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THE RELIABILITY OF CUBE COMPRESSIVE TEST TO MONITORING
7 AND 28 DAY CONCRETE STRENGTH

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ABSTRACT

Each concrete used for construction purposes must passed several tests set by Jabatan Kerja Raya that has been stated in the Standard Specification for Building Work JKR (2005). One of the mandatory tests is the compression test of concrete. This test is a necessary test to ensure the concrete used has a high quality and reach its maximum strength. The concrete compressive test result normally shows the value of strength which is higher than the actual strength of the concrete. This study was conducted to investigate the reliability of the concrete compression test results in statistical analysis. There are 269 data taken from six construction projects and improvements projects. This data is from G30 and G35 grades of concrete for concrete maturity on 7 days and 28 days. From analysis, it is proved that the strength of concrete received higher than the actual concrete strength with the average difference for the G30 at 7 days and 28 days maturity is 12.52 N/mm² and 12.93 N/mm² respectively. While for the G35, the average difference is 10.94 N/mm² and 7.17 N/mm² for 7 days and 28 days concrete maturity. Overall, the reliability of the concrete compressive strength is doubtable and this may be due to several factors such as method of curing, water / cement ratio and method of compaction use.

ABSTRAK

Setiap konkrit yang digunakan untuk tujuan pembinaan harus melepasi beberapa ujian yang telah ditetapkan oleh Jabatan Kerja Raya yang telah tertakluk didalam buku khasnya, Standard Specification for Building Work 2005. Salah satu ujian wajib adalah ujian mampatan konkrit. Telah menjadi satu keperluan ujian ini dijalankan untuk memastikan konkrit yang digunakan mempunyai kualiti yang tinggi dan mencapai kekuatan maksimum konkrit. Akan tetapi keputusan ujian konkrit kebiasaannya menunjukkan nilai kekuatan yang jauh lebih besar dari kekuatan sebenar konkrit tersebut. Kajian ini dijalankan untuk mengkaji keboleh percayaan keputusan ujian mampatan konkrit secara statistik analisis. Terdapat sejumlah 269 data yang diambil daripada 6 projek pembinaan dan penambahbaikan. Data tersebut adalah daripada gred konkrit G30 dan G 35 untuk tempoh kematangan konkrit pada hari ke 7 dan ke 28. Setelah dianalisis, terbukti bahawa kekuatan konkrit yang diterima adalah lebih jauh daripada kekuatan konkrit sebenar dengan purata perbezaan bagi G30 adalah 12.52 N/mm^2 untuk 7 hari tempoh kematangan dan 12.93 N/mm^2 untuk 28 hari tempoh kematangan. Manakala bagi G35, purata berbezaan adalah 10.94 N/mm^2 untuk 7 hari tempoh kematangan dan 7.17 N/mm^2 untuk 28 hari tempoh kematangan. Secara keseluruhannya, keboleh percayaan terhadap kekuatan konkrit adalah diragui dan ini mungkin disebabkan beberapa factor seperti kaedah pengawetan, nisbah air/simen dan cara pemadatan konkrit.

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENT	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
1	INTRODUCTION	
	1.1 Introduction	1
	1.2 Problem Statement	2
	1.3 Objective	3
	1.4 Scope of Work	3
2	LITERATURE REVIEW	
	2.1 Introduction to Concrete	4
	2.2 Characteristic of Fresh Concrete (Workability)	4
	2.3 Characteristic of Fresh Concrete (Hydration)	7
	2.4 Characteristic of Fresh Concrete (Bleeding)	8
	2.5 Properties of Hardened Concrete	9
	2.6 Destructive test (Compressive Test)	11
	2.7 Sampling and Testing	13
	2.8 Batching Plant	17
	2.9 Concrete Transportation	19

3**METHODOLOGY**

3.1	Introduction	21
3.2	Study Area	22
3.3	Data Collection	22
3.4	Analysis using SPSS	22
3.4.1	Key in Data	23
3.4.2	Scattering	25
3.4.3	Define Mean	27

4**RESULT AND DISCUSSION**

4.1	Introduction	30
4.2	Data Collection	30
4.3	Average Compressive Test	31
4.4	Obtain Concrete Strength and Concrete Grade again Sample (G30 day 7)	35
4.5	Mean Compressive Test for G30 day 7	36
4.6	Obtain Concrete Strength and Concrete Grade again Sample (G30 day 28)	40
4.7	Mean Compressive Test for G30 day 28	41
4.8	Obtain Concrete Strength and Concrete Grade again Sample (G35 day 7)	44
4.9	Mean Compressive Test for G35 day 7	45
4.10	Obtain Concrete Strength and Concrete Grade again Sample (G35 day 28)	48
4.11	Mean Compressive Test for G35 day 28	49
4.12	Differences between Obtain Concrete Strength Mean with Required Concrete Strength	51
4.13	Comparison Of Obtain Concrete Strength with Required Concrete Strength as State in Standard Specification for Building Work 2005 (JKR)	54

5 CONCLUSION AND RECOMMENDATIONS

5.1	Introduction	56
5.2	Conclusion	56
5.3	Recommendation	60

REFERENCES	61
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LIST OF TABLES

TABLE NO	TITLE	PAGE
2.1	Prescribed Mixes for General use per Cubic Meter of Concrete by Weight Batching	13
2.2	Compressive Strength Requirements for Prescribed Mix	14
2.3	28 Day Strength Compliance Requirements for Designed Mix	15
2.4	Quantities of concrete required	16
4.1	Record Compressive Data	31
4.2	Average Compressive Test for 3 Cubes	32
4.3	Case Processing Summary (G30 day 7)	37
4.4	Mean Compressive Test G30 day 7	37
4.5	Case Processing Summary (G30 day 28)	41
4.6	Mean Compressive Test G30 day 28	41
4.7	Case Processing Summary (G35 day 7)	45
4.8	Mean Compressive Test G35 day 7	45
4.9	Case Processing Summary (G35 day 28)	49
4.10	Mean Compressive Test G35 day 28	49
4.11	Differences between Obtain Concrete Strength Mean with Required Concrete Strength	52
4.12	Chemical Composite in Cement	52
4.13	Type of cement and it used	53
4.14	Percentages Difference between Proposed Grade Concrete with Standard Specification for Building Work 2005 (JKR)	55

LIST OF FIGURES

FIGURE NO	TITLE	PAGE
2.1	Slump Type	5
2.2	Hopper	6
2.3	Vebe test Apparatus set up	6
2.4	Illustration of the effect of water/cement ratio in concrete strength	10
2.5	Schematic of concrete batching and mixing plant	18
2.6	Batching and mixing process flowchart	18
2.7	Concrete Mix truck	19
3.1	Research flowchart	21
3.2	Analysis flowchart	23
3.3	Variable set up flowchart	24
3.4	Naming Variable	24
3.5	Keyed in data	25
3.6	Scattering process flowchart	26
3.7	Scatter plot	26
3.8	Overlay scatter plot	27
3.9	Determined mean flowchart	28
3.10	Define mean	28
3.11	Choosing variable	29
4.1	Obtain Strength and concrete grade again Sample (G30 day 7)	36

4.2	Obtain Strength and concrete grade again Sample (G30 day 28)	40
4.3	Obtain Strength and concrete grade again Sample (G35 day 7)	44
4.4	Obtain Strength and concrete grade again Sample (G35 day 28)	48
4.5	Loss strength through incomplete compaction	54
5.1	Relationship between concrete strength and sample G30 day 7	57
5.2	Relationship between concrete strength and sample G30day 28	57
5.3	Relationship between concrete strength and sample G35day 7	58
5.4	Relationship between concrete strength and sample G35day 28	59

CHAPTER 1

INTRODUCTION

1.0 Introduction

Concrete is important material in construction and nearly ninety percent of Malaysia building is making from concrete. Concrete composed aggregates, cement and water. Generally, this compound produced reaction between hydraulic cement and water. Grade of a concrete show the compressive strength of the concrete. The ratio of aggregates, cement and water was determined by design mix concrete form in achieving the desired strength of concrete.

To ensure the mix is achieved the design strength, few tests must be done. One of the common tests is cube strength test. The common test used was cube compressive test, which carry out at 3 days, 7 days and 28 days concrete maturity. There several reasons that require cube compressive test. First it is assumed that the most important properties of concrete as directly related to compressive strength. Second concrete has little tensile strength and is used primarily in compression and lastly structural design codes are based on compressive strength.

1.1 Problem Statement

It is mandatory requirement to take cubes samples for each batch of concrete used in construction. According to Standard Specification for Building Work 2005 (JKR), clause 4.2, emphasized that compressive strength tests shall be carried out during concreting work. Sampling shall be taken one sample per 10.0 m³ or every group of 10 batches for critical structures such as pre-stressed concrete, masts, cantilevers, columns, footing, pile caps, shear wall and retaining wall. Meant for slabs and beams one sample per 20.0m³ or every group of 20 batches. Meanwhile for raft foundation and mass concrete, one sample per 50.0 m³ or every group of 50 batches and for each sampling, three cubes shall be made from a single sample taken from a randomly selected batch of concrete. The sample shall be taken at the point of discharge from the mixer or, in the case of ready mixed concrete, at the point of discharge from the delivery vehicle. All cubes shall be clearly marked with undeletable paint with the date of casting and serial number for record. A recorded data shall be kept to identify each cube relating to the part of the concreting work. One cube from each sample batch shall be tested at 7-day compressive strength. The remaining two cubes from the sample batch shall be tested for the 28-day compressive strength.

The 28 – day strength of these cubes is regarded as the strength of the concrete placed. It is common average cube strength is higher than the target mean strength and this is well accepted. However, there is possibility the concrete strength can be reduced to some value that is acceptable. This project is proposed to statically study the concrete grade versus the in-situ strength.

1.2 Objectives

1. To identify the reliability of concrete strength at 7 day and 28 day for G30.
2. To identify the reliability of concrete strength at 7 day and 28 day for G35.
3. To identify the possibility to reduce the concrete grade.

1.3 Scope of work

1. Statistically study the concrete grade versus the in-situ cube strength.
2. Study areas cover Kuantan and Pekan.
3. Data collection only covers Kuantan and Pekan in Pahang Darul Makmur.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Concrete

Concrete is composite material that commonly use in construction industry, concrete composed of cementitious material, aggregate, water and chemical admixtures. Cementitious material can be fly ash and slag cement, but in construction Portland cement commonly used (Prof Madya Dr. A.B Mohamad Diah, 2000). Concrete is a name applied to any of a number of compositions consisting of sand, gravel, crushed stone, or other coarse material, bound together with various kinds of cementitious materials, such as lime or cements. When water is added, the mix undergoes a chemical reaction and hardens (Glen E.A and Richard H, 1997).

2.2 Characteristic of Fresh Concrete (Workability)

Workability can be interpreted as a pleasure to pour concrete into the mold. It can also be defined as the ability of concrete to be placed and compacted. Usually wet concrete are more workable than dry concrete, but concrete of same consistence may vary in workability.

Workability of a concrete can be measured using slump test, compacting factor test and vebe test. Slump test is measured by type of slump as shown in figure 2.1. A true slump is measured when the concrete is evenly to the cone and keeping more or less shaping. The cone should have $200 \pm 2\text{mm}$ diameter of base, $100 \pm 2\text{mm}$ diameter of top and $300 \pm 2\text{mm}$ of high (BS 1881: Part 102). A shear slump is said when the concrete the top portion of the concrete shears off and slips sideways. Collapse slump will happen when the concrete is collapse completely. Only true slump is satisfied to use in construction.

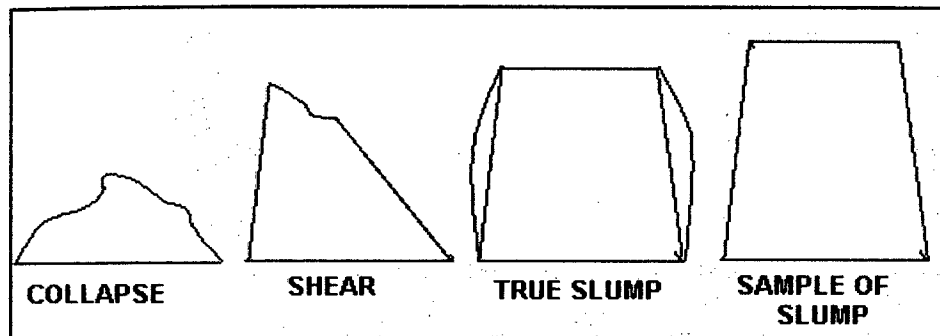


Figure 2.1: Slump type (Mu'men Tawfiq Atoom, 2000)

Second test in measured workability of a concrete is compacting factor test. Compacting factor test measures the degree of compaction resulting from the application of a standard amount of work. Compacting factor test is carry out by using hopper. Figure 2.2 show detail dimension of the hopper. A hopper should consist two conical hoppers mounted above a cylinder. The interior surface of the hopper and cylinder should be smooth and free from projections such as protruding rivets and shall be free from dents. Compacting factor is determined by dividing mass of partially compacted concrete with mass fully compacted concrete (BS 1881: Part 103).

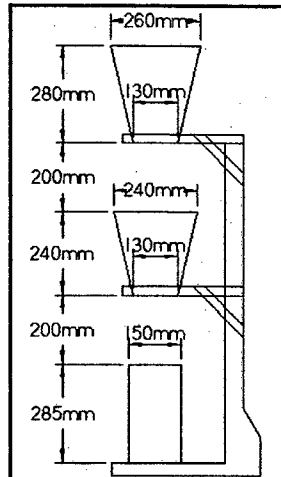


Figure 2.2: Hopper (Eric P. Koehler and David W. Fowler, 2003)

The third test usually use in determined workability of a concrete is vebe test. The Vebe time test is a more scientific test for workability than the Slump Test, in that it measures the work needed to compact the concrete. Set up of a vebe test is call Consistometer as shown in Figure 2.3. Consistometer comprising a container, a slump cone, a vebe table or vibrating table and a rotating arm (BS 1881: Part 103).

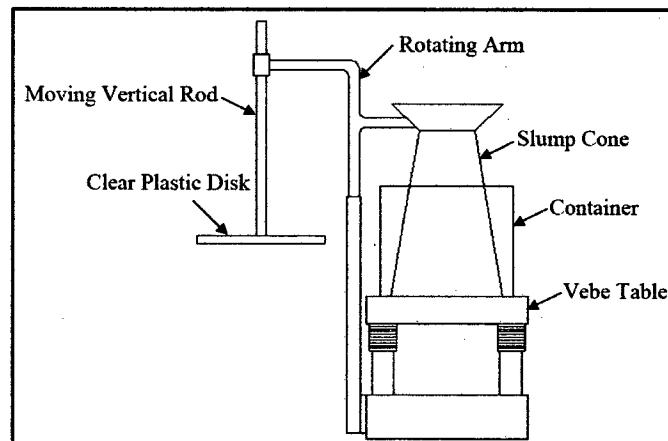


Figure 2.3: Consistometer (Eric P. Koehler and David W. Fowler, 2003)

Strength of concrete is adversely and significantly affected by the presence of voids in the concrete. It is vital to eliminate void in concrete in order to achieve a maximum density. Presence of voids in concrete reduces the density and greatly

reduces the strength. 5% of voids can lower the strength by as much as 30%. This requires sufficient workability for virtually full compaction to be possible using a reasonable amount of work under the given conditions.

2.3 Characteristic of Fresh Concrete (Hydration).

Concrete derives its strength from the hydration of cement particles. The hydration of cement is not a momentary action but a continuous process. Rate of hydration is fast at initial stage but continues over a very long period, rate of hydration is decreasing slowly with time. In actual work, a higher water/cement ratio is used. Since the concrete is open to atmosphere, water in the concrete evaporates and the available water in the concrete will not sufficient for effective hydration to take place particularly in the top layer.

If the hydration is continue, extra water must be added to refill the loss of water due to absorption and evaporation. Therefore, the curing process is the initial process in creating a conducive environment for the early period of hydration without interruption. The conditions required in this process are suitable temperature and ample moisture. During the hydration process, the concrete will release high heat of hydration. This heat is harmful the stability of the concrete volume. Hydration can produce shrinkage in the concrete and leading to cracks. If the heat generated be extracted in the correct way, the adverse effect caused by hydration of the concrete can be reduced. This process can be done with careful water curing methods.

2.4 Characteristic of Fresh Concrete (Bleeding)

Bleeding in concrete referred as profit water gain. Segregation form when some of water comes out to the surface of the concrete because water has the lowest gravity force among materials in concrete. Bleeding is normally seen in a very wet poor mixing concrete, poor mixing concrete and insufficiently mixed concrete. Sometimes the bleeding can be seen in thin structures such as roof slab or road slabs when it is exposed in the sunny weather. Bleeding rate increases with time up to about one hour or so and thereafter the rate decreases but continues more or less till the final setting time of cement.

While the water flows out crossing from inside concrete to the concrete surface. It will produce a continuous channel if the water / cement ratio used is more than 0.7 and the channel will remain ongoing bleeding and unsegmented. These channels are often responsible for causing bleeding permeability of concrete structures. In the beginning of the process, channeling can be intercepted by the aggregate. Bleeding of water may have accumulated the aggregate. Water retention of water and reduce the voids create the bond between aggregate and paste.

Sometimes, the cement will also be going out with water on the surface concrete. Formation of cement paste at the concrete surface is known as "Laitance". In such cases, the surface of the slab and sidewalk will not have good quality to use. Laitance that develop on the concrete will generate dust in summer and mud during the rainy season.

This process is normally called flaky aggregates. It is similar with situation when water is accumulates below reinforcing bar and it weaken bond between the reinforcement bar and concrete. The poor bond between the aggregate and the paste or the reinforcement and the paste due to bleeding can be remedied by re vibration of concrete. The formation of laitance and the consequent bad effect can be reduced by delayed finishing operations.

2.5 Properties of Hardened Concrete.

Hardening process is process when fresh concrete is continuous to harden and gain strength due to time. This process will carry out after preparation of fresh concrete. Once concrete has hardened it can be subjected to a wide range tests to prove its ability to perform as planned or to discover its characteristics if its history is unknown.

Properties of hardened concrete can be classified into strength, durability, deformation and permeability. Strength of concrete is commonly considered to be its most valuable property, from other characteristic such durability, impermeability and volume stability. Strength usually gives an overall picture of concrete quality because it is directly related to the structure of cement paste (Neville A. M., 1995).

Primary function of concrete is to carry applied loads and it usually express as strength. Strength is an index to other property performance including durability and permeability. The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water, and admixtures. The water/cement ration is the main factor for determine concrete strength. The effect of water/cement ratio to the concrete strength is shown in 2.4. The lower the water-cement ratio, the higher is the compressive strength. A minimum amount of water is necessary for the proper chemical action in the hardening process, but adding extra water in concrete will help in increasing concrete workability and for the same time reducing concrete strength. Actual strength of concrete is greatly affected by quality control procedures for placement and inspection. In United State concrete strength is denoted f'_c which is the compressive strength test is in cylinder 6 inches in diameter and 12 inches high. The compressive test is measured on the 28th day after concrete made. (Vahid. K. Alilou and Mohammad. Teshnehlab., 2010).

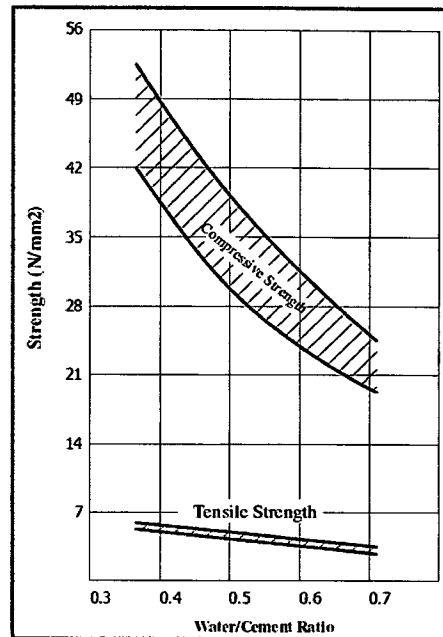


Figure 2.4: illustration of the effect of water/cement ratio in concrete strength, (Vahid. K. Alilou & Mohammad. Teshnehlab. 2010).

Durability is to concrete because it is essential that concrete should be capable to withstanding conditions that has been designed throughout the life of a structure (Neville, A. M. 1995). Weathering, reaction aggregate, attack by sulfates, efflorescence and reaction with organic chemicals are behavior of durability.

Permeability of concrete is process where liquid or gases can travel through concrete. This property is interest in relation to the water-tightness of liquid-retaining structure and the chemical attack (Neville, A. M. 1995). Concrete has a tendency to be porous due to the presence of void formed during or after placing. To produce concrete low permeability, full compaction and proper curing must carried out. Permeability of concrete can be reduced by reducing the water content or by increasing the cement content. Low permeability of concrete is important in increasing resistant to frost action and chemical attack and in protecting embedded steel against corrosion.

2.6 Destructive Test (Compressive Test)

In destructive test or compressive test, tests are carried out to the specimen's failure. Compressive test is carried out in order to understand a specimen's structural performance or material behavior under different loads. These tests are much easier to carry out, more information can be obtained, and are easier to understand than nondestructive testing. Compressive test is most suitable and economic.

The compression test shows the best possible strength concrete can reach in perfect conditions. The compression test measures concrete strength in the hardened state (Concrete Basics. August 2004). Strength of a given concrete specimen is influenced by several factors such as the rate of loading, moisture condition, specimen size and curing conditions. Furthermore, the type of testing machine influences the test result recorded. Consequently, we need to standardize procedures in the manufacture of test specimens and in their testing in order to assess accurately the quality of concrete (Neville, A. M., 1995).

In Malaysia, there have usually use three standard cord of practice which is BS 1881, Standard Specification for Building Work 2005 and MS 26 methods of testing. Hardened Concrete.

BS 1881 clarify that concrete strength tests should be conducted to determine the strength of concrete, the test specimens shall be concrete cubes made, cured and stored as explained in section 2.6 in this chapter. If the cube is badly moulds or clearly misshapen, then test should not proceed. Compressive strength should be calculating using equation 2.1.

$$\text{Compressive strength, } F_{cc} = F / A \quad \dots 2.1$$

Area, A = Width x Length (Area of specimen on which the compressive force acts)

Force, F = Maximum load recorded at failure expressed in Newton.

Calculate the compressive strength of each cube dividing the maximum load by the cross-sectional area. The result should be express to the nearest 0.5 N/mm^2 .

20 standard concrete samples and 20 duplicates sample are used to compute the mean and different in order to find sampling error. The average value and the difference rounded to the nearest 0.25 N/mm^2 . Mean and different for standard concrete is express as M_s and D_s , while mean and different for duplicates concrete sample is express as M_d and D_d . Record each calculation of the mean to the nearest 0.25 N/mm^2 . Sampling error and testing error is determined by using equation 2.2 until equation 2.6. Sampling error and testing error should be to the nearest 0.1% .

$$\text{Testing variance } (V_t) = (SD_s^2 + SD_d^2)/80 \quad \dots (2.2)$$

$$\text{Testing plus sampling variance } (V_{ts}) = S(M_s - M_d)^2/40 \quad \dots (2.3)$$

$$\text{Mean strength } (M) = (SM_s + CM_d)/40 \quad \dots (2.4)$$

$$\text{Sampling error (in per cent)} = (100 \sqrt{V_{ts}} - 0.5 V_t) / M \quad \dots (2.5)$$

$$\text{Testing error (in per cent)} = (100 \sqrt{V_t}) / M \quad \dots (2.6)$$

Second standard cord of practice that usually use is Standard Specification for Building Work 2005 (JKR). In this standard, the compressive strength of concrete shall be measured by crushing tests on nominal 150mm cubes as specified in MS 26 Testing Of Concrete - Part 1: Fresh Concrete - Section 4: Degree Of Compactability (Second Revision). A prescribed mix shall be judged on the basis of the specified mix proportions based on the batches observation. The mix proportion shall be within 5% of the values specified and the workability shall be chosen to suit the construction requirements as described in Table 2.1. Based from this specification, design mix strength should not more than 5% of the test results may be expected to

fall. Compliance with the specified characteristic strength shall be judged by tests made on cubes at an age of 28 days.

Table 2.1- Prescribed Mixes for General use per Cubic Meter of Concrete by Weight Batching (Standard Specification for Building Work 2005 (JKR))

Grade of Concrete 28 day strength of concrete (N/mm ²)		Nominal Max Size of Aggregate (mm) 20			Max Free water Cement Ratios
		Workability	Medium	High	
		Slump Limits (mm)	25 – 75	75 – 125	
15P	15	Cement (kg)	280	310	0.6
		Total Aggregate(kg)	1800	1750	
		Fine Aggregate (%)	35 - 50	35 – 50	
20P	20	Cement (kg)	320	350	0.55
		Total Aggregate(kg)	1800	1750	
		Fine Aggregate (%)	25 - 40	20 – 45	
25P	25	Cement (kg)	360	390	0.5
		Total Aggregate(kg)	1750	1700	
		Fine Aggregate (%)	25 – 40	30 – 45	
30P	30	Cement (kg)	400	430	0.45
		Total Aggregate(kg)	1700	1650	
		Fine Aggregate (%)	25 - 40	30 - 45	

2.7 Sampling and Testing

In Standard Specification for Building Work 2005 (JKR), sampling and testing should be carried out by an engineering laboratory approved by the S.O. For each sampling, three cubes shall be made from a single sample taken from a randomly selected batch of concrete. Compressive strength tests shall be carried out during the concreting work. Sampling for critical structures such as pre-stressed concrete, masts, cantilevers, columns, footing, pile caps, shear wall, retaining wall shall be taken one sample per 10.0 m^3 or every group of 10 batches. Meanwhile for slabs and beams one sample per 20.0 m^3 or every group of 20 batches for slabs and beams. For foundation and mass concrete samples should be taken one sample per 50.0 m^3 or every group of 50 batches. One cube from each sample batch shall be tested for the 7-day compressive strength. The remaining two cubes from the sample batch shall be tested for the 28-day compressive strength. The appropriate strength requirement of prescribe mix shall be complied at least one of the following conditions. First condition is none of the two test cubes is below the specified compressive strength as specified in table 2.2. Second condition is average strength of the two test cubes is not less than the specified compressive strength and the difference between the two strengths is not more than 20% of the average.

Table 2.2: Compressive Strength Requirements for Prescribed Mix (Standard Specification for Building Work 2005 (JKR))

Grades of Concrete	28-day Strength of Concrete	Cube Strength at 7 Days	Average Cube Strength at 28 Days
	N/mm^2	N/mm^2	N/mm^2
20P	20.0	14	20.0
25P	25.0	17	25.0
30P	30.0	20	30.0
40P	40.0	27	40.0

For designed mix, at least four samples (12 cubes) shall be taken of concrete on the first day of concreting for each grade of concrete to be used in the work, irrespective of the volume of concrete produced or the sampling rate. The average strength of the two cubes shall constitute the 28-day compressive strength of the sample. When the difference between the two results divided by their mean exceeds 15%, the test results shall be deemed invalid. For compliance purposes of the specified compressive strength, both of the following conditions shall be satisfied. First condition that must be satisfied is mean strength determined from the first two, three or four consecutive test results, or from any group of four consecutive test results complies with the appropriate limits in column A of table 2.3. In this respect, consecutive samples are samples taken at intervals for the day of concreting or one complete continuous process of concreting. Second condition must be satisfied is any individual test result complies with the appropriate limits in column B of table 2.3.

Table 2.3: 28 Day Strength Compliance Requirements for Designed Mix (Standard Specification for Building Work 2005 (JKR))

Specified Grade of Concrete	Group of Test Results:	A The mean of the group of the results exceeds the specified characteristic compressive strength by at least (N/mm ²)	B Any individual test result is not less than the characteristic compressive strength less (N/mm ²)
20 and above	First 2	1	3
	First 3	2	3
	Any consecutive 4	3	3
Below 20	First 2	0	2
	First 3	1	2
	Any consecutive 4	2	2