duced cracking and water-tight concrete. In contrast, Figure 7 is an example of the optimum mix proportion for improved flowability as well as workability; it is suitable for built-in tiling or highly steel-reinforced building structure. In Table 4 the fundamental mix proportions of flowing concrete for various purposes are summarized.

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Cement-Content Measurements with the Rapid-Analysis Machine

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The rapid-analysis machine (RAM) is a relatively new apparatus developed by the Cement and Concrete Association of England. RAM determines the cement content of fresh concrete by a wet-analysis process through a series of automatically controlled devices. This paper gives details of experience with this machine under controlled laboratory and normal field conditions. It was noted that the machine is capable of carrying out routine testing of fresh concrete efficiently under field conditions.

The traditional way of determining the satisfactory characteristics of concrete delivered to a site is to cast standard cylinders and to test these after curing at an age of 28 days. As techniques have advanced, certain accelerated test methods have come into vogue, and these enable the quality of the concrete to be predicted by tests at ages of only one or two days. However, even a day after a faulty concrete has been placed in a structure, the concrete has set, is hard, and will be expensive to replace.

Recognition of the advantages of being able to determine properties of the plastic concrete before it is placed into the structure is therefore growing. The rapid-analysis machine (RAM), although it does not produce all the required answers, does determine one of the critical characteristics of the concrete mix: its cement content. By using the equipment now available it is possible to make the test within 5 min of taking a sample.

OBJECTIVE

In addition to a brief description of RAM, the objective of this paper is to describe our experience with using this machine on concretes mixed under the various conditions below:

1. In the laboratory,
2. Ready mixed in a few selected highway contracts, and
3. As a part of the normal quality control tool on a nuclear power station site and a major airfield paving contract.

DESCRIPTION OF THE MACHINE

RAM, shown in Figure 1, is a floor-mounted automatic unit approximately 1 m^2 (3 ft^2) in plan and 1.5 m (5 ft) high and about 160 kg (360 lb) in weight. About an 8-kg (17-lb) sample of fresh concrete is fed into a hollow cylindrical elutriation column. Water pumped from a reservoir in the machine up through the elutriation column liquefies the sample, and the cement along with some sand particles are lifted off as a slurry. At the top of the column is a sampling head where a tenth of the slurry is collected by weirs and directed into a 150-μm (no. 100) sieve, while the rest of the slurry is being carried to a waste container.

On the sieve the slurry sample is vibrated and washed by a water spray into a conical conditioning vessel where it is stirred and dosed with flocculating agents.

The base of the conditioning vessel is a detachable collecting pot or constant volume vessel (CVV) in which the solids are precipitated. The water in the conditioning vessel is syphoned off to a constant level within the CVV. The weight of the CVV containing solids and water is proportional to the weight of materials of cement fineness (apparent cement content) in the original mix. From a calibration curve (Figure 2) prepared for the machine, this apparent cement content can be obtained, and now a correction factor (Figure 3) for silt (finer than 150-μm sieve) present in the aggregate can be applied to get the true cement content of the mix.

It has been reported (1) that in a sand stockpile the ratio of weights of material passing the 150-μm sieve to materials held on this sieve but passing the 300-μm (no. 50) sieve is fairly constant. This relationship can be established from the proportional weight of the CVV with sand retained on the 150-μm sieve screened through a 600-μm (no. 30) sieve for a nominal mix.

This estimated silt-correction curve (Figure 3) would remain valid unless a significant variation in the sand grading or mix proportion were to occur. The exact procedure for calibration and establishing the silt-correction curve is given in the machine manual.

Figure 1. Rapid-analysis machine.

PERFORMANCE UNDER LABORATORY CONDITIONS WITH KNOWN CEMENT CONTENT

Several batches of 0.0283-m^3 (1.0-ft^3) air-entrained concrete containing various amounts of cement were made in the laboratory (2). After initial mixing and tests for slump, unit weight, and air content were completed, five samples of approximately 6-8 kg (13-17 lb) each were taken from the pan mixer. A sixth sample was also collected from the remaining portion of the concrete after remixing for about 1 min. All these samples were weighed and de-entrained with a dosage of tributylphosphate before they were run through the machine.

Appropriate silt-correction factors were applied to each test result, and the actual cement content was determined. The cement content as determined by the machine was then compared with the actual cement factor used in the original mix, and the percentage error was calculated.

Table 1 summarizes these results. The laboratory standard sand used in these tests conformed to ASTM C33 requirements and contained about 6 percent pass 150-μm particles. The average corrections required for silt in the first and second, third and fourth, and fifth and sixth test mixes (Table 1) were about 8.5, 4.0, and 2.5 percent of the actual cement content, respectively. The overall variations between the actual cement content and the results obtained by the machine after applying the silt corrections were between +5.4 and -7.5 percent, the average being +1.3 to -3.8 percent.

SELECTED HIGHWAY CONTRACTS

RAM was mounted in a 2.7-t (3-ton) closed motorized vehicle with a 455-L (100-gal) water tank, and a 50-A, 120-V generator was installed in it. Four contracts were visited during this trial period, and the concrete for them was sampled from the ready-mix trucks.

After an initial discharge of about 0.4-0.8 m^3 (0.5-1.0 yd^3) of concrete, three samples each weighing about

Figure 2. Calibration curve.

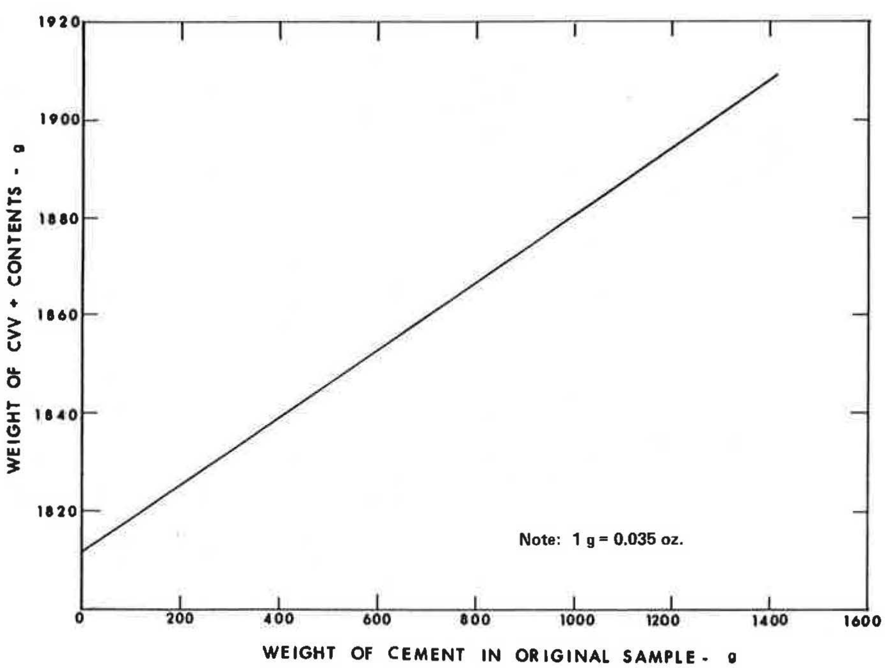
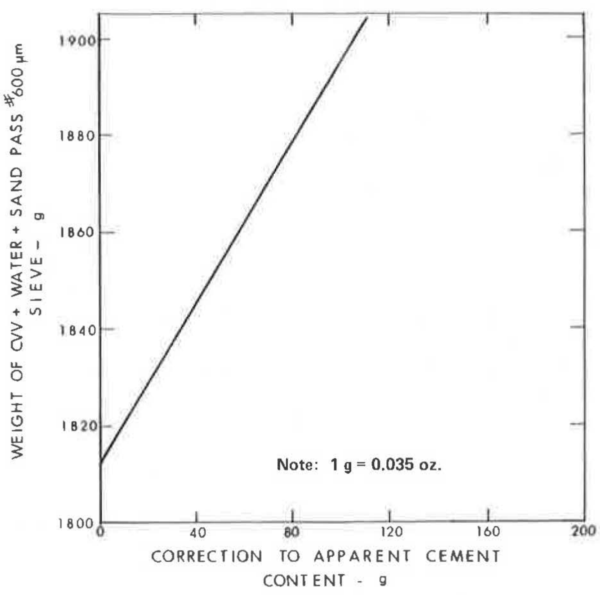


Figure 3. Silt-correction curve.



7 kg (15 lb) were scooped from the chute of the ready-mix truck and collected in small plastic buckets. The first sample was collected at the beginning, the second was somewhere near the middle, and the third was toward the end of the discharge. A fourth sample was also collected from the middle of the discharge for air content and unit-weight tests. This sample was discarded after the two tests were completed.

The current trials were designed to evaluate the performance of the RAM mobile unit, so it was felt necessary to carry out as many test runs as possible within a short period of time. No attempt was therefore made at this stage to test one representative sample by combining the three samples collected from one truckload. The procedure followed also gave an opportunity to see the mixing efficiency of a ready-mix truck. The average of three test results was taken as the cement content of the load.

The time taken to complete a set of three tests from one truckload was between 1 and 2 h. This included time taken to complete tests for unit weight and air content and to carry out normal calculations as shown in Table 2. A well-trained technician and a helper were required to carry out all necessary field operations.

Table 1. Summary of laboratory test results.

	Actual Cement Content (kg/m³)											
	313		314		366		368		416		419	
Sample	CC	%	CC	%	CC	%	CC	%	CC	%	CC	%
A	310	-0.9	314	+0.0	355	-3.0	361	-1.9	390	-6.3	426	+1.7
B	330	+5.4	315	+0.3	363	-0.8	374	+1.6	392	-5.8	-*	-*
C	317	+1.3	316	+0.6	370	+1.1	364	-1.1	385	-7.5	412	-1.7
D	316	+1.0	315	+0.3	350	-4.4	376	+2.2	-*	-*	416	-0.7
E	318	+1.6	315	+0.3	349	-4.6	349	-5.1	416	0.0	418	-0.2
F	313	+0.0	322	+2.5	375	+2.5	366	-0.5	415	-0.2	422	+0.7
Average	317	+1.3	316	+0.7	360	-1.6	365	-0.8	400	-3.8	419	+0.0

Notes: 1 kg/m³ = 0.06 lb/ft³.
CC = cement content determined by RAM in kg/m³; % = percentage difference from the actual amount of cement used.
*Minor mechanical problem with the machine.

Table 2. Field test results.

Truck No. and Mix No.	Sample: Time of Sampling	Sample: Location in Truck	Tests on Concrete: Slump (mm)	Tests on Concrete: Air (%)	Tests on Concrete: Unit Weight (kg/m³)	Tests in RAM: Weight of Sample (g)	Tests in RAM: Weight of CVV + Cement + Silt (g)	Tests in RAM: Weight of CVV + Sand Passing 600 µm Sieve (g)	Calculations from Graphs: Apparent Cement Content (g)	Calculations from Graphs: Silt Correction (g)	Actual Cement in Sample (12 - 13) (g)	Cement Factor [(14/9) × 8 kg/m³]	Average Cement Content (kg/m³)	% Difference from Specified Content
317			64	3.6	2417								374	-3.0
1	7:35	B				7672.5	1900	1864.3	1270	63	1207	380		
2	7:40	M				7672.9	1900.7	1866.2	1275	65	1210	380		
3	8:00	E				7671.9	1895.7	1865.0	1210	64	1146	361		
317			NT	6.0	2347								357	-1.7
1	9:15	B				7672.2	1893.9	1864.3	1190	63	1127	345		
2	9:25	M				7672.1	1896.8	1864.5	1235	63	1172	359		
3	9:35	E				7672.8	1899.2	1864.9	1265	64	1201	367		
318			NT	5.0	2372								377	+3.9
1	11:40	B				7672.8	1902.1	1867.5	1310	67	1243	384		
2	11:47	M				7671.9	1898.2	1865.5	1250	65	1185	366		
3	11:55	E				7672.1	1900.9	1861.5	1295	59	1236	382		
408			NT	6.8	2321								339	-6.6
1	1:25	B				7671.2	1899.8	1871.4	1265	71	1194	361		
2	1:35	M				7670.5	1894.7	1869.3	1190	69	1121	339		
3	1:40	E				7673.1	1899.2	1868.6	1120	68	1052	318		
318			NT	4.8	2385								375	+3.3
1	2:26	B				7671.6	1900.9	1872.5	1290	73	1217	378		
2	2:28	M				7671.2	1905.8	1875.6	1355	76	1279	398		
3	2:35	E				7672.5	1895.0	1872.0	1200	74	1126	350		

Notes: 1 mm = 0.039 in; kg/m³ = 0.06 lb/ft³; 1 g = 0.03 oz; 1 µm = 0.0039 in.
B = beginning of the discharge; M = middle of discharge; E = end of discharge; NT = not tested.

Table 3. Summary of field test results.

Item	Job No. 1	2	3	3	4
Specified cement content (kg/m^3)	474	337	337	363	363
No. of tests	13	6	30	22	15
Average cement content by RAM (kg/m^3)	468	326	330	356	365
Average difference from specified (%)	-1.4	-3.4	-2.3	-2.0	+0.5
Range of difference from specified (%)	-0.8 to -1.9	-2.3 to -4.5	+2.5 to -7.5	+0.6 to -5.7	+4.0 to -6.6
Average air content (%)	4.5	4.5	4.9	4.9	5.2
Average unit weight (kg/m^3)	2473	2406	2353	2387	2368

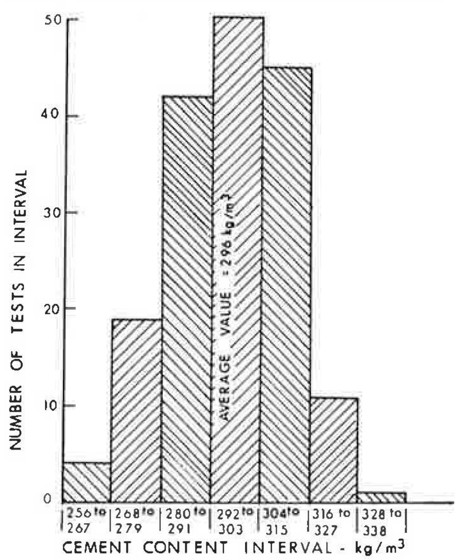
Note: 1 kg/m^3 = 0.06 lb/ft^3.

Table 4. Statistical analysis of test data from two contracts.

Contract	Specified Cement Content (kg/m^3)	No. of Tests	Mean Cement Content by RAM (kg/m^3)	Standard Deviation (kg/m^3)	Coefficient of Variation (%)
A					
With fly ash	234	119	233	15.6	6.7
Without fly ash	234	134	239	12.7	5.3
B	288	172	296	14.5	4.9

Note: 1 kg/m^3 = 0.06 lb/ft^3.

Figure 4. Test results of airfield paving contract.



Note: 1 kg/m^3 = 0.06 lb/ft^3.

A typical field data sheet is shown in Table 2, and a summary of the results of all the tests carried out during this phase of the evaluation is included in Table 3. It may be noted that the maximum variation in the cement content of job 3 was between +2.5 and -7.5 percent of the specified cement factor, based on the air content and the unit weight as measured before test runs. Other jobs showed smaller variations.

The following points were noted during the field operations.

1. The water tank needed refilling from a mobile tanker after every five or six tests. This was a time-consuming process. A constant source of water supply would be an advantage.
2. It was necessary to clean the machine after every five or six tests with diluted muriatic acid.
3. The shelf life of the flocculating agents was about two months.
4. No significant shift in calibration was noticed during these trials.
5. A periodic check on the grading of aggregates is required to make any adjustment of the silt-correction curve. Also, if the mix proportions are changed significantly, the curve should be reestablished.
6. The overall electromechanical function of the machine was satisfactory, although some problem was encountered with the solenoid valves. These were replaced easily.
7. The mobile laboratory vehicle required a reasonably level parking spot. This sometimes created a problem.

NORMAL QUALITY-CONTROL TOOL IN A NUCLEAR POWER STATION SITE AND AN AIRFIELD PAVING CONTRACT

RAM was used on two major contracts in Ontario. The first one was on a nuclear power station construction site and the second one was on an airfield paving contract (3).

During the initial stage of the operation it was found that the sampling technique was critical. After several trials, a sampling technique was developed that allowed a sample to be taken for testing in RAM without significantly delaying the other routine tests such as air content, slump, unit weight, and cylinder casting.

Four or five buckets of concrete were taken from a truck and spread out in a mixing tray, and a representative sample of about 7-9 kg (17-20 lb) was taken for RAM by random increments from the overall sample. The remaining concrete was used to carry out the other usual tests. The sample was processed through the machine and, after applying the proper corrections, the cement content was determined.

First Contract

The concrete for the nuclear project was used either with or without fly ash in the mix and had a cement content of 234 kg/m^3 (14 lb/ft^3). The appropriate corrections to be made were determined following the method described by Forrester, Black, and Lee (1). A periodic check on the calibration and the correction factor was carried out. The aggregate size was up to a maximum of 76 mm (3 in). However, aggregates larger than 38 mm (1.5 in) were removed after weighing but before processing the sample in the machine. The cement paste on these large particles was washed off into the test sample without causing any significant error in the final result. A total of 252 test results were analyzed in this contract.

Second Contract

The specified cement content in the airfield paving contract was 288 kg/m^3 (17 lb/ft^3), and the maximum nominal aggregate size was 38-mm crushed limestone. A total of 172 tests were carried out in this contract. The sampling and testing procedures were similar to the method described above.

Test Results

In both the above contracts the test results were well within the normal variations expected from a ready-mix truck. A statistical analysis of the test data was carried out; the standard deviations and coefficients of variation for each set of data are included in Table 4. Also, the distribution of the test data for the airfield paving contract is shown in Figure 4. A similar distribution was also noted for the other contract.

CONCLUSIONS

RAM is capable of carrying out a routine field testing of fresh concrete with good accuracy. The cement content of fresh concrete checked under field conditions usually varied within ±10 percent of the specified content. Any significant deviation from the specified cement content of a freshly mixed concrete can easily be detected by this test, and, if required, appropriate action can then be taken before the concrete has hardened.

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**P. K. Mukherjee was with the Ontario Ministry of Transportation and Communications when this work was done.*