Specifications for Quality Control: A Case Study

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One of the essential qualities of a specification is reasonableness. Court decisions and their economic consequences demand that specifications be based on reasonable requirements. Specifications that call for unnecessary perfection through so-called "hard" or "tight" requirements are hardly reasonable; furthermore, they do not assure performance. Specifications that attempt to control quality through extremely limited tolerances may in fact be counterproductive. When quality control efforts are directed to compliance with the letter of such specifications, quality may be compromised, contract administration may be difficult, and additional costs may be incurred, all without improving performance of the completed work. In this paper, a case study of a small paving project is presented to illustrate the problems created by a too-restrictive specification, Alternatives and comments to improve the specification are offered.

An essential attribute of a specification is reasonableness. Court decisions and economic consequences demand that specifications be reasonable. Specifications occasionally call for unnecessary perfection through so-called "hard" or "tight" requirements. Such specifications are hardly reasonable; furthermore, they do not assure performance. Specifications that attempt to control quality through extremely limited tolerances may in fact be counterproductive. When quality control efforts are directed to compliance with the letter of such specifications, quality may be compromised, contract administration may be difficult, and additional costs may be incurred, all without benefit to the performance of the completed work. In this paper, a case study is presented and test results from a small paving project are discussed. Comments and test results from similar projects are included to illustrate the impossibility of compliance with too-restrictive specifications, and some of the construction and administrative problems they create are noted.

The case study project included 10,500 yd^2 of apron area paving on the Harrisburg International Airport (HIA) at Middletown, Pennsylvania. The design for the apron pavement structure is based on Federal Aviation Administration (FAA) *Advisory Circular* AC-150/5320. The design load is 596 equivalent annual departures of an aircraft with 190,500-lb dual-wheel gear. Based on a modulus of subgrade reaction k of 150 psi, the pavement structure includes a 12-in.-thick crushed-stone subbase, 6-in.-thick Econocrete-stabilized subbase, and 14-in.-thick portland cement concrete pavement. The design calls for an Econocrete subbase with a minimum 28-day compressive strength of 750 psi and portland cement concrete pavement with a minimum 28-day flexural strength of 660 psi.

The specifications for Econocrete require compressive strength of not less than 500 psi at 7 days and a minimum of 750 psi at 28 days using test specimens prepared in accordance with ASTM C192 and tested in accordance with ASTM C39. The specifications also require the Econocrete to have a minimum of 200 lb/yd^3 of cement and a maximum 28-day compressive strength of 1,200 psi.

The upper-strength limit on the Econocrete layer is suggested by notes to the engineer in the FAA's specification for Econocrete Subbase, Item P-306, AC-150/5370-10. The FAA suggests the upper strength in order to prevent Econocrete-induced cracking in the overlying portland cement concrete pavement.

The specified strength limits do not accommodate the inherent strength variability of Econocrete. The specified maximum strength less the minimum specified strength results in a maximum range of 450 psi. The specification implied a maximum standard deviation of 75 psi and a tolerance of ± 225 psi. Thus a supplier of Econocrete is required to average 975 psi and control production variability to result in cylinder breaks of no more than a standard deviation of 75 psi if there is to be full compliance with this specification and no risk of rejection.

Additional insight into just how restrictive these requirements are is obtained by analysis of compressive strength test data from the HIA apron paving. Core samples were made at random in accordance with the specifications. Normal distribution of the test data was confirmed by plotting the test results on probability paper. Table 1 shows compressive strength at 7 days; Table 2, compressive strength at 28 days; and Table 3, compressive strength cores. Standard deviations for 7-day, 28-day, and cores are 138, 197, and 171 psi, respectively. These values compare favorably with the standard deviation for compressive strength of lean concrete (i.e., Econocrete) reported on runway construction at the Greater Pittsburgh International Airport where standard deviations of 238 psi for 7-day strength and 281 psi for 28-day strength are reported (*1*).

The mean compressive strengths for 7- and 28-day breaks at Harrisburg are lower than the mean compressive strength obtained on the Pittsburgh work. The mean compressive strength on the Pittsburgh work is reported to be 840 and

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TABLE 1 COMPRESSIVE STRENGTH AT 7 DAYS

CARGO APRON - HARRISBURG INTERNATIONAL AIRPORT
ECONOCRETE - 7 DAY COMPRESSIVE STRENGTH

Date	Compressive Strength (psi) Spec #1	Spec #2	Spec #3	Spec #4	Sample Average
5-14-85	531	548	690	707	619
5-15-85	536	561	546	569	553
5-16-85	607	582	601	599	597
5-17-85	552	585	580	573	573
5-20-85	527	554	531	538	538
5-29-85*	1220	1220	1203	1185	1207
5-30-85	686	644	644	637	653
6-03-85#					
6-04-85	412	398	412	408	408
6-06-85#					
6-07-85	571	571	622	647	603
6-10-85#					
6-11-85	539	548	539	543	542
6-12-85	500	485	516	506	502
Average Compressive Strength					559
Est. Standard Deviation for 7-day Strength n=4					69
Est. Standard Deviation for 7-day Strength n=1					138

* Data NOT included in Avg. and Std. Dev. computations
# Data comb. with following day due to low production

TABLE 2 COMPRESSIVE STRENGTH AT 28 DAYS

CARGO APRON - HARRISBURG INTERNATIONAL AIRPORT
ECONOCRETE - 28 DAY COMPRESSIVE STRENGTH

Date	Compressive Strength (psi) Spec #1	Spec #2	Spec #3	Spec #4	Spec #5	Sample Average
5-14-85	741	767	900	874	831	823
5-15-85	741	716	713	736	824	746
5-16-85	741	711	732	750	760	739
5-17-85	622	631	635	633	636	631
5-20-85	658	622	691	647	700	664
5-29-85	566	481	495	523	506	514
5-30-85	559	580	559	559	545	560
6-04-85	697	516	608	580	577	596
6-07-85	739	612	605	640	729	665
6-11-85	626	615	630	606	639	623
6-12-85	644	626	640	656	633	640
Average Compressive Strength						655
Est. Standard Deviation for 28-day Strength n=5						88
Est. Standard Deviation for 28-day Strength n=1						197

1,111 psi for 7- and 28-day strengths, respectively. The mean compressive strength on the HIA work was 559 psi for 7-day and 655 psi for 28-day compressive strengths. The strength differences are explained by the cement content of the mixes. The Pittsburgh mix contained 240 lb of cement per cubic yard and the Harrisburg mix 200 lb of cement per cubic yard.

The supplier of Econocrete to the Harrisburg work reported difficulty in meeting the specification on previous contracts containing this specification. On that work, the problem was exceeding the 1,200-psi maximum 28-day compressive strength. The mix approved for the previous work is shown in Table 4.

Table 5 shows the compressive strength test data submitted to support approval of the mix design on the previous project.

TABLE 3 COMPRESSIVE STRENGTH CORES

CARGO APRON - HARRISBURG INTERNATIONAL AIRPORT ECONOCRETE - COMPRESSIVE STRENTGTH				
	Core Strength			Sample
Date	Core #1	Core #2	Core #3	Average
*	688	553	892	711
5-29-85	495	646	689	610
5-30-85	435	541	470	482
6-04-85	769	411	505	562
6-07-85	1052	432	700	728
6-11-85	690	543	580	604
6-12-85	922	557	702	727
Average Compressive Strength				632
Est. Std. Dev. for Core Str. n=5				94
Est. Std. Dev. for Core Str. n=1				171

* Core 1,2,3 From 5-16,17,20

TABLE 4 MIX APPROVED FOR PREVIOUS WORK

ECONOCRETE MIX APPROVED FOR PREVIOUS WORK	
Ingredient	Quantity
Cement	250 pounds
Fine Aggregate	1919 pounds
Coarse Aggregate	1279 pounds
Water	38.5 gallons
Admixture	10 oz Pozzolith 122-N
Air Entraining Agent	6 oz MBAE-10
Air content	8.75 percent

TABLE 5 COMPRESSIVE STRENGTH, PREVIOUS MIX DESIGN

COMPRESSIVE STRENGTH		
Age Days	psi psi	Average psi
5	670	
5	640	655
7	740	
7	710	725
14	830	
14	810	820
28	970	
28	960	965

Table 6 shows the 28-day compressive strength obtained from field tests. The difficulty in meeting the maximum strength requirement is obvious because both 7- and 28-day strengths exceed the maximum specified strength of 1,200 psi.

Because of these difficulties in meeting the specified maximum strength on the previous project and reasoning that a reduction in cement would lower the maximum strength to the specified maximum, 50 lb of cement was removed from the mix design submitted for the cargo apron. The mix approved for the cargo apron is shown in Table 7.

Table 8 shows the compressive strength data submitted by the supplier to support approval of the mix design for the cargo apron. Except for June 4, the 7-day strength data (Table 1) compare favorably with the 7-day strength data submitted to support the mix approval; the 28-day strength data (Table 2) are smaller than the 28-day strengths so submitted.

Review and study of the approved mix reveals a water-cement ratio of about 18 gal of water per sack of cement and a cement content of about 6 percent. The mix was harsh, difficult to place, and difficult to finish; yet, it appeared to meet the specified strength requirements until the 28-day test results became available. Incidentally, the first low test result for 28-day strength occurred on the same date that Econocrete work was completed.

Figure 1 summarizes these field experiences by showing estimated population characteristics of the three Econocrete bases relative to the specification tolerances. How well did the Econocrete from these three projects meet the specifications? The results of this analysis are shown in Table 9. Two of these projects are in trouble on the maximum strength requirement and the third is in trouble on the minimum strength requirement.

The estimated percentage of the Econocrete with compressive strength more than 750 psi and less than 1,200 psi shows that only a small portion of the total quantity meets the specifications. The ultimate disposition of this noncompliance problem on the previous HIA work and the Pittsburgh work are not known; however, it is believed that penalties were not incurred nor was the Econocrete removed and replaced. The funding agency is adjusting reimbursement of costs because of the noncompliance on the HIA cargo apron. An interesting facet of this situation is that excess strength in the portland cement concrete pavement more than compensates for the strength deficiency in the Econocrete. Thus, the total pavement structure on the cargo apron more than satisfies the design load requirements.

COMMENTS

The data from these three projects suggest that there has not been compliance with both the upper and lower strength requirements on the same project. It is apparent from Figure 1 and Table 9 that attempting to meet the maximum-strength and minimum-strength requirements of this specification creates an impossible situation. There simply is not enough tolerance permitted by the specification to accommodate the production variability of Econocrete. This kind of perfection in specification requirements is detrimental to achieving quality construction.

An adequate restraint on maximum strength would likely be achieved through the economics of the competitive bidding process. A maximum-strength requirement seems unnecessary.

TABLE 6 COMPRESSIVE STRENGTH, PREVIOUS WORK

1983 PROJECT - HARRISBURG INTERNATIONAL AIRPORT
ECONOCRETE - COMPRESSIVE STRENGTH (psi)

7-Day			28-Day		
Spec #1	Spec #2	Sample Average	Spec #1	Spec #2	Sample Average
1326	1592	1459	2087	2087	2087
1167	955	1061	1733	1804	1769
1415	1309	1362	1804	1874	1839
1379	1238	1309	1592	1662	1627
1149	1043	1096	1574	1485	1530
1238	1149	1194	1379	1397	1388
1415	1273	1344	2016	2051	2034
1203	1238	1221	1998	2016	2007
1167	1468	1318	1751	1715	1733
1291	1397	1344	1609	1892	1751
1238	1256	1247	1663	1839	1751
1450	1485	1468	1663	1945	1804
1503	1220	1362	920	886	903
1432	1468	1450	1910	1486	1698
Average		1302			1709
Est. Standard Deviation for 7-day Strength n=1					146
Est. Standard Deviation for 7-day Strength n=2					126
Est. Standard Deviation for 28-day Strength n=1					300
Est. Standard Deviation for 28-day Strength n=2					299

TABLE 7 MIX APPROVED FOR CARGO APRON

ECONOCRETE MIX APPROVED FOR CARGO APRON

Ingredient	Quantity
Cement	200 pounds
Fine Aggregate	1945 pounds
Coarse Aggregate	1296 pounds
Water	38.5 gallons
Admixture	8.0 oz Pozzolith 122-N
Air Entraining Agent	8.0 oz MBAE-10
Air Content	9.74 percent

TABLE 8 COMPRESSIVE STRENGTH, CARGO MIX DESIGN

COMPRESSIVE STRENGTH

Age Days	psi	Average psi
5	530	
5	550	540
7	580	
7	600	590
14	710	
14	730	720
28	800	
28	780	790

TABLE 9 HOW WELL SPECIFICATIONS WERE MET

COMPLIANCE WITH SPECIFICATION TOLERANCES

SPECIFICATION REQUIREMENT	HIA CARGO	HIA PREVIOUS	PITTSBURGH RUNWAY
Est. percent < 750 psi	69	0	11
Est. percent > 750 < 1200 psi	31	4	27
Est. percent > 1200 psi	<1	96	62

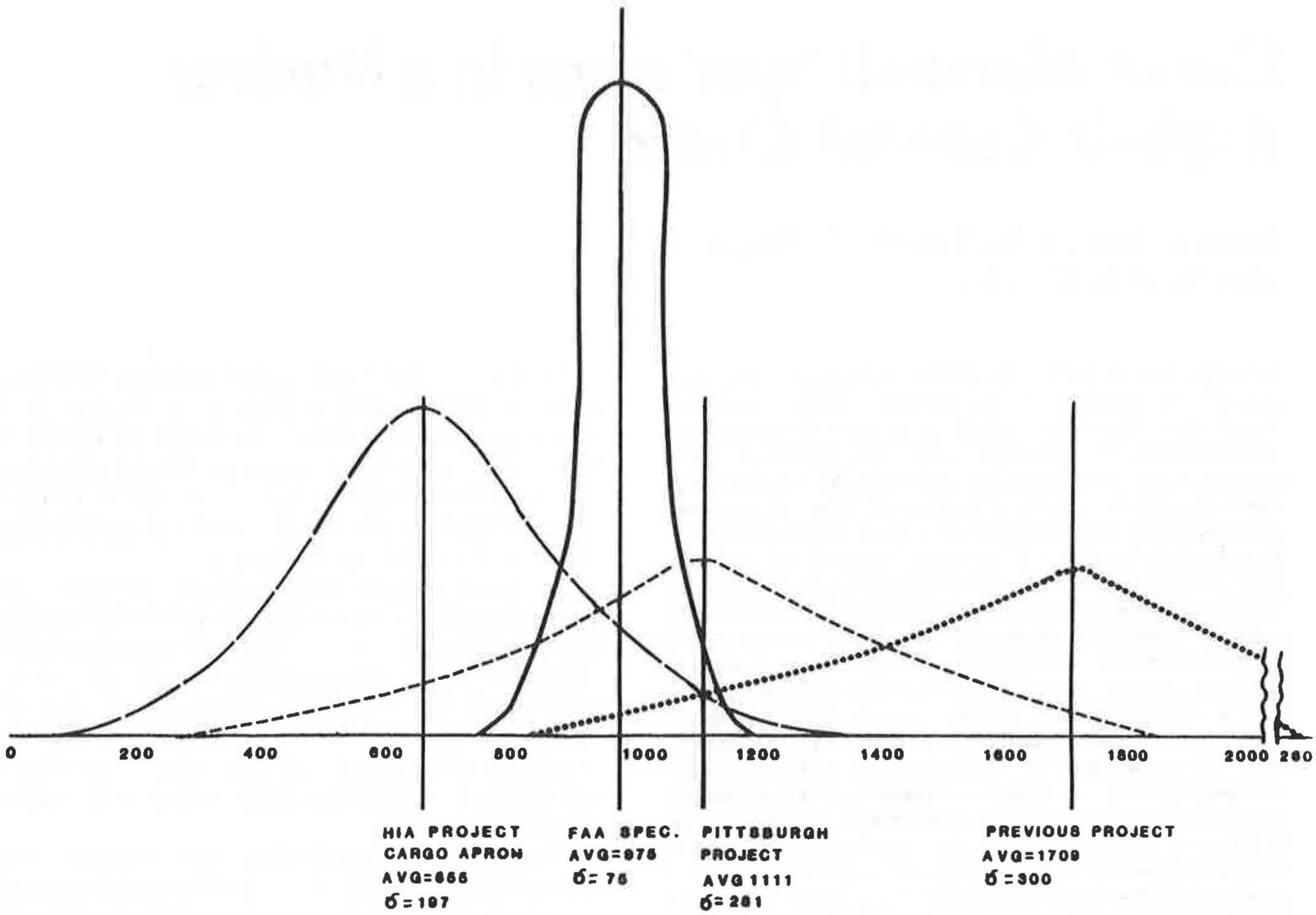

FIGURE 1 Econocrete 28-day compressive strength.

Except for the 1,200-psi maximum-strength requirement, the specification should achieve quality construction.

As for controlling the influence of Econocrete crack patterns, field experience with Econocrete subbase shows that the most important factor in controlling reflective cracking is the use of an adequate and properly applied bond breaker. Without bond, strength levels greater than 1,200 psi do not cause reflective cracking. Any concern for the reflection of random cracks in Econocrete through overlying pavement layers would be better satisfied by specifying bond inhibitors or breakers. A commonly used bond breaker is a wax-based concrete curing compound. This material serves the dual function of a cure coat and a bond breaker. The wax-based curing compound is applied in two applications. The first coat is applied immediately after placing the Econocrete as a cure coat at an application rate of 200 ft^2/gal. The second application is made within 24 hr of placing the overlying pavement at a rate of 200-250 ft^2/gal.

REFERENCE

1. D. G. Rose. Construction of Runway 10R-28L at the Greater Pittsburgh International Airport. Presented at Airport Seminar, Orlando, Fla., March 1980.

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