RESEARCH CORPORATION OF THAILAND

RESEARCH PROGRAMME NO. 21
MATERIALS FOR CONCRETE

RESEARCH PROJECT NO. 21/6
DESIGN OF CONCRETE MIXES

REPORT NO. 1
ELEMENTARY MIX DESIGN TECHNIQUE

BY
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ASRCT, BANGKOK 1973
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ELEMENTARY MIX DESIGN TECHNIQUE

By Jens Overgaard* and Narong Sukapaddhanadhi*

SUMMARY

A relatively simple method of designing concrete mix to obtain a concrete that matches given requirements, both in the soft and the hardened state, is described. It emphasises on showing contractors and manufacturers of concrete and concrete products how to control the various properties of concrete. The report is not intended to give recipes for different set mixes. This, on the other hand, should enable users to design and, where necessary, to adjust concrete mixes to meet specific requirements.

As some of the diagrams reflects results from a limited number of laboratory experiments, users are encouraged to plot results obtained from their practical work in the diagrams and, where necessary, adjust the diagrams to match their own experience.

INTRODUCTION

The cement based building materials constitutes in Thailand - as in most other countries - the largest single group of the country's consumption of building materials, and the local cement factories produces cement of a quality that fulfils internationally recognized standard.

However, the concrete produced is often of a fairly poor quality, and as its constituents are generally good, it can only be because of inadequate manufacturing technique and quality control.

There are as present no Thai Standard for Concrete and Reinforced Concrete Structures and specifications are therefore usually set for each individual job. They vary from very loose requirements of a volumetric mix to more precise requirements of minimum strength, type of aggregates and cement, control etc.

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Regardless of unclear specifications and responsibilities, neither the builder nor the contractor wants to see their new structure collapse or deteriorate at an early stage, and without a Standard Specification to refer to, it becomes a question of tradition and economy how good concrete that will go into the structure.

However, with a rational approach and a little knowledge of concrete technology the contractor will be in a better position to predict the quality of the concrete he is making, and it is this technique that is described here.

Manufacture of good concrete also calls for quality control. The benefits that can be obtained by using quality control and procedures for testing concrete are described in another ASRCT publication: Quality control on concrete.

ELEMENTARY MIX DESIGN TECHNIQUE

To ensure a good quality concrete, there are a number of factors to consider:

1. Water-cement ratio, w/c
2. Cement content, kg/m^3
3. Compaction (handtamp or vibrate)
4. Soundness of aggregates and grain distribution
5. Quality of cement (type)
6. Mixing
7. Curing condition.

These seven are some of the most important.

As the initial stage of making concrete, that is designing the mix, there are usually two demands to comply with:

1. Consistency of the fresh concrete (slump in cm)
2. Strength of the hardened concrete (kg/cm^2) or durability.

CONSISTENCY

The consistency is mainly dependent on the amount of water added— more water results in softer and more easily workable concrete, but unfortunately extra water will also result in lower strength unless we add extra cement at the same time. Since cement is costly, we want to minimize the cement content, and we will therefore also have to minimize the water content.

The amount of water needed to give a certain consistency depends almost only on the grain size distribution of the sand and the shape of the grains. Sand with a high percentage of large grains with a round shape and a smooth surface will need less water than aggregates with fewer large grains of a flat or angular shape and a rough surface.

The possibilities for manipulating the grain size distribution of the sand to reduce the necessary amount of water are usually limited to mixing two or three different sands. Sieving and removing or adding certain fractions are usually too expensive operations.

It is however necessary to have about 13-17% material passing the 0.125 mm sieve (including the cement), otherwise the fresh concrete will not have sufficient cohesion and it will have a tendency to "separate" when poured out of the mixer or into the mould. Only when the cement content reaches about 400 kg/m^3, will the cement alone constitute 17%. It is therefore important when making concretes with low cement content to have enough fine material in the sand. It is also easier to compact a concrete which has enough fine material.

Some reduction of the water can be achieved by adding a small percentage of chemicals, commercially sold as "plasticizers". They should be used with care and the manufacturer's instructions must be followed minutely, since otherwise they can do more harm than good.

The size of the stones should always be chosen as large as possible. But also here limits are set by the distance between the sides of the mould and the spacing of the reinforcement. A choice of the most suitable maximum grain size can be obtained from Table 1.

TABLE 1. MAXIMUM GRAIN SIZE FOR VARIOUS STRUCTURES

Smallest dimension of the structure (cm)	Unreinforced (mm)	Medium reinforced (mm)	Heavily reinforced (mm)
5 - 15	16 - 32	16 - 32	8 - 16
15 - 30	32 - 64	16 - 32	16 - 32
30 - 75	64	32 - 64	32

The amount of sand to be added to the stones to achieve a good grain size distribution depends on the biggest grain size used and the method of compacting the concrete in the mould, see Table 2.

TABLE 2. PERCENTAGE OF SAND (SMALLER THAN 4 MM) IN AGGREGATE

Maximum grain size in mm	8	16	32	64
Placing by hand tamping	65%	50%	40%	35%
Placing by vibrating	60%	45%	35%	30%

The grain size distribution of the sand for concrete should be smooth and preferably fall within the limit of the two curves a and b in Figure 1. The grain size of the stones is less important, but it should not be too uniform. The curve d is an example of a good combination of sand and stone.

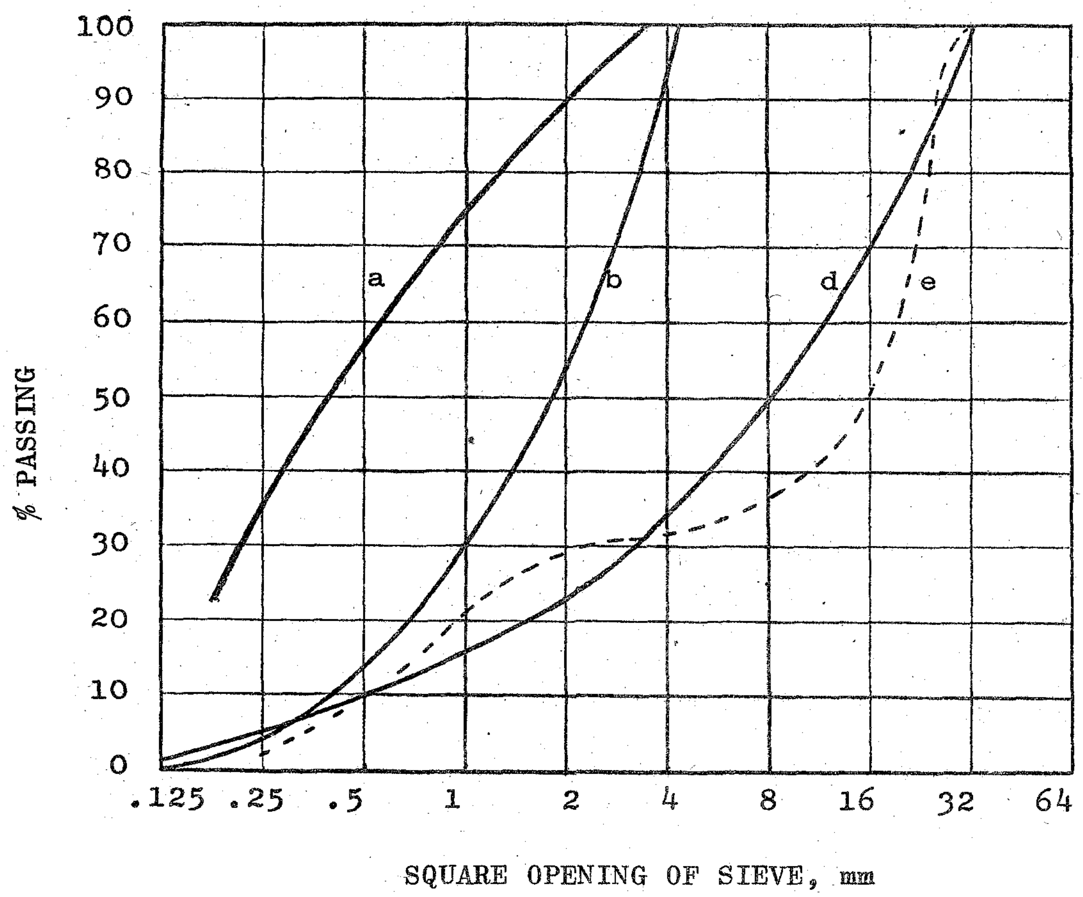


Figure 1. Grain size distribution for concrete sand and mixed aggregates.

Test have been made in the laboratory to establish the relation between water content and slump for concrete made with common aggregates available in Bangkok. The grain size was distributed as curve e in Figure 1 (65% crushed limestone, maximum grain size 30 mm and 35% construction sand). This relation is given in Figure 2, and it can be used as a guideline when disigning concrete mix with such materials. Users should plot their own results on the graph and adjust the line to suit their own experience, when enough results have accumulated.

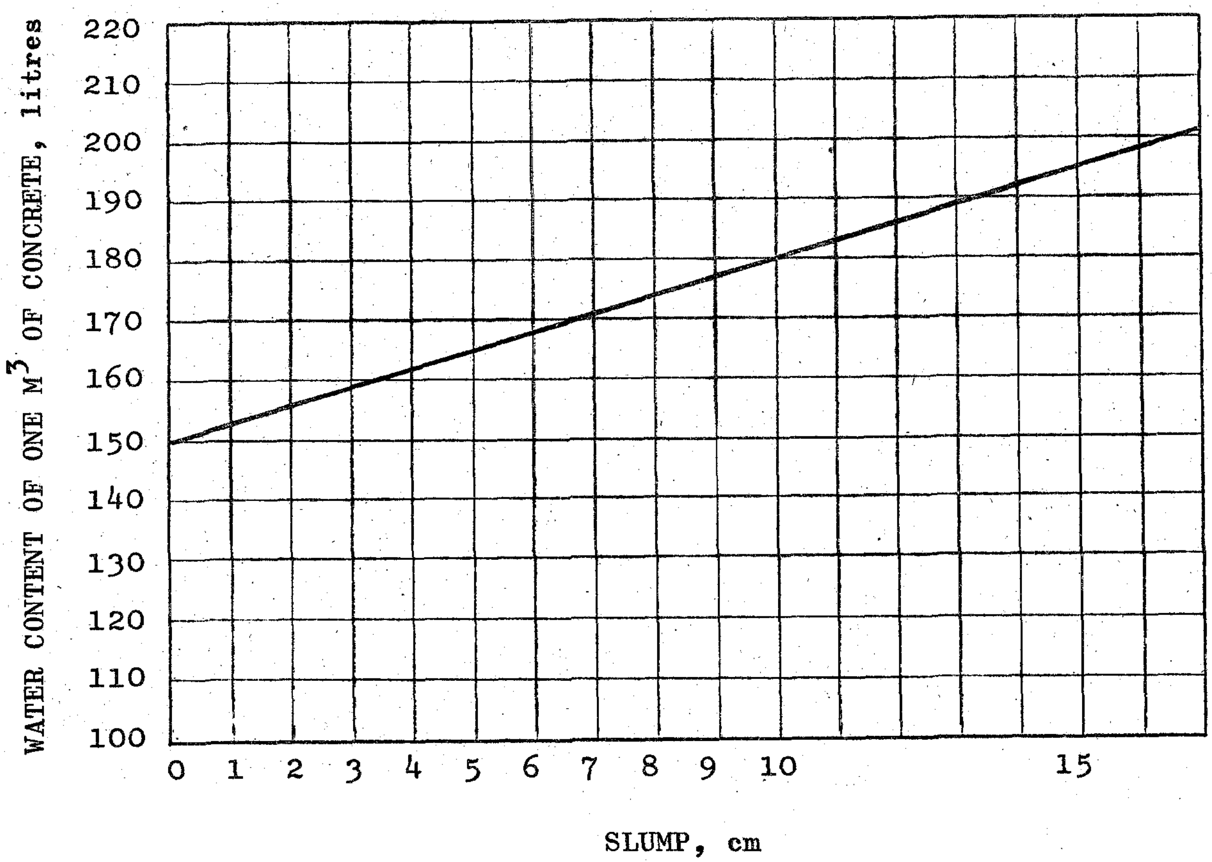


Figure 2. Water content in relation to plasticity measured by slump cone.

Concrete with a low cement content and a high water content may have a tendency to gather water on the surface and inside the concrete beneath the bigger stones. It is especially the case when the sand has a low content of filler -- the very fine particles. This is called "bleeding" and should be avoided by either reducing the water content or adding filler, such as fly ash or fine ground silica sand.

The consistency has a strong influence on the ability of concrete to fill the mould well and eliminate its air content. It should therefore be adjusted to the type of construction in question and the method of compaction. Table 3 may be used as a guideline.

TABLE 3. MAXIMUM SLUMP FOR VARIOUS LOADBEARING BUILDING COMPONENTS

	Handtamped concrete	Vibrated concrete
Thin heavily reinforced walls, beams, or columns	15 cm	8 cm
Slabs, beams, and reinforced walls	12 cm	5 cm
Thick unreinforced walls or foundations	10 cm	5 cm
Large unreinforced bodies	8 cm	5 cm

A certain amount of air will always remain in the concrete, even with a very thorough compaction. By vibrating the concrete, it is possible to drive out more of the air entrained by the mixing, than by tamping by hand. An estimate of the remaining air can be obtained from Table 4.

TABLE 4. NATURAL AIR CONTENT IN LITRES PER M^3 PLACED CONCRETE

Size of largest stones in mm:	8	16	32	64
Placed by tamping	30	25	20	15
Placed by vibrating	20	15	10	5

DURABILITY AND STRENGTH

If a durable and waterproof concrete is desired, certain limits for water-cement ratio and cement content has to be observed. First the cement paste itself (cement + water) must be waterproof, and experience has shown that this is the case, when the water-cement ratio does not exceed 0.65 for Portland cement and 0.85 for rapid hardening cement. Second, there must be enough cement paste to fill the cavities between the grains in the aggregate and a surplus of about 10-20%, depending on the means of compaction. The volume of cavities in per cent, can be found by first determining the bulk specific gravity of the well mixed and compacted aggregates, G, and insert in the formula:

$$\text{open volume in } \% = 100\left(1 - \frac{G}{2.65}\right)$$

This open volume usually amounts to 20-25%. The density of most cements is 3.1 kg/l. We can now determine the minimum quantity of cement necessary for making a durable and dense concrete:

Open volume : 20% or 200 litres/m^3

Cement paste (cement + water) : 200 litre + 10% = 220 litres

water/cement ratio : 0.65

$$\frac{\text{cement}}{3.1} + \text{cement} \times 0.65 = 220 \text{ litres}$$

$$\text{cement} = \frac{220}{(\frac{1}{3.1} + 0.65)} = 227 \text{ kg cement/m}^3 \text{ concrete}$$

This is equivalent to $4\frac{1}{2}$ bags cement per m^3 concrete, or the well known volumetric mix 1:3:5.

Experiments have shown that for a given type of cement, compaction and curing conditions, only the water-cement ratio will influence the compressive strength. This relationship can, within the limits $0.35 < w/c < 1$, be expressed as:

$$\text{compressive strength} = K(\frac{1}{w/c} - 0.5)$$

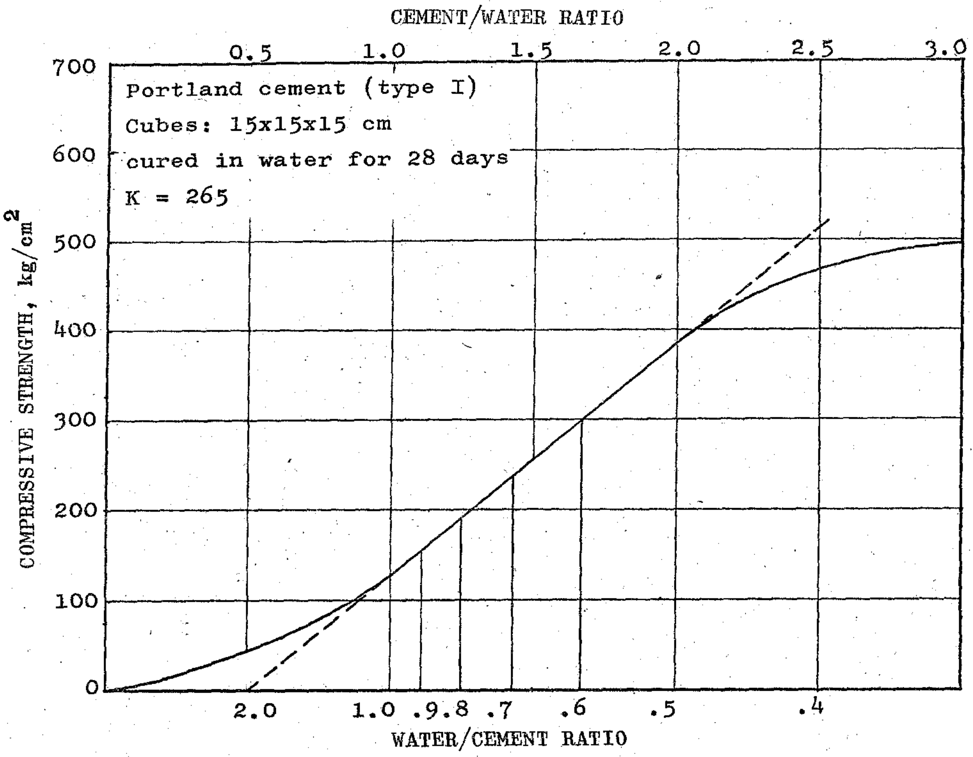
where K is a constant depending on the type of cement, the shape of the specimens used in testing and how they are cured.

Figure 3 shows an example of the relationship between compressive strength and the water-cement ratio for both Portland cement (Type I) and rapid hardening cement (Type III). The two curves are based on 15 x 15 x 15 cm cubes, cured in water for 28 days for Type I and for 14 days for Type III.

AGE AND CURING

The strength of concrete increases fast during the first days, especially when the water-cement ratio is low, and it keeps increasing for a long period of time if only the necessary water is available.

Particularly during the first two weeks it is very important that the concrete is kept wet; if not, the final strength may be as low as 30% of what proper curing would have given.



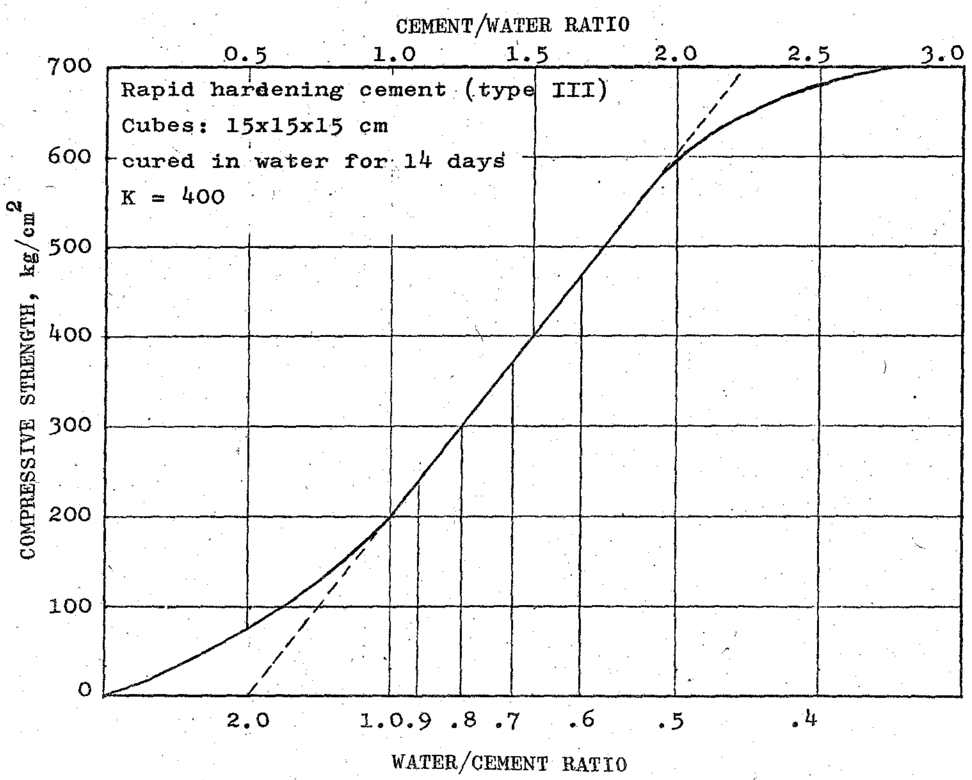


Figure 3. Example of relationship between compressive strength of concrete cubes (15 x 15 x 15 cm) and water/cement ratio. Top: Portland cement. Bottom: Rapid hardening cement.

Rapid hardening cement gains about 2/3% of its final strength already after one week and is therefore used where an early removal of formwork is important. (See Figure 4.)

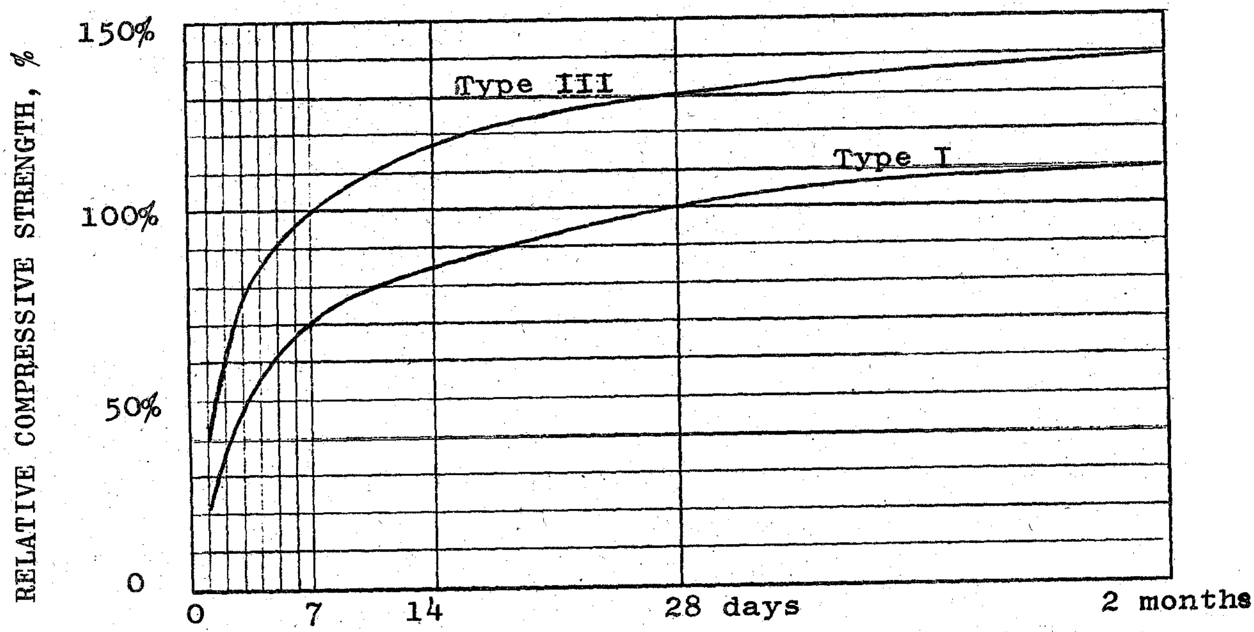


Figure 4. Development of strength in concrete during the first two months.

SHAPE OF SPECIMENS FOR TESTING STRENGTH

Cubes of different sizes are used for testing the compressive strength and cylinder shaped specimens are also common. The most frequent types of specimens are:

Cubes: 20 x 20 x 20 cm
Cubes: 15 x 15 x 15 cm
Cylinder: diameter: 15 cm, height: 30 cm

The same concrete will give different results depending on the shape of the specimen.

Figure 5 shows how small sized cubes have a higher compressive strength than larger ones. It should be noted that small cubes usually show more variation of the results than the larger.

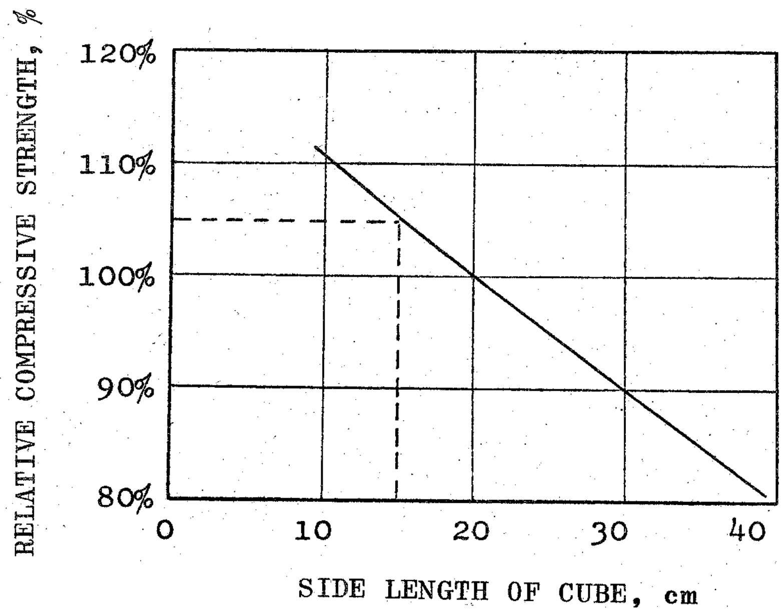


Figure 5. Influence of the cube size on the compressive strength.

When comparing results obtained by 20 cm cubes to 15/30 cm cylinders, it can be assumed that a cylinder will show 80% of the strength of a cube.

MIX PROPORTIONS

Whenever possible the material components of concrete should be measured by weight, and establishing their individual proportions for a trial mix may be done in the following manner:

1. <u>The water/cement ratio</u> is fixed with regard to strength and durability (Figure 3).

2. <u>The workability</u> is chosen depending on the type of construction and the means available for compacting the concrete (Table 3).

3. <u>Maximum stone size</u> is determined by the dimensions of the construction and the spacing of the reinforcement (Table 1).

4. The percentage of sand must suit the chosen stone size and the workability (Table 2).

5. The water content is estimated. The water necessary to give a certain workability depends on the grain size distribution of the sand and its grain shape (Figure 2).

The proportions are then calculated as in the example below. It should however be expected that some adjustment will be necessary after a trial mix has been made and also during the construction period.

EXAMPLE

Let us assume we need a concrete with an average compressive strength of 300 kg/cm^2 tested by cylinders, wet cured for 28 days. It is to be used for 15 cm floor slabs and beams.

Portland cement Type I can be used as well as rapid hardening cement Type III.

No vibrators are available.

1. w/c ratio: A 300 kg/cm^2 cylinder strength is asked. To convert this to 15 cm cubes, used in Figure 3, we use Figure 5 and the coefficient 0.8

$$\text{Cylinder strength} = 300 \text{ kg/cm}^2$$

$$\text{20 cm cube strength} = \frac{300}{0.8} = 375 \text{ kg/cm}^2$$

$$\text{15 cm cube strength} = \frac{375 \times 105}{100} = 394 \text{ kg/cm}^2$$

Figure 3 then shows that if Portland cement (Type I) is used, w/c = 0.5 will give the required strength, and if rapid hardening cement (Type III) is used, w/c = 0.77 is sufficient.

2. Workability (slump) should, for the given conditions, be about 12 cm (Table 3).

3. In Table 1 we find that the stones should not be bigger than 16 mm for a medium reinforced 15-cm floor slab.

4. The sand should then, according to Table 2, constitute 50% of the total sand and stone mix.

5. With a water content of 185 litres/m^3 we can expect a slump of about 12 cm (Figure 2). If the slump of the trial mix is different from this, we will have to adjust the water content by either adding or subtracting 3 litres of water per cm slump. For example if the slump is 14 cm, we will instead use 185 - (2 x 3) = 179 litres/m^3.

We decide to use Type III cement as it gives us the lowest cement consumption and the w/c = 0.77 is less than 0.85 which is the upper limit, when a dense and durable concrete is desired.

TABLE 5. EXAMPLE OF A MIX CALCULATION

Material	Density (kg/l)	Amount per m^3 concrete (kg)		(litres)	
Water	1.0		185		185
Air	0		0		25
Cement, w/c = 0.77	3.1	$\frac{185}{0.77}$ =	240	$\frac{240}{3.1}$ =	77
W + A + C =			425		287
Sand + Stones =	2.65	713 x 2.65 =	1890		713
Sand : 50 %	2.65	945			
Stones: 50 %	2.65	945			
Total			2315		1000

This calculation assumes that both sand and stones are dry, but the sand may well contain some water. If the stones are dry but the sand contains for example 5% water, in this case 945 x 0.05 = 47 litres, we must take 47 kg extra of sand when preparing the mix and only add 185 - 47 = 138 litres of water. The water content of the sand should therefore be checked regularly as a surplus of water will reduce the strength of the concrete considerably. In this case 47 litres of extra water would result in a w/c - ratio of $\frac{185 + 47}{240}$ = 0.97 and a strength of 205 kg/cm^2; a reduction of almost 50%. By measuring the slump of every batch, we get a warning of changes in the water content before it is too late.

The mix has been calculated for one cubic metre, but the mixer may not hold more than half a cubic metre, indicating that we only use half of the calculated amounts. This means we should use 120 kg cement for each batch, but as a bag of cement contains 50 kg, it is more practical to adjust the amounts in such a way that in each batch we can use two whole bags of cement.

Cement: 2 bags $= 100$ kg

Water: $(185 - 47) \times \frac{100}{240} = 57$ litres

Sand: $(945 + 47) \times \frac{100}{240} = 413$ kg

Stones: $945 \times \frac{100}{240} = 394$ kg

BATCHING BY VOLUME

For minor construction or repair works, where economical use of materials is less important, the amounts of sand, stone, cement, and water are often measured by volume in proportions that experience has shown are suitable for particular jobs. However, the proportions only refer to the cement, the sand, and the stone. For example 1:3:5 means one volume cement to three volume sand to five volume stones, but as we have just seen the unfavourable effect of too much water, it is important to know how much can safety be added. Table 6 therefore gives the quantities of materials for four common proportions and their usual field of application.

TABLE 6. AMOUNT OF MATERIALS IN LITRES PER BAG OF CEMENT

Mix proportion by volume	Sand	Stone	Maximum amount of water, when the sand is: fairly dry (2%)	fairly humid (5%)	Strength of 20 cm cubes in kg/cm^2	Field of application (hand-tamped, slump about 10 cm)
PORTLAND CEMENT TYPE I						
1 : 2 : 2	74	74	22	19	400	Piles, thin waterproof walls, underwater casting.
1 : 2 : 3	74	111	26	23	320	Reinforced concrete, floors and walls in pools, driveways, stairways, silos.
1 : 3 : 5	111	185	38	35	180	Foundations, retaining walls, floors for light load.
1 : 4 : 7	148	259	50	46	110	Foundations for light load, fillings.
RAPID HARDENING CEMENT, TYPE III						
1 : 2 : 2	82	82	25	22	500	Piles, thin waterproof walls, underwater casting.
1 : 2 : 3	82	123	31	29	390	Reinforced concrete, waterproof walls and floors, water tanks, repairwork.
1 : 3 : 5	123	205	42	38	230	Reinforced concrete, ramps, pavings for light load.
1 : 4 : 7	164	287	58	52	120	Foundations for light load, fillings.