TABLE 1--GENERAL SURVEY OF THE CONCRETE STRENGTH SERIES

Series	n (*)	Division in sub-series	Observation period (days)	Type of specimen	Mean daily sample rate
A	1786	A1...A9	1158	cubes (200 mm)	3.26
B	945	B1...B5	1044	cylinders	2.59
C	534	C1...C3	1233	"	2.32
D	1468	D1...D8	303 (D1...D4)	cubes (158 mm)	4
			422 (D5...D8)		4
E	1158	E1...E6	267 (E1...E3)	cubes (158 mm)	4
			526 (E4...E6)		2

(*) Total number of test results

TABLE 2--GENERAL CHARACTERISTICS OF THE CONCRETE STRENGTH SERIES

Series	n	$\bar{x}_n$ (MPa)	s_n (MPa)	δ (%)
A	1786	46.5	6.56	14.1
B	945	36.8	5.30	14.4
C	534	42.1	6.62	15.7
D	1468	59.9	3.68	6.1
E	1158	72.3	5.94	8.2

TABLE 3--GENERAL CHARACTERISTICS OF THE SUBSERIES

Sub-series	n	$\bar{x}_n$ (MPa)	s_n (MPa)	δ (%)
A1	200	45.8	5.47	11.9
A2	199	48.8	6.35	13.0
A3	200	50.2	6.78	13.5
A4	200	48.3	5.73	11.9
A5	200	44.5	5.74	12.9
A6	200	44.8	5.89	13.1
A7	200	46.3	6.33	13.7
A8	200	43.2	6.08	14.1
A9	187	46.8	7.13	15.2
B1	200	39.0	5.40	13.9
B2	200	34.9	4.83	13.8
B3	200	36.5	5.33	14.6
B4	200	37.0	4.69	12.7
B5	145	36.4	5.52	15.2
C1	200	46.1	6.67	14.5
C2	200	40.9	5.17	13.6
C3	134	37.9	5.01	13.2

Sub-series	n	$\bar{x}_n$ (MPa)	s_n (MPa)	δ (%)
D1	200	59.8	3.64	6.1
D2	196	59.6	3.17	5.3
D3	200	61.7	3.52	5.7
D4	200	59.0	4.25	7.2
D5	200	59.3	3.96	6.7
D6	200	59.8	3.44	5.8
D7	200	60.5	3.05	5.0
D8	72	58.1	2.95	5.1
E1	200	68.0	4.06	6.0
E2	199	69.0	4.05	5.9
E3	200	69.3	4.91	7.1
E4	200	76.7	4.61	6.0
E5	200	75.6	4.95	6.5
E6	158	75.7	5.53	7.3

TABLE 4--SERIAL CORRELATIONS r_1 TO r_5 OF THE 31 SUBSERIES

Sub-series	r_1	r_2	r_3	r_4	r_5	Highest lag of significant r_k
A1	0.425	0.386	0.276	0.263	0.286	8
A2	0.258	0.128	0.113	-0.011	0.028	1
A3	0.226	0.084	0.091	0.072	0.083	1
A4	0.302	0.173	0.169	0.060	0.006	3
A5	0.196	0.115	0.044	0.011	0.096	1
A6	0.286	0.090	0.177	0.033	-0.023	3
A7	0.277	0.213	0.185	0.174	0.121	4
A8	0.227	0.089	0.145	0.143	0.120	7
A9	0.462	0.375	0.337	0.300	0.343	5
B1	0.323	0.287	0.077	0.149	0.076	2
B2	0.493	0.412	0.409	0.202	0.134	6
B3	0.536	0.535	0.449	0.393	0.358	12
B4	0.600	0.511	0.509	0.464	0.351	14
B5	0.199	0.145	-0.039	0.015	-0.097	1
C1	0.451	0.401	0.372	0.362	0.325	7
C2	0.437	0.319	0.300	0.328	0.244	6
C3	0.384	0.194	0.210	0.183	0.223	5
D1	0.432	0.326	0.306	0.237	0.080	4
D2	0.488	0.385	0.242	0.132	0.185	11
D3	0.461	0.412	0.246	0.269	0.217	5
D4	0.586	0.513	0.431	0.402	0.416	10
D5	0.561	0.341	0.272	0.198	0.103	3
D6	0.366	0.201	0.053	0.037	0.064	2
D7	0.389	0.211	0.180	0.221	0.241	5
D8	0.341	0.211	0.133	0.023	0.009	1
E1	0.369	0.144	0.227	0.146	0.116	3
E2	0.255	0.030	-0.018	0.107	0.104	1
E3	0.575	0.412	0.388	0.396	0.330	9
E4	0.358	0.278	0.263	0.179	0.104	6
E5	0.252	0.148	0.089	0.125	-0.037	1
E6	0.360	0.168	0.095	0.028	-0.010	1

TABLE 5--CALCULATED VALUES OF z_1 AND z_2 ACCORDING TO EQUATIONS (8) and (9)

Subseries	z_1		z_2	
	n = 5	n = 10	n = 5	n = 10
A1	0.704	0.662	0.799	0.801
A3	0.622	0.472	0.878	0.933
A4	0.628	0.532	0.874	0.898
A5	0.570	0.443	0.921	0.947
A6	0.572	0.509	0.918	0.911
A7	0.646	0.566	0.857	0.876
A8	0.551	0.508	0.934	0.912
Independent observations	$1/\sqrt{5}=$ 0.447	$1/\sqrt{10}=$ 0.316	1	1

TABLE 6--GENERAL CHARACTERISTICS OF THE CEMENT STRENGTH RECORDS

Subseries	n	$\bar{x}_n$ (MPa)	s_n (MPa)	δ (%)
F1	200	49.8	3.09	6.20
F2	200	50.8	2.92	5.75
G1	200	56.2	2.78	4.95
G2	200	57.4	3.14	5.47
H1	200	48.3	3.88	8.03
H2	200	46.6	2.92	6.27
I1	200	50.1	1.81	3.61
I2	200	52.4	2.21	4.22

TABLE 7--SERIAL CORRELATIONS OF THE CEMENT STRENGTH RECORDS

Sub-series	r_1	r_2	r_3	r_4	r_5	Highest lag of significant r_k
F1	0.595	0.508	0.435	0.365	0.294	12
F2	0.616	0.548	0.484	0.462	0.388	8
G1	0.207	0.157	0.014	0.107	0.118	2
G2	0.432	0.246	0.235	0.201	0.177	4
H1	0.481	0.454	0.403	0.328	0.166	4
H2	0.269	0.191	0.228	0.057	0.063	3
I1	0.330	0.349	0.402	0.287	0.274	6
I2	0.583	0.525	0.566	0.560	0.549	13

TABLE 8--PROPERTIES OF SAND DATA (378 OBSERVATIONS)

	Mean value	Standard deviation	Coefficient of variation
Fineness Modulus	2.991	0.154	5.1 %
Moisture content (%)	6.09	1.92	31.5 %

TABLE 9--SERIAL CORRELATIONS OF SAND DATA (378 OBSERVATIONS)

	r_1	r_2	r_3	r_4	r_5
Fineness Modulus	0.380	0.243	0.283	0.199	0.154
Moisture content (%)	-0.026	0.100	0.083	0.013	0.056

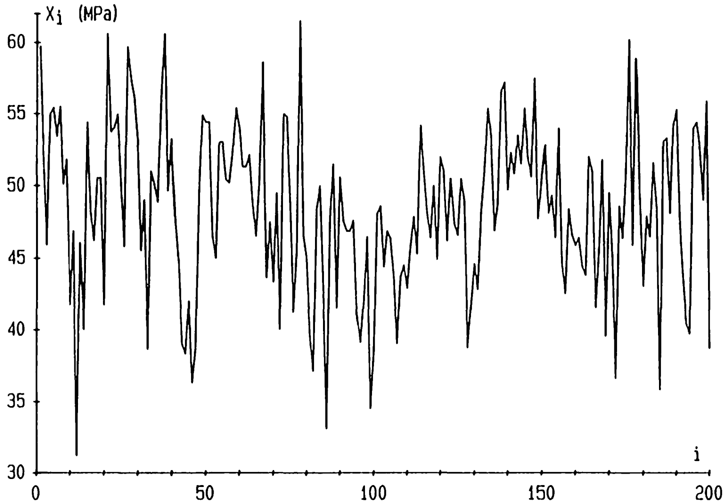

Fig. 1 -- Representation of Subseries A4

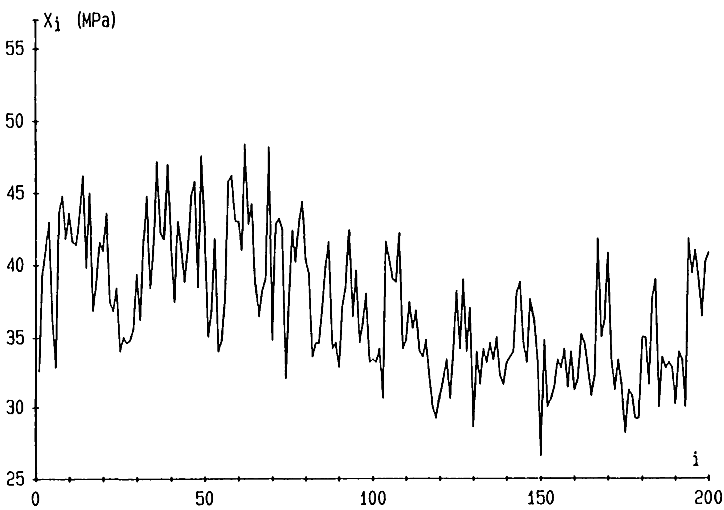

Fig. 2 -- Representation of Subseries B4

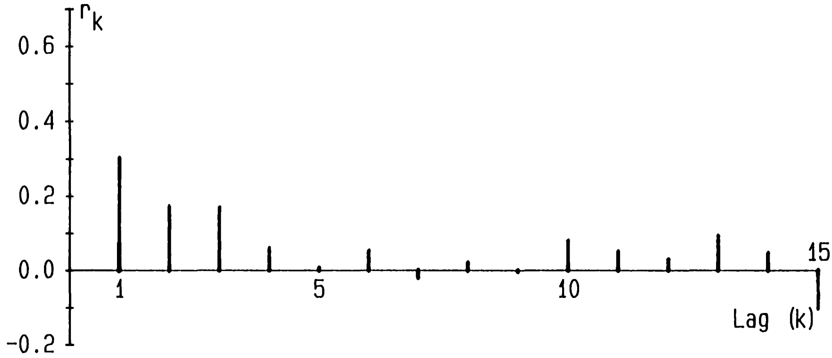

Fig. 3 -- Correlogram of Subseries A4

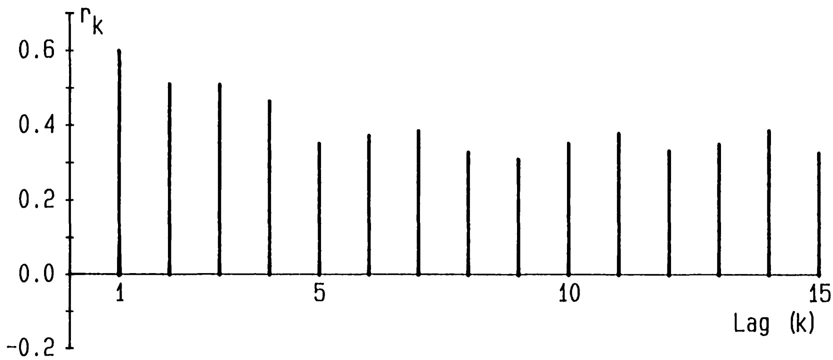

Fig. 4 -- Correlogram of Subseries B4

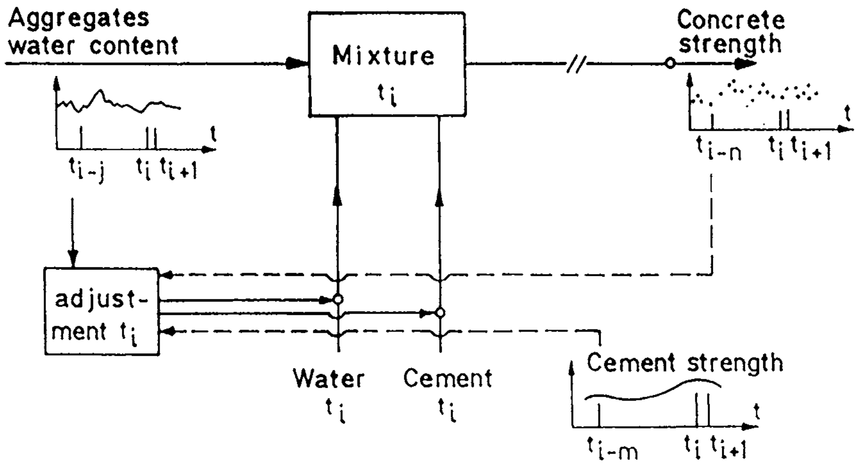

Fig. 5 -- Schematic representation of concrete production; adapted from (2)

SP 104-14

Quality Concrete Production for the California State Water Project

by J.H. Lawder and R.F. Adams

Synopsis -- The organization and procedures used in the quality production of about 8 million cubic yards of concrete of all kinds for the California Water Project are described. These included design aspects, specifications, the concrete laboratory and construction inspection forces, coordinated by a concrete engineer working full time as an internal consultant responsible for quality. Concrete strength requirements and the analysis of concrete strength results for acceptability of performance were based on concepts set forth in ACI Standard 214.

Keywords: compressive strength; concretes; inspection; quality assurance; quality control; statistical analysis; tests; water supply

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INTRODUCTION

The California State Water Project was built for the State of California by the Department of Water Resources to transport excess water from Northern California to supply the water deficiencies of the more arid southern areas where the majority of the population resides. The extent of the project is shown in Fig. 1.

The first phase of the project, which was completed in the 1970's, cost some 2-1/2 billion dollars and covered a length of several hundred miles, as shown in Fig. 1. This phase required about 8 million cu yd (6 Mm^3) of concrete in 22 dams and reservoirs, 6 power plants, 15 pumping stations, 540 miles (870 km) of aqueduct which includes 415 miles (670 km) of canal, 85 miles (135 km) of pipeline, 20 miles (32 km) of tunnel and 16 miles (26 km) of channel and reservoir, and miscellaneous structures.

Following completion of the first phase, work on the project has continued, but at a slower pace, to build or complete facilities included in the project but deferred until the need developed. Already, the East Branch of the aqueduct is being enlarged by the addition of "sideboards" to increase the capacity and the enlargement of pumping plants and power plants and addition of siphon barrels and other necessary work.

Prior to the start of final design and construction, those responsible for building the project recognized the need for a coordinated program for control of quality concrete production, and of firm and attentive inspection of concrete construction for the project. This paper briefly describes the program.

The honoree of this Symposium, Lewis H. Tuthill, was hired by the Department in 1956 and served until 1969 when he retired. Mr. Tuthill was given the responsibility of starting the concrete construction program and setting the standards for it. He was fully supported by the Department management in carrying it out. The success of the program under Mr. Tuthill's direction is shown by the continuing excellent condition of the 8 million cubic yards (6 Mm^3) of concrete used in the structures and canal lining.

OVERALL CONCRETE QUALITY PROGRAM

Project Concrete Engineer Tuthill provided overall direction and coordination of the concrete work in the following areas:

Design -- Provided technical information and assistance to designers and reviewed designs to determine that they were practical and satisfactory from the standpoint of concrete construction with appropriate concrete.

Specifications -- Indicated the necessary requirements and reviewed the completed specifications.

Central Concrete Laboratory -- Provided guidance to the Concrete Laboratory in its work on materials investigations and approval of sources of materials for concrete, materials testing, trial mixes, training programs including evaluation of strength and other test results in accordance with standard procedures, and review of field laboratory operations.

Construction -- Provided technical assistance and information to the construction forces. Regularly reviewed concrete construction and inspection to see that specifications were being properly interpreted and followed.

CONSTRUCTION QUALITY PROGRAM

Once a contract was awarded, primary responsibility for the concrete operations was exercised by the field construction offices. Materials from previously unapproved sources were referred to the Central Concrete Laboratory for approval. Field inspection personnel confirmed performance of all aspects of the work, including production of aggregates, batching and mixing, preparations for placing concrete, placing, finishing, protection and curing, for conformance to specification requirements.

Field laboratories tested a random sample of each class of concrete routinely (at least once each shift) to insure that it also met specification requirements. Field laboratories and batch plant testing facilities were equipped to make all routine tests necessary to assure concrete quality, such as grading, cleanness, and moisture tests of aggregates, false-set tests of cement, air content, unit weight, temperature, slump, and strength tests of concrete. These tests generally followed applicable ASTM Standards.

Some of the less routine testing, such as quality tests of aggregates, tests of admixtures and curing compounds, and confirmation testing of portland cement and pozzolans was done by the Central Concrete Laboratory.

Approval of each new lot of portland cement for shipment was based on a guarantee, supported by a copy of their tests of it, submitted by the manufacturer. The confirmation tests of