to materials and products, indicate relationships between elements of the project, provide information regarding location dimensions and sizes, and provide details of connections. Thus the drawings will help define where the different mix designs will be used. The specifications define requirements for materials, workmanship, and quality assurance procedures, including submittals for mix designs. It is important that the information shown in the specifications and on the drawings be coordinated so as not to create conflicts.

Any mix design requirements that are intended to be enforced need to be stated on the construction documents, either on the drawings or in the specifications. Where there are General Notes but no specifications special care should be exercised to verify that the notes include all of the requirements that will be enforced. Similarly the construction documents should not include provisions that the designers are not willing to enforce.

The separation between drawings and specifications is not absolute. A common example of this is when a table is included in the drawings that correlates the type of concrete mix used for different portions of the work and indicates the mix design properties that are specific to each mix. This approach can make it easier to coordinate the drawings and specifications but it is important to make sure that information included on the drawings does not conflict with the information in the specifications. Input from a concrete supplier is that this approach usually results in a more complete submittal package.

The technical specifications are divided into sections describing different types of work. On some projects there may be several specification sections that define concrete mixes. Some common examples include site concrete specified by the project civil engineer and landscaping concrete specified by the landscape architect in addition to the building concrete specified by the structural engineer. When there are multiple specification sections specifying concrete it is important that there is a common understanding of who is reviewing which mix design.



When there are multiple specification sections that specify concrete mixes consideration should be given during design to coordinating these sections to allow the contractor to minimize the number of mix designs. When different specifications define concrete mix designs for concrete that will be visible in the completed structure it may be appropriate to coordinate the requirements to assure that the different mixes will look the same.

In addition to the technical specification sections authored by the engineer the prime design professional will include specification sections addressing topics such as submittal procedures and the handling of substitutions. The mix design reviewer should be familiar with these specification sections.

The individual specification sections are divided into 3 parts typically titled General, Products, and Execution.

PART 1 - General is where non-technical provisions such as administrative, regulatory, and submittal requirements are listed. This is where any testing of source materials would be specified.

PART 2 - Products is where the mix design requirements and the material specifications are defined.

PART 3 - Execution contains requirements related to the batching, transporting, and placement of the concrete. This part also contains testing and inspection activities performed during construction. Thus the mix design review will not usually use the information in this part.

## Technical Content Commonly Addressed in Specifications

The focus of this section is on identifying information commonly provided in specifications along with information to help the engineer determine what to specify. Key issues are identified and references to resources are provided but it is not the intent to provide specific recommendations on material properties or what should be specified.

References that the engineer may find useful include:

- *ACI Manual of Concrete Practice*
- *Guide to Improving Specifications for Ready Mixed Concrete*, NRMCA Publication 2PE003

### A. Submittal Requirements

The specifications need to spell out the contents of the submittal in detail since there is no code requirement that the mix designs be submitted for review nor that it be reviewed by the engineer of record. Typically these requirements are listed in PART 1 of the specifications.



Only require that information be submitted that you intend to review. If information needs to be submitted to confirm that something was done but which you will not review then it should be designated as an informational submittal.

1. Mix Design

The specifications should list all of the items to be included in the mix design submittal. The following are often required.

1. Mix identification by means of class or location where mix will be used.
2. Strength of concrete.
3. Target slump or slump flow, w/cm, density, and air content.
4. List of all materials, admixtures, and additives along with their proportions.
5. Nominal maximum aggregate size and combined aggregate gradation (percent passing on every sieve size).
6. Calculations and test results required by ACI 318 Section 5.3.
7. Shrinkage test results when shrinkage limits are specified.
8. Test results of total chloride content.
9. Information on concrete materials as per Section 4.1.2.3 of ACI 301.
10. For lightweight aggregate submit test results per ASTM C330.
11. For normal weight aggregate submit test results per ASTM C33, including the cleanness value, sand equivalent, and alkali-silica reactivity (ASR) potential and mitigation, if required.
12. Mill certificate for the cement indicating the source of the cement and compliance with the project specifications.
13. Mill analysis for supplementary cementitious materials (including fly ash and slag cement) and aggregates from the manufacturer.
14. Certification by the manufacturers that the admixtures conform to specified standards.
15. Whether mix is appropriate for pumping.
16. Thermal control plan. While this may be considered a separate submittal it should be reviewed in conjunction with the mix design submittal.

2. Material Certificates and Product Data

List the material certificates and specific product data that you wish to see. Product catalogs may provide a lot of information but unless they contain specific information that will establish that the product or material complies with the



specification requirements they need not be provided for review. There is no need for information that does not provide evidence of compliance with one of the specification requirements. If a product was specified by brand name and or product number then requiring submittal of a catalog sheet provides no benefit or added assurance.

It is not feasible for the aggregate and cementitious material suppliers to provide material certificates and test results that are based on the actual materials that will be provided. Aggregate and cementitious material test certificates usually represent the average results for a particular lot or period of production. It is not unreasonable to require that the certificates and test results are current and have been produced within the last 12 months. This will provide some protection against unanticipated changes in the material sources.

Sometimes concrete mix design submittals will include Material Safety Data Sheets (MSDS) for the materials in the mix. MSDS document the potential environmental and safety hazards associated with handling the materials and the precautions that workers that are handling the materials should take to mitigate these hazards. OSHA regulations require that an employer, such as a contractor, be informed about the hazards and keep them on file on the job site. Some owners may require that the MSDS be submitted to them. However, because MSDS sheets do not pertain to the performance of the concrete and are outside of the scope of the structural engineer's work the engineer is not responsible for reviewing these sheets. Instead, the engineer should note them as "not reviewed" and return them without a shop drawing stamp or further comment.

3. Manufacturer's Recommendations and Instructions

In general manufacturer's recommendations and instructions are not reviewed by the design professionals because they are part of the contractor's means and methods and thus are outside of the design team's scope. If they are submitted, the reviewer should note that they were "not reviewed" and return them without a shop drawing stamp or further comment.

4. DSA/OSHPD Additional Requirements

When the project is subject to the jurisdiction of either DSA (K-12 schools) or OSHPD (hospitals) the following requirements should be addressed in the specifications:

- CBC Section 1903A.3 requires the reporting of the percentage of total cementitious materials for each type of cementitious material used in the mix.
- CBC Section 1903A.4 prohibits the use of Class C fly ash. Also, if more than moderate amounts of slag cement or fly ash are used, then the mix design



must be validated based on field experience or trial mixtures. This limitation does not appear to apply when the cement is provided by ASTM C595 and ASTM C1157.

- CBC Section 1903A.5 requires enforcement agency approval for deviations from aggregate size limitations. This section also requires the testing for reactivity using ASTM C289 if new aggregate sources are used or if problems have been reported. It is not clear how the engineer can determine if this is a new source for the agency or if the agency believes problems have been reported.
- CBC Section 1905A.1.1 requires  $f'_c$  to be greater than or equal to 3,000 psi. This section also does not allow  $f'_c$  to be greater than 8,000 psi without special permission.
- CBC Section 1905A.2 requires a registered engineer to determine the basic proportions of concrete mixture. Given that the acceptance criteria is objective it is not clear what additional constraints that the registered engineer is expected to impose.

5. LEED Submittals:

Require submittals to include documentation that verify compliance with LEED requirements, such as the cement and aggregates be locally sourced.

B. Mix design properties

The concrete mix properties need to be specified for each class of concrete used on the project. It is fairly common practice to provide a table of mix properties on the drawings with the specifications providing more detail on the individual properties.

1. Compressive Strength

Specify the compressive strength for each class of concrete. Indicate the age at which the strength is required. For example, it might be 3 days for form removal or tendon stressing, 56 days for a mix with high volume fly ash (HVFA) or 28, 56 or even 90 days for mass concrete applications. Be realistic in strength expectations and avoid specifying high early strength for HVFA applications.

A higher concrete compressive strength than required to carry the loads may be required by other criteria such as w/cm limitations, modulus of elasticity, and the provisions of ACI 318 Section 4.3 triggered by the concrete exposure. Recommendations in other ACI documents and from other sources may also impact the minimum concrete strength specified.



Section 1.1.1 of ACI 318 sets a minimum compressive strength of 2,500 psi for structural concrete.

ACI 318-08 requires that the strength tests records used to calculate the standard deviation and concrete strength be no more than 12 months old. This creates situations where producers are unable to establish a standard deviation and must use the higher overdress values from Table 5.3.2.1 to calculate the required average strength. This results in higher cementitious contents and higher cost mixes. It is our understanding that ACI 318 has realized the problems with this change and intends to revert back to the 24 month criteria.

Concrete producers have a chronic problem in obtaining copies of the concrete strength test results from past projects and as a result are at times compelled to design for higher target concrete strengths. The engineer is often limited in his or her ability to compel that the results from the owner's testing laboratory be provided directly to the concrete supplier because all communication to the contractor and his suppliers are typically through the contractor. One approach to this is to require evidence of compliance to ASTM C94 which requires that the test results be provided to the concrete supplier.

2. Concrete Density

Concrete density is normally specified as either light weight, normal weight or heavy weight concrete. Normal weight concrete is assumed to be approximately 145 pcf. When light weight or heavy weight concrete is specified it is necessary to also specify maximum or minimum density in pounds per cubic foot. The test method for air-dry or equilibrium density is ASTM C567. The density of light weight concrete may be reported as the calculated density, oven dry density or air dried density. This allows the contractor to choose the method of compliance.

Specified concrete density is usually significant when there is a concern about fire rating (light weight), radiation shielding (heavy weight), structural weight, or capacity of members. Light weight concrete is often specified at 110 pcf to take advantage of fire rating for certain assemblies and in such cases higher densities may not be appropriate. Sometimes light weight fine aggregate may be needed to meet this and lower densities.

3. Maximum Aggregate Size

Maximum aggregate size needs to be coordinated with the specified concrete cover and the rebar congestion. The code limitations on maximum aggregate size are specified in ACI 318 Section 3.3.2. It needs to be appreciated that some concrete suppliers will have different aggregate gradations and thus may not have exactly the maximum size specified.



In general the larger the maximum aggregate size is then the less cement paste is needed. This reduces the cost of the concrete, reduces the carbon footprint of the concrete, and helps to limit shrinkage.

4. Slump/Slump Flow

Specify the maximum slump or require the contractor to specify a target slump for each mix design with the understanding that if the slump varies by more than that the tolerance the batch will be rejected. If the slump tolerance is not explicitly stated in the specifications the tolerance will be defined by ASTM C94 if it is referenced.

NRMCA suggests that the engineer should stop specifying slump because the slump limit might result in a mix design that will be hard to place. This concern is addressed when the contractor is required to specify a target slump which would be used to reject mixes when the field slump is not within tolerance of the target value.

When concrete did not have admixtures such as super-plasticizers, slump was a good indication of the amount of water in the concrete mix. This is not the case with modern day concrete mixes, but slump is still a good indicator of the consistency of one batch with respect to another.

It is suggested that a maximum be placed on the target slump of no more than eight inches unless slump flow tests are used to verify the mix will not segregate.

When the slump is specified this is the target value and the allowed variation is defined by ASTM C94 if it is referenced.

If the contractor is allowed to adjust the slump or if a low w/cm is specified the specifications should allow the use of superplasticizers.

If slumps in excess of 8 in. are allowed or if the use of self-consolidating concrete is contemplated the engineer should specify the test methods and the limits to control segregation.

5. Water Cementitious Materials Ratio

The water-cementitious materials ratio (w/cm) should be indicated. Water cementitious materials ratio has replaced the use of water cement ratio (w/c). The w/cm is the ratio of the weight of the water to the combined weight of all cementitious materials. Refer to the definition in Appendix E.

The water cementitious materials ratio is often driven by code requirements (e.g., ACI 318 Section 4.3), other ACI standards and guides, or by the manufacturer of the flooring material. The commentary to ACI 318 Section 4.1.1 suggests that the  $f'_c$  specified will be reasonably consistent with the specified w/cm. ACI 318 Section 4.1.2 notes that code w/cm maximums do not apply to light weight concrete, but because of the concerns about the drying of concrete with flooring adhesives applied it is probably still appropriate to specify a w/cm for light weight concrete.

#### 6. Limitations on use of Supplementary Cementitious Materials

Specify applicable limits on supplementary cementitious materials (SCMs) such as slag cement, fly ash, metakaolin, and silica fume. While the NRMCA recommends against specifying upper and lower bound limits on SCMs there are a number of common situations where this is necessary. Some examples include using the concrete provisions in CALGreen (Sections A4.403.2 and A5.405.5.2.1) defining minimum amounts, limiting pozzolans to minimize concrete slab finishing problems, or the durability provisions in Chapter 4 of ACI 318 which may require or limit the use of SCMs.

Concrete mixes with high volumes (percentages) of fly ash and slag have been used with success. High volume fly ash mixes have used 60% by weight of Class F fly ash. Slag cement has been used at a replacement of 40 to 50 percent by weight and may be used up to 80 % for mass concrete. In severe freeze thaw conditions ACI 318 limits the maximum amount of SCMs.

The amount and type of SCMs used can significantly affect setting time, susceptibility to plastic shrinkage cracking, rate of strength development, heat of hydration, and project sustainability goals. In addition the use of pozzolans may impact the concrete finish especially for trowelled slabs.

PCA's *Design and Control of Concrete Mixtures* includes an excellent discussion of SCMs.

#### 7. Durability Requirements

ACI 318 Sections 4.2 and 4.3 specifies durability requirements for several exposure classes. These requirements can be addressed in the specifications by either specifying the exposure classes and requiring the contractor to develop mix designs that satisfies the specific code requirements or by specifying the specific parameters applicable for each concrete mix. Concrete suppliers prefer the second approach. There are tradeoffs but whatever approach is selected it is necessary to verify that all of the code issues have been addressed in a manner so that it is clear what the contractor should do.



When the engineer specifies the specific parameters, as opposed to having the contractor develop the mix design based on performance criteria, the engineer may have to specify the cement type, percentage of air entrainment, and the percentage of fly ash or pozzolan. In the case of Exposure Class S3 the need to base the amount of pozzolan or slag cement on service record or test data may effectively preclude the engineer from specifying the percentages of these materials.

Determination of whether there is a concern about chemical (usually sulfate) attack from soil or groundwater will typically require input from the geotechnical engineer.

8. Aggregate Reactivity

Related to durability is the concern about Alkali-Silica Reactivity (ASR) which has to do with the chemical interaction between the silica from the aggregate and the alkalis from the cement.

Often the specifications will require that when aggregates are tested for ASR that the results be innocuous. When the contractor is allowed to use potentially reactive aggregates the specifications should make it clear that the contractor has the responsibility of providing a concrete mix that mitigates the problem.

Reactivity between cementitious material and aggregates can often be mitigated by providing a suitable amount of pozzolan or slag cement. Evidence of innocuous behavior may be provided with data from ASTM C289, C1260, C1293, and/or C295. Evidence of appropriate mitigation of potential deleterious aggregates may be provided with data from ASTM C1567, which is referenced from ASTM C33. The appendix to ASTM C33 provides additional information.

When pozzolans such as fly ash are used considerations should be given to the previously discussed limitations on the use of fly ash.

9. Chloride Content

Chloride content needs to be controlled. This can be done by requiring compliance with the appropriate exposure class in ACI 318 Table 4.3.1.

ACI 318 Table 4.3.1 defines the allowable chloride content for various applications. The amount of chloride ions can be obtained by testing individual concrete ingredients and based on the proportions of the ingredients calculating total ion content. Alternately it is acceptable to test samples of hardened concrete to find the total ion content.



In Northern California sand dredged from San Francisco Bay is often used. Concrete containing washed marine sands and small amounts of marine “blend” sands can often meet the maximum allowable amount of chlorides for conventionally reinforced concrete. Mixtures containing these sands may also comply with requirements for post-tensioned and prestressed concrete, although common practice is to exclude these sands from these applications.

Recycled water and admixtures are other sources of chlorides. Even when overall chloride limits are specified it is common practice to specify that accelerators not contain calcium chloride.

10. Shrinkage Limits

When it is desired to formally control drying shrinkage the limits should be defined in the specifications. The specifications should also clearly address the number of days of drying, the size of the samples, the testing protocol and modifications to the curing or drying procedures. See the previous discussion on shrinkage control strategies.

While the primary shrinkage testing protocol is ASTM C157 much of the existing data for concrete shrinkage in California is based on a modified procedure from the SEAONC “Supplementary Recommendations for Control of Shrinkage in Concrete”. This protocol recommends a 7-day moist cure followed by 28-days drying. The initial or zero reading is taken at the end of the 7-day moist curing period.

Shrinkage testing should be performed upon laboratory trial batches. ASTM C157 notes that the drying shrinkage test is intended as a laboratory test and that results from specimens cast in the field may exhibit up to twice the shrinkage of laboratory prepared specimens.

11. Percentage of Air Entrainment

When air content is required by ACI 318 the amount is defined in Table 4.4.1. Sometimes contractors will prefer the use of air entrainment to make the concrete easier to place.

Indicate the percentage of air entrainment required at the point of deposit. The air content at the point of deposit can differ significantly from the air content at the truck. Indicate if the contractor is allowed to use air entrainment when not otherwise required. When mixes use fly ash it may be difficult to produce consistent air content.

Air entrainment for slabs that are to have a steel trowelled finish can result in blistering or delamination if not finished properly.



12. Admixtures

The specifications need to be clear what admixtures are mandatory for specific mixes and which can be used at the contractor's option. Where possible the generic admixture specifications should be referenced.

Specifying admixtures generically is preferred because:

- Concrete suppliers do not typically have admixtures from multiple manufacturers.
- Engineers typically do not have the expertise to determine whether one admixture is superior to another if both comply with the specified standard or if they are compatible with the aggregate and cementitious materials used.
- If for some reason the admixture listed by name did not comply with the ASTM standard or was incompatible with other admixture the contractor would still be in compliance with his contract if he used it, whereas if a performance specification is used the liability remains with the contractor.
- The consolidation of the concrete admixture business and technology improvements have created a situation where some of the admixtures commonly listed in specifications are no longer available.

In general the dosage rates will be selected by the individual designing the concrete mix. The dosage rate for admixtures should be in accordance with the manufacturer's recommended range. This will be found in the data sheets provided with the submittal. For some specialty admixtures it may be appropriate for the engineer to specify dosage rates although this is the exception.

The constraints imposed by the lack of dedicated batching tanks do not apply to specialty admixtures that are hand batched.

C. Material Properties

1. Cementitious materials

Indicate acceptable cement standards and the cement types. Alternately the acceptable cement types could be defined as part of the mix design properties. Note that the type designations are unique for each of the cement standards.

ACI 318 now talks in terms of cementitious material and not just cement. No distinction is made between the several cementitious materials listed in Section 3.2.1 of ACI 318 although by convention ASTM C150, ASTM C595, and ASTM C1157 are specified as cement with the others being referred to as supplementary

cementitious materials. ASTM C150 is no longer the only type of cement specified.

ASTM C150 is the standard specification for portland cement. There are 5 basic cement types defined in this standard. Type I is the least restrictive, for use when the special properties specified for the other types are not required. Type II is designed for general use and has moderate sulfate resistance properties. Type III is similar to Type I but is manufactured differently to produce high early strength concrete. Type IV is used for mass concrete where the rate and amount of heat generated by hydration needs to be minimized. Type V is similar to Type II but has a higher resistance to sulfates. Cements that are designated with multiple types, such as Type II/V, meet the specifications of both types and can be used when either type is specified. ASTM C150 Type II/V is the most commonly used cement in California. These cements also meet the less restrictive requirements for Type I cement.

ASTM C595 specifies hydraulic cement created by blending portland cement with one or more SCMs to create a blended hydraulic cement. ASTM C1157 is a performance oriented cement specification that includes portland and blended cements. ASTM C595 and C1157, as well as C150, are the referenced standards for blended and portland cement in the voluntary CALGreen Section A5.405.5.

It is suggested that the specifications not limit which cementitious materials can be used unless there are specific technical or other constraints. For example if expansive cement is needed ASTM C845 can be specified.

## 2. Supplementary Cementitious Materials (SCMs)

The types of SCMs that will be allowed and the corresponding standards should be listed. The normally available SCMs include Class F fly ash, slag cement, silica fume, and metakaolin (a type of Class N fly ash).

SCMs may be incorporated singly with cement (a binary blend), or in combination with another SCM, a ternary blend. Some cement manufacturers produce blended cement that incorporates the SCM in the cement (i.e. Type I-P cement). When this is done the total amount of SCM would include both the SCM added and the SCM incorporated in the cement.

The type of fly ash (F or C) is determined by the type of coal used and firing conditions at a specific power plant. There are no plants producing Class C fly ash supplying the California market. Thus Class C fly ash is not commonly available in California.

## 3. Fine Aggregate (sand)



List the material specification, ASTM C33, for fine aggregate as well as supplemental requirements. The primary supplemental requirement for fine aggregate is the limits on aggregate reactivity in ASTM C33 Appendix X1. ASTM C33 provides for several methods to evaluate an aggregate for potential alkali-silica reactivity (ASR) including ASTM C1260 and ASTM C1293. ASTM C1260 is a 16 day test whereas ASTM C1293 is a one year test. ASTM C1260 is a severe test and many aggregates that have a satisfactory record of performance fail it. A modification of ASTM C1260, ASTM C1567 is used to determine the appropriate mitigation for potential ASR. The specifications should make it clear what tests shall or can be used to evaluate reactivity.

Some project specifications may include a requirement for sand equivalent of the fine aggregate. This is a cleanliness test using Caltrans Test Method 217. Caltrans requires a minimum sand equivalent value of 71. Caltrans Test Method 217 provides the procedure for measuring the relative proportions of detrimental fine dust or clay-like material in soil or fine aggregates and is represented as a unitless number. The higher the number is the smaller the proportion of fine dust or clay in the aggregates.

#### 4. Coarse Aggregate

The specification for coarse aggregate should list the aggregate types that will be used, typically normal weight and light weight, the applicable standard, either ASTM C33 or ASTM C330, as well as supplemental requirements.

The primary supplemental requirement for coarse aggregate is the limits on aggregate reactivity in ASTM C33 Appendix X1. ASTM C33 provides for several methods to evaluate an aggregate for potential alkali-silica reactivity including ASTM C1260 and ASTM C1293. ASTM C1260 is a 16 day test whereas ASTM C1293 is a one year test. ASTM C1260 is a severe test and many aggregates that have a satisfactory record of performance fail it. A modification of ASTM C1260, ASTM C1567 is used to determine the appropriate mitigation for potential ASR. The specifications should make it clear what tests shall or can be used to evaluate reactivity.

Some project specifications may include a requirement for cleanness of the coarse aggregate. This is evaluated using Caltrans Test Method 227. Caltrans requires a minimum cleanness value of 71. Caltrans Test Method 227 provides an indication of the relative proportions of clay-sized material clinging to coarse aggregates or screenings and is represented as a unitless number. The higher the number is the smaller the proportion of clay in the aggregate.

When light weight concrete is specified consideration should be given to the types of light weight aggregates provided. There is evidence that concrete made with some types of pumice aggregate can have lower shear strengths than accounted

for by the reduction factors in Section 8.6.1 of ACI 318.<sup>2</sup> This concern can be addressed by either prohibiting the use of pumice aggregate or by specifying a minimum splitting tensile strength.

Limitations on aggregate gradation have sometimes been provided but current practice is not to specify these constraints, which is consistent with the approach of making the contractor responsible for issues related to workability and placeability of concrete.

When it is desirable to use crushed (recycled) concrete as coarse aggregate in new concrete the specifications will need to define any additional criteria for acceptance of this material. Two sources of guidance on the use of recycled concrete are Federal Highway Association Technical Advisory T5040.37 and ACI 555, *Removal and Reuse of Hardened Concrete*.

#### 5. Water

Mix water may consist of municipal water, well water, recycled or reclaimed water, or a combination. It was once assumed that mix water should be “potable” though this is no longer the case and specifications should not require the use of potable water. ACI 318 Section 3.4 defines the criterion for mix water to be ASTM C1602. This criterion is also stated in ASTM C94.

ASTM C1602 has optional limits on sulfates, chlorides, alkalis, and total solids that can be specified if appropriate. These optional limits are seldom specified.

#### 6. Admixtures

Commonly used admixtures such as water-reducing (normal and mid-range), accelerating, retarding, high range water-reducing (super plasticizers), shrinkage reducing and viscosity modifying admixtures should be specified generically using the appropriate ASTM Standards. Refer to the discussion on admixtures in Section B.12 above.

In some cases the dosage rates of the allowed mixtures will need to be specified.

The contractor should be required to verify the compatibility of the admixtures when used in combinations used for the specified mixes.

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<sup>2</sup> The recommendation to specify minimum splitting tensile stress values when pumice aggregate is allowed is based on a concern that the default shear stress reductions were based on stronger lightweight aggregates and may not be appropriate for pumice aggregates. This concern is supported by low splitting tensile stress test values reported by “Properties of LWAC made with natural lightweight aggregates” by Project Programme of Brite/EuRam project BE96-3942 and by “High Strength Natural Lightweight Aggregate Concrete with Silica Fume”; by A. Yeginobali, K.G. Sobolev, S.V. Soboleva and M. Tokyay; ACI SP 178-38.



### Special Considerations

Lean concrete and controlled low strength concrete (CLSM):

On some projects low strength (lean) concrete is used for backfill of utility trenches or to fill in areas where the soil has been over excavated. By convention this lean concrete has been specified with an  $f'_c = 2,000$  psi, which is lower than the scope of ACI 318. If a significant amount of cement is used this material can be very difficult to excavate in the future.

CLSM is a mixture of aggregate, fly ash and small amounts of cement that has been developed as a replacement for low strength material used to backfill soil. CLSM is typically specified to have a maximum compressive strength of not more than 75-150 psi. (Note that a common soil bearing value of 3,000 psf is equivalent to a compressive strength of about 21 psi). As a result the material is less expensive than lean concrete, uses less cement, may incorporate recycled or non-specified materials and is thus more sustainable, and is easier to excavate with hand tools.

CBC Sections 1804.2 and 1804.6 give guidance on the use of CLSM and make the point that the geotechnical engineer be involved in establishing the criteria for the use of this product. Based on the fact that CLSM is not structural and thus not subject to special inspection it may be appropriate for this to be specified in the grading or site work concrete specification sections. This should be coordinated during preparation of contract documents.

## APPENDIX D

### REVIEW OF MIX DESIGN STRENGTHS

#### A. Methods of Documenting Concrete Strengths

ACI 318 Section 5.3 requires that test data be used to validate the required concrete strength. This can be done either by the use of field strength test records or by making and testing trial batches. This process is summarized by ACI 318 Figure R5.3. The basic approach is that the lower the standard deviation is the less overdesign is required. The use of laboratory trial batch results requires an overdesign that is usually significantly higher than that based upon the strength history.

When the strength test records or trial batches required by Section 5.3 are not available Section 5.4 allows for the use of concrete proportioned based on other experience or information if a higher target strength is used. Because the use of this option will be dependent on the particular circumstances of the project and the information available these guidelines are not in a position to provide any guidance on the use of this option. Because of the uncertainty associated with this approach some project specifications do not allow this option.

ACI 318 Section 5.5 gives permission to reduce the amount by which the test data must exceed the specified compression strength as a result of data obtained during construction, thus allowing the mixture proportions to be adjusted.

#### B. Evaluating the Test Results

When starting to evaluate the test results a basic question that must be answered is whether the mix design can be qualified based on field strength test results or whether the results from a series of trial mixtures are required. Field strength test results can be used if there are at least 10 consecutive tests for mixtures using similar materials under similar conditions. If this condition is not satisfied the mix must be qualified based on the results of a series of trial mixtures.

At least 15 test results are required to establish a standard deviation used to determine the required average strength,  $f'_{cr}$ . A modification factor is applied to the standard deviation when less than thirty tests are used. Such tests shall be for concrete mixes having strength within 1,000 psi of the required compressive strength,  $f'_c$ . When less than 15 test records are available Table 5.3.2.2 establishes the required average strength.

Test records used to determine the average compressive strength must include at least 10 consecutive tests. In order to qualify as consecutive tests the field strength test records must have been performed over a period of at least 45 days and have been based on similar concrete mixes within 1,000 psi of the specified concrete strength.

A similar mix is considered to be one incorporating similar materials and proportions and that is not more restrictive than the mix under consideration. For example, a mix having a w/cm ratio



of 0.55 could be used to support a mix with a w/cm ratio of 0.50 if the materials and proportions are similar. Similarly, a 5 sack mix can be used to support a 6.0 sack mix, as long as their design strength is within 1,000 psi of each other. Likewise, a 20% fly ash mix could be used to support a 15% fly ash mix as long as the w/cm ratio is the same or higher since the 20% fly ash mix would be expected to produce a lower strength than the proposed mix.

Similar mixes should have the same maximum aggregate size and similar gradations.

The concept of similar materials is not clearly defined and is subject to interpretation. Obviously the use of the same source of materials (cement, fly ash, aggregates, and types of admixtures (types not brands)) complies but this is not a requirement.

How close the materials and mix proportions of similar mix designs have to be is a judgment call. The ready mix producer bears most of the risk if the mix does not perform, thus normal practice is to give the supplier a lot of flexibility. Because of the possibility that similar mix designs may be used to justify the submitted mix design it may be appropriate to request information on the similar mixes. This will make it possible to verify whether a mix design qualifies as a similar mix.

If satisfactory test records are not available then trial mixtures are needed (Reference Section 5.3.3.2 of ACI 318). This requires multiple laboratory trial batches with a range of proportions that would produce a range of strengths that bracket the required compressive strengths. The commentary in ACI 318 makes it clear that when multiple types of cementitious materials are used, more trial batches are needed to explore the sensitivity of compressive strength to variations in mixture proportions. The number of trial batches is not explicitly defined. The requirements for qualification by trial batches have changed in ACI 318-08 and it is not clear that all of the concrete suppliers have adjusted their practices to reflect these provisions.

The practice of submitting the results of a single trial batch does not comply with the requirements for qualification by trial batches.

ACI 318 Section 5.4.1 allows the design professional to allow the use of the mix when strength is justified based on other “experience or information” when  $f'_c$  is not greater than 5,000 psi. Under this provision the design professional has the option of accepting a mix design that is submitted without sufficient test records or trial batches, including mixes that are based on a single trial batch, if in his or her judgment the mix is otherwise adequate.

## APPENDIX E

### DEFINITIONS AND TERMINOLOGY

This is a compilation of general terminology related to hydraulic cement concrete, concrete aggregates, and other material used in or with hydraulic cement concrete and is based on ASTM C125-07. For other common definitions refer to Chapter 2 of ACI 318 and Section 2.2 of the CBC.

**absorption, *n*** - the process by which water is drawn into and tends to fill permeable pores in a porous solid body; also, the increase in mass of a porous solid body resulting from the penetration of a liquid into its permeable pores.

**admixture, *n*** - a material other than water, aggregates, hydraulic cementitious material, and fiber reinforcement that is used as an ingredient of a cementitious mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing.

*accelerating admixture, n* - admixture that accelerates the setting and early strength development of concrete.

*retarding admixture, n* - admixture that retards the setting of concrete.

*water-reducing admixture, n* - admixture that either increases the slump of freshly mixed mortar or concrete without increasing the water content or that maintains the slump with a reduced amount of water due to factors other than air entrainment.

*water-reducing admixture, high-range, n* - a water-reducing admixture capable of producing at least 12 % reduction of water content when tested in accordance with ASTM C494 and meeting the other relevant requirements of ASTM C494.

**aggregate, *n*** - granular material, such as sand, gravel, crushed stone, or iron blast-furnace slag, used with a cementing medium to form hydraulic-cement concrete or mortar.

*coarse aggregate, n* - (1) aggregate predominantly retained on the No. 4 sieve; or (2) that portion of an aggregate retained on the No. 4 sieve.

*fine aggregate, n* - (1) aggregate passing the 3/8-in. sieve and almost entirely passing the No. 4 sieve and predominantly retained on the No. 200 sieve; or (2) that portion of an aggregate passing the No. 4 sieve and retained on the No. 200 sieve.

*high-density aggregate, n* - aggregate with relative density greater than 3.3.

*light weight aggregate, n* - aggregate with bulk density less than 70 lb./ft.<sup>3</sup>, such as pumice, scoria, volcanic cinders, tuff, and diatomite; expanded or sintered clay, shale, slate,

diatomaceous shale, perlite, vermiculite, or slag; and end products of coal or coke combustion.

*normal-density aggregate, n* - aggregate that is neither high nor low density with bulk density typically ranging between 70 lb./ft.<sup>3</sup> and 120 lb./ft.<sup>3</sup>.

*Normal weight aggregate, n* - see *normal-density aggregate*.

**air content, n** - the volume of air voids in cement paste, mortar, or concrete, exclusive of pore space in aggregate particles, usually expressed as a percentage of total volume of the paste, mortar, or concrete.

*air void* - see **void, air**.

**blast-furnace slag, n** - the nonmetallic product, consisting essentially of silicates and aluminosilicates of calcium and other bases, which is developed in a molten condition simultaneously with iron in a blast furnace.

**bulk density, n** - *of aggregate*, the mass of a unit volume of bulk aggregate material (the unit volume includes the volume of the individual particles and the volume of the voids between the particles).

**cement, hydraulic, n** - a cement that sets and hardens by chemical reaction with water and is capable of doing so under water.

**paste, cement, n** - the binder in a cementitious mixture composed of hydraulic cementitious material and water that may also contain admixtures; when part of concrete or mortar, it includes the material from aggregates finer than No. 200 sieve.

**cementitious material (hydraulic), n** - an inorganic material or a mixture of inorganic materials that sets and develops strength by chemical reaction with water by formation of hydrates and is capable of doing so under water. Cementitious material includes supplementary cementitious materials.

**class of concrete (A, B, C, etc.), n** - many projects refer to the different mix designs as Concrete Classes. This nomenclature and the concrete mixes associated with the class will vary from project to project.

**concrete, n** - a material that consists of a binder within which are embedded particles of aggregate; often fine and coarse; a mixture of mortar and coarse aggregates.

**concrete, fresh, n** - concrete which possesses enough of its original workability so that it can be placed and consolidated by the intended methods.



**concrete, hardened**, *n* - concrete that has developed sufficient strength to serve some defined purpose or resist a stipulated loading without failure.

**concrete, self-consolidating**, *n* - concrete mixtures that can be placed without the need for mechanical consolidation.

**consistency**, *n* - *of fresh concrete, mortar, or grout*, the relative mobility or ability to flow.

*crushed stone* - see **stone, crushed**.

**density**, *n* - mass per unit volume (preferred over deprecated term **unit weight**).

**drying shrinkage**, *n* - a volume change that results in the reduction in the dimensions of a section or specimen of concrete due to a loss of moisture.

*entrained air* - see **void, air**.

*entrapped air* - see **void, air**.

**expanded blast-furnace slag**, *n* - the light weight cellular material obtained by controlled processing of molten blast furnace slag with water or water and other agents, such as steam or compressed air or both.

**fibers**, *n* - slender filaments, which may be discrete or in the form of bundles, networks, or strands of natural or manufactured materials, which can be distributed throughout a fresh cementitious mixture.

**fineness modulus**, *n* - *of aggregate*, a factor obtained by adding the percentages of material in the sample that is coarser than each of the following sieves (cumulative percentages retained), and dividing the sum by 100: No. 100, No. 50, No. 30, No. 16, No. 8, No. 4, 3/8-in., 3/4-in., 1-1/2-in., 3-in., 6-in.

**fly ash**, *n* - the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gases from the combustion zone to the particle removal system.

*hydraulic cement* - see **cement, hydraulic**.

**maximum size** (*of aggregate*), *n* - in specifications for, or description of aggregate, the smallest sieve opening through which the entire amount of aggregate is required to pass.

**mortar**, *n* - a mixture of cement paste and fine aggregates; in concrete, the material (exclusive of fibers) occupying the space between coarse aggregate particles.

**nominal maximum size** (*of aggregate*), *n* - in specifications for, or description of aggregate, the smallest sieve opening through which the entire amount of the aggregate is permitted to pass.

**pozzolan**, *n* - a siliceous or siliceous and aluminous material, which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

*relative density*, *n* - see **specific gravity**

**slag cement**, *n* - granulated blast furnace slag that is ground to cement fineness with or without additions and meets ASTM C989.

**sack of cement**, *n* - a sack of cement weighs 94 pounds.

**sand**, *n* - fine aggregate resulting from natural disintegration and abrasion of rock or processing of completely friable sandstone.

**segregation**, *n* - the unintentional separation of the constituents of concrete or particles of an aggregate, causing a lack of uniformity in their distribution.

*self-consolidating concrete*, *SCC* - see **concrete, self-consolidating**.

**silica fume**, *n* - very fine pozzolanic material, composed mostly of amorphous silica produced by electric arc furnaces as a by-product of the production of elemental silicon or ferro-silicon alloys (also known as condensed silica fume and microsilica).

**slump**, *n* - Reference ACI 318 Section 5.3.3.2 –A measure of the consistency in the mix. Prior to the use of admixtures slump was often considered a good indicator of concrete strength and durability.

**slump flow**, *n* - the average diameter of the spread concrete mass, obtained from two measurements perpendicular to each other, after a self-consolidating concrete has ceased to flow during a slump-flow test. Slump flow of self-consolidating concrete is measured using Test Method ASTM C1611. Reference ACI 318 Section 3.6.

**specific gravity**, *n* - the ratio of mass of a volume of a material at a stated temperature to the mass of the same volume of distilled water at a stated temperature.

**stone, crushed**, *n* - the product resulting from the artificial crushing of rocks, boulders, or large cobblestones, substantially all faces of which have resulted from the crushing operation.

**supplementary cementitious material**, *n* - a slag cement or pozzolan that contributes to the properties of concrete or mortar through hydraulic or pozzolanic activity, or both.



**unit weight**,  $n$  - *of aggregate*, mass per unit volume. (Deprecated term—use preferred term **bulk density**).

**void, air**,  $n$  - a space in cement paste, mortar, or concrete filled with air; an entrapped air void is characteristically 1 mm or more in width and irregular in shape; an entrained air void is typically between 10 and 1000  $\mu\text{m}$  in diameter and spherical or nearly so.

**water-cement ratio**,  $n$  - the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of portland cement in concrete, mortar, or grout, stated as a decimal. This term is not used in ACI 318-08 which refers to water cementitious materials ratio (w/cm). This term, abbreviated as  $w/c$ , is applicable only to cementitious mixtures in which the only cementitious material is portland cement.

**water-cementitious material ratio**,  $n$  - the ratio of the mass of water, exclusive only of that absorbed by the aggregates, to the mass of cementitious material (*hydraulic*) in concrete, mortar, or grout, stated as a decimal (see also **water-cement ratio**).

**workability**,  $n$  - *of concrete*, that property determining the effort required to manipulate a freshly mixed quantity of concrete with minimum loss of homogeneity.

## APPENDIX F

## REFERENCE DOCUMENTS

**ASTM REFERENCES:**

**C33, *Standard Specification for Concrete Aggregates*:** This specification defines the requirements for coarse and fine aggregate used in normal weight concrete. Light weight aggregate is not covered in C33; it is instead covered in ASTM C330.

**C94, *Standard Specification for Ready-Mixed Concrete*:** This standard contains the specification for ready-mixed concrete manufactured and in freshly mixed and unhardened state.

**C109, *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*:** This test method covers determination of the compressive strength of hydraulic cement mortars, using 2-in. or [50-mm] cube specimens.

**C125, *Standard Terminology Relating to Concrete and Concrete Aggregates*:** This standard is a compilation of definitions of terms that are used in other ASTM concrete standards under the jurisdiction of Committee C09.

**C150, *Standard Specification for Portland Cement*:** This standard contains the standard specification for portland cement, including definition of each cement type such as Type II, Type V, etc.

**C151, *Standard Test Method for Autoclave Expansion of Hydraulic Cement*:** This test method covers determination of the autoclave expansion of hydraulic cement.

**C157, *Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete*:** This test method covers the determination of the length changes in hydraulic cement mortar that are produced by causes other than externally applied forces and temperature changes.

**C185, *Standard Test Method for Air Content of Hydraulic Cement Mortar*:** This test method covers the determination of the air content of hydraulic cement mortar.

**C186, *Standard Test Method for Heat of Hydration of Hydraulic Cement*:** This test method covers the determination of the heat of hydration of hydraulic cement.

**C187, *Standard Test Method for Amount of Water Required for Normal Consistency of Hydraulic Cement Paste*:** This test method covers the determination of the normal consistency of hydraulic cement.

**C191, *Standard Test Methods for Time of Setting of Hydraulic Cement by Vicat Needle*:** These test methods determine the time of setting of hydraulic cement by means of the Vicat needle.



**C204, *Standard Test Methods for Fineness of Hydraulic Cement by Air-Permeability***

**Apparatus:** This test method covers determination of the fineness of hydraulic cement using the Blaine air-permeability apparatus.

**C289, *Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Chemical Method)***

This test method covers the determination of the potential for deleterious alkali reactivity of aggregate by testing the reaction of the aggregate to a chemical solution.

**C295, *Standard Guide for Petrographic Examination of Aggregates for Concrete:*** This guide outlines procedures for the petrographic examination of materials used for concrete aggregates.

**C330, *Standard Specification for Lightweight Aggregates for Structural Concrete:*** This specification covers light weight aggregates intended for use in structural concrete.

**C430, *Standard Test Method for Fineness of Hydraulic Cement by the 45- $\mu$ m (No. 325) Sieve:*** This test method covers the determination of the fineness of hydraulic cement.

**C451, *Standard Test Method for Early Stiffening of Hydraulic Cement (Paste Method):*** This test method covers the determination of early stiffening in hydraulic-cement paste.

**C567, *Standard Test Method for Determining Density of Structural Lightweight Concrete:***

This test method provides procedures to determine the oven-dry and equilibrium densities of structural light weight concrete.

**C595, *Standard Specification for Blended Hydraulic Cements:*** This specification pertains to blended hydraulic cements using slag, pozzolan, limestone, or some combination of these, with portland cement or portland cement clinker or slag with lime.

**C618, *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete:*** This specification covers the use of coal fly ash and raw or calcined natural pozzolan in concrete.

**C845, *Standard Specification for Expansive Hydraulic Cement:*** This specification covers hydraulic cements that expand during the early hardening period after setting.

**C989, *Standard Specification for Slag Cement for Use in Concrete and Mortars:*** This specification covers three strength grades of slag cement for use as a cementitious material in concrete and mortar.

**C1038, *Standard Test Method for Expansion of Hydraulic Cement Mortar Bars Stored in Water:*** This test method covers the determination of the expansion of mortar bars made using hydraulic cement, of which sulfate is an integral part.

**C1157, *Standard Performance Specification for Hydraulic Cement:*** This standard contains the performance specification for hydraulic cements. It is related to hydraulic cement standards C150 and C595.



**C1260, *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)***: This test method covers the determination of the potential for deleterious alkali-silica reaction of aggregate using mortar bars.

**C1293, *Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction***: This test method covers the determination of the susceptibility for expansive alkali-silica reaction of an aggregate or combination of an aggregate with pozzolan or slag. The determination is by measurement of length change of concrete prisms.

**C1567, *Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)***: This test method covers the determination of the potential for deleterious alkali-silica reaction of combinations of cementitious materials and aggregate in mortar bars. It is a modification to the test method outlined in C1260 and is used to determine mitigation measures.

**C1602, *Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete***: This specification covers the compositional and performance requirements for water used as mixing water in hydraulic cement concrete.

#### **ACI REFERENCES:**

**ACI 301, *Specifications for Structural Concrete***: This document covers general construction requirements for cast-in-place structural concrete and slabs-on-ground.

**ACI 318, *Building Code Requirements for Structural Concrete and Commentary***: The Building Code Requirements for Structural Concrete (“Code”) covers the materials, design, and construction of structural concrete used in buildings and where applicable in non-building structures.

**ACI 555, *Removal and Reuse of Hardened Concrete***: This report presents information on removal and reuse of hardened concrete.

#### **Caltrans REFERENCES:**

**Caltrans Test Method 217, *Method of Test for Sand Equivalent***: This test method provides the procedure for measuring the relative proportions of detrimental fine dust or clay-like material in soil or fine aggregates.

**Caltrans Test Method 227: *Method of Test for Evaluating Cleanness of Coarse Aggregate***: The cleanness test provides an indication of the relative proportions of clay-sized material clinging to coarse aggregates or screenings.



## APPENDIX G

### AGGREGATE REPORT

The SEAONC Construction Quality Assurance Committee produced “The San Francisco Bay Area Concrete Aggregate Report 2008”. This report provides more detailed general information on concrete aggregates and information on the various aggregates used in the Bay Area when the report was issued.

The full report can be downloaded from: <http://seaonc.org/committees/construction-quality-assurance/tech-forum/san-francisco-bay-area-concrete-aggregate>