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ACCOUNTABILITY - THE PRICE YOU PAY FOR QUALITY WORK

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INTRODUCTION

Quality dynamics starts with knowing (1) what you want to build; (2) how to obtain materials; and (3) how to construct as intended. This can be achieved by following simple steps and focusing attention on the details related to the appropriate products and systems involved in each project. By specifying the design attributes required, you control the products or systems selected. After years of experience in the construction industry, I am convinced that quality results during construction are controlled by testing and inspection, especially of workmanship. To achieve quality during construction, testing and inspection of the work in a timely manner provides accountability - the price you pay for quality work.

REFLECTIONS

In our Architectural/Engineering practice at Smith, Hinchman & Grylls (SH&G), Quality Assurance is annotated in the contract documents, and the Quality Control Program is performed during construction. Quality of appearance and performance of the work is paramount for a successful project. Good documentation and coordination of the contract drawings and specifications provide good communication between team players and help tie together the work. The contract documents should address all the requisite topics. The Quality Assurance program describes individual responsibilities and communication needs; the wall designs and materials; inspection requirements; testing and evaluation of the test data; response to non-conforming conditions; and what records should be required. Quality Control is defined as the process during construction wherein these tasks are implemented and made accountable.

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To achieve consistency of the constructed work, the contractor is requested to show his intent. Submittals properly inform the design team on what and how the contractor intends to proceed. In masonry, for example, after submittals are approved, a sample wall is constructed to demonstrate what materials and workmanship are required for the project, as annotated on the project drawings and specifications. These work tasks set the ground rules for the project and establish what is required. The sample wall represents the project standard, and serves as a basis for judging new work throughout the project. Therefore, the work should have small variations in any of the perceived tolerances, providing consistency in appearance. To obtain this level of understanding by the construction team, a well-organized, well-documented and well-executed Quality Assurance/Quality Control Program is necessary.

Accountability of the contractor's work is the common theme that needs to be reinforced throughout the project. Good programs are useless if the contractor's work is not checked and verified through random or continual testing and inspection. Compliance with the contract documents by the contractor is one example of being held accountable by the contract. The scope of inspection at the construction site could include the structure, the exterior envelope and other relevant areas. Inspections are generally not being done by the General Contractors and Construction Managers because of the increased competition for projects and the increased expense for qualified inspectors. Being competitive in the construction arena often really means a reduced scope of services provided by the contractor. The owner needs to respond and provide competent inspection services on an as-required basis to meld the design and the construction, and to ensure that the owner gets what he bargained for. This approach will help to minimize expensive legal proceedings. Verification of the work provides the accountability necessary to fulfill the goals in the QA/QC Program.

Today, observations are professionally correct for Architects and Engineers. However, observations are limited and vague. No observations would be more appropriate, because at least then one's duty is clearly defined and understood. By contract the contractor and sub-contractors are responsible for their own inspections of their work. Remember the fox in the chicken coop, beware of temptation. If the owner requires inspection to best control quality, specific parts of their project are then inspected. The owner's designated representative would have the duty to perform inspections on behalf of the owner. Wherever inspections are required, they will help reduce risk and obtain the level of performance required during construction.

My experience and practice has been focused on the exterior envelope. In the last ten years I have been primarily involved in the design, construction and inspection of our masonry buildings. I have also provided consultation services for owners, contractors and lawyers. The following scenario will highlight certain procedures in this process that expand the ordinary responsibility of the professional in the typical Quality Control program to a new level of involvement in masonry projects.

THE QC HIGHLIGHTS WITHIN THE PROCESS

During years of experience in field-inspecting masonry work for our projects, I have been satisfied with the final product most of the time. This level of satisfaction has usually been based on the amount of inspection time involved for a given project. Generally, the more timely the inspection, the better the product. It should be explained that the masonry contractors have the difficult task of following different project requirements from architect-to-architect and from engineer-to-engineer. Sometimes it is very difficult for the mason to discern which method is right or wrong after being told that this is right for this project and wrong for another.

Communication between the architect and the contractor is paramount in the process. Naturally, the drawings and specifications communicate the accepted standards for design, materials, wall assemblies, workmanship and simple details for construction. However, our program is unique because we communicate with all levels: the general contractor, masonry contractor and the masonry crew. Working with the masons adds another dimension of success for the project, because for the first time the crew is included in the communications process.

Just a reminder: the architect/engineer should review and approve all submittals before any construction is performed, either on the sample wall or any other construction. The approved materials should be ordered for the sample wall and delivered in enough time so there are no delays for this construction and the start of the masonry work. Long-lead items should be considered in a timely manner so as not to delay the project. Brick and its special colors, textures and shapes and any special products could cause delays in the work.

The sample wall is our facilitator between the mason and the architect/engineer. The construction of this wall by the masonry contractor is performed at an area on the site where it will not interfere with any project-related construction. This wall establishes the project standard for materials, design-construction parameters, workmanship, construction tolerances and any substitutions. This construction is the learning place for the mason and establishes the requirements for the project.

The sample wall is constructed according to the drawn layout. The project's typical conditions and details are referenced from the sample wall elevations and sections. Each constructed step of the sample wall is photographed during its construction by the architect. The mason will ask questions and explanations will be provided by the architect. Again, this is the time to learn what is required and what are the critical limitations and constraints. As a point of interest, the drawings and specifications are not seen by the mason doing the work. He has no idea what is required except for what the foreman tells him during construction. Furthermore, the foreman usually is the one that constructs the sample wall. Therefore, the masons doing the work are not exposed to the design requirements. In SH&G's QC program, we take the information to the mason by having a slide presentation where each slide focuses in on a design requirement to be incorporated in the masonry wall. Generally, the SH&G contract requires that all masons see the slide presentation before they start work.

This is just the beginning, because we know from experience that most masons will not remember all of the items discussed, may disagree, or may be confused with some parts of the presentation. We believe that you learn from repetition and reinforcement, so we inspect for each identified work task with each individual. Each of these tasks is reviewed as many times as necessary, until the work being installed meets the project standard represented by the sample wall. When the masons are performing as required, our inspection site visits will be less necessary. Inspection will continue at a less frequent pace until the final work is accepted.

Any non-conforming problems are observed early on, because they are usually apparent at the beginning of the work. Only with inspection will most of these defects are discovered in a timely manner. Observations, in general, are not timely or specific enough to find initial defects on a regular basis. All defective work needs to have corrective procedures applied to provide conforming alternatives.

A master checklist provided to the foreman and the masonry crew helps in-house inspections by the masonry contractor and serves as a reminder to the crew and the foreman when the work is performed. The masonry contractor is legally responsible for his work. With this documentation they are able to police their own work for compliance with the contract documents. Therefore the checklist provides an overview of the project standard. It provides the mason with information he never had before and he can use as a reference during the project, which helps to enhance quality work. Even at this level of understanding, independent inspections for the owner are required.

Masonry inspection can only be effective when the inspector has an in-depth knowledge of masonry design and construction; knows how to read construction documents; has a complete understanding of the project scope; has experience and background knowledge on the mason's skills associated with acceptable workmanship; and knows the industry standards and codes. A terse definition of inspection that I like states "view closely and critically," where a detail review of the work is performed during and after the masonry construction. Unless you understand what you are looking for you may never see the problem. Masonry inspection qualifications are not defined in the new ACI 530 and 531 masonry code and specification. However, masonry inspection will be required for all new masonry construction where the local municipality has adopted the 1993 BOCA Code, which references the new masonry code and specification. Inspection is a major part of the QA/QC program. Without it accountability for the masonry work is not possible.

Masonry workmanship demonstrates each individual's skills to construct a product. Workmanship involves knowing the scope of masonry construction; providing consistency; locating the elements within acceptable tolerances and following established quality standards; appearance is inspected for conformity and completeness; and confirming performance by testing. These are the basic attributes that are judged when masonry construction is inspected.

The success of this QA/QC program depends on the owner's awareness of the things that can go wrong and having respect for the program. The general contractors and construction managers are not masonry inspectors and do not provide this type of service. This is also true of the testing agencies that I have been involved with during my inspections. There is a need for this type of service by qualified professionals and consultants. Their efforts would minimize on-site problems, eliminate costly repair work, and reduce the risk for litigation. The owner should not be involved in any legal proceedings.

Testing of the mortar on-site using ASTM C780 has made the masonry contractor a very humble individual. Before you test the mortar as the benchmark for the project, the units and mortar are bonded together to find the correct recipe for the mortar so that the units and the mortar are compatible. Thereinafter, mortar testing on the project is randomly performed to verify that the mortar production is consistent with the original recipe.

Before you advise the owner of a testing agency, you should inquire as to what experience the agency has on the various masonry tests required for the project. Few testing agencies know how to properly perform certain tests. For example, the mortar tests under ASTM C780 should be performed by an experienced individual so the test data is consistent. The test results should be reviewed no more than two days after the mortar was sampled to be useful to the design and construction teams. These tasks help assure better bond between the units and the mortar. Acceptable bond should be optimized to minimize water intrusion into the masonry assembly. When the mortar is consistent, better results can be achieved. Also, psi checks are made to determine strength when required. Testing makes the contractor accountable for the work performed by his people.

A CASE HISTORY

A case history has been included to share this experience with you. This project experience has provided useful feedback to improve our QA/QC masonry program at SH&G.

MORTAR RECIPE

After the submittals are approved, the first QC task prior to the construction of the sample wall is to find the best mortar recipe for the approved masonry units. One should be aware that the mortar becomes compatible with the masonry unit in this relationship, not the converse. It should be noted that production runs of clay units do not undergo major physical changes that will affect its performance on a typical basis. More specifically, the IRA and the surface bedding characteristics are important features that contribute to bond and stay relatively uniform. Ingredients affecting the bond of the mortar include the amount of water; the amount of cementitious material; sand gradation; and the ratio between the cementitious material and aggregate. Furthermore, the temperature and humidity are factors that will alter the water from the initial mortar recipe during the construction period. The mortar recipe found by trial and error represents the optimal bond at the mortar-masonry unit interface.

To achieve this goal, a mortar recipe is mixed and the ingredients identified, tested and recorded. The process begins when one of the two masonry units is mortared on the bed surface and then the other unit is pressed into the other unit under uniform pressure. The mortar extrudes from the bed joint while being pressed together to obtain a mortar width of approximately 3/8 of an inch. The units stay together for approximately 1 minute. Then the units are pulled apart. The mortar usually sticks to one unit. The mortar is then removed and the units are left to dry. When the water evaporates, the cementitious material present on the masonry bedding surface indicates the amount of material and where contact was made. If areas are found not coated by the cementitious materials, the water and/or cementitious materials are changed to optimize contact with a more fluid or sticky material for use between masonry units. These steps are repeated until optimum coating is achieved. This mortar recipe is used for the construction of the sample wall. The mortar data extracted from the ASTM C780 field test is used and compared with future mortar productions for consistency throughout the project. Again, the water amount is changed with temperature and humidity during each weather change from one season to another.

The field testing of mortar using ASTM C780 has brought about some discussion on its usefulness. Mortar consistency is the primary objective. Tests confirm mortar results during production. It reports on the amounts used for each mortar component: water, sand and the cementitious material. There are strength tests that are used to gage the psi levels when required. Again, good bond is the primary objective and it is based on consistency of the mortar, which in turn helps minimize water intrusion at the unit-mortar interface. The main problem today is that most laboratories are not familiar enough with this test method, and their data can be inaccurate and misleading. To overcome this difficulty, we have requested that the testing agency provide one person who would be trained by the architect, using our twelve-page instruction manual, to provides step-by-step instructions on how to perform each part of this test in a defined sequence. Two new data sheets were developed: one sheet provides space for all of the data so that each mortar test is compared with every other one, and the other sheet lists each formula and the data in the proper sequence, as tested. All the data and mathematics can be checked on one sheet. See Appendix A for copies of these sheets.

In our opinion, the cement-aggregate ratio is the best way to police mortar production for consistency. Without changing the ASTM C780 test methods, a field check had to be found to determine what the theoretical cement-aggregate ratio should be. This field check assumes that the ingredients were perfectly measured, using the actual density of the sand at the time of the calculation. SH&G needed a way to target the cement-aggregate ratio and set the acceptable range for judging the results of the ASTM C780 test data. This introduced the theoretical cement-to-aggregate ratio. This ratio, which is determined mathematically, provides a target value if all aspects of the batch work and test are perfectly performed. The theoretical value is compared to the actual cement-to-aggregate ratio determined by the test method, showing the variation that occurred during the on-site mortar batch work. This theoretical ratio is a great check on the accuracy of the mason's labor tender who made the mortar.

The theoretical ratio uses the density of the sand from the sand pile in pounds per cubic feet multiplied by the cement-to-sand ratio by volume divided by the density of the cementitious materials. This ratio is expressed by weight and not by volume. The following is an example of how to determine the theoretical cement-to-aggregate ratio.

Example: *Material Data*

sand density	=	*80#/CF*
volume ratio	=	*3*
cement density	=	*75#/CF*

Theoretical Ratio = sand density x volume ratio for cement to sand ÷ cement density

TR = 80#/CF x 3 ÷ 75#/CF

TR = 3.2

I hope this illustration will stimulate interest. Let us say, for example, that the test result for the cement-to-aggregate ratio from the laboratory was 3.5 and the theoretical value by calculation was 3.2 as illustrated. From this test result, it would be apparent that this mortar batch had a slightly higher sand content. The numerical difference between the laboratory test and the mathematical results were 0.3. These results were acceptable because the tested ratio was not more than ± 0.4 the range, determined from experience, that could be achieved. The variation in the mortar production must be minimized. Consistency in the production of the mortar is important for bond between the mortar and the masonry units. This test highlights the mortar production at that given moment.

CONCLUSION

I hope that our project experience will be helpful to your QA/QC program. Construction happens: do you want to control your project or do you want someone else to oversee your designs?

APPENDIX A
REPRESENTATIVE DATA REPORT

ASTM C780 DATA REPORT

report no. 101

date DEC. 21, 1994 - 10:45 am.

A1	Consistency		84.0 mm
A2	Consistency Retention	15 minutes	78.0 mm
		30 minutes	70.0 mm
		45 minutes	65.0 mm

A5	Mortar Water Content		
	wt. of container, alcohol	A	644.0 grams
	wt. of container, alcohol, mortar	B	1357.0 grams
	wt. of wet mortar	C = (B − A)	713.0 calc.
	wt. of dry mortar	D	622.0 grams
	wt. of water	E = (C − D)	91.0 calc.
	mortar water content, wet %	F = [E / C] × 100	12.8 calc.
	mortar water content, dry %	G = [E / D] × 100	14.6 calc.

A4	Mortar Aggregate Ratio		
	wt. of container, alcohol	H	644.0 grams
	wt. of container, alcohol, mortar	I	1350.0 grams
	wt. of wet mortar	J = (I − H)	706.0 calc.
	wt. of dry mortar	k = J / [1 + (G / 100)]	616.1 calc.
	wt. of 100+ fraction - dry	Y	414.0 grams
	wt. of sample sand		451.0 grams
	wt. of blank dry sand	R	421.0 grams
	wt. of dry sand 100+	W	375.0 grams
	wt. of dry mortar 100+, cor.	Q = (Y × R / W)	464.8 calc.
	wt. of dry mortar 100−, cor.	P = (K − Q)	151.3 calc.
	cement: aggregate ratio	1 : Q / P	3.07 calc.

A6	Mortar Air Content	
	gross air content	6.6 %

A7	Compressive Strength of Molded Mortar Cylinders	
	7 days	____ p.s.i.
	28 days	____ p.s.i.
	28 days	____ p.s.i.

Weather Notes	
ambient temperature	40 °F
Relative Humidity	— % RH
Wind Velocity	CALM mph
Mortar Temp.	57 °F

LOOSE SAND WT. = 88.4 LBS/FT³ @ 7.1% MOISTURE

SH&G Preconstruction and Construction Evaluation of Mortars for Unit and Reinforced Masonry ASTM C-780

10:45 am - 84.0 mm

REQ'D 28 DAY COMP. STRENGTH: 1800psi

General Information

Project: V.A. HOSPITAL
~~SH&G~~ T.E.C. Project No. 24557
Sample No. 101 ☒ AM ☐ PM
Masonry Contractor: MONTE COSTELLA
Mortar Specified: TYPE "S"
Architect/Engineer: S.H. + G

Mixer Manufacturer

Type: PADDLE
RPM: —
Condition: GOOD

Materials

Cement, Portland: —
Cement, Masonry: HURON - TYPE 'S'
Sand:
Water:
Admixture:

Mixture

Mixture	Order	Volume	Weight
Cement, Portland			
Cement, Masonry			
Lime			
Sand			
Water			
Admixture			

Mixing Information

Charging Time:
Mixing Time:
Time:

Sampling Information

Sample Board: 57°F
Mortar Board:
Sample Time: 10:45 A.M.

Ambient Conditions

Temperature: 40°F
Relative Humidity: —
Wind Velocity: CALM

Plastic Mortar Properties

Consistency, mm — 15 min: 78.0
Consistency Retention, mm — 30 min: 70.0
45 min: 65.0

Mortar Water Content

Wt. Content, Alcohol	(A)	644.0 g
Wt. Content, Alcohol, Mortar	(B)	1357.0 g
Wt. Mortar, Wet	(C)	713.0 g
Wt. Mortar, Dry	(D)	622.0 g
Wt. Water	(E)	91.0 g
Mortar Water Content, Wet %	(F)	12.8
Mortar Water Content, Dry %	(G)	14.6

Mortar Aggregate Ratio

Wt. Content, Alcohol	(H)	644.0 g
Wt. Content, Alcohol, Mortar	(I)	1350.0 g
Wt. Mortar, Wet	(J)	706.0 g
Wt. Mortar, Dry	(K)	616.1 g
Wt. 100+ Mortar, Dry	(Y)	414.0 g
Wt. Sand, Received	(R)	451.0 g
Wt. Sand, Blank, Dry		421.0 g
Wt. 100+ Sand, Dry	(W)	375.0 g
Wt. 100+ Mortar, Dry, cor	(Q)	464.8 g
Wt. 100– Mortar, Dry, cor	(P)	151.3 g
Cement: Aggregate Ratio	1 :	3.07

Mortar Air Content

Method: PRESSURE METHOD - TYPE B, WHITE METAL
Gross Air Content, %: 6.6
Aggregate Content, %: —
Net Air Content, %: —

Job Site Curing Temperature

Maximum °F: 78
Average °F: 76
Minimum °F: 74

Location Observed: BUILDING 102 ELEVATOR TOWER EXTERIOR BRICK (WEST AND NORTH SIDE) APPROX. 9 FT ABOVE LEVEL 5

Hardened Mortar Properties

Mortar Compressive Strength
Specimen: 3" x 6"
Mold:
Cure:

Spec No.	Test Age	Total Load	Strength psi (kPA)	Avg.
	3d			
	3d			
	3d			
	7d			
	7d			
	7d			
	28d			
	28d			
	28d			

2" x 2" Cube of (3" x 6" Cylinder)

Spec No.	Test Age	Total Load	Strength psi (kPA)	Avg.
2436 A1	7d			
B2	28d			
C3	28d			

Mortar Splitting Tensile Strength

Spec No.	Test Age	Total Load	Strength psi (kPA)	Avg.
	3d			
	3d			
	3d			
	7d			
	7d			
	7d			
	28d			
	28d			
	28d			

Miscellaneous

Date Tested: DEC. 21, 1994
Observed by:
Reported by: PAUL STUTSMAN
Reviewed by:

SH&G Preconstruction and Construction Evaluation of Mortars for Unit and Reinforced Masonry ASTM C-780

Date	7/6	7/13	7/18	7/19	7/22	7/26	8/15	8/25	9/8	9/23	10/6	10/20	10/27	11/14	11/25	12/3	12/21				
Sample No. / AM or PM	85. / PM	86. / PM	87. / PM	88. / AM	89. / AM	90. / AM	91. / PM	92. / AM	93. / AM	94. / AM	95. / AM	96. / AM	97. / AM	98. / PM	99. / PM	100. / PM	101. / AM				
Gallons of Water	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
Shovels of Sand	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—				
Mix Temp. (°F)	88	86	83	84	82	72	75	79	75	70	59	66	57	65	50	43	57				
Mortar Water Content, Wet %	11.5	13.6	13.5	12.7	14.3	14.1	14.2	10.7	10.8	13.5	13.4	13.7	12.0	12.8	11.9	12.6	12.8				
Mortar Water Content, Dry %	13.0	15.8	15.6	14.5	16.7	16.4	16.6	11.9	12.1	15.6	15.5	15.9	13.6	14.7	13.6	14.4	14.6				
BY WT.* Mortar Aggregate Ratio ACTUAL	2.85	2.85	3.16	3.34	3.49	3.38	3.18	2.98	3.04	3.69	3.12	3.17	2.87	3.04	3.57	3.58	3.07				
Mortar Aggregate Ratio REQ'D	3.38	3.25	3.38	3.26	3.36	3.36	3.77	3.36	3.40	3.34	3.90	3.47	3.38	3.40	3.39	3.41	3.54				
Air Content %	6.3	6.0	6.1	6.2	5.8	6.3	5.8	6.8	6.7	6.4	7.1	7.3	7.8	7.3	7.8	7.7	6.6				
Plastic Mortar Properties Block 0 Min.			84.0		85.0			82.0													
15 Min.			78.0		76.0			73.0													
30 Min.			67.0		70.0			66.0													
45 Min.			58.0		63.0			60.0													
Plastic Mortar Properties Brick 0 Min.	83.0	83.0		85.0		84.0	84.0		82.0	84.0	79.0	84.0	79.0	81.0	82.0	73.0	84.0				
15 Min.	72.0	79.0		80.0		74.0	77.0		69.0	77.0	69.0	73.0	73.0	76.0	76.0	68.0	78.0				
30 Min.	57.0	71.0		73.0		69.0	66.0		55.0	73.0	62.0	69.0	69.0	72.0	72.0	64.0	70.0				
45 Min.	49.0	64.0		66.0		63.0	56.0		47.0	67.0	56.0	64.0	65.0	66.0	67.0	61.0	65.0				
Hardened Mortar Properties 7 Day																					
28 Day																					
28 Day																					
56 Day																					
Ave.																					