On any given site properties of materials used will vary over the period of construction. This variability contributes to the overall variation in the measured strength of concrete which arises mainly from the aggregate water content during the day, temperature changes and inaccurate batching of the component materials, the production process (i.e. plant control, resulting in changes from the intended mix proportions) and the sampling, making and testing of concrete specimens. It is difficult to determine the proportion of the overall variation arising from each of these sources.

The variation in concrete strength typically obtained from tests at a site show more results close to the mean value and fewer at the extremes. It is now accepted that the variation in concrete strengths follows a normal distribution curve which is characterized by two parameters, its mean m and its standard deviation **s**, the latter being a measure of variability.

$$s = \text{sq.rt}\ [\text{sigma}\ (x - m)^2 \ / \ (n - 1)]$$

where x = an individual result
n = the number of results
m = the mean of n results
sigma = summation

With poor control there is a wide scatter of results giving a high standard deviation; the better the control the lower the standard deviation.

Due to the distribution of the results, there is always the possibility, however remote, that a result less than the specified strength will be obtained. It has now become general practice to specify not a minimum strength but a **"characteristic strength".** below which a specified proportion of the test results, often called **"defectives"**, may be expected to fall. The characteristic strength may be defined to have any proportion of defectives; BS 5328, BS 8110 have all adopted a 5 percent level of defectives for concrete. Thus, **the characteristic strength of concrete is defined as "that value of strength below which 5 percent of the population of all possible strength measurements of the specified concrete are expected to fall"**

6.1 Margins required for mix design

Because of the variability of concrete strength, the mix must be designed to have a mean strength greater than the specified characteristic strength by an amount termed the "margin". Thus

$$fm = fc + ks$$

where
fm = the target mean strength
fc = the specified characteristic strength
s = the standard deviation
k = statistical constant

The statistical constant k is derived from the mathematics of the normal distribution and increases as the proportion of defectives is decreased; for example :

k = 1.28 for 10 percent defectives
k = 1.64 for 5 percent defectives
k = 2.33 for 1 percent defectives

The magnitude of standard deviation **s** varies from site to site. An analysis of tests results of project works in the Emirate show a range of 4 - 5 N/mm2 for commonly used C30 grade concrete.

For concrete having a 5 percent defective level, k = 1.64 and the margin is 1.64 **s**.

For a specified characteristic strength of 30 N/mm2 and a standard deviation of 5 N/mm2,

The margin = 1.64 x 5 = 8.2 N/mm2,

Then, the target mean strength = 30 + 8.2 = 38.2 N/mm2

The standard deviation may be specified for a given job based on experience. In many cases there is information on standard deviation to be expected (with&a3096Hready-mixedete, for example). The reliability of the value of the standard deviation increases with the number of results used in its calculation and it is generally recommended that at least 20, and preferably 40, results are used.

6.2 Grades of concrete

Whether concrete is specified in terms of mix proportions or performance, BS 5328 requires the specification of the quality of concrete in terms of a 28-day characteristic strength grade but BS 5328 also includes flexural and indirect-tensile strength grades, Table numbers 1, 2 and 3.

6.2.1 Tension Strength

The main measure of the structural quality of concrete is its compressive strength. While concrete is best employed in a manner which utilizes its favourable compression strength, its tension strength is also of consequence in a variety of situations. The knowledge of tensile strength is of value in estimating the load under which cracking will develop. The absence of cracking is of considerable importance in maintaining the continuity of a concrete structure and in many cases in the prevention of corrosion of reinforcement. Cracking problems occur when diagonal tension arising from shearing/torsional stresses develops, thus the shear and torsion resistance of reinforced-concrete members appears to depend primarily on the tension strength of the concrete. Also, the conditions under which cracks form and propagate on the tension side of reinforced concrete flexural members depends strongly on the tension strength. The most frequent case of cracking is due to restrained shrinkage and temperature gradients. An appreciation of the tensile strength of concrete helps in understanding the behaviour of reinforced concrete even though the actual design calculations do not in many cases explicitly take the tensile strength into account.

6.2.1.1 Flexural Strength - Flexural Test

There are considerable experimental difficulties in determining true tensile strengths for concrete. In direct tension test, minor misalignments and stress concentrations in the gripping devices are apt to mar the results. Tension properties have been measured in terms of the **modulus of rupture**, i.e., that computed **flexural tension** stress at which a test beam of plain concrete would fracture. Because this nominal stress is computed on the assumption that concrete is an elastic material, and because this bending stress is localised in the outermost fibers, it is apt to be the larger than the strength of concrete in uniform axial tension. It is thus a measure of, but not identical with, the real actual tension strength. Nevertheless, the flexural test is very useful.

In some types of construction, such as roads or airport runways, mix design of concrete on the basis of flexural strength is frequently preferred because flexural tension there is a critical factor.

BS 1881 : Part 118 describes the test method.

6.2.1.2 Indirect Tensile Strength - Splitting Test

An indirect method of applying tension is in the form of splitting a cylindrical specimen. The result of the so called **split-cylinder test** has established itself as a measure of tensile strength of concrete.

A 150mm X 300mm, concrete cylinder is inserted in a compression testing machine in the horizontal position, so that the compression is applied uniformly along to opposite generatrices. It can be shown that in an elastic cylinder so loaded, a nearly uniform tensile stress exists at right angles to the plane of load application. Correspondingly, such cylinders, when tested, split into two halves along that plane, at a stress which can be computed. Because of local stress conditions at the load lines and the presence of stresses at right angles to the aforementioned tension stresses, the results of the split-cylinder tests likewise are not identical with the true axial tensile strength.

Cubes can also be subjected to the splitting tests, the load being applied through semi-cylindrical pieces resting against the cube on centre lines of two opposing faces. The method yields the same result as the splitting test on a cylinder. The splitting tests are simple to perform and give more uniform results than the other tension test. The strength determined in the splitting test is believed to be closer to the true tensile strength of concrete than the modulus of rupture.

ASTM Standard C496 and BS 1881 : Part 117 cover these test methods

6.2.1.3 Correlation with Compressive Strength

Tensile strength, whichever way determined, does not correlate well with the compression strength. It appears that for normal weight aggregate concrete the tensile strength depends primarily on the strength of bond between hardened cement paste and aggregate. The shape of the coarse aggregate particles affects the relation between the water / cement ratio and the flexural tensile strength. With a given water / cement ratio angular aggregate produces a higher flexural tensile strength than rounded or irregular aggregate. The compression strength, on the other hand, is much less determined by these particular characteristics and is sensibly independent of the shape of the aggregate particles. Tensile strengths (N/mm2) of normal weight aggregate concretes can be estimated from the following expressions :

True tensile strength	0.24 to 0.40 sq.rt (fcu)
Indirect tensile strength	0.48 to 0.56 sq.rt (fcu)
Flexural tensile strength	0.72 to 1.00 sq.rt (fcu)

Where, fcu is characteristic cube strength (N/mm2)

The smaller of the foregoing factors apply to high strength concrete, and larger to the low strength concretes. These approximate expressions show that the tension and compression strengths are by no means proportional and that any increase in compression strength, such as that achieved by lowering the water-cement ratio, is accompanied by a much smaller percentage increase in tensile strength.

TABLE 1 - COMPRESSIVE STRENGTH

Concrete grade	Characteristic compressive strength at 28 days, N/mm2
C 7.5	7.5
C 10	10.0
C 12.5	12.5
C 15	15.0
C 20	20.0
C 25	25.0
C 30	30.0
C 35	35.0
C 40	40.0
C 45	45.0
C 50	50.0
C 55	55.0
C 60	60.0

TABLE 2 - FLEXURAL STRENGTH

Grade	Characteristic flexural strength at 28 days, N/mm2
F 3	3.0
F 4	4.0
F 5	5.0

TABLE 3 - INDIRECT TENSILE STRENGTH

Grade	Characteristic indirect tensile strength at 28 days, N/mm2
IT 2	2.0
IT 2.5	2.5
IT 3	3.0

6.2.2 **Selecting Compressive trength Grade of Concrete**

For reinforced concrete, the lowest grade should be C25 for concrete made with normal-weight aggregates.

For prestressed concrete, the appropriate grade of concrete should be selected from the preferred grades. Grades C30 and C40 are the minimum recommended for post-tensioning and pre-tensioning respectively.

6.2.3 Selecting Tensile Strength Grade of Concrete

Though the standard BS 8110 : Structural Use of Concrete does not directly specify the required tensile strength grade, the design tensile stresses are specified in terms of characteristic compressive strength as given by the expression (refer clause 6.2.1.3 above) namely,

Tensile strength = **f** sq.rt (fcu)

where the value of factor **f** depends upon the design considerations, such as the serviceability and ultimate limit states of the structural member. These values are specified in codes of practices for the design of reinforced concrete and prestressed concrete structures and members.

In prestressed concrete structural element, the BS 8110 classifies prestressed concrete structure or element depending on the amount of flexural tensile stresses allowed under service loads as follows :

Class 1 : no flexural tensile stresses.

Class 2 : flexural tensile stresses but no visible cracking.

Class 3 : flexural tensile stresses but with specified crack widths in the range of 0.1 to 0.2 mm.

Considering the environmental conditions, Class 3 elements should not be used.

7. DURABILITY OF STRUCTURAL CONCRETE

A durable concrete element is one that is designed and constructed to protect embedded metal from corrosion and to perform satisfactorily in the working environment for the life-time of the structure.

One of the main characteristics influencing the durability of concrete is its permeability to the ingress of water, oxygen, carbon dioxide and other potentially deleterious substances. Permeability is governed by the constituents and procedures used in making the concrete. With normal weight aggregates a suitably low permeability is achieved by having an adequate cement content, a sufficiently low free water / cement ratio, by ensuring complete compaction of the concrete, and by sufficient hydration of the cement through sound curing methods.

The factors influencing durability include :

[a] the cover to embedded steel
[b] the type of cement
[c] the cement content and water cement ratio of the concrete
[d] the aggregate properties and deleterious contaminants
[e] workmanship, to obtain full compaction
[f] efficient curing, and of course
[g] the environment

7.1 **Corrosion of Steel**

Corrosion of steel in concrete is one of the major problems with respect to the durability of concrete structures. The enormous amount of money required for repair measures results in a strong need to improve durability of new structures in the first instance as well as guarantee the durability of existing structures after repair or strengthening.

The protection of the steel in concrete against corrosion depends upon the alkaline environment provided by an adequate thickness of good quality concrete cover. It is now generally accepted that steel in concrete is protected by the passivity induced by the highly alkaline nature of the porewater. The primary task of the concrete cover is to form a physical and chemical barrier against the penetration of deleterious substances tending to destroy passivation. The most important substances with respect to depassivation of reinforcement are carbon dioxide causing carbonation of the concrete and chlorides.

The steel in concrete is protected against corrosion providing the ph at the steel surface is not reduced significantly from its initial high values of 12.5 to 13.5 or the chloride content at the steel surface does not exceed a ph-dependent critical value. The above mentioned critical values at the steel surface may be breached by penetration of substances from the outside namely penetration of carbon dioxide (initiation by CO_2) and penetration of chloride (initiation by chloride).

7.1.1 **Salt Contamination** - The protection provided by the alkalinity is only effective if a certain chloride content is not exceeded. This critical chloride content can be attained in two different ways, (a) by incorporating too high an amount of chloride in the original mix - be it via the raw materials or the additives - or (b) by penetration of chloride ions into the concrete from the outside environment.

In the case of incorporation of chlorides in the original mix, one cannot speak of an initiation period for corrosion, because the reinforcement will be initially in the state of corrosion. Whether corrosion will subsequently take place at a rate that is harmful depends upon other factors.

7.1.2 **Carbonation** - The ph of the **uncracked concrete** may change by ingress of acids from the environment. These acids are mainly the CO_2 in air and the SO_3 in water. Of these, CO_2 in air is of major importance.

Initially CO_2 will not be able to penetrate deeply into the concrete because it will be bound within the surface layer by basic reaction. The CO_2 combining with calcium hydroxide released by cement hydration process. As a result, ph changes from 13 - 14 to a near neutrality condition. However, as the outermost portion of the concrete becomes carbonated the carbon dioxide will ingress further and as soon as the ph at the reinforcement is near neutrality the passivation of the steel will be lost.

Diffusion rate of carbon dioxide is low in water saturated pores compared to the diffusion in air, while the diffusion of chlorides the reverse is the case. Diffusion of Cl ions take place only in water.

7.1.2.1 **Influence of cracks** - Evidently, carbonation can penetrate much faster into the interior of concrete via cracks than it does through uncracked concrete. As regards the pure process of carbonation, the same basic interrelation as given for uncracked concrete are valid for carbonation in the region of cracks as well. In addition, the increasing humidity in the interior of a concrete member as well as the crack itself causes a lower permeability of concrete.

The water in the crack will evaporate more slowly than the water at the concrete surface after re-wetting. Therefore, lower values of the diffusion coefficient must be applied for carbonation within cracks compared to those relevant for carbonation of uncracked concrete.

Crack widths - Crack widths can be controlled by adequate reinforcement and such controlled cracks normally range between 0.1mm to 0.3mm wide at the surface. **The permissible crack width in exterior members exposed to particularly aggressive environment is 0.15mm.** The amount CO_2 diffusing through the crack increases with increasing crack widths. Consequently, carbonation rate within the crack increases as well.

Permeability in the crack space - The permeability in the crack space is dominantly influenced by the type and the amount of deposits in the crack space. Deposits may originate from the environment (dirt) as well as from the interior of the concrete member itself (lime). In the latter case, the deposits may result from effused and carbonated alkalis (so-called self-healing of cracks) or from rust products of corroding reinforcing bars. The density and consequently the permeability of the deposits is strongly influenced by the environmental conditions (specially changing humidity), the concrete mix and the concrete cover.

The effectivity of deposits with respect to a decreasing permeability within the crack face also is highly dependent on the type of loading. Dynamic loading causes change in crack widths and consequently the densifying effect of deposits is reduced, whereas this densifying effect may be of importance in the case of static loads.

The decreased permeability caused by deposits as well as the effusion process may result in a deep passivation of concrete areas where the ph-values depressed by carbonation are increased as a result of alkali effusion and decreased permeability.

7.1.3 **Chlorides in the mix**

The presence of chlorides, as contaminants in the original mix can set up immediate corrosion depending upon its amount in relation to the cement content in the mix. The severity and extent of which will depend on chemical and physical interaction with the hydrated cement matrix.

Chlorides react with calcium aluminates and, to a lesser extent, calcium alumino ferrites in the cements to form chloroaluminate and chloroferrite hydrates. Thus some binding of chloride to the hydrated cement compounds occurs, the predominant reaction being that of the formation of the chloroaluminate hydrate known as Friedel's salt.

The stability of this, and other solid chloride binding hydrates is, however, governed by their chemical equilibrium with chloride dissolved in the aqueous phase contained in the pore liquid. Thus to retain stability there will be continuing requirement for a proportion of chloride to remain in the pore liquid. It is this solution or "free" chloride which is available to promote corrosion. The proportion of free chloride will be dependent on several factors, including the total amount of chloride in the concrete and the binding capacity of the cement and will be modified by the source of chloride. Cement with low C3A contents will be less able to bind chlorides than those with greater amounts.

The presence of excessive amount of sulphate in the concrete can also influence the stability of the Friedel's salts. Research has shown that when sulphate and chloride are incorporated within the original concreting materials, the sulphate is likely to react preferentially with C3A forming calcium sulphoaluminate hydrates and inhibiting the formation of the chloroaluminate hydrates. This inhibition has the effect of increasing the free chloride concentration in the pore liquid and so enhancing the probability of propagation of chloride-induced corrosion.

The risk of chloride induced corrosion increases considerably after carbonation of concrete, because initially bound chlorides are released after carbonation and thus increase the amount of free "corrosive" chlorides.

As a rule, all processes involved will be accelerated with increasing temperature.

The general corrosion is likely to be controlled by the "time of wetness" (a term already accepted in atmospheric corrosion studies) of the concrete. Recent work has shown that relative humidities below 50 percent are unlikely to be sufficient to stimulate corrosion of steel in carbonated and chloride-free concrete, whereas approaching 100 percent RH produces high rates of corrosion. Therefore temperature differential within R.C. members in hot humid climates where air-conditioners are used may be a factor inducing early corrosion.

7.2 **Planning** - The most severe environmental conditions are frequent wetting and drying cycles. Therefore, measures to keep water away from the concrete surfaces by an adequate selection of the structural form and structural detailing should be considered. Another important requirement is to avoid weak points within the structure that may lead to frequent wetting and drying e.g. leaking joints, wide single cracks (>> 0.5 mm), horizontal surfaces which trap water, etc.

Design detailing of exposed thin and slender sections need special attention from the point of view of protection of reinforcing steel against corrosion. Horizontal projections, such as chezzas could be avoided as they have been serious cause for corrosion.

7.3 **Crack Widths** - While a clear influence of crack width on the time of corrosion exists, for crack widths between 0.15 and 0.3 mm and concrete covers between 2 and 4 cm, the time of initiation may be decisively shorter than 2 years under unfavourable circumstances.

Test result show, that after depassivation anodic dissolution takes place in the region of the cracks, whereas the steel surface besides the depassivated crack area, that means the steel surface between the cracks acts as cathode. Because the cathodic process is the dominating rate determining process, an influence of crack widths on corrosion rate nearly does not exist.

If the concrete cover is of high quality, the corrosion damage remains low, even in the region of cracks with widths upto 0.3mm. In case of very aggressive environmental conditions additional measures of protection are required in the region of cracks as well as uncracked areas.

7.4 **Cement Type** - If a sulphate resistant portland cement with a low C3A content is used, it should be considered that both the diffusion resistance and the binding capacity for chlorides will be lower than for ordinary portland cement. As a consequence chlorides penetrates much faster into this concrete than they do into OPC-concrete with comparable composition and strength.

7.5 **Water-Cement Ratio** - The water/cement ratio is of decisive influence on the permeability of the concrete and should be decreased with increasing environmental aggressivity. Depending on the environmental conditions water-cement ratios between w/c = 0.5 and w/c = 0.4 should be chosen for outdoor conditions.

7.6 **Cement Content** - The amount of cement content varies, in general, between 250 and 450 kg/m3 of concrete. The binding capacity of Cl ion will be proportional to the cement content. Further, higher cement contents in the mix improves workability leading to sufficiently low permeability. High cement content produce more alkaline mixes.

7.7 Execution

7.7.1 **Concrete cover** - The quality of the concrete cover can be considered to be the most important structural parameter with respect to reinforcement corrosion, whereas quality means thickness and permeability. Depending on the environmental conditions minimum values of the concrete cover between 30 to 75 mm can be considered to be the lower limits to ensure durable passivation of steel in uncracked concrete.

7.7.2 **Workability -** In order to avoid badly compacted concrete, especially in the outer layers, fluid concrete should be used, especially in the case of closely spaced reinforcement or in the case of a complicated structural form to be poured.

7.7.3 **Curing -** The potential quality of concrete cover with respect to permeability can only be achieved if an adequate moisture curing is guaranteed. The required duration of curing depends on the concrete composition, the environment during and immediately after curing and the environment during use. The required duration of curing increases with :

- decreasing velocity of hardening of cement
- increasing cement content
- decreasing environmental humidity during curing
- increasing aggressivity of environment during use.

Depending on all the parameters mentioned, the required duration of moisture curing may extend beyond 14 days or more. Lax curing will significantly reduce the life of concrete. Chloride diffusion concentrations typically doubles in an eight month period because of difference in curing technique.

Curing should begin immediately after placement of concrete. Fog spray of water can be dosed over green concrete and covered with plastic sheets. Care of the young concrete during the first six hours is very critical to the future service performance.

The curing could be included as a separate item in the schedule of quantities and paid for so that effective curing is ensured.

7.8 Critical chloride content

The decisive parameter with regard to corrosion of steel in concrete is the percentage of free-chlorides (corrosive ions) in the porewater, related to the percentage of inhibitive ions, especially (OH) ions.

For reinforced concrete, prestressed concrete and heat-cured concrete containing embedded metal, the limits of chloride contents as shown in Table 4 should not be exceeded for minimizing the incipient danger of corrosion.

Table 4 - Maximum Limits of Chloride and Sulphate Content as a Percentage by Weight of Cement in the Mix

	Type of Concrete	Chlorides as Cl	Sulphates as SO3
[a]	For reinforced concrete		
	if made with OPC / MSRPC	0.30	
	if made with SRPC	0.06	
			3.70
[b]	Prestressed concrete and Heat-cured reinforced concrete	0.10	
[c]	For mass concrete		in all cases
	if made with OPC / MSRPC	0.60	
	if made with SRPC	0.12	

Note : The OPC and MSRPC cements can also contain chlorides, the relevant standard BS 12 allows upto 0.1% Cl. Therefore any chloride content present in the cement has to be taken into account while computing total Cl in the mix. In case the cement contains the maximum limit of 0.1% Cl, then the aggregates, water and admixtures used for prestressed concrete or heat cured reinforced concrete should be **absolutely free of chlorides**

7.9 Additional measures

Extremely harsh aggressive environmental conditions, salt contaminations in the mix, poor planning and execution has often contributed to the development of corrosion damage and cannot be totally ruled out. These aspects have lead to an increased interest in providing corrosion protection to the reinforcement additional to that provided by the concrete cover. In particular efforts have been directed towards developments in four main areas, the use of pore blockers, and corrosion inhibitors, the use of metallic and organic coatings, the application of corrosion resistant alloys for concrete reinforcement and cathodic protection.

8. ENVIRONMENT

Significant deterioration of reinforced concrete is likely to occur in marine tidal and splash zones and in aerated sabkha environments within very short periods. Overall, the most aggressive environments, based upon salt ingress are the sabkha zones followed by marine splash and marine tidal zones, marine submerged zones in turn. If saturation effects are considered, the submerged sabkha and marine location will become potentially the least aggressive as far as reinforced concrete is concerned because of oxygen deficiency.

It would appear that airborne salt attack occurs in UAE concretes. It therefore should not be assumed that external superstructure is immune to long-term salt ingress; surface sealers should be considered as standard protection in new structures.

Sulphate ingress in the most aggressive sabkha conditions would be minimal, indeed it is greater in marine splash and tidal conditions. It is suggested that conventional OPC concrete is suitable for permanently submerged situations because of oxygen deficiency. In sabkha capillary rise locations (typical Dubai foundations) tanked, air-entrained type (II) or air-entrained OPC concrete are perhaps best alternatives.

Air-entrained concrete appeared to retard the early diffusion of chlorid ions. The mechanism responsible is believed to be associated with the creation of a cellular network of discontinuous voids which destroy capillary structure and reduced bleeding. The continuous capillary passages which assist ingress of deleterious elements in conventional concrete are thus reduced. It is suggested that OPC or Type (II) air-entrained concrete with a water / cement ratio of 0.42 or less, should be used in the aerated marine environment in conjunction with a surface sealer / barrier as appropriate. Table numbers 5 and 6, give requirements for ensuring durability for different exposure conditions.

TABLE 5 - CRITERIA FOR REINFORCED CONCRETE FOR DURABILITY

(Nominal Maximum Size of Aggregate 20mm)

Exposure Conditions	Min. Cement Content kg/m3	Concrete Grade	Max. Free W/C Ratio	Type of Cement	Min. Cover (mm)
[1] Super-structure, inland with no risk of windborne salts	330	C 25	0.52	OPC, BS 12 ASTM TYPE 1	30
[2] Super-structure in sabkha area or near coast exposed to windborne salts	350	C 30	0.5	CFOPC, BS 12 ASTM TYPE 2	40
[3] Concrete submerged in sea water	370	C 35	0.48	CFOPC, BS 12 ASTM TYPE 2	45
[4] Marine structures splash zone and inter-tidal zone	370	C 40	0.42	CFOPC, BS 12 ASTM TYPE 2 (aerated)	60 to 75
[5] Substructures in capillary rise zone, discharge of waste, washing down, etc.	400	C 45	0.42	OPC, CFOPC, BS 12 ASTM TYPE 1/V SRPC BS 4027 (Tanking)	75 to 100

TABLE 6 - DURABILITY OF UN-REINFORCED CONCRETE

(Nominal size of aggregate 20mm)

Exposure Conditions	Min. Cement Content kg/m3	Lowest Concrete Grade	Max. Free W/C Ratio
[1] Marine concrete in splash, fluctuating water, and capillary rise zones	300	C 30	0.50
[2] All other constructions	275	C 25	0.55

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ON
READY-MIXED CONCRETE

DUBAI MUNICIPALITY
NOTE NUMBER 005,
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1. INTRODUCTION

The application techniques of concrete production and placement has become more sophisticated. One of the improvements was the establishment ready-mix industry where uniform concrete is produced industrially in a well-controlled manner and delivered ready for placing. This type of concrete offers numerous advantageous in comparison with the conventional method of manufacture. In the past 10 years there has been a tremendous increase in the use of ready-mixed concrete in the U.A.E. The industry is well established and is likely to develop further.

Ready-mixed concrete is particularly useful on the congested sites where little space for the mixing plants and for extensive aggregate stockpiles is available, but perhaps the greatest single advantage of ready-mixed concrete is that it may be made under better conditions of control than are normally possible on construction sites. A great deal of uncertainty and variability associated with the production of concrete on many a site is removed.

Nowadays a significant proportion of the concrete placed is ready-mixed. The concrete supplied can be for all types of work, from lean concrete in roads to high strength concrete for structures. On large sites, even though the contractor elects to site batch, the operations may be similar to a typical ready-mixed-concrete plant operation.

The use of ready-mixed concrete demands efficient organisation of the day-to-day concrete requirements in the works, and it calls for good coordination between the contractor and supplier at all stages from ordering to delivery of the concrete. The placing and compaction remain, of course, the responsibility of the personnel on the site. Because of the large batches of concrete that have to be handled, speed in conveying the fresh concrete into place as quickly as possible when it arrives on site is crucial, time is very important especially in summer in order to minimize the adverse effect of the increased slump loss at elevated temperatures.

2. SPECIFICATION

ASTM C94 and BS 5328 are specifications for the material, freshly-mixed concrete. They address the separate and joint responsibilities of the various parties in a typical job - the client, specifying agency, contractor and ready-mixed concrete producer. Included are the basic elements of both prescription and performance specifications. Appropriate test methods are defined.

The Engineer considering the possibility of using ready-mixed concrete should satisfy himself that the organisation of the plant, the control of the materials, the quality of the output and the capability of the supplier to meet the construction schedule satisfy the requirements of the project specifications.

The responsibility for acceptable performance of concrete in place is divided inevitably between the concrete producer who must deliver acceptable material, the contractor who must place it, and the specifier who must structure appropriate specifications and plans. Since strength test results are weighted heavily in the acceptance of the material and since strength is not usually determined until the concrete has been in the structure for 28 days, it is considered prudent to regulate further the procedures used to proportion, batch, mix and deliver the concrete.

3. BASIS OF PURCHASE

Ready-mixed concrete is concrete manufactured for delivery to a purchaser in plastic and unhardened state. The basis of purchase is by volume of freshly mixed concrete as discharged from the mixer, the unit of measure being cubic meter. It should be understood that the volume of hardened concrete may be less than expected due to waste and spillage, over excavation, spreading forms, some loss of entrained air, or settlement of wet mixes, none of which are the responsibility of the producer.

4. SPECIFICATION OF CONCRETE

The concrete is to have certain specified minimum properties, **(Refer DM ADVISORY NOTE 004)** and that it is to be produced as economically as possible. The basis for determining the proportions of the concrete to produce the required quality both in the fresh and in the hardened state can be either prescribed or designed.

4.1 **Prescribed Mix** - is a mix for which the purchaser specifies the proportions of the constituents and is responsible for ensuring that the proportions prescribed will produce a concrete with the performance he requires such as the requirements for the workability, placeability, durability, surface texture and density, in addition to those for structural design.

Prescribed mixes may be used only for small work, when the 28-day strength of concrete does not exceed 20 N/mm2 and the cements use are traditional portlands. Owing to the variability of the mix ingredients, concrete having fixed cement-aggregate proportions, and a given workability vary widely in strength. No control testing is necessary, reliance being made on the weight of the ingredients. However, to ensure that the mix to be prescribed results in the strength required, reference may be made to the mixes prescribed in the standard BS 5328 by quantities of dry ingredients per 100 kg of cement and by slump for grades of concrete in the range of 7 to 30. Though these mix proportions are adjustable due to differences in the characteristics of local aggregate resources, e.g. grading, they do provide some guidance.

4.2 **Design Mix** - is a mix for which the purchaser is responsible for specifying the required performance and producer responsible for selecting the mix proportions to produce the desired performance i.e. the concrete mix has to be designed to meet the performance requirements. It is therefore commonly referred to as Designed Mix in order that the implication of the meaning is broad based.

The performance characteristics of concrete in terms of its grade and durability result in the specification of a strength, minimum cement content and / or water cement ratio.

There has been a change away from the prescribed to the performance specifications and in fact virtually the norm nowadays in large and important works.

4.3 Control of Chlorides and Sulphates

The acceptable levels of equivalent acid soluble chlorides and sulphates as specified for aggregates and water are indicative and are subject to over-riding limits for the mixes as given in Table 1 below.

Table 1 - Maximum Limits of Chloride and Sulphate Content as a Percentage by Weight of Cement in the Mix

Type of Concrete	Chlorides as Cl	Sulphates as SO3
[a] For reinforced concrete		
if made with OPC / MSRPC	0.30	
if made with SRPC	0.06	
		3.70 in all cases
[b] For mass concrete		
if made with OPC / MSRPC	0.60	
if made with SRPC	0.12	

The ready mixed concrete producer should test the constituents of the concrete to establish these contents for compliance and certify that the total chlorides and sulphates in the mixes he produce are within permissible limits irrespective of whether the purchaser specifies the control of these deleterious salts in the concretes he orders.

The permissible levels of chlorides and sulphates quoted in Table 1 should not be considered as mean values for the whole of the works, but applies to each batch of concrete delivered.

5. MATERIALS

5.1 **Cement** - Cement should conform to specifications BS 12, BS 4027, ASTM 150 or **DM ADVISORY NOTE NUMBER 002.,** as specified. The purchaser should specify the type or types required. Rapid hardening cement should not be used. Unless otherwise specified, low alkali cements are always to be used.

Blended cements such as portland cement with ground granulated blast furnace slag, pulverised fuel ash and similar pozzolonas may be allowed after the cements and pozzolonas as such are tested fully by an independent authority for conformance to specified standards. Fly ash should not be used with SRPC cements.

5.2 **Aggregates** should conform to specifications BS 882, ASTM C33 or **DM ADVISORY NOTE NUMBER 001,** as specified.

5.3 **Water**

5.3.1 The mixing water should be clear, apparently clean and free from matter harmful to concrete in its fresh or hardened state. Potable water can be used. Water of questionable quality should comply with the physical tests of Table 2 and chemical limitations listed in Table 3.

The temperature of water for concrete should not be less than 5 degree celsius nor more 25 degree celsius. Water may be cooled to not less than 5 degree celsius by the gradual addition of ice but on mixing, no ice particles should be present in the mix. Ice should be the product of frozen water which complies with acceptance criteria of Tables 2 and 3.

5.3.2 Washed water from mixer washout operations may be used provided tests of wash water comply with the criteria limits shown in Table 4 and when the purchaser approves of its use. Wash water should be tested at weekly intervals or as specified by the purchaser.

Table 2 - Acceptance Criteria For Mixing Water

	Limits	ASTM Test
Compressive strength, min.% control at 7 days	90	C 109
Setting time, deviation from control, h:min.	from 1:00 early to 1:30 later	C 191

Table 3 - Chemical Limitations for Mixing Water

Maximum concentration,	Limit, ppm	ASTM Test Method
1. Chloride as Cl	250	D 512
2. Sulphates as SO3	350	D 516
3. Alkali carbonates and bicarbonates	500	D 513
4. Total dissolved ions, including, 1, 2, & 3 above	2000	D 1888

Table 4 - Chemical Limitations for Wash Water

Maximum concentration	Limits, ppm	ASTM Test Method
1. Chloride as Cl	250	D 512
2. Sulphate as SO3	1500	D 516
3. Alkalis as (Na2O + 0.658 K2O)	600	C 114
4. Total solids	50,000	AASHTO T26, D1888

NOTE : The concentration of Cl and SO3 in the mixing water, wash water, aggregates and other sources should not exceed the allowable limits expressed as percentage of cement content of the concrete mix as specified in Table 1.

5.4 **Admixtures** - admixtures should conform to appropriate ASTM or BS specifications. Further, it should be proved beyond doubt they do not harm the setting strength and durability of concrete.

Chloride and chloride based admixtures should not be used.

In any given instance the required dosages will vary. Therefore, a range of dosages should be allowed which will permit obtaining the desired effect.

Where recycled wash water is used, attention should be given to effects on the dosage rate and batching sequence of admixtures.

While allowing the use of admixtures, account should be taken of their effects on design requirements and that there are satisfactory data on their stability and assurance of quality control. Where necessary, records concerning the details and performance of such admixtures should be maintained.

6. ORDERING INFORMATION

The purchaser should specify the following :

- Designated size or sizes of coarse aggregates.
- Workability of concrete and any particular handling characteristics it may need to have e.g. pumpability, conveying or skipping.
- Recommended air content for air-entrained concrete at the point of discharge.
- Whether the mix proportions are prescribed or to be designed.

6.1 When the purchaser prescribes the proportions of the concrete mix, he should also specify the following :

- Dry weight of aggregates (coarse & fine) and cement.
- Water-Cement ratio, nominal.
- If admixtures are required, the type, name and dosage.
- Cement type.

6.2 When the purchaser requires the manufacturer to design the mix, he should also specify the following :

- Required characteristic strength of concrete.
- Cement type, minimum cement content, kg/m3.
- Maximum free water / cement ratio allowed and limitation on minimum water / cement ratio, if any.
- If admixtures are required, the type, name and dosage to be used.

6.3 The concrete producer, prior to the actual delivery of the concrete, furnish a statement to the purchaser giving :

- The sources, specific gravities & water absorption of aggregate used.
- Dry weights of aggregates, cement and water per cubic meter of concrete that will be used in the manufacture of concrete ordered.
- Density, kg/m3 of compacted freshly mixed concrete.
- Particulars of admixtures, if any, used.
- In the case of mixes prescribed by the purchaser, the strength of concrete achieved.
- In the case of designed mixed concrete, the manufacturer should furnish evidence to the purchaser that the materials to be used and proportions selected will produce concrete of the quality specified.

- Whatever be the strengths attained, the quantity of cement used should not be less than the minimum specified and that the specified maximum water cement ratio is not exceeded.

The ready-mixed concrete supplier should control the mixes that will meet all the specified requirements. It is implicit that the mix should be homogeneous and should not segregate within the tolerance ranges of the specified workability.

7. WORKABILITY

The degree of workability may be assessed at the point of delivery by slump test, as per BS 1881 : Part 102. The following tolerances apply for the slumps :

Nominal Slumps	Tolerance
50mm and less	+/- 10mm
50mm to 100	+/- 20mm
More than 100mm	+/- 30mm

Concrete should be available within the permissible range of slump for a period of 30 minutes. The first and last 1/4 m3 discharged are exempt from this requirement. If the user is unprepared for discharge of concrete from the vehicle, the purchaser is responsible.

8. PUMPED CONCRETE

A significant portion of ready-mixed concrete is nowadays pumped. In order to be able to be pumped, the mix must satisfy certain requirements. Broadly speaking, the mix must not be harsh or sticky, too dry or too wet, i.e. its consistency is critical. Unsatisfactory concretes cannot be pumped. The mix has to be cohesive, should not bleed, and be unsegregated. A slump of between 40 and 100mm, or a compacting factor of approximately 0.90 to 0.95, or a Vebe time of 3 to 5 seconds is generally recommended. The coarse aggregate content should be high, but the grading should be such that there is a low void content. For practical mixes with maximum aggregate size of 20mm, the optimum fine aggregate content lies between 40 and 45 percent, and the material finer than 300 micron should represent 15 to 30 percent of the weight of fine aggregate. It has been shown that volumetric cement content has to be at least equal to the void content of the aggregate but very fine material other than cement such as finer fractions of sand or a suitable additive, silica fume or fly ash, can be included with the latter.

9. MEASURING MATERIALS - BATCHING

The various specification requirements for batching systems are designed to accomplish one or more objectives. The primary concern is the quality of the product. Important secondary objectives are to see that the customer also obtains the quantity of the concrete ordered and the quantities of cement and admixtures where those are a part of the purchase agreement.

Specification for most scales or weigh batches contain two kinds of tolerances - scale accuracy and batching accuracy tolerances. The scale accuracy tolerances are applicable during calibration and are designed to ensure that accurate equipment is used. Batching accuracy tolerances are much more liberal and are intended to govern the operating conditions. The batching tolerances generally apply to the indication of the primary or master device. Somewhat more liberal tolerances are permitted for secondary devices such as slave dials or recorders.

9.1 Measurement of Materials

Materials such as cement and aggregates are weighed. Water is sometimes weighed on a scale but most of the time it is measured by bulk volume. Liquid admixtures are measured by volume in a variety of meters and other positive displacement devices and calibrated containers.

Some specification requires individual batchers for cement, pozzolonas, and each aggregate size. However, weighing cement and pozzolona can be permitted if pozzolona is weighed last, but not with aggregates. Aggregates may be weighed cumulatively or individually.

Batched materials should be measured out within the following tolerances and discharged into the mixer (Table 5).

Table 5 - Batching Accuracy Requirements

	Material	Percent
1.	Cement	
	above 30% of scale capacity	+/- 1
	below 30% of scale capacity	-0, +4
2.	Aggregates	
	[a] individual batchers	+/- 2
	[b] cumulative batchers, % of required cumulative weight	
	above 30% of scale capacity	+/- 1
	below 30% of scale capacity	+/- 3
3.	Water	
	[a] added by weight or volume	+/- 1
	[b] total mixing water required in the batch including water in aggregates, ice, and water batched from plant & mixers.	+/- 3
4.	Admixtures	
	by volume or by weight	+/- 3

9.2 Batching Systems and Controls

The batching systems are generally of three types and are defined as follows :

- A manual control batcher is one that is actuated manually with the accuracy dependent on the operator's visual observation.

- A semi-automatic batcher is one that, when actuated, starts the weighing operations and stops automatically when the required weight has been reached. An interlock prevents batcher discharge until the required material is within tolerances.

- An automatic batcher starts and stops automatically and includes interlocks to (a) prevent charging until the scale returns to zero; (b) prevent charging if the discharge gate is open; (c) prevent discharge if the charging gate is open; and (d) prevent discharge until the material is within tolerances.

Batching systems consist of required combinations of these various types of batches and the interlocks. Virtually all automatic batching systems include provisions to switch over to manual control.

10. MIXING CONCRETE

10.1 Mixing

There are two principal categories of ready-mixed concrete. In the first, the mixing is done at a central plant and the mixed concrete is then transported, usually in an agitator truck. In transit the drum rotating slowly at about 1 or 2 revolution per minute so as to prevent segregation and undue stiffening of the mix. When the truck arrives on site, the drum should always be speeded up to about 10 to 15 revolutions per minute for at least 2 minutes to make sure that the concrete is thoroughly mixed and uniform before discharge. Such concrete is known as **central-mixed** concrete.

In the second category is transit mixed or **truck-mixed** concrete. Here the materials are batched dry at a central plant but are mixed in a mixer truck either in transit to the site or immediately prior to the concrete being discharged. The drum of the mixer should be rotated for 100 revolutions after the water has been added. As mixer drum usually rotates at about 10 to 15 revolutions per minute at the fast speed the mixing time required is about 7 to 10 minutes. Due to dry mixing, the mixer blades wear out rapidly. The blades should therefore be inspected regularly to ensure conformity with original setting.

Transit mixing permits a longer haul and is less vulnerable in case of delay, but the capacity of a truck used as a mixer is only about three-quarters of the same truck used solely to agitate pre-mixed dry concrete. Sometimes, the concrete is partially mixed at a central plant in order to increase the capacity of the agitator truck. The mixing is completed enroute. Such concrete is known as **shrink-mixed** concrete. Truck mixers usually have a capacity of 6m3 but 7.5m3 truck also exists. In both cases, water is added only minutes before reaching the point of discharge so that the initial setting time is not exceeded.

A truck mixer can discharge concrete at about 0.5m3 per minute, so that a fully loaded 5m3 truck discharging continuously takes only about 10 minutes. Although it may not always be possible to discharge at this rate, it is advantageous for the concrete to be discharged as quickly as possible especially when concreting during high ambient temperature conditions.

It should be explained that agitating differs from mixing solely by speed of rotation of the mixer. It may be noted that the speed of mixing affects the rate of stiffening while the total number of revolutions controls the uniformity of mixing. **And overriding limit of 300 revolutions in toto is laid down in ASTM C94 specification.** This is to limit grinding of soft aggregates and other undesirable effects on concrete in hot weather.

Of the three systems of mixing, central mixing is to be preferred.

10.2 Uniformity of Mixing

In any mixer, it is essential that sufficient interchange of materials between different parts of the chamber takes place, so that uniform concrete is produced. The efficiency of the mixer can be measured by the variability of the mix discharged into a number of receptacles without interrupting the flow of concrete. For instance, in Belgium the mix is discharged in eight parts and these are compared for homogeneity. A rather rigid test of ASTM Standard C94 lays down the samples of concrete should be taken from about 1/6 and 5/6 points of a batch, and the differences in the properties of the two samples should not exceed any of the following :

Density of concrete calculated to an air-free basis	16 kg/m3
Air content, volume % of concrete	1 percent
Slump	25mm when the average is 100mm, and 40mm when the average is 100 to 150mm.
Percentage aggregate retained on 5mm sieve	6%
Density of air-free mortar	1.6%
Compressive strength, average 7-day strength	7.5%

11. DELIVERY AND DELIVERY TIME

The main problem in the production of ready-mixed concrete is maintaining the workability of the mix upto the time of placing. Concrete stiffens with time and handling ready-mixed concrete often takes quite a long while. In the case of transit mixing, water need not be added till nearer the commencement of mixing, but the time during which the cement and moist aggregate are allowed to remain in contact should be limited to about **90 minutes** although an amendment to BS 5328 allows two hours.

Unless, however, the initial workability is high, the stiffening caused by prolonged agitation result in a concrete of very low workability especially in hot weather, when a high loss of water by evaporation takes place in addition to the loss of free water by hydration of cement. For this reason, concrete is sometimes re-tempered by the addition of water immediately before discharge; the workability is thus restored but it must be realized that resultant compressive strength will be affected and therefore retempering should not be permitted.

However, the argument of slump control versus water/cement ratio control continues. The solution lies in use of the statistical approach to water/cement ratio specifications which recognizes inherent variability and which encourages use of average water / cement ratio well below the intended maximum.

The producer is responsible for the ordered slump for 30 minutes after discharge of the concrete at the job site. Use of super-plasticizer to re-temper ready-mixed concrete on site instead of adding re-tempering water is recommended, subject to plasticizer being acceptable and proven to be harmless to concrete.

12. HOT WEATHER CONCRETING

The producer should deliver the ready-mixed concrete during hot weather at concrete temperatures as low as practicable. The temperature of concrete at the point and the time of delivery should be maintained at 25 degree celsius in peak summer to ensure that the temperature of the placed concrete does not exceed 35 degree celsius. To assist in keeping the temperature of concrete low it may be necessary to :

[1] Protect aggregate stockpiles from direct sun by shading.

[2] Use chilled water for mixing. Use of flaked ice to replace part of the mixing water is recommended. Truck mixers should be equipped with water tanks to supply chilled mixing water as may be required for truck-mixed concrete.

[3] Paint truck mixer drums white and insulate.

[4] Reduce hauling distance.

13. BATCH TICKET INFORMATION

The manufacturer of the concrete should furnish to the purchaser with each batch of concrete before unloading at the site, a delivery ticket on which is printed, stamped or written, information concerning said concrete as follows :

[1] Name of ready-mix batch plant.
[2] Serial number of ticket.
[3] Date.
[4] Truck number.
[5] Name of purchaser.
[6] Specific designation of the job.
[7] Specific class or designation of the concrete.
[8] Amount of concrete in cubic meters.
[9] Time loaded or of first mixing of cement and aggregate.
[10] Time when water is added to the mix for the first time.
[11] Reading of revolution counter at the first addition of water.
[12] Type and brand, and amount of cement.
[13] Type and brand, and amount of admixtures.
[14] Information necessary to calculate the total mixing water added by the producer. Total mixing water includes free water on the aggregates, water and ice batched at the plant, and water added by the truck operator from the mixer tank.
[15] Maximum size of aggregate.
[16] Weights of fine and coarse aggregate.
[17] Ingredients certified as being previously approved.
[18] Certifying that Chlorides and Sulphates are within specified limits.
[19] Signature or initials of ready-mix representative.

The representative of the purchaser should ascertain and record the delivery ticket number for the concrete and the exact location in the work at which each load represented by strength test is deposited.

14. QUALITY CONTROL

The manufacturer should afford all reasonable access for making necessary checks of the production facilities and for securing necessary samples to determine if the concrete is being produced in accordance with the specifications.

The contractor should afford all reasonable access and assistance for the procurement of samples of fresh concrete at the time of placement to determine conformance of it to the specification.

Slump, air content, and temperature test should be made at the time of placement at the option of the supervisor as often as is necessary for control checks. In addition, these tests should be made when specified and always when strength specimens are made.

The purchaser is responsible for deciding and informing the producer of the regime of sampling and testing which the purchaser will adopt. However, tests should generally be made with a frequency of not less than one test for each 10, 50, or 100 metre cube concrete depending upon the type of structure as shown in Table 6. Each test should be made from a separate batch. On each day concrete is delivered, at least one strength test should be made for each class of concrete. In any case, the minimum number of test specimens shall be six, three for 7-day test and three for 28-day test.

The producer should designate and maintain records for the concretes produced with codes numbers to enable the identification of class of concrete, name of the job, name of the client, etc....

The producer should supply calibration certificates for the testing machines and scales of the measuring equipments.

Sampling and testing of constituents materials, curing and testing of concrete, fresh and hardened, should be carried out in accordance with BS 1881 unless stated otherwise.

Table 6 - Sampling Rates

Type of Structure	Sampling to Represent a Volume of m3
1. Critical structures e.g. masts, cantilevers, columns	10
2. Intermediate structures e.g. beams, slabs, bridge decks	50
3. Heavy concrete construction e.g. breakwaters, solid rafts	100

14.1 Analysis of Fresh Concrete

In considering the ingredients of a concrete mix, one has to check whether actual proportions correspond to those specified. In practice, mistakes, errors, and even deliberate actions can lead to incorrect proportions. Therefore it is necessary to determine the composition of the concrete at an early stage; the two values of greatest interest are the cement content and water / cement ratio. The standardized test is prescribed in BS 1881 and the test has to be commenced virtually as soon as the concrete has been discharged from the mixture because loss of water can occur.

Compliance is assumed if the results of the analysis tests on fresh concrete show that :

- Cement content is not less than 95% of the specified minimum or more than 110% of the specified maximum.

- Free-water / cement ratio should not be more than 110% of the specified value.

Compliance of cement content can also be assessed by observation of the batching or from autographic records, in which case it should not be less than 95% of the specified minimum or more than 105% of the specified maximum.

As regards water / cement ratio, the **compliance** can also be assessed using the workability test results provided satisfactory evidence is available of the relationship between free-water / cement ratio and workability for the materials used.

14.2 Air-Content of Concrete

The percentage air-content determined from individual samples taken at the point of placing the concrete should be with +/- 1.5 of required value.

14.3 Temperature of Fresh Concrete

The temperature of the concrete at the time of delivery should not be more than the specified maximum plus 2 degree celsius, beyond which concrete should not be allowed for pouring unless sufficiently cooled and the initial setting time is not exceeded.

14.4 Density of Fully Compacted Concrete

The density, kg/m3, of fully compacted concrete should be +/- 5% of the value established at the mix design stage.

14.5 Strength Testing

For the assessment of strength, the sample should be taken at the point of discharge, it should be representative of the whole batch with increments being taken from different parts of the batch. Two test specimens should be prepared and cured for 28-days under specified conditions either normal or any other regime agreed to between the producer and purchaser.

On completion of curing, the specimens tested, the average of two results is taken as the test result.

Additional tests maybe made at other ages to obtain information for determining form removal time or when structure may be put in service.

Compliance with the specified characteristics strength is assumed if the conditions given in both (a) and (b) are met :

(a) the average strength determined from any group of four consecutive test results exceeds the specified characteristic strength by

3 N/mm2 for concretes of grade C20 and above,
2 N/mm2 for concretes of grade C7.5 to C15.

(b) the strength determined from any individual test result is not less than the specified characteristic strength minus.

3 N/mm2 for concretes of grade C20 and above,
2 N/mm2 for concretes of grade C7.5 to C15.

Quantity of concrete represented by strength test results.

The quantity of concrete represented by any group of four consecutive test results includes the batches from which the first and last samples were taken together with all intervening batches. When a test result fails to comply with (b) above, then only the particular batch from which the sample was taken would be at risk.

14.6 Non-Compliance

The action to be taken in respect of the concrete which is represented by the test results that failed to meet the requirements is to be determined by the purchaser. The consequences vary greatly. This may range from qualified acceptance to rejection and removal in the most severe cases. In determining the action to be taken, the purchaser should have due regard to the technical consequences of the kind and degree of non-compliance, and to the economic consequences of alternative remedial measures to ensure the integrity of any work in which the concrete has been placed.

Before determining the action to be taken, it is necessary to establish the validity of the test results, the mix proportions actually used and its effect on durability and the possible influence of any reduction in concrete quality and on strength.

The purchaser should carry out tests, if need be on hardened concrete. These may include non-destructive methods, proving load tests and / or taking of core samples.

The producer and purchaser confer in this connection and if they cannot agree, the matter can be arbitrated upon.

15. QUALITY ASSURANCE

Presently, there is no effective supervision / surveillance of ready-mix concrete plants, operations and ability to supply consistently the quality of the concrete grades ordered. Acceptance is generally made taking into account the personal integrity of the person and that of his company. There is an urgent need of a scheme to assist and certify the plants.

The Quality Scheme for Ready-Mixed Concrete (QSRMC) operation in United Kingdom has established to provide effective Quality Assurance Standards for ready-mix concrete. Under this Scheme technical regulations have been designed which contain two principal requirements :

- The establishment of a quality management system, and

- The achievement of product conformity through the application of detailed technical procedures viz design, control and production process.

The problem of obtaining accurate testing and of deciding what to do when test result fail to conform to specifications, continue to create problems for specifiers, contractors and producers. Increasingly sophisticated automation and recording devices will be more reliable and efficient and reduce batching errors to the practical minimum. Developments in the specifications, quality control, accelerated strength testing have great potential for reducing and quantifying the risks assumed by producers, contractors and clients alike. With a well conceived scheme / programme, improved testing and improved quality control of constituent material, the incidence of defective concrete could be reduced.

One additional change will be necessary if the system is to evolve. That is, the prescriptive requirements must be reduced or eliminated and the concrete producer must be able to change materials and proportions rapidly in response to varying materials, weather, job conditions, and acceptance testing procedures used for.

ADVISORY NOTE

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PRECAST CONCRETE PAVING BLOCKS

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C O N T E N T S

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ADVISORY NOTE
ON
PRECAST CONCRETE PAVING BLOCKS

DUBAI MUNICIPALITY
NOTE NUMBER 006
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1. INTRODUCTION

Concrete block paving is a product which has enjoyed increasing acceptance all over the world. It is a pavement surface particularly suited to the diverse requirements of to-day's traffic.

The use of concrete blocks for paving came into prominence in Holland and Germany in the 1950 s. Since then it has grown extensively, both there and in many other European countries where the market increased at compound rates. This high acceptance level is in large measure due to versatility of concrete block paving, in response to both aesthetic and high load situations where its traditional features, combined with its appearance, scale and load supporting ability enable it to contribute in a beneficial way to the environment. Concrete block paving is also cost-effective, does not require the use of expensive specialist paving plant, simple and cheap to lay, low in initial cost and provides a maintenance free surface throughout the design life of the pavement.

Although good appearance has undoubtedly had a major influence upon the popularity of concrete paving blocks, their practical advantages have helped considerably to extend their use and there has been a growing use of this form of paving in the U.A.E., in common with other countries. There are now many manufacturer's producing paving blocks in the country.

Access to services, which are frequently and unavoidably laid beneath carriage ways, can create a major problem in breaking out and reinstating the pavement. With concrete blocks, this problem is minimal and involves very little cost. Once the road surface has been broken into, the blocks can be lifted and recovered for re-use. The authority responsible for maintenance need only hold a very small stock of blocks to replace the few damaged in opening the trench. Concrete blocks can be trafficked immediately after reinstatement and making-good is invisible.

Modern housing estate roads are often complex in layout. Curves are introduced and road widths varied to add interest to the development, to make the best use of land and to restrict traffic movement and speed. This complexity adds considerably to the difficulties of construction and to the cost of traditional roads, but causes few problems when blocks are used.

Concrete blocks provide an ideal surfacing for many forms of pavement where the traffic travels at a low-speed (50-60 km/h). This includes many roads, goods yards, storage areas, dock side paving, roll-on roll-off and container terminals.

The blocks can also be used as an industrial surface, being highly resistant to point loads associated with trailer jacks or heavy duty racking or impacts. They are not readily damaged by high surface stresses, but form a flexible surfacing which can accommodate uneven settlement whilst still retaining continuity. If unacceptable settlements does occur, the blocks can be removed and re-used after the settlement has been made good . This ability to re-use the surfacing makes for considerable long term economies

Some road surfaces are softened by oil spillage, but this cannot happen to blocks although their surface may become stained. This resistance to oil is probably a major reason for their choice for car and lorry parks, bus lay-bys, bus stations, and petrol-station forecourts.

Colour can easily be introduced to produce colour concrete blocks. Pavers' range of colours make it possible to create a mosaic of parking space lines and directional signs, and eliminating painting. These will have an indefinite life which can, however, be terminated at will by unplugging the coloured blocks and replacing them with blocks of the surrounding colour.

In areas liable to uneven ground settlement, such as trench backfills or reclaimed land, blocks have special advantage in that they can be lifted and majority recovered for re-use.

Since its introduction to the country concrete block paving has consistently increased its range and volume of applications such as pedestrianization schemes (residential developments, town centers, shopping precincts, sports centers, hotel fore courts etc.) , car parks, or on roads catering for low-speed vehicular traffic.

This **ADVISORY NOTE** states the requirements for precast concrete paving blocks, giving criteria for materials, performance levels, dimensional deviations and guidance on items that should be considered while specifying them.

2. STANDARDS

The pre-cast concrete paving blocks are covered by the following standard specifications.

BS 6717 : Part 1. "Specification for Paving Block", is a manufacturing specification. It specifies requirements for the blocks intended for the construction of low speed roads and industrial and other paved surfaces subjected to all categories of static and vehicular loading and pedestrian traffic.

ASTM C 936. "Standard Specification for Solid Concrete Interlocking Paving Units" covers the requirements for the pavers manufactured for the construction of the paved surfaces.

DIN 18501 . " Concrete Pavement Setts" applies to pavement setts with or without facing concrete manufactured from mineral aggregates for the paving of roads, paths and squares.

3. CONCEPTS

Paving blocks covered by the above specifications are designed to form a structural element and the surfacing of the pavements, having the block to block joints filled so as to develop frictional interlock.

Concrete paving blocks form a 'flexible' surfacing because some degree of articulation can occur but the block still remain in contact. Friction between the vertical sides of the blocks provides interlock and load transfer to neighbouring units. This ability to articulate without significant joint opening can only be achieved with **small** units. Although blocks do have considerable load-spreading ability, without an adequate foundation they will be dislodged vertically. Block may also be moved horizontally by forces from vehicle tyres; to prevent this, blocks are made of special plan shapes or, in the case of rectangular blocks, are laid in a herringbone pattern.

The blocks most commonly used for roads are 60 mm and 80 mm thick and are small enough, in width and weight, to allow them to be picked up in one hand. For heavy industrial applications, 80 mm /100 mm thick blocks are used and, in some instances, 120 mm. No scientific reason has been established for using thicker blocks, but one possibility is that thicker blocks are less liable to rotate about their horizontal axis in areas where there is a great deal of slewing or breaking of very heavy loaded wheels.

In all cases, the blocks are laid on a layer of sharp sand and then vibrated with a steel-faced plate vibrator, which produces an even running surface and compact the sand, some of which is forced between the joints, starting the development of the interlock. The nominal thickness of the laying-course sand, after vibration, is 50 mm. Detailed advice on laying is covered by BS 6717:Part 3 "Code of Practice for Laying".

3.1 Shapes

The blocks are made in various shapes. The specifications place virtually no restriction on the plan shape of a block but seeks to ensure that the blocks can be picked up with one hand and that, when laid correctly, they will fit closely together. Convenient length : Width ratios are 1 1/2 and 2 but, to allow manufacturers freedom in shape design, the specification lay down only the limits for overall plan dimensions of blocks.

BS 6717: Part 1 specifies that rectangular blocks shall be 200mm in length and 100mm in width. The shaped blocks shall be of any shape fitting within a 295mm square co-ordinating space and shall have a width not less than 80mm.

ASTM C936 specifies that units shall not be greater than 240mm in length, or 160mm in width while DIN 18501 limits only the length to be not more than 280mm.

To minimize cutting and promote ease of laying, **special starter** blocks needed for various paved surface configurations are also produced by manufacturers of repute associated with the standard block types.

3.2 Thickness

As per British standard, the preferred thicknesses are 60mm, 65mm, 80mm and 100mm, while German specifications provides, in addition to these, 120mm and 140mm. The American specification however, specifies that the thickness shall not be greater 140mm.

The thickness of the paving blocks shall be selected in the light of the sub-base material, the subgrade soil, the load and the shape of the blocks.

3.3 Special Features

The blocks are produced with the following special features and the purchaser should specify the units having the desired particular features while ordering.

3.3.1 **Chamfer.** An edge chamfer around the wearing surface of blocks is to be preferred as it will subtly emphasises the laid pattern and reduces trip risk. The standard however, does not preclude the square edge profiles. British standard specifies that a chamfer size should not exceed 7mm in width or depth.

3.3.2 **Colour.** The blocks are produced in colours-red, buff, charcoal, grey, brown, etc.- so that a wide variety of designs are possible for special effects and demarcation. The blocks are generally produced in **"through " colours** and when required the units can be **"surface applied" reflective colour** types.

3.3.3 **Surface Finish.** The blocks are made with different types of wearing course or textured surfaces.

4. MATERIALS AND MANUFACTURE

4.1 Materials

4.1.1 **Cement** used in the manufacture of precast concrete paving block should comply with the requirements of either OPC (BS 12) or SRPC (BS 4027) or MSRPC (ASTM Type 2) or **DM ADVISORY NOTE NUMBER 002.,** as specified.

4.1.2 **Aggregates** used should consist of naturally occurring crushed or uncrushed materials comply with either BS 882 (except grading requirements in clause 5) or **DM ADVISORY NOTE NUMBER 001.,** as specified.

4.1.2.1 Coarse Aggregate

The coarse aggregate used should be 10mm nominal size.

4.1.2.2 Fine Aggregate

Paving blocks manufactured using fine aggregates containing excessive amounts of acid-soluble material are prone to develop polish quickly and become slippery. To ensure that paved surface does not develop polish but retains a micro-structure to give a good low-speed skidding resistance when trafficked, limit on the **acid-soluble material** in fine aggregates is specified.

Results obtained by using accelerated wear machine on pavement quality concrete have shown that, when natural siliceous sand forms all or part of the fine aggregate, adequate resistance to skidding is retained. In the case of precast concrete paving blocks it is possible that other fine aggregates will have similar adequate skidding resistance but, unless evidence of this can be provided, it is preferred that the fine aggregate used in the manufacture of the blocks should contain a minimum of 25% natural siliceous sand.

Pending a development of a test method for skid resistance of precast concrete block paving, BS 6717 excludes the use of fine aggregate containing significant amounts of acid-soluble material, some of which have found to give poor polishing resistance. More specifically, the standard stipulates that the fine aggregate shall contain not more than 25% by mass of acid-soluble material.

The percentage of acid-soluble material shall be determine by the test method described in BS 812 : Part 119

4.1.2.3 **Deleterious Salt contamination**

In particular, deleterious salt contents in aggregates should not exceed the following limits depending upon the cement type used in the concrete mix.

Salts as % wt. of agg.	Aggregate Fine	Aggregate Coarse
Acid soluble chlorides (Cl) % Max.		
when SRPC cement is used	0.03	0.02
when OPC or MSRPC cement is used	0.05	0.04
Acid soluble sulphates (SO3) % Max.	0.30	0.30

4.1.3 **Water** shall be clear and free from organic impurities, having a pH value in the basic range of 7 - 9. The inorganic impurities should not exceed the following limits :

	Maximum concentration	Limits, ppm
[1]	Chloride as Cl	250
[2]	Sulphates as SO3	350
[3]	Alkali carbonate and bicarbonates	500
[4]	Total dissolved ions, including 1, 2, 3 above	2000

4.1.4 **Pigments** used should comply with BS 1014.

4.1.5 **Admixtures** used should comply with requirements of BS 5075 : Part 1. However, chloride and chloride based admixtures should not be used. Preference should be for the use of lignosulphonate based water reducing agents.

4.1.6 **Control of chlorides and sulphates** The acceptable levels of equivalent acid soluble chlorides and sulphates as specified above for aggregates and water are indicative and subject to the over-riding limits for the mixes as given below :

	By weight of cement in the mix
Acid soluble chlorides (Cl) % Max.	
If concrete made with OPC / MSRPC	0.40
If concrete made with SRPC	0.12
Acid soluble sulphates (SO3) % Max.	3.7

4.2 Manufacture

The manufacturing process of blocks is carried at some plants in the Emirate on the latest automatic machines. Batching of mix constituents, mixing and moulding operations does not involve any manual involvement. Accuracy in size and shape of the blocks is ensured through vibration presses. The block pellets are belt conveyed to the curing chambers. The curing process involves steam treatment. Curing time ranges from 8 to 10 hours. Following the curing process, the blocks are automatically depalletised and sent to the cuber. The block cubes are then dispatched to the storage yard.

5. REQUIREMENTS

5.1 Cement Content

Concrete used for paving blocks, in orde to ensure durability, have a higher cement content of not less than **400 kg/m3** of the compacted concrete.

5.2 Condition

Pavement blocks shall be manufactured with a dense structure, free from cracks. Pores resulting from the manufacturing process are of no significance where serviceability is concerned, provided that the requirements specified in the following paras 5.3 to 5.7 are met.

In **composite paving blocks,** the wearing surface layer must be formed as an integral part of the core concrete of the block and shall be not less than 5mm thick. These shall comply with compressive strength requirement (para 5.5) without **delamination.**

5.3 Dimensional Tolerances

Blocks must be manufactured to accurate dimensions. The dimensional tolerances are meant to ensure that blocks can be laid closely together and allow the development of interlock when the joints are filled with sand.

The permissible deviation from the stated work size of paving blocks, measured in accordance with appendix A1 of BS 6717 : Part 1, shall be +/- 2mm for length and width and +/- 3mm for thickness. In addition, normality between block sides and the wearing surface; and parallelism of the opposite faces shall be assessed in accordance with appendix A2 of BS 6717 : Part 1.

5.4 Water Absorption

Water absorption (average of 3 specimens) tested in accordance with ASTM method C140 "Method of Sampling and Testing Concrete Masonry Units" shall not be greater than 5% with no individual result greater than 7%.

5.5 Compressive Strength

At the time of delivery to the work site, or at the latest when they are 28-days old, the compressive strengths as required by different specifications are given below :

Standard	**Test sample size**	**Conditioning of specimens**	**Strength not less than Average (N/mm2)**	**Individual (N/mm2)**
BS 6717	16 Nos.[(1)]	Wet [(2)]	49	40
ASTM C936	3 Nos.	Dry	55	50
DIN 18501	5 Nos.	Dry	60	50

(1) BS 6717, however states that, if the average crushing strength of the first four blocks tested is not less than 54 N/mm2 and if none of these four blocks has a crushing strength of less than 40 N/mm2, the consignment shall be considered to comply with this standard.

(2) The wet specimen indicate a lower strength compared to its strength in dry condition. The loss of strength due to wetting of a specimen is caused by dilation of the cement gel by adsorbed water : the forces of cohesion of the solid particles are then decreased.

The **Dubai Municipality** requires that average strength of 10 paving blocks sampled in accordance with clause 6.4 of this NOTE and tested as described in appendix B of BS 6717 : Part 1 shall not be less than 49 N/mm2 and with no block less than 40 N/mm2.

5.6 Tensile Strength

The consensus of the task group responsible for formulation of ASTM C936 is that compressive strength does not truly express a significant property of paving block. Rather, flexural property evaluated by means of a tensile splitting test will be more meaningful. Test data in this respect is being developed and evaluated to arrive at a specification value.

5.7 Performance

Field performance of paved surfaces in few cases has not been very satisfactory. The surfaces showing signs of erosion. The causes could be inadequate strength, poor resistance to attacks from sulphate and chloride bearing sub-soil water at places where the water table is too close to surface, and / or stagnant surface water where the paved surfaces are not laid to required falls and gradients to shed the water to drain away.

Choice of suitable cement type, selection of suitable aggregates, proper design of concrete mixes, application of adequate vibro-compaction effort during manufacture of blocks and adoption of sound practices for the construction of paved surfaces would definitely ensure satisfactory service performance. As an additional measure, use of silicate or similar type of additives could be used integrally with the mix to reduce the permeability of cement matrix of the block to further enhance the service performance.

5.7.1 **Test for Performance against Salt Attack**

The blocks complying with the requirement specified in paras numbers 5.2 to 5.6 above are meant to ensure their satisfactory in-service performance. However, there is no specific standard test method for the **direct** assessment of overall service performance of block units and block paved surfaces exposed to aggressive actions of salt-laden surface conditions. There is a need to evolve an accelerated test method for this purpose.

Perhaps, DIN 52206 "Testing Roofing Slates, Acid Resistance Test", ASTM D3774 "Aggregate Durability Index" and ASTM C88 "Standard Test Method for Soundness of Aggregates" could provide guidance in the development of such method.

5.7.2 **Test for Abrasion Resistance**

Abrasion resistance is one of the service performance requirements in ASTM specification. Neither BS nor DIN standards specify any requirement for abrasion resistance of paving blocks, while ASTM C936, Clause 4.4 does. This clause requires that when tested in accordance with ASTM C418, "Test Method for Abrasion Resistance of Concrete by Sand Blasting", specimen shall not have a greater volume loss than 15 cm3 per 50 cm2 and average thickness loss shall not exceed 3mm.

This test method covers the laboratory evaluation of the relative resistance of concrete surface to abrasion. This procedure simulates the action of water borne abrasives and abrasives under traffic on concrete surfaces. As there is not much of water borne abrasive action in the prevalent service conditions of the Emirate, this test method is not quite applicable. Other test procedures are available in ASTM Standards for measuring abrasive resistance of concrete surfaces.

They are outlined in :

> ASTM C779 "Test Method for Abrasion Resistance of Horizontal Concrete Surfaces"
> and
> ASTM C944 "Test Methods for Abrasion Resistance of Concrete or Mortar Surfaces by Rotating - Cutter Method".

The C944 closely represent the prevalent service conditions and hence recommended as an alternative to C418 for evaluating relative wear resistance of paving blocks.

6. QUALITY CONTROL

6.1 Sources

Individual paving units shall be obtained from approved source(s) or manufacturer(s) but no section of the paving shall be constructed with a mixture of units from differing sources.

6.2 Visual Inspection

All units shall be hard, sound, square, clean with sharp well defined arises and free of cracks or other defects that would interfere with the proper placing of the unit or impair the strength and service performance of the paved surfaces. Minor chipping resulting from customary methods of handling in shipment and delivery, shall not be deemed grounds for rejection.

The purchaser or his authorized representative shall be permitted access to the place where paving blocks are manufactured, for the purpose of examining and sampling the materials and the finished blocks from the lots ready for delivery.

6.3 Compliance

Compliance with the requirements specified shall be verified by inspection, comprising internal control and third party inspection.

6.3.1 Internal Control

The manufacturer shall operate a quality control scheme which shall be available for inspection by prospective purchaser and inspecting agency. Type, minimum scope and frequency of internal control shall be as follows :

[a] Once per day of production and for each manufacturing machine,the block dimensions and squareness shall be checked for four units.

[b] Twice per week of production and for each manufacturing machine, but at least once per 1000 Nos. of blocks, the compressive strength shall be checked for four blocks deriving from the production of different days.

Deviations from the scope and frequency of testing may exceptionally be permitted by the inspection agency and are also permissible in cases where the inspection, especially of the records of internal control, has not given rise to any complaints and are adequate for the works in question.

6.3.2 Third Party Inspection

Third party mentioned herein shall be the **Dubai Municipality Laboratory.** The inspection shall involve testing of the following :

[a] Dimensions
[b] Compressive strength
[c] Water absorption
[d] Abrasion resistance
[e] Cement content of the mix
[f] Constituent materials of concrete

6.3.3 Certificate of Compliance

The manufacturer shall provide the purchaser with a certificate of compliance with the specification. This certificate shall state that the manufacturer has made arrangements for his products to be sampled and tested at regular intervals.

6.4 Sampling

A representative sample of paving blocks required for test purposes shall be selected to the mutual satisfaction of manufacturer, and purchaser. The sample shall be taken either immediately before delivery, or as soon after delivery as convenient to all parties.

Two specimens shall be drawn at random from each group of 1000 blocks for every designated 5000 block section or part thereof in a consignment. All samples shall be clearly marked at the time of sampling in such a way that the designated section or part thereof and the consignment represented by the sample, are clearly defined.

6.4.1 Number of Specimens

The nuber of specimens required for each test shall be as follows :

[a] For routine testing

For dimensional checks and compressive strength determination : 10

[b] For optional testing, when specified

Water absorption determination	: 3
Abrasion resistance test	: 3

Test for cement content determination from the broken fragments of blocks tested for compression.

6.4.2 Identification

[a] **Mark on blocks :** Line mark(s) not exceeding 3 mm projection and 5 mm wide on the side faces of units and groove(s) matching to the projection(s) on the opposite side face. Number of line marks, their position and spacing shall be according to those assigned by Dubai Municipality to each of the manufacturer.

[b] The metallic strap tying each consignment unit / cube (e.g. package of blocks) to be embossed / clipped to furnish the following information :

- Manufacturer's Logo
- Lot Number
- Production Number
- Date of Production
- D.M. Certification Mark

[c] Certificate of Compliance as per 6.3.3

ADVISORY NOTE

NUMBER : 007 **AUGUST, 1990**

CONCRETE MASONRY BLOCKS

ADVISORY NOTE
ON
CONCRETE MASONRY BLOCKS

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C O N T E N T S

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ADVISORY NOTE
ON
CONCRETE MASONRY BLOCKS

DUBAI MUNICIPALITY
NOTE NUMBER 007
AUGUST 1990

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1. INTRODUCTION

It is essential that the choice of form of construction and design decisions are made with the actual exposure conditions in mind. Because the corrosion of reinforcement is the main cause of rapid deterioration of the concrete and loss of structural integrity, there is a strong case for using block work or plain concrete wherever this is an acceptable alternative to reinforced concrete. Unreinforced masonry or unreinforced concrete containing no crack-control reinforcement has many applications and they can be more durable in aggressive exposure conditions than concrete which is reinforced only to limit crack-widths.

Masonry is an assemblage of structural units, either laid in-situ or constructed in prefabricated panels, in which the structural units are bonded or solidly put together with mortar or grout. Structural units comprise calcium silicate (sandlime) bricks (BS 187) ; clay bricks and blocks (BS 3921); stone masonry (BS 5390); precast concrete masonry units (BS 6073) and reconstructed stone masonry units (BS 6457).

This **ADVISORY NOTE** states the requirements for precast concrete masonry blocks, giving criteria for materials, performance levels, dimensional deviations and guidance on items that should be considered while specifying them.

2. STANDARD

The BS 6073 : Parts 1 & 2 specifies precast concrete bricks and blocks designed both for load bearing and non-load bearing masonry and used primarily to build external and internal walls as specified in BS 5628 : Parts 1, 2 and 3, Code of Practice for Use of Masonry.

For the purpose of distinguishing between a brick, a block and a panel, the following definitions apply :

A **brick** is a unit not exceeding 337.5mm in length, 225mm in thickness or 112.5mm in height.

A **block** is a unit exceeding in length or height, the dimensions stated for a brick but no work size dimension to exceed 650 mm.

A **panel** is a unit in which the height exceeds the length or six times the thickness, and is outside the scope of this standard.

The specification covers masonry units made using lightweight aggregate concrete, autoclaved aerated concrete and normal weight concrete. But in this **NOTE,** the block units made with concrete using natural aggregates only are considered.

3. MATERIALS AND MANUFACTURE

3.1 Materials

3.1.1 **Cement** used in the manufacture of concrete masonry block should comply with the requirements of either OPC (BS 12), (ASTM Type I) or SRPC (BS 4027), (ASTM Type V) or MSRPC (ASTM Type II) or **DM ADVISORY NOTE NUMBER 002.,** as specified.

The cement content in the concrete mix used for the manufacture of blocks should not be less than **200 kg/m3** of concrete.

3.1.2 **Aggregates** used should consist of naturally occurring crushed or uncrushed materials complying with either BS 882 (except grading requirements in clause 5) or **DM ADVISORY NOTE NUMBER 001.,** as specified. The coarse aggregate used should be 10mm nominal size for standard blocks. In particular, deleterious salt contents in aggregates should not exceed the following limits depending upon the cement type used in the concrete mix.

Salts as % wt. of agg.	Aggregate Fine	Aggregate Coarse
Acid soluble chlorides (Cl) % Max.		
when SRPC cement is used	0.03	0.02
when OPC or MSRPC cement is used	0.05	0.04
Acid soluble sulphates (SO3) % Max.	0.30	0.30

3.1.3 **Water** shall be clear and free from organic impurities, having a pH value in the basic range of 7 - 9. The inorganic impurities should not exceed the following limits :

	Maximum concentration	Limits, ppm
[1]	Chloride as Cl	250
[2]	Sulphates as SO3	350
[3]	Alkali carbonate and bicarbonates	500
[4]	Total dissolved ions, including 1, 2, 3 above	2000

3.1.4 **Pigments** used should comply with BS 1014.

3.1.5 **Admixtures** used should comply with requirements of BS 5075 : Part 1. However, chloride and chloride based admixtures should not be used. Preference should be for the use of lignosulphonate based water reducing agents.

3.1.6 **Control of chlorides and sulphates :** The acceptable levels of equivalent acid soluble chlorides and sulphates as specified above for aggregates and water are indicative and subject to the over-riding limits for the mixes as given below :

	By weight of cement in the mix
Acid soluble chlorides (Cl) % Max.	
If concrete made with OPC / MSRPC	0.40
If concrete made with SRPC	0.12
Acid soluble sulphates (SO3) % Max.	3.7

3.2 **Manufacture**

The manufacturing of blocks is carried at various plants in the Emirate using the latest automatic machines. Batching of mix constituents, mixing and moulding operations do not involve any manual involvement. Accuracy in size and shape of the blocks is ensured through vibrations involving hydraulic pressure with a high speed of 360 rpm. The block pellets are belt conveyed to the curing chambers. The curing process involves steam treatment. Curing time ranges from 8 to 10 hours. Following the curing process, the blocks are automatically depalletised and sent to the cuber. The block cubes are then dispatched to the storage yard.

In some plants, the blocks are normally produced by semi-manual operations In such cases, the blocks should be made in approved block making machines. The materials for all blocks shall be correctly measured / batched and mixed in approved mechanical mixers and shall be gauged with sufficient water to enable the materials to bind together under pressure. Water / cement ratio shall be strictly governed to produce stiff mix of zero slump. The concrete mix is then placed in the block making machines in layers and machine vibrated and simultaneously applying pressure. Immediately after moulding, the blocks shall be placed on clean, level, non-absorbent pallets. The blocks shall be protected from the direct sun rays in an approved manner. Blocks shall be cured by being kept thoroughly wet by means of water, sprinklers or other approved means for a specified period but in all cases not less than 10 days. After which they can be stacked in honeycomb fashion. Solid stacking should not be permitted. Each batch of blocks shall be marked in a distinguishing manner.

4. CONCRETE BLOCKS

The concrete block has become increasingly popular in the Gulf, primarily because of its inherent advantages as a building material. It not only provides strength, economy and resistance to fire, but its insulation qualities make it ideal for hot climates.

4.1 Types of Blocks

Solid Block : A block having no formed holes or cavities.

Hollow Block : A block which has one or more formed holes or cavities which pass through the block.

Cellular Block : A block which has one or more formed holes or cavities which do not wholly pass through the block.
The thickness of the closed face should not be less than 20mm.

Special Types : These include quoin or closure units , split fluted block, textured face block, fair faced block, screening block, purpose-made shaped units for arches, etc.

4.2 Shape

The shape of a block is that of a body defined by rectangles. Their end faces may be plain and provided with grooves or be grooved and tongued.

Though blocks with plain end faces are specified and in fact some block manufacturing plants in the Emirate do produce such blocks, but from the performance point of view , blocks with profiled / grooved end faces are to be preferred. Typical profiled / grooved end face details as specified in BS 6073 : Part 2 or DIN 18151 : Lightweight concrete hollow blocks or DIN 18152 : Lightweight concrete solid bricks and blocks could be adopted.

Grooves and tongues provided on end faces should ensure proper keying of the joint faces, with the depth of fit of the tongue in the groove being not less than 10mm.

The cavities in the hollow and cellular blocks should be evenly distributed and must have voids ranging between 25 to 50 percent with a minimum external shell thickness of 35mm or 1.75 times the nominal maximum size of aggregate, whichever is greater.

4.3 Dimensions and Tolerances

Standard dimensions or work size of a block are the manufacturer's designated dimensions. To obtain the nominal size of masonry block, add the nominal mortar joint width, which is normally 10mm, to the work size length and height of the block, while the thickness remains unchanged.

No overall dimensions (length, height or thickness) should differ by more than 3mm at any point from the standard dimensions.

When measuring the length of grooved and tongued blocks, the tongue shall be ignored.

Tolerances for special shapes of units for which special tolerances are necessary, the purchaser should agree on the shape, tolerance and appropriate methods of measurements with the manufacturer. Likewise, end face groove patterns, dimensions, and associated limit deviations should also be agreed upon.

BS 6073 : Part 2 specifies a range of work sizes of blocks. The lengths range from 390mm to 590mm with appropriate heights and thicknesses from 60mm to 250mm. For the blocks made using normal weight aggregate concrete, however, the weight of an individual unit from the handling consideration point of view restrict the choice of work sizes. A 390mm dimension for the length could be quite suitable. Locally both hollow and solid blocks are manufactured with the following dimensions :

Length (mm)	Height(mm)	Thickness(mm)
390	190	190
390	190	140
390	190	90
400	200	200

Strictly, some of the above dimensions are non-standard. A full-size modular block's standard dimensions should be 390mm in length, 190mm in height, and 200mm in thickness

Load bearing block sizes are to have thickness not less than 200mm.

5. PHYSICAL REQUIREMENTS

At the time of delivery to the work site the blocks shall conform to the following physical requirements :

5.1 Strength

Masonry blocks of thickness 75mm or greater are tested for compressive strength and those with thickness less than 75mm are tested for transverse strength.

5.1.1 Compressive Strength

Ten block specimens, as sampled in accordance with clause 6.4 shall be tested in compression as specified in BS 6073 : Part 1, Appendix 'B'.

Compressive strength of a specimen is obtained by dividing the maximum load carried by the specimen during the test by the gross-cross-sectional area of the unit. The gross area of a unit is the total area of a section perpendicular to the direction of the load, including areas within cells and within re-entrant spaces unless these spaces are to be occupied in the masonry by portions of adjacent masonry.

D.M. Specification requires that concrete blocks shall have an average compressive strength of 12.5 N/mm2 with a minimum individual strength of not less than 10 N/mm2 for load bearing blocks; and an average strength more than 7.5 N/mm2 with a minimum individual strength not less than 6 N/mm2 for non-loading blocks.

The BS 6073 : Part 2, however requires that for a specified strength, say, **G,** and the average of the ten results, **Xav** shall satisfy the following two conditions :

[a] **Xav** greater than or equal to **G**

and

[b] **Xav** greater than or equal to **(0.9 G + 0.62 S)**

where **S** is the standard deviation of the sample.

It can be shown that the conditions stipulated in the DM Specifications, in other words, requires a standard deviation of 2 or less for load bearing blocks case and 1.21 or less for non-load bearing blocks.

The British Standard permits a secon sample of ten units to be tested in case the first set of results does not satisfy both the conditions. A similar option should be provided when the test results are assessed on the basis of DM Specification as well.

TEST SPECIMENS - BS 6073 specifies a sample of ten specimens to be tested while ASTM C140 (Standard Methods of Sampling and Testing of Concrete Masonry Units) specifies three units and DIN 18152, six units for initial testing and three numbers for routine testing. Further, air-dry samples are subjected to load according to ASTM & DIN specifications while BS 6073 require the test specimen shall be test loaded in soaked-wet condition. The wet specimen indicate a lower strength compared to its strength in dry condition. The loss of strength due to wetting of a compression test specimen is caused by the dilation of the cement gel by adsorbed water : the forces of cohesion of the solid particles are then decreased.

5.1.2 Transverse Strength

For determination of transverse strength, blocks are tested in accordance with appendix 'C' of BS 6073 : Part 1. The average transverse strength of five blocks shall be not less than 0.65 N/mm2.

5.2 Drying Shrinkage

Drying shrinkage is defined as the change in linear dimension of the test specimen due to drying from a saturated condition to an equilibrium weight and length under specified accelerated drying conditions.

The average drying shrinkage of a sample of masonry units tested in accordance with appendix 'D' of BS 6073 : Part 1 should not exceed 0.05 %.

5.2 Water Absrption

Water absorption (average of 3 units) tested in accordance with ASTM method C140 shall not exceed 15% of its dry weight.

5.3 Apparent Density

The apparent density, is the mass of the block dried to constant mass at 105 degree centigrade divided by the unit volume (product of length, width and height). The dry mass is found by drying whole units or fragments. The results shall be expressed in kg/m3 as the mean of three results. The apparent density is determined in accordance with a method given in Appendix 'C' BS 6073 : Part 2.

5.4 Optional Requirements

The purchaser shall also specify any other required properties, such as net area, colour and texture.

The net area of hollow block is required for assessing the characteristic compressive strength of hollow concrete blocks filled with in-situ concrete. A method for determining net area is given in Appendix 'C' BS 60733 : Part 2.

6. QUALITY CONTROL

The strength of masonry unit is the main significant factor in the determination of the characteristic strength of masonry walls. Safety factors used in the application of the design procedures of load bearing masonry walls is related to the quality control exercised. The value adopted should be commensurate with the degree of control exercised during the manufacture of the block units, and the ability of the supplier to meet the requirements for compressive strength of the units. Two levels of controls are recognized :

- First, the normal category where the strength meet the requirements of BS 6073 : Part 2

- Second, the special category where the supplier agrees to supply the units to a specified "acceptance limit for strength " with a probability of not more than 2.5% of being below the acceptance limit, and operates a quality control scheme to enable the acceptance limit is consistently being met in practice.

6.1 Sources

Individual masonry units shall be obtained from approved source(s) or manufacturer(s) but no section of the work shall be constructed with a mixture of units from differing sources.

6.2 Visual Inspection

All units shall be hard, sound, square, clean with sharp well defined arises and free of cracks or other defects that would interfere with the proper placing of the unit or impair the strength or permanence of the construction. Minor chipping resulting from customary methods of handling in shipment and delivery, shall not be deemed grounds for rejection. For load bearing walls cracked blocks shall not be permitted.

Where units are to be used in exposed wall construction, the face or faces that are to be exposed shall be free of chips, cracks, or other imperfections, except that if not more than 5% of a shipment contains small chips not larger than 20mm, this shall not be deemed grounds for rejection. Further, the manufacture shall supply batches of units to ensure that no patchiness results from allowable manufacturing or natural variations in colour.

The purchaser or his authorized representative shall be accorded proper facilities to inspect and sample the units at the place of manufacture from the lots ready for delivery.

6.3 Compliance

Compliance with the requirements specified shall be verified by inspection, comprising internal control and third party inspection.

6.3.1 Internal Control

The manufacturer shall operate a quality control scheme which shall be available for inspection by prospective purchaser and inspecting agency. Type, minimum scope and frequency of internal control shall be as follows :

[a] Once per day of production and for each manufacturing machine, the block height shall be checked for three units.

[b] Once per day of production and for each manufacturing machine, dimension and apparent density shall be checked for one unit.

[c] Once per week of production and for each type of solid or hollow block and manufacturing machine, but at least once per 1000 m3 of processed concrete, the compressive strength shall be checked for three units deriving from the production of different days.

Deviations from the scope and frequency of testing may exceptionally be permitted by the inspection agency and are also permissible in cases where the inspection, especially of the records of internal control, has not given rise to any complaints and are adequate for the works in question.

6.3.2 Third Party Inspection

Third party mentioned herein shall be the **Dubai Municipality Laboratory.** The inspection shall involve testing of the following :

[a] Dimensions
[b] Compressive strength
[c] Drying shrinkage
[d] Water absorption
[e] Constituent materials of concrete

6.3.3 Certificate of Compliance

The manufacturer shall provide the purchaser with a certificate of compliance with the specification. This certificate shall state that the manufacturer has made arrangements for his products to be sampled and tested at regular intervals.

6.4 Sampling

A representative sample of masonry units required for test purposes shall be selected to the mutual satisfaction of manufacturer, and purchaser. The sample shall be taken either immediately before delivery, or as soon after delivery as convenient to all parties.

The specimens shall be drawn at random from every designated section or part thereof in a consignment. All samples shall be clearly marked at the time of sampling in such a way that the designated section or part thereof and the consignment represented by the sample, are clearly defined.

6.4.1 **Number of Specimens**

The number of specimens required for each test shall be as follows :

For dimensional checks and compressive strength determination	: 10
Drying shrinkage determination	: 4
Water absorption determination	: 3
Apparent density determination	: 3

For the strength, drying shrinkage, absorption and apparent density 20 units shall be selected from each lot of 10,000 units or fraction thereof and 40 units from each lot of more than 10,000 or less than 100,000 units. For lots of more than 100,000 units, 20 units shall be selected from each of 50,000 units or fraction thereof contained in the lot. Additional specimens may be taken at the discretion of the purchaser.

6.4.2 **Identification**

[a] **Mark on Blocks :** Quality control mark, as approved by Dubai Municipality, shall be provided in the form of "frog" on top face of each block.

[b] The metallic strap tying each consignment unit (e.g. package of blocks) to be embossed / clipped to furnish the following information :

- Manufacturer's Logo
- Strength Class
- Lot Number
- Production Number
- Date of Production
- D.M. Certification Mark

[c] Certificate of compliance as per clause 6.3.3