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THE ROLE OF READY MIXED CONCRETE IN THE CONSTRUCTION INDUSTRY

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by

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København, august 1977

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Ken Newman, Director-General, British Ready Mixed Concrete Association

to the

Danish Concrete Association 2 March 1977

Summary

Throughout the world, the amount of site-placed concrete which is manufactured off the job site increases once the cost of labour becomes high in relation to the cost of materials. This paper reviews the pattern of growth of the ready mixed concrete industry and describes the standards which have been established for the production, supply and quality control of ready mixed concrete.

Ready mixed concrete is both a product and a service. Typical methods of production and delivery are outlined and the various techniques used to control the quality of concrete described in detail. These include routine checks on cement and aggregate materials, and fresh and hardened concrete.

The special nature of ready mixed concrete is reflected in the contract conditions between the supplier and purchaser and the procedures for assessing the liability of the supplier when the product does not comply with the specification. Finally, an examination is made of possible future trends in the specification, control and assessment of ready mixed concrete.

INTRODUCTION

Twenty years ago, the European contractor mixed all his own concrete on site. Since then, as the cost of labour has increased in relation to the cost of materials and production equipment, so has the amount of site-placed concrete which is manufactured off the job site. Table 1 shows the rapid growth for the ready mixed concrete industry in Europe in the past fifteen years, during which time production has increased in many countries by eight to ten times. For example, in the United Kingdom, in 1960 there were still fewer than two hundred plants producing only 4 million cubic metres of concrete. Today there are over eleven hundred plants producing 26 million cubic metres of concrete, in which 42% of the total UK cement production is utilised. Table 2 shows the percentages of cement delivered in the UK to each of five main sectors or channels of sale of cement for the calendar year 1976. These cement end use figures confirm those for other European countries and indicate that about 85% of the total cement is consumed in structural concrete of all types. Of this 22% is used in pre-cast products and 62% in site-placed concrete, which can be mixed either on or off the construction site. In the UK, two thirds of site-placed concrete is now ready mixed.

WHAT IS READY MIXED CONCRETE ?

Ready mixed concrete is both a Product and a Service which, to be acceptable to the contractor, must give Value for Money. In providing the Product, ready mixed suppliers must deliver freshly mixed concrete of the workability required by the contractor and having potential qualities in the hardened state which satisfy the engineer's specification. In providing a Service, the supplier must deliver the Product in the quantities required and at a rate to suit the contractor's handling and placing requirements.

In contractual terms, ready mixed concrete companies are specialist material suppliers selling a partially finished product, the end quality of which depends upon the workmanship of the contractor.

When transferring responsibility for concrete production to the ready mixed plant, the contractor must provide full details of the main specification concerned with concrete mixes and production, together with any additional placing and handling requirements which might affect the supplier's choice of materials and mix proportions. With such a new industry as ready mixed concrete,

Table 1

GROWTH OF READY MIXED CONCRETE IN EUROPE

Country	Started	Ready Mixed Concrete Production - million m^3									Cement % of total
		1960	1966	1968	1970	1971	1972	1973	1974	1975	1975
Austria	1960	0.08	0.90	1.10	1.61	2.50	3.20	3.40	3.40	3.50	16.5
Belgium	1956			3.61	4.72	5.16	5.35	5.53	5.93	5.73	30.4
Denmark	1926		1.27	1.53	2.25	2.50*	3.00*	3.50	3.10	2.80	31.8
Finland	1958	0.17	1.51	1.92	2.50	2.85	2.90	3.35	4.00	3.90	57.6
France	1933	0.24	3.81	8.20	13.50	16.77	19.50	23.00	25.00	23.20	24.6
Germany (West)	1903	3.20	18.00	22.10	37.70	50.00	57.50	56.90	48.40	45.70	42.0
Gt. Britain	1930	4.60	16.80	21.70	23.30	25.20	26.67	31.65	27.83	26.72	42.0
Netherlands	1948		4.55	5.87	6.64	6.69	6.76	6.67	6.67	7.02	38.4
Norway	1930				2.40	2.40	2.50	2.50	2.40	2.50	44.0
Spain	1942	0.04	1.20	3.50	5.00	6.90	9.00	13.00	15.31	14.60	18.9
Sweden	1932	2.40	6.00	6.60	8.00	7.75	7.50	6.40	6.20	5.70	48.6
Switzerland	1933	0.03	2.50	3.70	5.35	6.40	7.90	8.00	7.63	5.33	36.9

Source: European Ready Mixed Concrete Organisation

* - Estimate

Table 2

CHANNEL OF SALE FIGURES FOR CEMENT IN THE UNITED KINGDOM IN 1976

CHANNEL OF SALE	TONNES	PERCENTAGE
Ready Mixed Concrete	6,314,870	40.7
Site and Other Uses	3,329,884	21.5
Precast Concrete	3,429,308	22.1
Merchants' Yards	2,110,371	13.6
Asbestos Cement	321,007	2.1
Total	15,505,440	100.0

Ready Mixed Concrete represents 65% of the Site Placed Concrete market in the U.K.

originally there was no common practice. Purchasers and suppliers in each country have established their own procedures on a basis of trial and error with inevitable mistakes and misunderstandings. It is to try and overcome these problems that the European Ready Mixed Concrete Organisation (ERMCO) is now drafting a Code of Good Practice for the specification, production and use of ready mixed concrete. This Code covers requirements for concrete mix description and compliance, and for concrete production procedures, including personnel, materials, plant and equipment and internal production control. The ERMCO Code will be available for use as a basis for a fully detailed National Standard where none exists already, or can be referred to in future documents provided by international organisations such as CEB, ISO and CEN.

READY MIXED CONCRETE AS A PRODUCT

If the engineer is to have confidence in ready mixed concrete he requires assurance that the concrete is of the required quality, contains suitable materials and has been manufactured under controlled conditions by experienced staff, using reliable equipment.

Production Standards

The ERMCO Code of Practice gives detailed requirements for personnel, materials, plant and equipment, operating procedures and internal quality control (self-control). These standards reflect what has become established as good practice in the ready mixed concrete industry throughout Europe. For example, in the United Kingdom, the British Ready Mixed Concrete Association has introduced an Authorization Scheme[(1)] which defines standards in the following sections -

- A Personnel
- B Materials
- C Plant and Equipment
- D Operating Procedures
- E Quality Control Procedures for Designed Mixes

Those depots which comply with the minimum standards of Personnel, Materials, Plant and Equipment, and Operating Procedures (Sections A-D) are designated as "BRMCA Approved Depots" and are approved for the supply of prescribed mixes. Those depots which, in addition, comply with the minimum standards for Section E Quality Control Procedures for Designed Mixes are designated as "BRMCA Approved Depots with Quality Control Procedures" and are approved for the supply of prescribed mixes and designed strength mixes.

All the 1100 depots of BRMCA Members are certified as "BRMCA Approved Depots", and over 400 of these depots are classified as "BRMCA Approved Depot with Quality Control Procedures".

Approved Depot certificates are issued on the basis of inspections and reports by BRMCA Regional staff, who are all Chartered Engineers. All depots of BRMCA Members must comply with the basic part of the Scheme and be certified as"BRMCA Approved Depot". Where a depot fails to maintain standards or to correct promptly deficiencies which may adversely affect the quality or quantity of concrete supplied, this will result in the withdrawal of the certificate and deletion of the depot from the Approved List.

For Section A-D depots the inspections are carried out at a minimum rate of one each year. For those depots with Section E, the control procedures and records are inspected at least twice each year. After each inspection, Engineers issue Reports on which are indicated the status or recommendations as follows -

Reaffirmed with or without comments
Reaffirmation withheld pending improvements
Recommendation for suspension
Recommendation for withdrawal

<u>Personnel</u>

As in the ERMCO Code, the BRMCA Authorization Scheme requires that -

"All personnel concerned with production, delivery and control of ready mixed concrete shall receive training in the activities they have to carry out".

In conjunction with the Ceramics Training Board (the government training board responsible for ready mixed concrete), the BRMCA has prepared comprehensive Training Objectives for all personnel concerned in the production of ready mixed concrete.[(2)] These Training Objectives introduce a new philosophy which aims to provide specific instructions for staff engaged in various activities.

At the moment almost all teaching in schools, colleges, universities and in subsequent working life is directed at providing a wide education and understanding of any particular subject which the individual must then apply to his particular job. The new approach to training being introduced in the cement and concrete field is based on comprehensive lists of the particular activities involved in the various jobs. For ready mixed concrete, Job Grades have been considered at three levels, i.e. Practice (Operative), Supervision and Management.

Job Activities at these three levels are given in the three work categories of Production, Technical and Commercial. In the Training Objectives Booklet a total of 65 Lists of Job Activities have been prepared. For example, in the field of Production there are a total of 17 Job Activities for ready mixed concrete personnel at the Operative level.

Recently the BRMCA has completed the preparation of two Instructor Manuals for ready mixed concrete mixing operatives and truck drivers. This new approach to training will be complete when personnel receive Certification (following written and practical tests) that they have the knowledge and skills to carry out the various activities demanded by their job. Such Certification might be in the form of a "Passport" which successive employers and examining bodies complete to confirm his skill and experience, and that he has completed various stages of training.

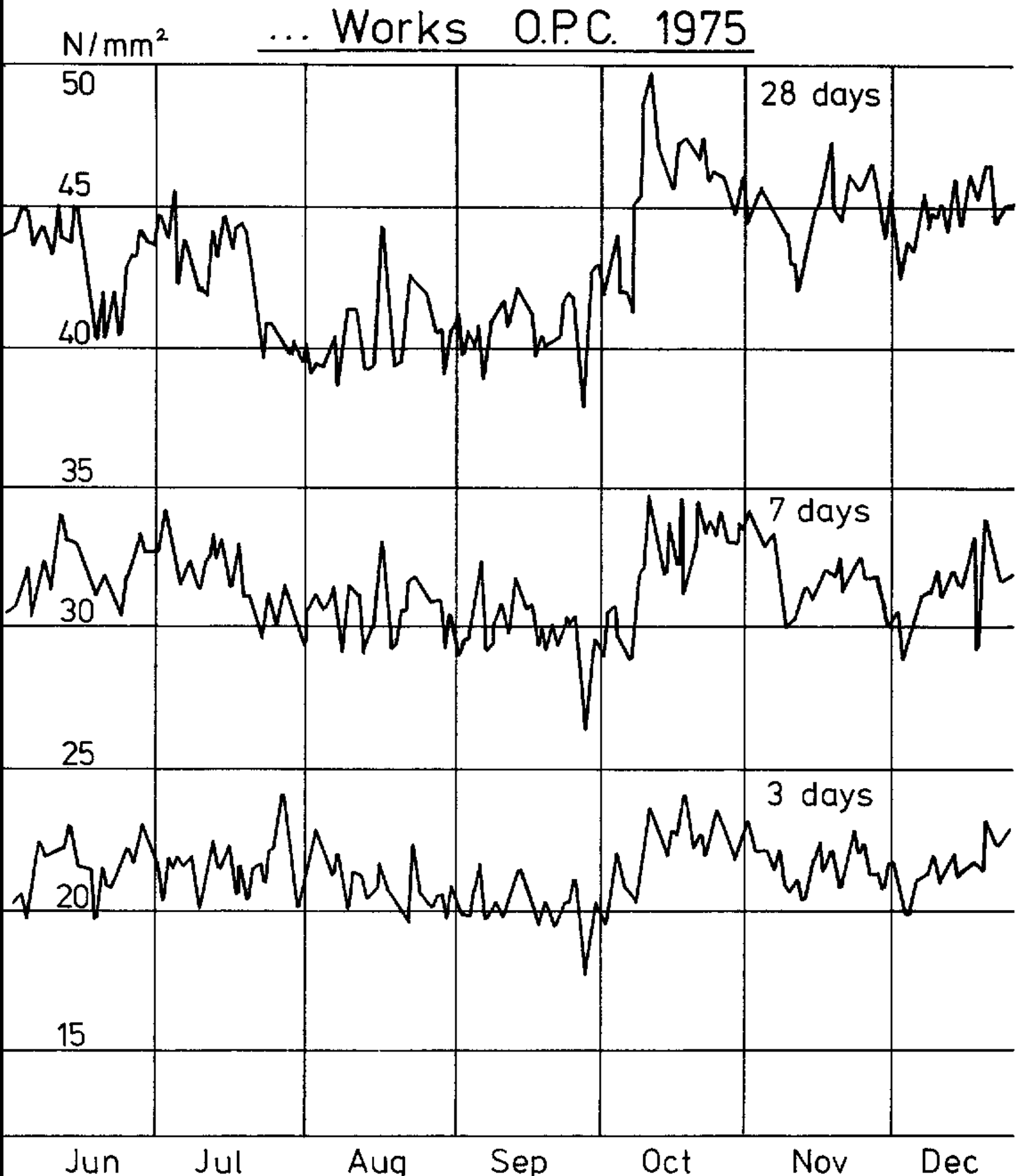
Materials

When defining the required concrete materials, specifications should adopt the "performance" approach, i.e. to define properties in terms of the actual performance required rather than specify a material from a particular source.

The main concern of the ready mixed concrete supplier is the actual quality and variability of the materials he uses. There is a great lack of data provided by aggregate suppliers, for example, on the average grading of their aggregates and the variability from this average. But it is the variation in the quality of cement which is of most concern to the ready mixed supplier since this directly affects the strength of concrete.

For many years European cements have had a reputation for reliable quality in excess of the specification and good performance in use. This has led many to believe that cements are extremely uniform in quality, whereas this is not the case. Figure 1 shows the variation in the qualities of cement in terms of the 3, 7 and 28 day strengths from a UK works during the second half of 1975. These values have been taken from the Certificates supplied by the maker, which are his results of tests carried out on daily or weekly bulk average samples. It will be seen that in one three-weekly period in the autumn the strength increased by some 30% (from 37 to 49 N/mm^2), followed in the next month by a fall of some 12% (from 49 to 43 N/mm^2). Both these changes would be directly reflected in the quality of ready mixed concrete and are outside the knowledge and control of the ready mixed supplier.

Figure 1


... Works O.P.C. 1975
N/mm²
50
45
40
35
30
25
20
15
28 days
7 days
3 days
Jun
Jul
Aug
Sep
Oct
Nov
Dec

These variations are confirmed by the figures given in Table 3 which so show the variations in quality of cement from 24 works in the UK during 1976. In recent years there has been a trend towards a smaller number of cement works, which distribute cement by rail throughout the UK to various depots. This means that the supplier may be using cement from several works, resulting in further unpredictable variations in the quality of his concrete. BRMCA Members are continuing with their efforts to obtain an "early warning" of significant variations from the average cement quality supplied by British cement makers. There is no reason to believe that the situation is different in other European countries.

Plant and Equipment, Operating Procedures

In line with the ERMCO Code, Sections C and D of the BRMCA Authorization Scheme define the requirements for plant and equipment and its operation written in "performance" terms, i.e. by defining what the plant should be capable of and not the way it should be designed.

Detailed requirements are given for material storage, batching, mixing and transporting equipment defining the principles of design and the minimum accuracy of scales and meters. In the Section on operating procedures, guidance is given on the handling, measurement and batching of cement, aggregates and other materials, with recommendations concerning the use of central and truck-type mixers. There are further clauses on calculation of batch weights and on delivery and its associated documentation.

Internal Control Procedures (Self-Control)

When referring to the "quality control of concrete" it is important to differentiate between the following procedures -

1 Compliance or Acceptance Control in which tests are made and results assessed to judge whether the concrete supplied complies with the specified requirements. Compliance judgement is based on test results on randomly taken samples representative of the lot to be judged

2 Internal Production Control (Self-Control) in which the supplier carries out visual inspections and tests on the concrete materials, plant, fresh and hardened concrete to maintain the quality of his production in accordance with the specified requirements in an optimal economic way

Table 3

VARIATIONS IN QUALITY OF CEMENT FROM WORKS IN THE UNITED KINGDOM

Cement Works	Period	28 day Mean Strength N/mm^2	Standard Deviation N/mm^2	Range	
				Lowest	Highest
1	Jan-Nov 1976	41.85	1.57	38.5	44.5
2	Nov 75-Oct 76	42.14	1.139	39.0	44.5
3	Jan-Nov 1976	41.80	0.81	39.5	43.5
4	Nov 75-Oct 76	40.4	0.87	38.5	42.0
5	Jan-Nov 1976	42.60	1.78	38.4	46.4
6	Jan-Nov 1976	43.10	1.14	40.7	45.5
7	Jan-Nov 1976	36.74	1.76	32.60	41.10
8	Jan-Nov 1976	41.50	1.15	39.50	43.50
9	Jan-Nov 1976	44.20	2.16	38.90	47.20
10	Nov 75-Oct 76	38.8	0.80	37.0	41.0
11	Nov 75-Oct 76	42.1	1.70	38.2	46.1
12	Jan-Jul 1976	41.60	0.70	40.5	44.0
13	Nov 75-Oct 76	42.2	0.95	40.3	44.1
14	Jan-Nov 1976	43.80	1.22	41.0	46.0
15	Nov 75-Oct 76	42.2	1.394	38.5	45.8
16	Jan-Nov 1976	41.50	0.77	39.0	44.5
17	Jan-Nov 1976	40.47	1.32	37.5	43.5
18	Jan-Nov 1976	41.10	2.00	37.5	45.0
19	Jan-Nov 1976	43.10	1.33	38.0	46.5
20	Dec 75-Nov 76	41.3	1.397	37.0	44.0
21	Nov 75-Oct 76	42.8	1.28	38.5	46.0
22	Jan-Nov 1976	41.80	2.01	37.0	47.5
23	Jan-Nov 1976	44.50	2.34	39.0	52.0
24	Nov 75-Oct 76	41.0	2.0	38.0	47.5

Control Systems At the time when most concrete was site mixed by the contractor, classic mix design and quality control techniques were established. These were aimed at arriving at the initial selection of mix proportions for a job where no previous data were available, followed by regular sampling and testing. At first the only method of assessing the results was to plot them on a Calendar Chart (see Figure 2). When a result fell below the minimum strength line, arbitrary decisions were made whether to reject the concrete or to alter the mix proportions.

Once a sufficient number of results had been obtained (usually 40), the value of mean strength and standard deviation were calculated. This procedure might have been referred to as "Backward Control" since this merely indicated the variability of concrete produced in the past. The next development was the use of the Shewart Chart in which results were plotted in a Calendar form and assessed relative to Warning and Action Limits (see Figure 3). Depending on the degree of control exercised, action was taken where one or more results fell outside either 1 in 10 (1.28 x standard deviation) or 1 in 40 (1.96 x standard deviation) lines drawn above and below the mean value. The main limitation of these systems is that they do not indicate the points of change or the amount of corrective action which is required.

More recently the ready mixed industry has introduced "Forward Control" methods involving Cusum techniques (See Figure 4). It should be appreciated that the information obtained by purchasers when operating testing plans to judge compliance with the specified requirements is not of any interest to the supplier who is operating internal production control systems. The supplier is concerned with the control of all his production, whereas the purchaser is concerned only with the acceptability or otherwise of the concrete being supplied to his job. These differing requirements have led to the application of the same quality control principles but from differing viewpoints.

Since the early work of Stanton Walker, in the 1940's, it has long been accepted that the strength of the concrete is randomly variable and, therefore, better described by a distribution rather than a single value. Throughout Europe this distribution is usually assumed to be Normal (Gaussian). All evidence supports this assumption, although the

Figure 2

Control Charts

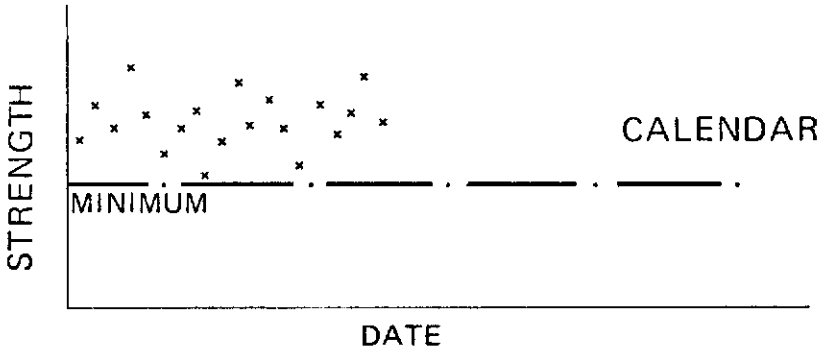


Figure 3

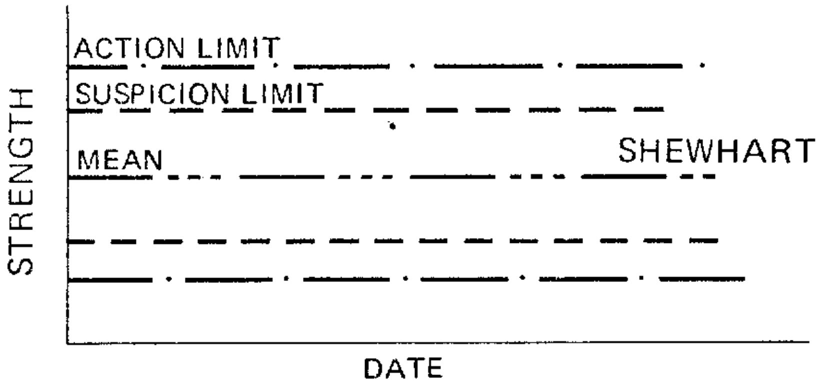
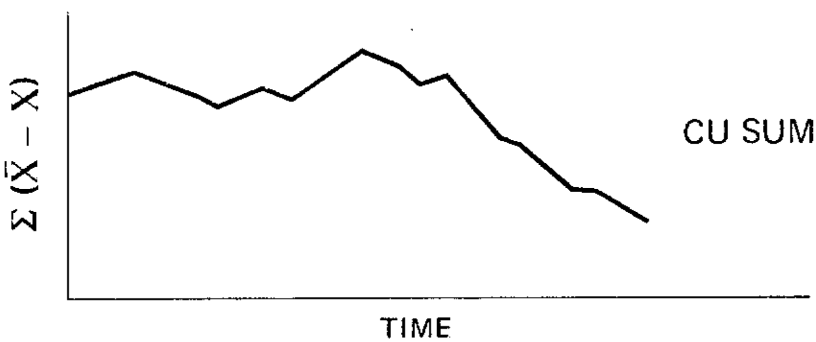


Figure 4



distributions for high and low strength concretes exhibit skewness due to the upper and lower practical limits of concrete strength.

The Normal distribution is defined by two parameters, the Mean, establishing the level of quality, and the Standard Deviation, which describes the degree of variability about the mean (see Figure 5). The strength required by the designer is now designated as characteristic strength, i.e. the value below which a certain percentage of defectives may be expected to fall. Most international bodies have standardised on the 5% defectives level. In order to achieve this characteristic strength, the supplier must ensure that this value is exceeded by a margin which is at least 1.64 x the standard deviation. Recent developments in ready mixed concrete production control have concentrated on the initial design of concrete mixes and their continuing assessment and adjustment of proportions in order to provide concrete of the required characteristic strength. This involves determining the target strength (the quality factor) which is influenced primarily by cement quality and the quantity of water in the mix, and the design margin (the variability factor) which is affected by variability in materials, batching, mixing and testing.

The five stages of internal production control are as follows :-

1 <u>Target values</u>
   Establishment of average or expected values for the relevant properties of fresh and hardened concrete and its constituent materials

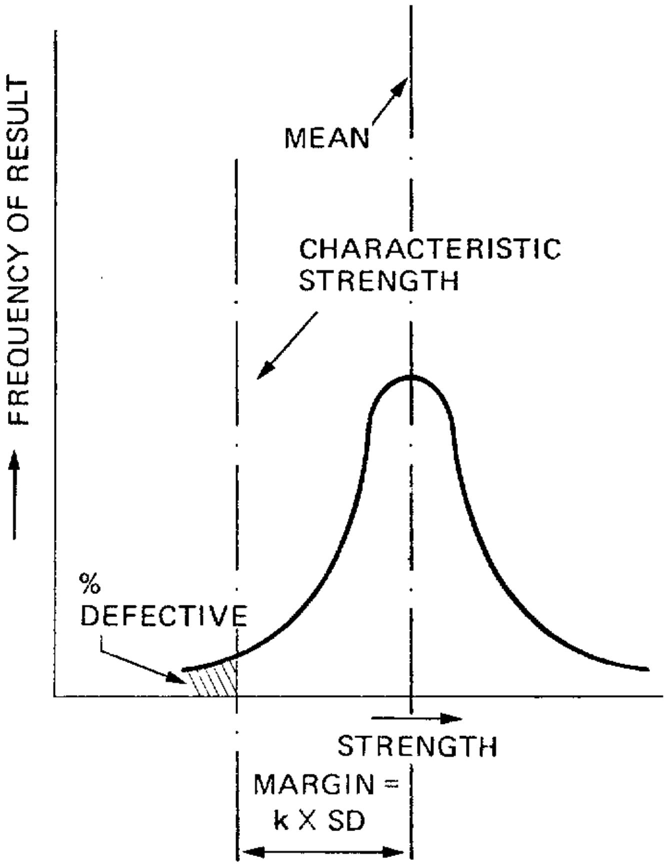
2 <u>Testing</u>
   Regular and continuous random inspection and testing of concrete and its constituent materials

3 <u>Analysis</u>
   Continuous analysis of test results (preferably on a graphical basis) and comparison with the established or expected target values

4 <u>Mix adjustment</u>
   When significant changes from the target values are detected, adjustments of the mix proportions to restore the situation

5 <u>Diagnosis</u>
   Examination of the materials and production procedures to identify the cause of the significant change

Figure 5


FREQUENCY OF RESULT
MEAN
CHARACTERISTIC STRENGTH
%
DEFECTIVE
STRENGTH
MARGIN =
k X SD

Mix Design Because of the large range of mixes supplied, ready mixed suppliers in Britain design their concrete mixes for the aggregates available as a series from very rich to very lean mixes (see Figure 6). The weights of cement, sand, aggregate and water to provide 1 cubic metre are listed in the depot batch book, usually in cement content increments of 5 kg/m^3. The cement content for different target strengths is obtained from a 28 day strength/cement content correlation chart (see Figure 7). In principle, one chart is required for every source of cement, type of aggregate, percentage of sand and required workability. In practice, when only one cement and aggregate are used, one chart is established for one particular workability, usually 75 mm slump. At least 100 results are required to establish the correlation curve.

Cusum Analysis Once production begins, concrete is sampled and tested regularly, the tests for designed mixes being strengths of cubes. The analysis of cube results is facilitated by the use of the cumulative sum technique, developed by Ready Mixed Concrete Ltd., England.[1] Cumulative sum (Cusum) charts are drawn by plotting the accumulated sum of the differences between each result and the average value expected. This average value, or target mean strength, can be calculated from previous data, or may be an assumed value, i.e. based on an initial standard deviation of 6 N/mm^2. If a Cusum graph is horizontal, the average of the results over that period is the same as the target value. A rise or fall in the Cusum graph indicates that the average value over that period is greater or smaller respectively than the target value set. The advantage of the Cusum method is that relatively small changes in the average appear quite clearly as different slopes. The Cusum chart, therefore, provides a continuous and immediate record of the trend of the average values.

Cusum charts are plotted on both values of mean strength and standard deviation. To obtain the individual Cusum mean strength value, the target mean strength is subtracted from each 28 day cube result. The Cusum standard deviation is obtained by subtracting the target Range (which is 1.128 x the standard deviation) from the difference between the successive pairs of results.

Figure 6

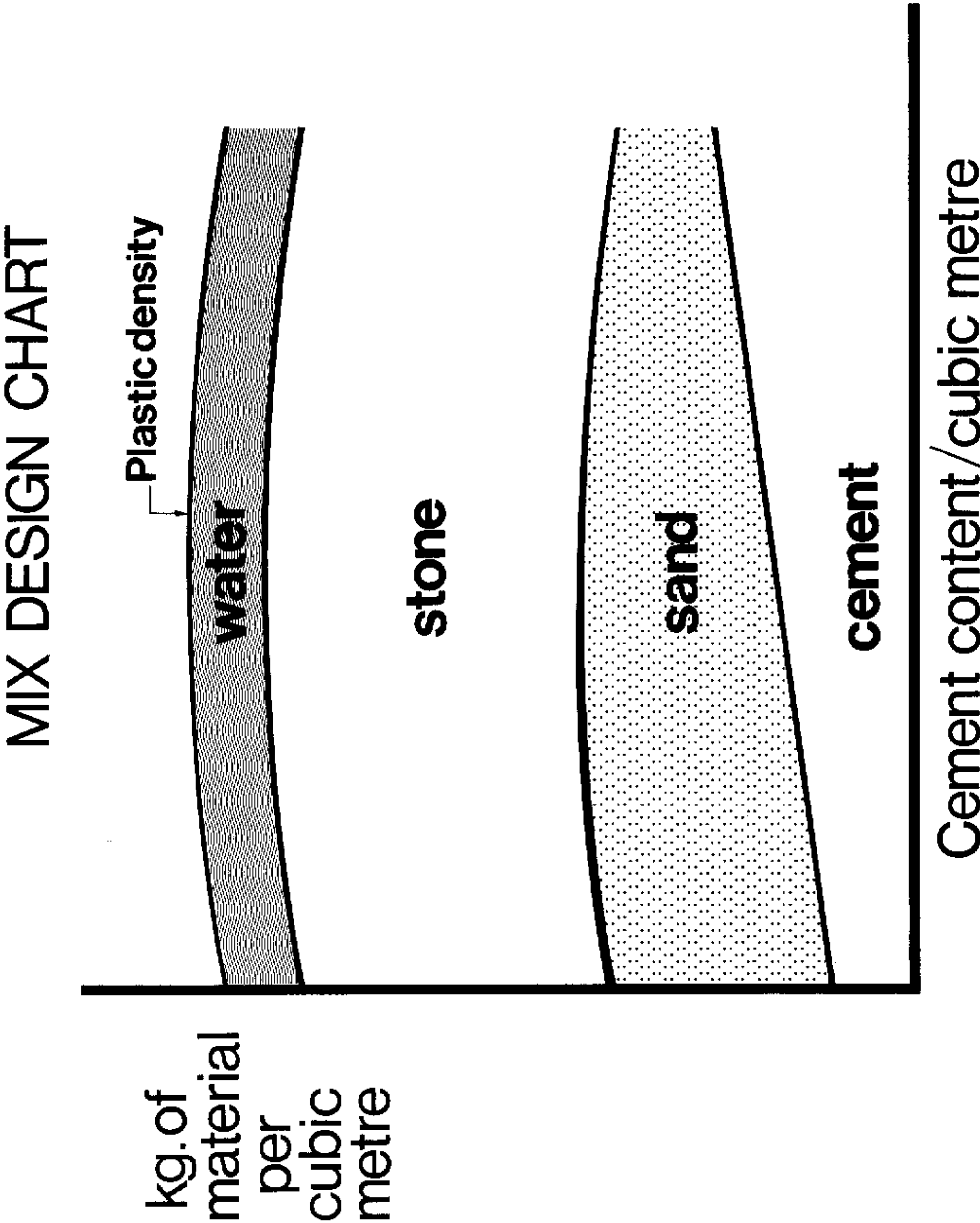
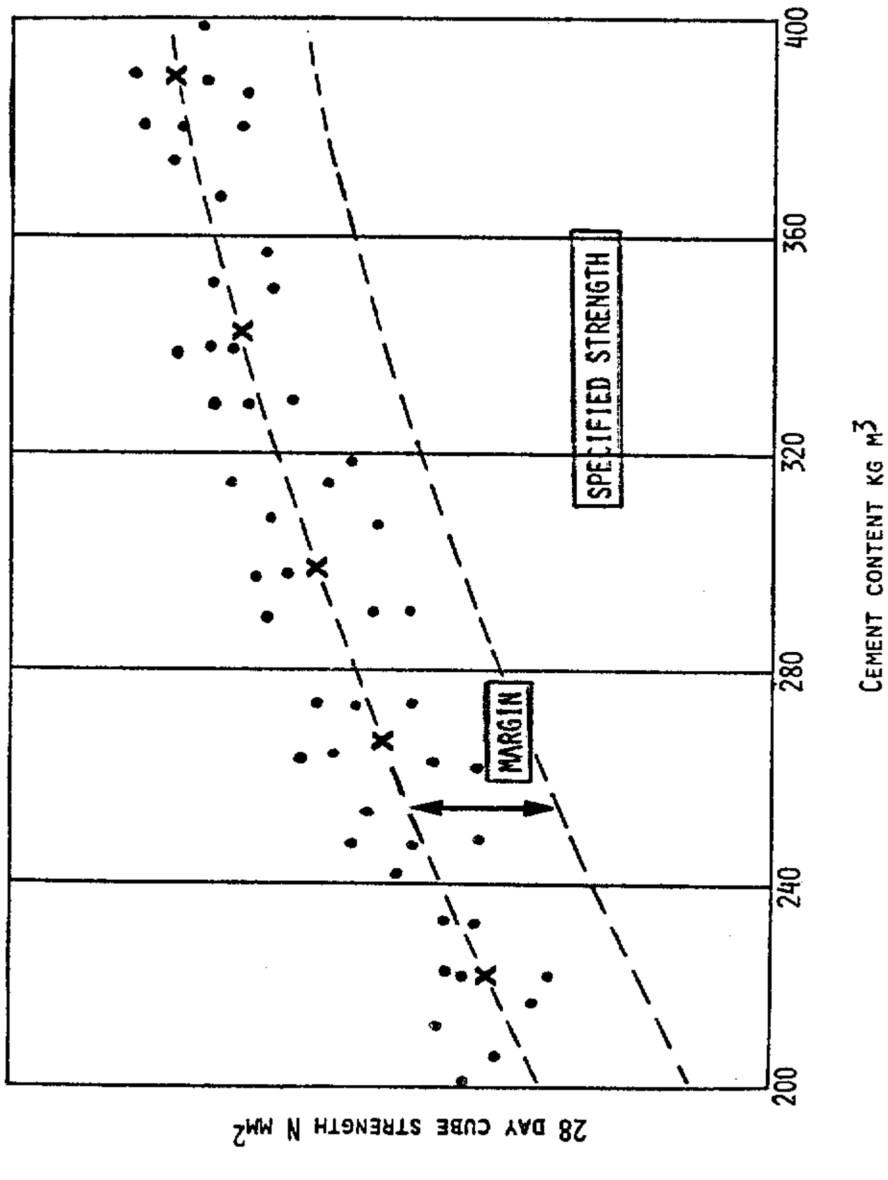

MIX DESIGN CHART
Plastic density
water
stone
sand
cement
Cement content/cubic metre
kg.of material per cubic metre

Figure 7.


SPECIFIED STRENGTH
MARGIN
200
240
280
320
360
400
CEMENT CONTENT KG M3
28 DAY CUBE STRENGTH N MM2

The plots of Cusum M (mean strength) and Cusum R (standard deviation) are examined continuously using specially constructed truncated V-shaped masks on transparent sheets. Each sheet contains a family of action (inclined) lines for each production standard deviation. The mask is laid on the Cusum chart with the lead point over the last entry and the centre line horizontal. A change from the target standard deviation and mean strength values is considered to have occurred when the relevant Cusum plot crosses the action line or its continuation on the mask.

The magnitude of the change in N/mm^2 for change in mean strength or standard deviation depends on the number of results between the lead point and the point where the action line first crosses the Cusum plot, and the current target standard deviation of the depot. From graphs relating change of mean strength, current target standard deviation and number of results, the magnitude of the change can be estimated.

When a significant change is detected, it is assumed that the situation can be restored by an increase or decrease, as required, in the cement content of the mix. The necessary amount can be obtained from the strength/cement content correlation charts. Where such data are not available, it can be assumed that changes of 1 N/mm^2 and 0.5 N/mm^2 in the mean and standard deviation respectively can be restored by changes in cement content of 6 kg/m^3. In practice, changes are normally restricted to increments of 5 kg/m^3.

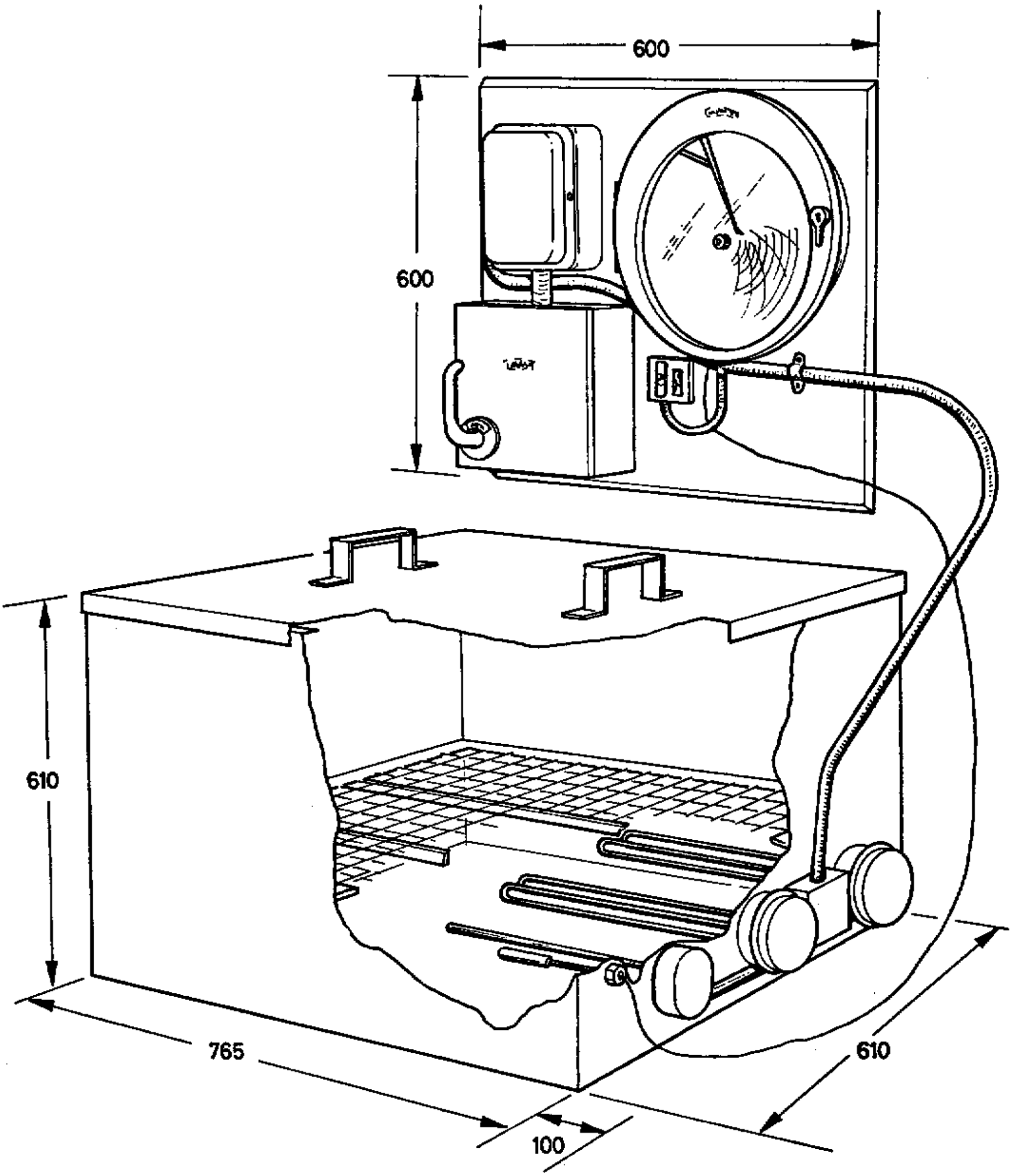
The Cusum method can, of course, be carried out on each particular mix supplied from the depot and on 28 day cube results. However, this approach involves much work in the making of tests and subsequent analysis, and detects changes only 1 month after they actually occurred. To overcome these faults RMC Ltd introduced two important developments, involving -

(i) the use of results of cubes subjected to a 1 day accelerated curing regime

(ii) the designation of one mix as a Reference Mix to which test results from other mixes can be correlated

Grant Accelerated Test Method Since 1960 the accelerated curing system developed by N.T. Grant[3] has been used by RMC Ltd in the testing of over 250,000 cubes and the control of 20 million m^3 of strength mixes. The system involves the casting of a pair of test specimens, one subjected to an accelerated curing regime and the other the normal 28 day curing. After a 2-hour pre-cure period the cubes are put into tanks of cold water, usually at the end of the day, which is then heated to 82° C in

Figure 8



about two hours (see Figure 8). After a further 14 hours heating, the curing regime ends (usually at about 09.00 hours the following morning) and the power is switched off. The cubes are removed from the mould and then tested immediately. 27 days later the second cube after normal curing is tested and the results can then be compared.

Over the years RMC Ltd have accumulated many thousands of test results, from which a forecasting system has been developed using Standard Correlation Tables and Curves (see Figure 9). Portland cements have different rates of hydration due to changes in cement chemistry and fineness and, therefore, result in different correlations between normally cured 3 or 7 day cubes or 1 day accelerated cubes and 28 day cubes. This is reflected in different correlation curves and the RMC method is aimed, firstly at identifying which particular correlation applies to the concrete supplied from any one production unit and then, secondly, at checking that the correlation curve or table being used still applies. The initial correlation is obtained from not less than ten separate samples from different batches. Once this has been established, subsequent accelerated and 28 day results are used to verify that the correct correlation table is being used. This is achieved by estimating the 28 day strength from each accelerated result, and then comparing this with the actual 26 day result. The correlation differences (actual 28 day result minus estimated 28 day result) are added cumulatively and the Cusum plots checked as before with appropriate V-masks. Once a significant change is detected, a new correlation table is selected to ensure a better prediction of 28 days results from accelerated values.

The use of this accelerated method to predict 28 day results provides a powerful "Forward Control" system, which enables mix proportions to be adjusted within one day to ensure that the concrete supplied is capable of complying with the specification requirements. RMC Ltd use the accelerated method on about half their plants and at the others they use forecasting from normally cured 7 day cubes.

Use of Reference Mixes The quality of concrete is affected primarily by the quality of cement used, whereas the variability is affected by variations in materials, batching, mixing and testing. Evidence indicates that for a given production unit, the standard deviation is independent of the concrete strength level above about 20 N/mm^2. Therefore, all mixes above this strength level produced by a depot will be subject

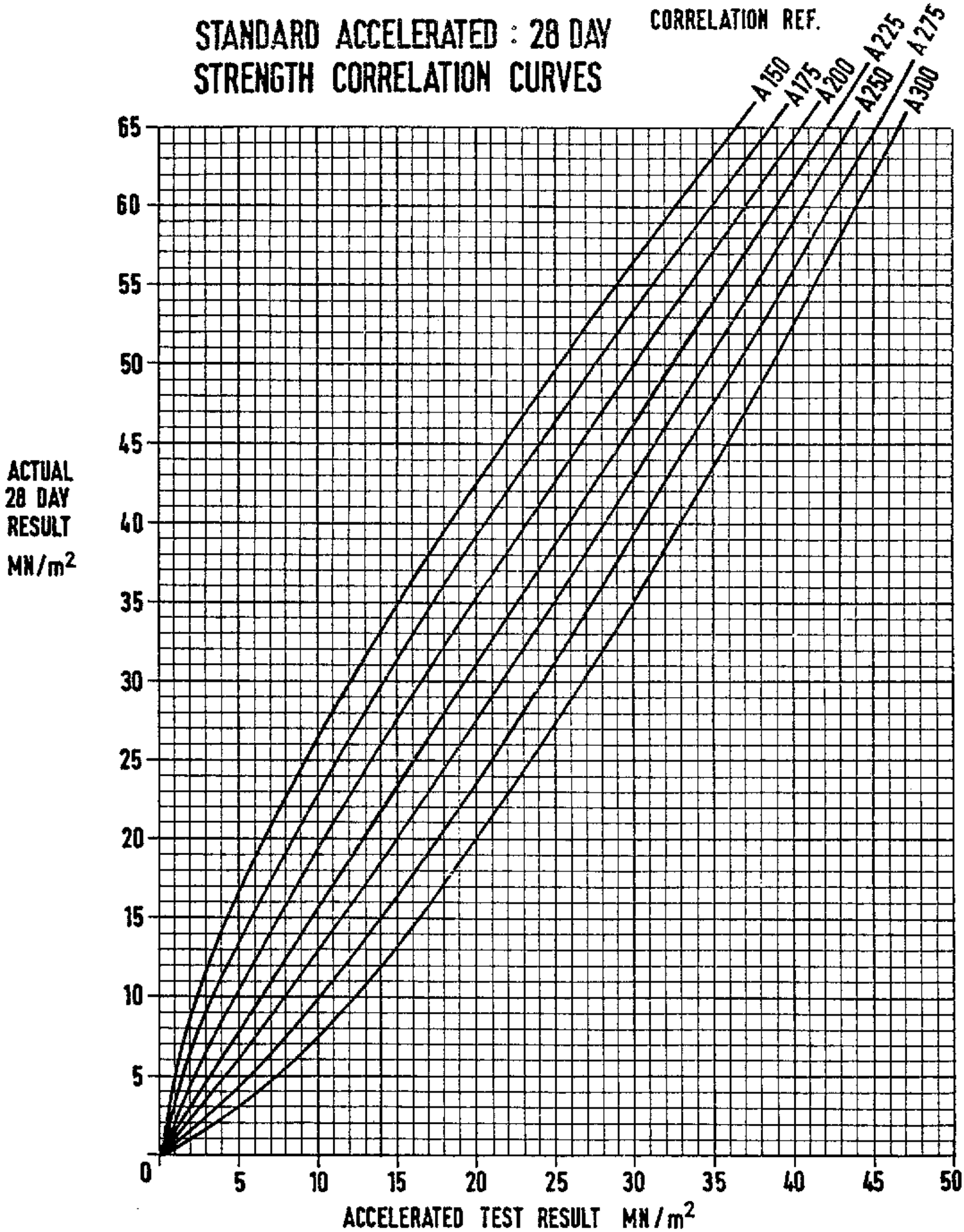

STANDARD ACCELERATED : 28 DAY STRENGTH CORRELATION CURVES
CORRELATION REF.
A150
A175
A200
A225
A250
A275
A300
ACTUAL 28 DAY RESULT MN/m2
0
5
10
15
20
25
30
35
40
45
50
55
60
65
ACCELERATED TEST RESULT MN/m2

Figure 9.

to similar degrees of variability. This permits the use of the Reference Mix approach in which one mix (normally the one produced in the highest quantities from the depot) is used as the basis for the analysis of test results. Test results from other mixes can be used in the Cusum analysis provided they can be correlated with the reference mix and their target mean strengths are not less than 27 N/mm^2 and preferably within 7.5 N/mm^2 of the target mean strength of the reference mix. Such mixes are termed "Approved Mixes". The 28 day cube strength/cement content correlation charts are established from the results of such mixes with 75 mm slumps and aggregates containing either 40 or 20 mm nominal maximum size. Concrete with different workabilities can be included by making adjustments to convert the cement contents to an equivalent mix of 75 mm workability, using an appropriate conversion chart. Mixes of slumps in excess of 150 mm are not included and separate correlation charts have to be established for mixes containing admixtures and cements other than ordinary or sulphate resistant Portland cement.

The use of reference mixes allows the building up of information more rapidly and when the target mean or target standard deviation Cusum plots indicate a change in the reference mix, the same contents of other mixes are adjusted accordingly, using the strength/cement content correlation chart.

<u>Other Uses of Cusum Analysis</u> The Cusum approach which allows rapid assessments of variations from the target mean value can be used for other properties of concrete, including -

Workability in terms of slump in mm
Water added at the mixer in litres/m^3
Moisture content of sand and coarse aggregate %
Sand grading % passing of particular sieve size
Material stocks

<u>Visual Inspection and Control Schedules</u> A complete internal control system for ready mixed concrete involves a combination of both visual inspections and tests. The principles of internal production control and the methods of applying the results of inspections and tests are defined in full in the ERMCO Code of Good Practice. The various

inspections and tests which should be made, their purpose and frequency are listed in the following Schedules -

1 Materials control
2 Plant and Equipment control
3 Concrete control

READY MIXED CONCRETE AS A SERVICE

If the contractor is to have confidence in ready mixed concrete, he requires assurance that the supplier can meet all his delivery requirements, has sufficient capacity of production, material supplies and vehicles, and will provide the correct quantities.

Production capacity depends upon the size of the plant, its speed of operation, and continuity of supplies. There is a difference between the manufacturer's rated capacity for a plant and the actual output which can be achieved, which depends upon the time required to complete one batching cycle. For example, a 5 m^3 plant with a batching cycle of 2 minutes will have a production capacity of 150 metres an hour, whereas if its batching cycle is 6 minutes, its capacity is only 50 metres an hour. Allowing for breakdowns and other delays, the actual production capacity will only be two-thirds of these figures. The production capacity is dependent, too, on a reliable and continuous supply of cement and aggregate materials.

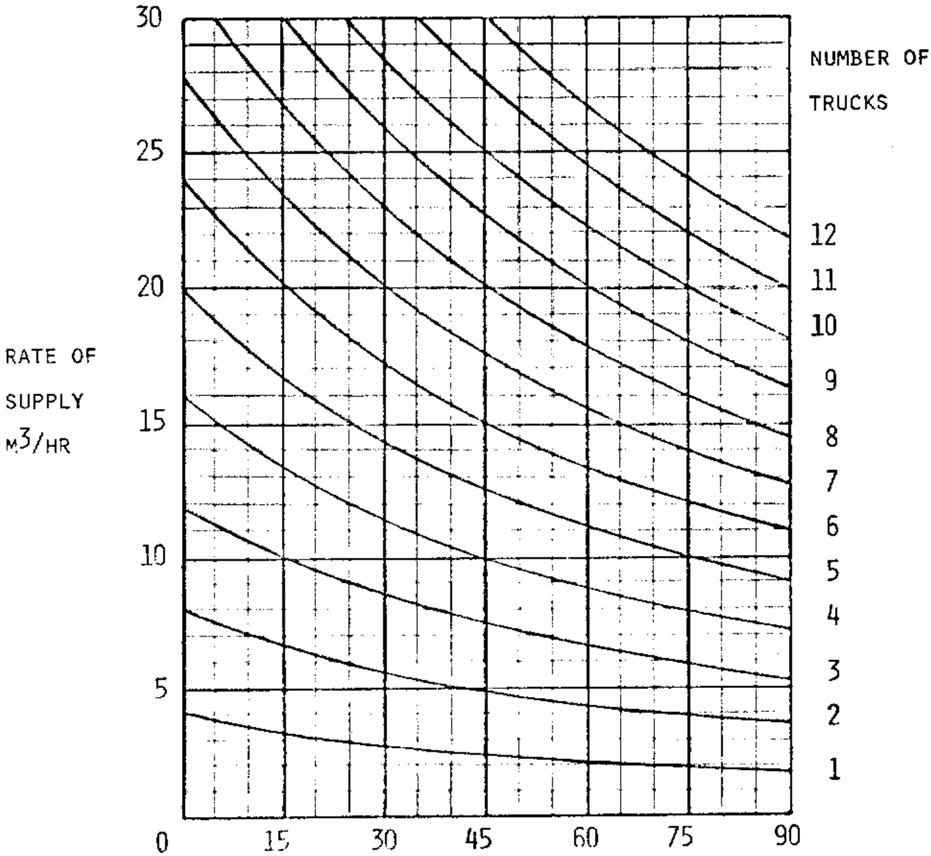
The rate of supply of concrete to a site is, for a given number of vehicles, entirely dependent on the time the truck is kept on site. For the example given in Figure 10, if a contractor asks for a supply of 20 m^3 per hour and gives assurance that the waiting time on site will be only 15 minutes, then the supplier will allocate a total of six 5 m^3 vehicles to achieve this rate. However, if there are delays on site, and the contractor increases the truck waiting time to 45 minutes, then six vehicles will only be able to maintain a rate of 15 m^3 per hour. If the contractor insists on a rate of supply of 20 m^3 per hour, then another two trucks will be required. But where are the two trucks to come from, and who will pay for them ? Contractors still do not appreciate that by keeping trucks on site they are slowing down their own rate of supply.

In the early days of ready mixed concrete, there were complaints of short measure but now the reputable supplier can ill-afford to be suspected of delivering short quantities. In the BRMCA Authorization Scheme, one of the first checks made by Engineers is that the batch weights are capable of producing 1 cubic metre.

Figure 10

RELATION BETWEEN RATE OF SUPPLY AND

TIME TRUCK IS KEPT ON SITE



TIME TRUCK KEPT ON SITE - MIN

TRUCK CAPACITY $5M^3$

TOTAL JOURNEY TIME 60 MIN

LOAD/WASH OUT TIME 15 MIN

READY MIXED CONCRETE AS VALUE FOR MONEY

Any satisfactory end product depends upon the correct and economic solution to the equation -

End Product = Design + Material Quality + Workmanship

Throughout Europe there is a growing demand by purchasers for the assurance that any product or service is suitable for the purpose and of uniform quality.

Assurance of Quality

Full quality assurance and the supply of satisfactory products depends upon proper communication and cooperation between the purchaser and the supplier who, between them, should cover the following four points -

1 Purpose A manufacturer can only supply a satisfactory product if the purchaser clearly states his requirements. The purchaser requires his product to be suitable for the intended purpose and to continue to perform as required for an appropriate period. This can be most readily achieved by the manufacturer if the requirements are specified in "performance" terms ideally, or, if not, in detailed "method" terms. Details should be given of the tests used to confirm compliance with the specification, different tests being used for the performance and method approaches, and also of the method of assessing the results. Ideally the specification should state the fitness for purpose of the product if properly used. With ready mixed concrete the problem is that suppliers sell concrete as a semi-finished product whose performance in the finished structure will depend much upon the contractor's workmanship. This illustrates the difficulty of drafting a full end-product specification in performance terms.

2 Production Capability The purchaser requires confirmation that the product has been produced under conditions of quality control to an agreed level. This can be done in two ways, firstly by accepting the internal production control (self-control) system operated by the manufacturer or, secondly, by seeking confirmation from independent control organisations that a system of self-control is being operated by the manufacturer. In practice the second alternative can be achieved by each sector of industry drafting its own detailed standards for production and control, on which each individual

company could then base its own working instructions. The independent inspection organisation would then assess each manufacturing unit to confirm that the required standards were being followed.

3 Acceptability The purchaser requires confirmation that the particular product he is buying does comply with his specified requirements. This can be achieved in one of four ways -

(i) the purchaser carrying out tests and assessing the results in accordance with appropriate compliance criteria

(ii) tests for the purchaser being carried out by an independent testing organisation, assessment of the results again being made in accordance with appropriate compliance criteria

(iii) acceptance by the purchaser of the producer's internal control as confirming compliance with specified requirements, i.e. self-control

(iv) confirmation by an impartial third party, acceptable to the purchaser, that the producer's internal control provides adequate proof of compliance with the specified requirements ,i.e. auto control.

In each case, the responsibility of the independent control organisation, the manufacturer and the purchaser and their respective liability for a defective product, must be clearly spelt out in contracts between the various parties.

4 Liability The purchaser requires the manufacturer to accept liability if a product proves to be defective or not suitable for the purpose. Under Common Law, which is being expressed in new European laws, the manufacturer is liable for claims from a purchaser if a product proves to be defective or not suitable for the intended purpose. An important trend for the future will be the clear definition of responsibility and apportionment of blame for defective materials and products.

The peculiar nature of ready mixed concrete and the many inconsistencies in specification and ordering procedures which still occur, mean that suppliers are not yet prepared to give unlimited liability. On those occasions when things do go wrong, the purchaser can be assured that reputable suppliers will discuss any reasonable claims in order that a fair and realistic solution can be reached wherever possible.

Economics

The other way in which the purchaser can ensure that he receives value for money is by checking that the total cost of his construction is economic. Often the quoted prices for ready mixed concrete appear to be much higher to the purchaser than site-mixing. However, if he makes a full cost comparison he will see that ready mixed concrete will often provide a more economic and efficient job.

The subject of comprehensive cost comparison has been examined by Illingworth[4], who shows that a truly valid cost comparison involves a three-stage analysis comprising -

(i) a direct comparison of alternatives in which the total concrete process, i.e. mix, haul and place, are considered

(ii) assessment of intangible factors, including situations which may or may not occur or items to which money cannot readily be allocated

(iii) consideration of the influence of alternative methods on related items and the contract as a whole

Satisfaction in Practice

In practice the engineer will be satisfied if ready mixed concrete complies with the specification. Tests carried out at the Testing Station of the Greater London Council (the authority responsible for the quality of building construction in London) confirm that BRMCA Members in London are some of the few suppliers who provide construction materials in compliance with the specified properties. Table 4 shows that, whereas the failure rate for ready mixed concrete is only 1% or 2%, that for other materials, including concrete products, aggregates and steel can be as high as 12% to 60%.

The considerable growth in ready mixed concrete in the past 15 years suggests that the contractor gets the Service he requires and considers ready mixed is Value for Money.

CONCRETE MIX DESCRIPTION AND COMPLIANCE

Concrete Mix Description and Orders

Most European specifications now distinguish between two types of concrete mix -

Prescribed Mix which is a mix where the purchaser defines a cement content per cubic metre and other essential items to produce the concrete he requires; and the supplier provides a properly mixed

Table 4

GREATER LONDON COUNCIL TESTING STATION

FAILURE OF CONSTRUCTION MATERIALS TO COMPLY WITH SPECIFIED PROPERTIES

Material	1968 No. of Tests	1968 % Defectives	1972 No. of Tests	1972 % Defectives	1975 % Defectives
Aggregates	582	20	204	37	20
Bituminous Paving			74	60	60
Building Sand					40
Concrete Blocks			32	15	12
Clay Bricks			182	20	12
Paving Flags and Kerbs	70	19	66	60	60
Reinforcing Bars					
Cold Worked	) 74	17			) 5
Hot Worked	)	5			)
Concrete - Site Mixed	3139	2	830	1.5	
Concrete - Ready Mixed	4334	2	3400	1.2	1.4

concrete in compliance with these requirements. The minimum information to be provided by the purchaser for a prescribed mix is as follows -

(a) cement content per cubic metre
(b) workability or class of consistence
(c) type of cement
(d) nominal maximum size of aggregate
(e) type of aggregate (where necessary)
(f) procedures for judging compliance with the cement content

Designed Mix which is a mix where the purchaser defines the essential requirements to provide the properties he requires; and the supplier selects the mix proportions and produces a properly mixed concrete in accordance with these requirements. The minimum information to be provided by the purchaser for a designed mix is as follows -

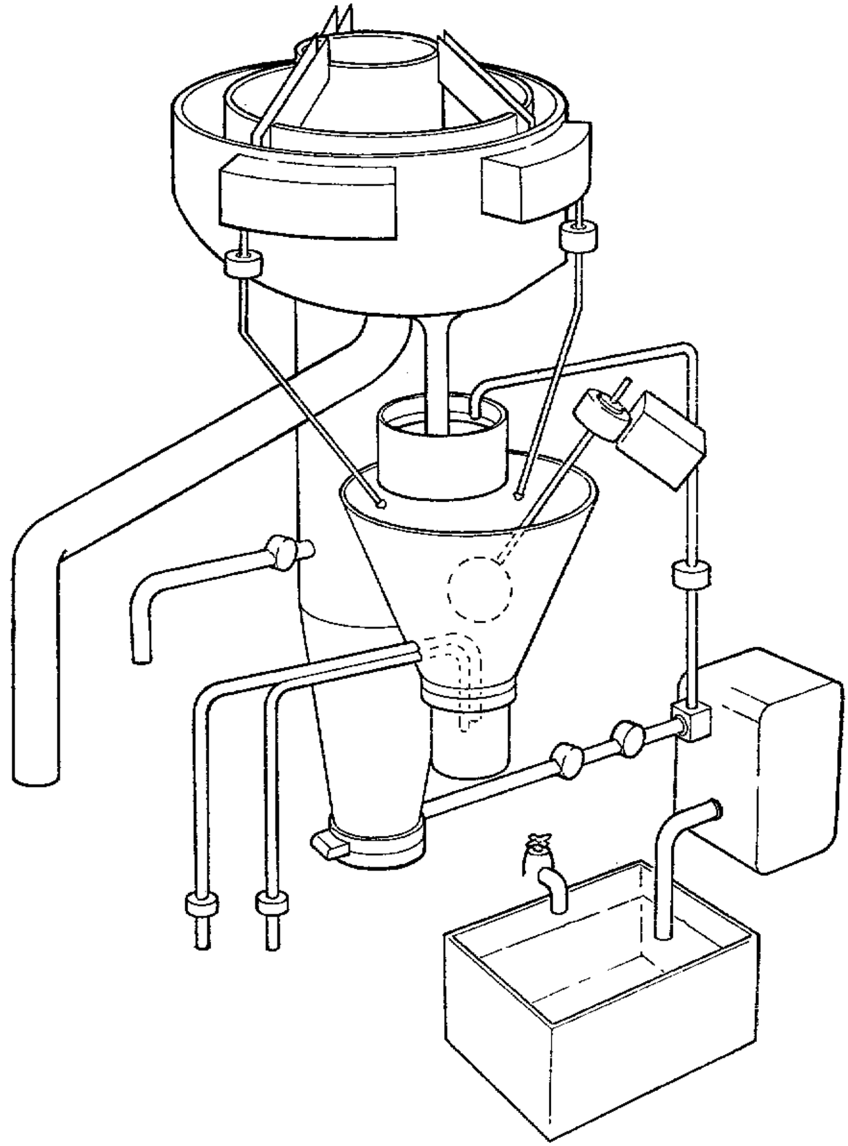
(a) strength grade
(b) workability or class of consistence
(c) type of cement
(d) nominal maximum size of aggregate
(e) procedures for judging compliance with the specified strength grade

Judgement of Compliance for Prescribed Mixes

Prescribed mixes should be judged solely on the basis that the cement content is in accordance with the required value subject to tolerances related to errors in batching, sampling and testing. Although of importance to the engineer, strength tests have no role to play in the judgement of compliance for prescribed mixes.

Recently in Great Britain several test methods have been developed for measuring rapidly the cement content of fresh concrete. In particular the Rapid Analysis Machine (RAM) developed by C&CA provides a method of measuring cement content within ten to twenty minutes (see Figure 11). However, a recent field investigation of the RAM[5] showed that problems in calibration and measurement of silt content mean that cement content cannot be measured to an accuracy of better than $\pm$ 20%. For this reason, BRMCA consider that, as yet, such methods cannot be accepted as a standard test for compliance with prescribed mixes. Until this stage is reached, compliance with specified requirements may be -

Figure 11



(i) assumed to have been achieved provided that the specified cement content is stated on the delivery ticket, or

(ii) assessed by observation of batching in relation to the required batch weight

Judgement of Compliance for Designed Mixes

Designed mixes should be judged solely on the basis that cube strengths meet specific compliance rules. The procedure for judging compliance should include the following items -

(i) methods of sampling and testing (in accordance with National Standards)

(ii) number of test specimens to be made from each sample representative of a batch (not less than two specimens per sample)

(iii) age of concrete at the time of test

(iv) rate of sampling and quantity of concrete represented by each sample

(v) compliance rules for assessing the results of tests

(vi) action in the event of non-compliance with the compliance rules

Growth in the use of ready mixed concrete has led to a more detailed assessment of the statistical implications of the different compliance rules which have been established. As mentioned previously, the strength of concrete is now considered to be randomly variable, with results falling within the Normal (Gaussian) distribution. The engineer takes account of this distribution in his design by defining the characteristic strength, which is usually the strength below which not more than 5% of the results may be expected to fall.

When the characteristic strength is based on 5% defectives, for a Normal distribution with population standard deviation σ, the margin between the characteristic strength and the true mean μ of the required distribution will be 1.64σ. This relationship is relevant only to the true mean and standard deviation of the complete population of results. In practice only estimates of these two values can be derived from a finite sample of n results, and the error of estimate of the true value increases considerably as the sample number n decreases. The accuracy of the estimate can be expressed in terms of 95% confidence limits, i.e. there is a 95% certainty that the true value varies from the estimated value by a plus or minus amount which depends upon the true standard deviation and the number of results considered.

The probable error in mean value can be expressed as -

$$\frac{\pm k\sigma}{\sqrt{n}}$$

where   is the standard deviation of the infinite population,

n is the number of results

and   k = 2 for 95% confidence

The accuracy of standard deviation can be determined from the ratio -

$$\frac{\text{Estimated standard deviation (S)}}{\text{Population standard deviation } (\sigma)} = \frac{\chi^2}{n-1}$$

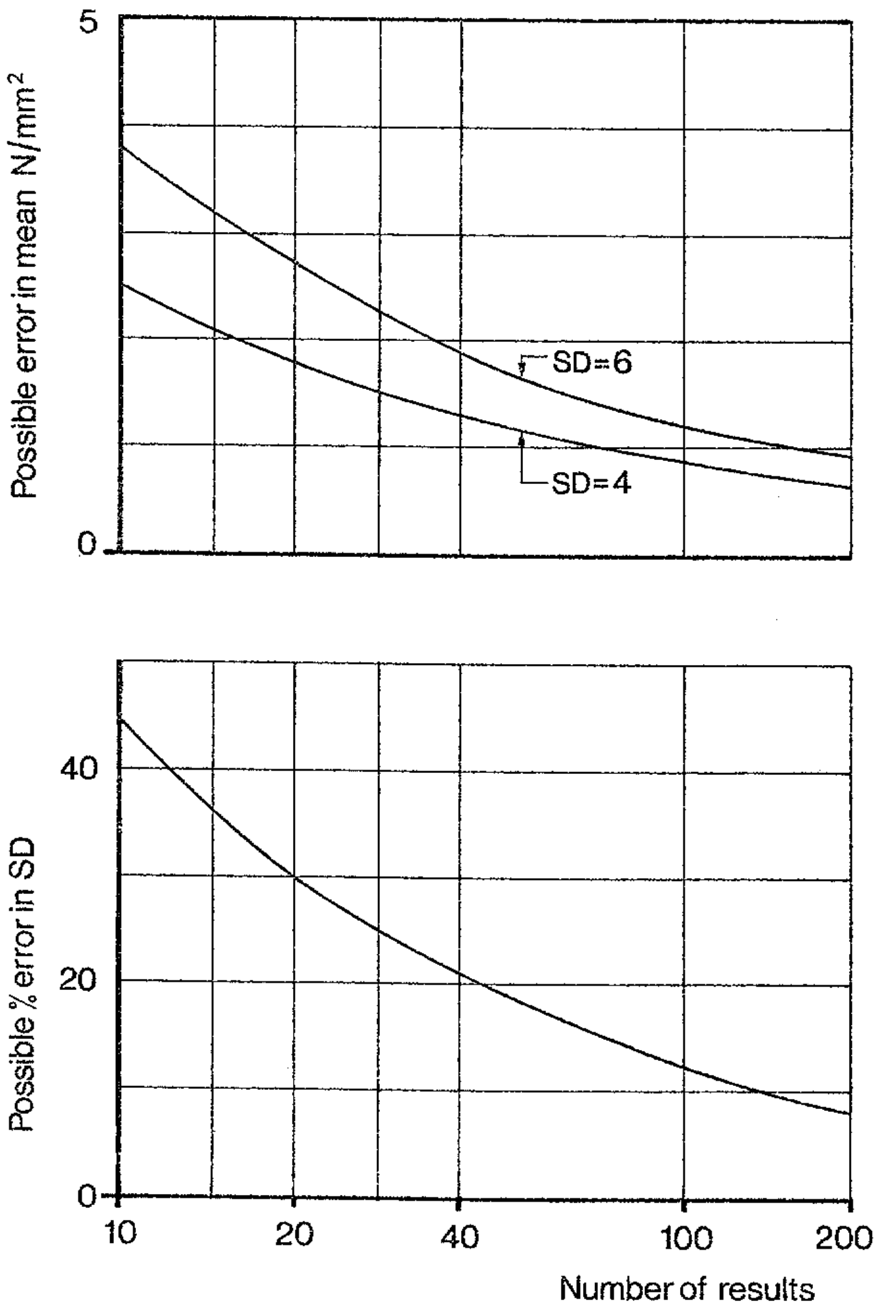
where χ^2 is the "Chi-squared" distribution. The variation in possible error in mean and standard deviation with number of results is shown in Figure 12. For a situation where the true standard deviation is 5 N/mm^2 and actual mean of 30 N/mm^2, the 95% confidence limits of estimate of the true values are as follows -

No. of Results n	95% Confidence Value lies between	
	Standard Deviation	Mean
100	4.3 - 5.7	29.0 - 31.0
40	3.9 - 6.1	28.4 - 31.6
25	3.6 - 6.4	28.0 - 32.0
10	2.8 - 7.2	26.8 - 33.2

This shows the extreme difficulty in trying to judge whether the few test results available do fall within the required, acceptable distribution.

Operating Characteristic Curves   The ideal compliance plan is the one which will reject all concrete from distributions with a failure rate greater than 5% and accept all concrete with distributions equal or lower than a 5% failure rate. This ideal can only be obtained in theory if an infinite number of results were analysed. In practice, only a few results are available and, therefore, there is always a risk to the purchaser that he will accept concrete which is non-complying and, on the other hand, a risk to the supplier that he will have concrete rejected which does in fact comply. These risks can be demonstrated by the OC (Operating Characteristic) curve in which the percentage defectives (failure rate)

Figure 12.


5
0
Possible error in mean N/mm²
SD=6
SD=4
40
20
0
Possible % error in SD
10
20
40
100
200
Number of results

is plotted against the number of batches (expressed as a percentage of all batches tested) which will be accepted if the concrete is produced and inspected at that failure rate (see Figure 13).

The ideal testing plan is represented by a rectangular OC curve with 100% acceptance below 5% defectives,100% rejection above 5% defectives,connected by the 0-100 vertical line at the 5% defectives level. Each testing plan has its own OC curve with concrete being rejected when the assessment of results falls above and to the right of the curve and concrete being accepted when the assessment of results falls below and to the left of the curve.

The Operating Characteristic curve shows clearly the limitations of a compliance plan which is based on an absolute minimum value. When such a plan is applied to successive results, in each case there is a 50% chance that the results will be accepted or rejected and, in turn, a 50% chance that the result does not fall within the required distribution. This is shown as an Operating Characteristic curve going through the 100% acceptance and 0% defectives point and the 50% acceptance and 50% defectives points.

However, the purchasers' and suppliers' risks depend also on the way the testing plan is applied. For example, the two sets of compliance requirements used in Great Britain are that compliance with the specified characteristic strength may be assumed if -

(i) the average strength from any overlapping group of four consecutive test results exceeds the specified characteristic strength by not less than 0.82 x the current standard deviation (CP 110)[6], or by 3 N/mm^2, (BS 5328)[7]

and

(ii) each individual test result is greater than 85% of the specified characteristic strength (CP 110) or not more than 3 N/mm^2 below the specified characteristic strength (BS 5328)

The CP 110 plan produces the operating characteristic curve shown in Figure 14. This shows that for one application of the plan, the supplier has a 5% risk that acceptable concrete will be rejected. On the other hand, the purchaser has an even (50%) chance that concrete will be accepted at the 20% defectives level. However, continued application of the compliance plan reduces the probability of acceptance by the factor $P(a)^n$ where n is the number of applications and P(a) is the average probability of acceptance per single application. The effect of repeated applications is that after five

Figure 13

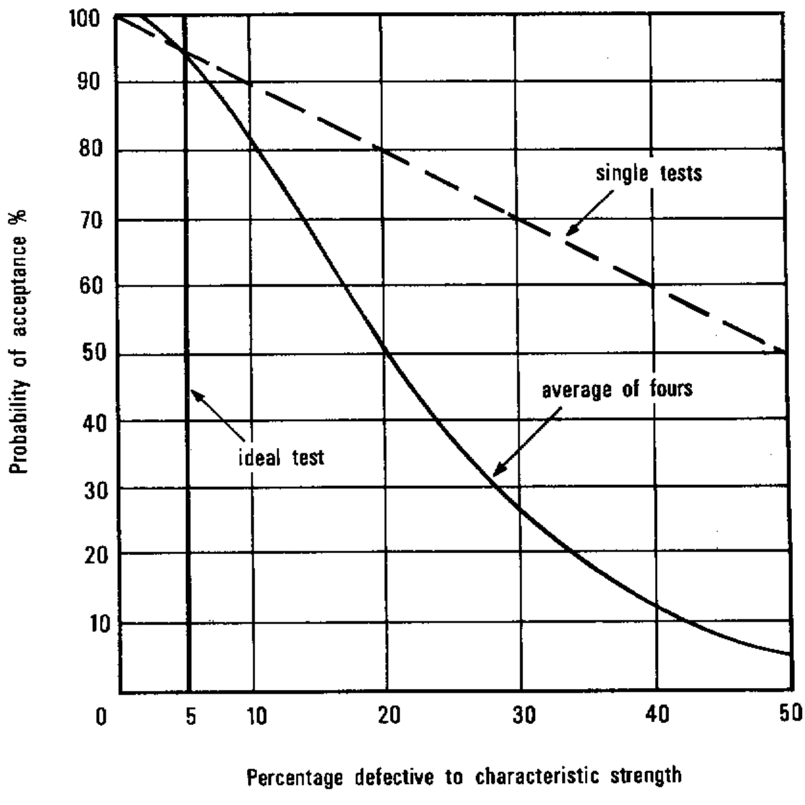
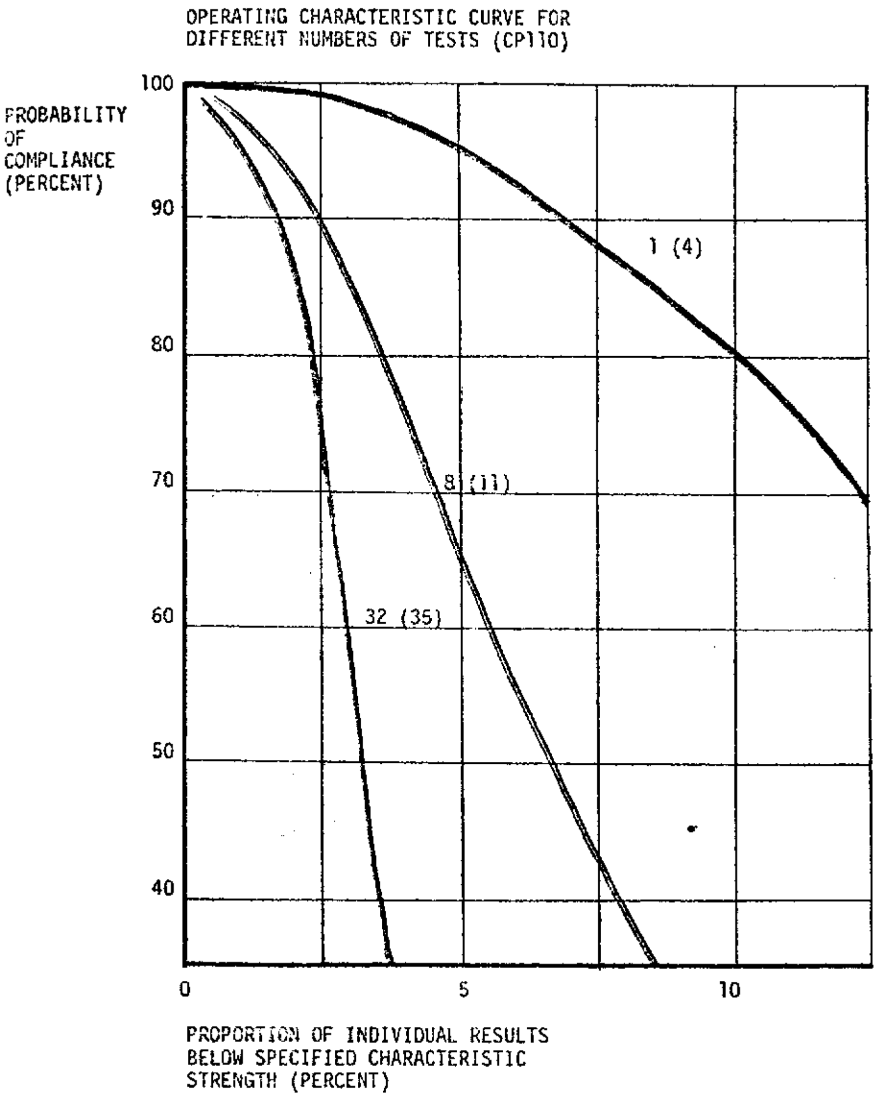

Probability of acceptance %
100
90
80
70
60
50
40
30
20
10
0
5
10
20
30
40
50
single tests
average of fours
ideal test
Percentage defective to characteristic strength

Figure 14.


OPERATING CHARACTERISTIC CURVE FOR
DIFFERENT NUMBERS OF TESTS (CP110)
PROBABILITY
OF
COMPLIANCE
(PERCENT)
100
90
80
70
60
50
40
1 (4)
8 (11)
32 (35)
0
5
10
PROPORTION OF INDIVIDUAL RESULTS
BELOW SPECIFIED CHARACTERISTIC
STRENGTH (PERCENT)

applications the producer's risk of having complying concrete rejected is increased to 23% and after ten applications to 40%. It is for this reason that BRMCA have recommended Members that they should design their mixes on a 1% defectives level, in order that there is a reasonable risk of complying with the defectives required by the purchaser.

Another important influence on any compliance plan is whether this is based on a knowledge or estimate of the supplier's standard deviation in the operation of the plan itself. Changes in standard deviation are very difficult to detect with any degree of significance because of the high standard errors associated with the standard deviation calculation. The CP 110 compliance plan, as does many other European plans, employs an estimate of the standard deviation based on previous tests. An alternative approach used in BS 5328 is to assume a value of standard deviation by requiring means of 4 to exceed the characteristic strength by a fixed margin. Figure 15 shows that for one application of the criterion,paradoxically the supplier, with a low standard deviation, runs a greater risk of rejection of complying concrete than the supplier with a high standard deviation.

This brief examination of compliance plans confirms that the establishment and operation of any compliance criterion is extremely complicated. In practice the so-called purchaser's and supplier's risks will depend, not only on the operating characteristic curve for the compliance plan, but also upon the nature and severity of any sanctions involved in the event on non-compliance, the structural importance of the concrete being tested, the legal implications of non-compliance and the commercial environment in which the contract is being operated. It is imperative that any testing plan should be clearly stated and should be operated strictly in relation to the frequency of sampling, the accuracy of performing the tests and the detailed procedures to be carried out in the event of non-compliance.

<u>Action in the Event of Non-Compliance</u>

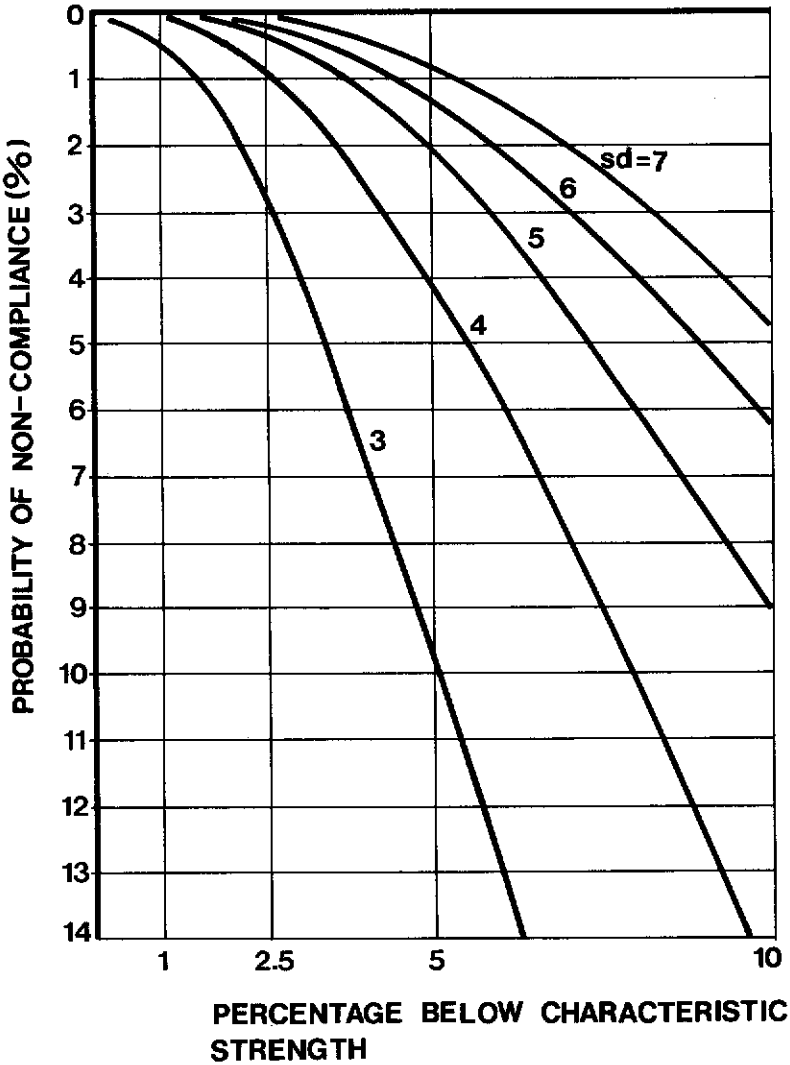
This is an area which requires more detailed definition in the future. A specification should detail the procedure to be followed when cube results do not comply with the specification, and take account of -

(i) identification of the suspect concrete
(ii) assessment of the validity of test results
(iii) assessment of the quality in-situ by further destructive or non-destructive tests
(iv) decisions concerning the acceptance or rejection of concrete in-situ

Figure 15.

Implications of the forthcomming British Standard for Concrete

1 Probability of non-compliance with the `means-of-four´ criterion



The British Standard Committee responsible for the CP 110 Code of Practice is currently preparing detailed recommendations concerning the assessment of the strength of concrete in a structure. The work of N.Petersons[8] in this field is of considerable importance.

FUTURE TRENDS

This paper has outlined some of the developments in the field of ready mixed concrete and the considerable expertise that now exists in the standards of production and the use of local materials, often of variable quality, to produce concrete of uniform and consistent quality in compliance with national and international Standards. However, the industry's role is to supply concrete to the place of deposit from a truck mixer. It cannot expect to provide expertise in construction techniques and workmanship. If concrete is to be a reliable end product, suitable for the purpose intended, all those involved in design, supply of materials and workmanship must satisfy the previously mentioned requirements for quality assurance. The four points of quality assurance, i.e. Purpose, Capability, Acceptability, Liability, might be covered for the categories of personnel, materials and product quality and workmanship in the manner shown in Table 5.

Other important trends in the future include -

(i) A greater awareness by the purchaser of the inherent variability of concrete, the implications of compliance plans and the inevitable risks to the purchaser and the supplier

(ii) The abandonment of the engineer's requirement for trial mixes to substantiate the supplier's mix proportions. Even if a trial mix is demanded and approved, the test results will apply only to the particular quality of materials used at the time. The supplier still has to carry out his self-control to maintain the quality in accordance with the specification

(iii) The use of results from accelerated curing regimes to judge compliance with the specification. This method, which is gradually being introduced in the UK reduces the delay in decision-making from 28 to 1 day.

Table 5.

ACHIEVING QUALITY ASSURANCE IN PRACTICE

	PERSONNEL	MATERIAL QUALITY (INCL. TESTING)	WORKMANSHIP
1 PURPOSE	DEFINITION OF JOB ACTIVITIES AND TRAINING OBJECTIVES	DEFINITION OF REQUIREMENT IN PERFORMANCE TERMS	DEFINITION OF METHODS WITH PERFORMANCE ASSESSMENT
2 CAPABILITY	CERTIFICATION FOLLOWING WRITTEN AND PRACTICAL TESTS	INTERNAL PRODUCTION CONTROL SYSTEM (SELF CONTROL) OR WITH INDEPENDENT PARTY (AUTO CONTROL)	INDEPENDENT ASSESSMENT OF PERSONNEL AND METHODS, OR EVIDENCE OF PREVIOUS WORK
3 ACCEPTABILITY	RECOGNITION OF SKILL AND EXPERIENCE BY PROFESSIONAL BODIES	COMPLIANCE TESTS BY USER OR INDEPENDENT PARTY (ACCEPTANCE CONTROL)	COMPLIANCE BASED ON PERFORMANCE TESTS BY USER OR INDEPENDENT PARTY
4 LIABILITY	TEN YEARS' RESPONSIBILITY FOR MAJOR DEFECTS		

(iv) Improvements in the standards of sampling, making, curing and testing cubes, including Certification of approved laboratories, which is essential to the proper judgement of compliance

(v) There is still a great gap between the two different approaches to the quality control of concrete, as shown, on the one hand, by compliance or acceptance control by the purchaser and, on the other hand, by internal production control (self-control) methods operated by the supplier. As has been suggested by N. Shipley, the most important future development could be the harmonisation of compliance testing and control procedures into one operation. Such an approach could be achieved by the internal production control systems (self-control) being assessed by independent third parties, who would issue appropriate certificates to purchasers.

(vi) Other recent developments in ready mixed have been recorded in the papers presented at the Conference held last October at Dundee University[10]

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APPENDIX

Referat af mødet i Dansk Betonforening den 2. marts 1977:

I England er variationerne i cementkvaliteten den vigtigste faktor ved styring af produktionen af fabriksbeton. Styrken, bestemt efter den standardiserede prøvningsmetode, svingede inden for perioden oktober 75 - oktober 76 mellem 40MN/m^2 og 50 MN/m^2. Fra en enkelt producent målte man endda dette udsving inden for 3 uger. Problemerne forværres desuden i England af, at brugeren i mange tilfælde ikke ved, hvilken cementfabrik der leverer den benyttede cement. Man har nemlig centrallagre, hvortil flere fabrikker leverer, og hvor deres cementer blandes tilfældigt i siloerne. Ken Newmann, Director-General, British Ready Mixed Concrete Association (BRMCA) nævnte dette i sit foredrag "The Role and Ready Mixed Concrete in The Construction Industry", som blev holdt den 2. marts i Dansk Betonforening.

I England bruges godt 40% af den samlede cementproduktion til fabriksbeton. I Danmark er tallet kun ca 30%, til gengæld bruges her en større procentdel i betonelementindustrien.

Ca 1100 fabriksbetonproducenter er medlem af BRMCA. Denne sammenslutning har opstillet en såkaldt autorisationsplan, der definerer standards for:

1. Personalet. Der kræves, at alle, som er beskæftiget med produktion, levering og kontrol af fabriksbeton, har modtaget uddannelse indenfor de felter, de beskæftiger

sig med.

2. Materialerne.

3. Fabriksanlæg og udstyr.

4. Betjening af udstyret.

5. Kvalitetskontrol og styring af betonrecepter.

Kvalitetskontrollen omfatter 3 afdelinger.

A. Kontrol af materialerne (modtagekontrol).

B. Proceskontrol.

C. Produktkontrol.

Produktkontrollen finder sted hos aftagerne af fabriksbetonen. De bestiller en beton med en bestemt karakteristisk trykstyrke σ'_{bk}.

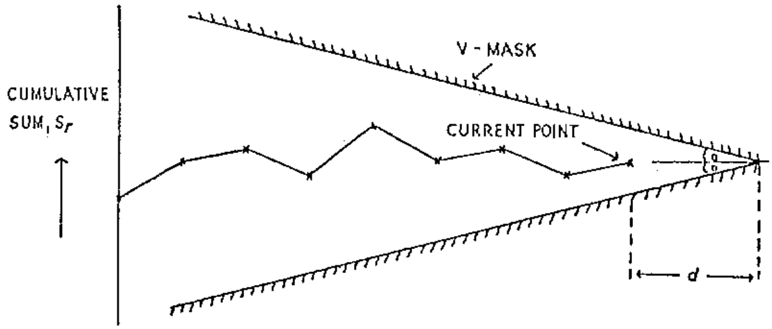
De udtager ved modtagelsen én eller flere stikprøver på hver 4 terninger. For hver stikprøve på 4 udregnes styrkegennemsnittet. Betonen godkendes, hvis det for alle stikprøverne gælder, at

$$\bar{x} - 0{,}82 \cdot Z \geq \sigma'_{bk}$$

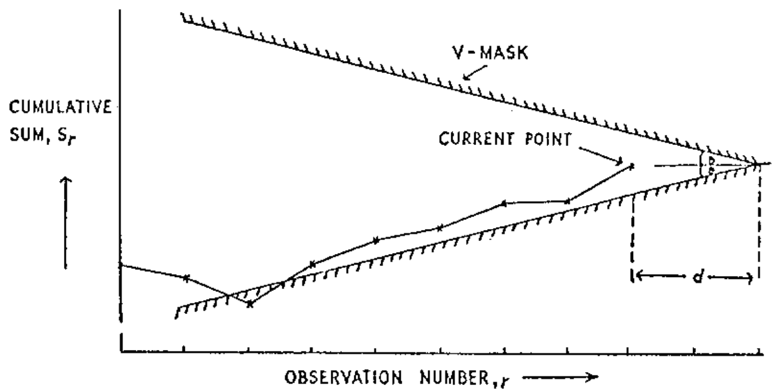
hvor $\bar{x}$ er gennemsnittet af 4, og Z er spredningen på produktionen. Z opgives i dokumenteret form af fabrikken. Kan fabrikken ikke klare denne dokumentation (fordi produktionen har løbet for kort tid), benyttes $Z = 6\ MN/m^2$.

Proceskontrollen køres ved kontrolkort. Man styrer processen ved at ændre cementmængden. Der kan i den forbindelse nævnes 2 punkter, hvor man benytter sig af en avanceret

Process Mean Close to Reference Value



Process Mean Higher than Reference Value



teknik:

I stedet for sædvanlige $\bar{X}$-R-kort benyttes ca 400 af de 1100 tilsluttede fabrikker den såkaldte CUSUM-teknik. Den er udviklet af det engelske firma RMC. Den er baseret på, at man adderer de enkelte prøveresultaters differens med den middelværdi, man styrer efter. På figuren ses 2 eksempler. Hvis den fremkomne kurve gennem en for lang periode har for stor hældning, betyder det, at processen er ude af kontrol. Ved indlæggelse af en såkaldt "V-mask" ("skygget" på figuren) kan man afgøre, hvornår processen er gået ud af kontrol. Ved et andet diagram kan man derefter bestemme, hvor meget cementmængden skal ændres.

Det store problem ved styringen af processen er, at man normalt først har styrkeresultaterne 28 dage efter, at betonen er udstøbt. For at imødegå dette, har man udviklet et apparat til accelereret prøvning. Man bestemmer terningstyrken efter 18 timer, idet terningerne er varmebehandlet i et specielt konstrueret apparat. Dette udstyr til bestemmelse af 18-timers styrken produceres kommercielt under navnet Grant Accelerated Test Method. Prisen er 800 £, og der er solgt et meget stort antal heraf. Man følger samtidig (også v.h.a. CUSUM-teknikken) at korrelationen mellem accelereret 18-timers styrke og 28 døgns styrken er passende høj.

CUSUM-teknikken må siges at være mere operationel end de sædvanlige $\bar{X}$-R-kort, men måske nok lidt mere krævende af det personale, som skal udføre beregningerne. Ved "Grant Accelerated Test Method" er der det minus, at den kræver en veldokumenteret sammenhæng mellem 18-timers styrken og 28-timers styrken. Denne sammenhæng kan ændres, når tilslagsmaterialerne ændres.

I det mindste 1 dansk fabriksbetonproducent anvender på nuværende tidspunkt (og har allerede gjort det 3/4 år) begge de nye teknikker i sin processtyring.

I England viser statistikken, at fabriksbeton sammenlignet med andre materialer, kun i meget ringe grad bliver kasseret ved kundernes modtagekontrol. Således viser "Greater London Council Testing Station", at kun 1.4% af de udsendte stikprøver ikke kunne godkendes i 1975.

Man søger iøvrigt at dokumentere fabriksbetonens høje kvalitet ved at yde 10 års garanti mod større skader.

PS. Ken Newmanns foredrag vil i løbet af 1977 blive udgivet i Dansk Betonforenings publikationsserie.

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