The Effect Of Different Influencing Parameters On The Design Of Concrete Mixes

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Abstract

The aim of this research work is to judge whether the inclusion of different influencing parameters on some concrete characteristics have been justified and materialized in four methods of mix design namely ACI , D.O.E , Murdock & the Basic, These were used to design mixes of a given workability (a slump of 75- 90 mm) at four strength levels 20 , 30 ,35 ,&40 MPa , the results indicated that at a random strength of 30 MPa :

1. CI method: highest cement content, lowest w/c ratio, lowest gravel content.
2. D.O.E method: second highest cement content, second richest mix, second lowest w/c ratio.
3. Murdock method: highest sand content, lowest water content, low cement content.
4. Basic method: lowest cement content, lowest sand content, highest gravel content, and leanest mix.

Keywords: Mix design, Influencing parameters, ACI, D.O.E, Murdock, and Basic.

تأثير العوامل المؤثرة المختلفة على تصميم الخلطات الخرسانية

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الخلاصة

يهدف البحث إلى الحكم على أحقية (مشروعية) إدخال أو استعمال عوامل مؤثرة مختلفة على بعض خواص الخرسانة وهل كان لإدخالها فاعلية وأحقية في أربعة طرق تصميم مختلفة وتحديداً طريقة المعهد الأمريكي للخرسانة ، الطريقة البريطانية الحالية ، طريقة ميردوك وطريقة البيسك (أوين) والتي استعملت لتصميم خلطات . خرسانية ذلت القوام الثابت (هطول ثابت) ولأربعة مستويات من مقاومة الانضغاط 20 , 30 , 35 , 40 ميكا باسكال . أعطت نتائج البحث ولمستوى مقاومة عشوائي (30) ميكا باسكال ما يلي :-

1. طريقةالمعهد الأمريكي (ACI):أعلى محتوى أسمنت / متر مكعب ، أوطأ نسبة ماء/ أسمنت (وزنية) أوطأ محتوى ركام خشن .
2. الطريقة البريطانية الحالية (D.O.E): ثاني أعلى محتوى أسمنت / متر مكعب ، ثاني أغنى خلطة كونكريت ، ثاني أوطأ نسبة ماء/ أسمنت.
3. طريقة ميردوك (Murdock):أعلى محتوى ركام ناعم، أوطأ محتوى مائي، محتوى أسمنت واطئ
4. طريقة البيسك (Basic) : أوطأ محتوى أسمنت / متر مكعب ، أوطأ محتوى ركام ناعم ، أعلى محتوى ركام خشن وأكثر خلطة تفتقر إلى الاسمنت .

- المقصود بالمحتوى – متطلب وزن / متر مكعب (Content) or (Demand) .

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Foreword:

The problem of designing a concrete mixes consists of selecting the correct proportions of cement, fine and coarse aggregate and water to produce concrete having the specified properties. Sometimes a fifth ingredient, an admixture is used, there are many properties of concrete that can be specified e.g. workability, strength, elastic modulus, and durability requirements[1].

The most fundamental way to specify mix parameters is in terms of the absolute volumes of the different materials required in a concrete mix. A more practical method, based on similar principles, is to refer to the weights of materials in a unit volume of fully compacted concrete.

Four different design methods were selected on the grounds of their different influencing parameters and design philosophies, those are,: the ACI [2] [3] , the D.O.E. [4] (current British method), Murdock [1], and the Basic (Owen's) methods [5], more detailed information will be given in the proceeding sections.

Aim of Research :

In the present research , the effect of different influencing parameters of the design methods considered on concrete characteristics (at the given workability) will be investigated.

Literature Review:

In this section, four different design methods will be discussed in detail as follows:

1. **Design of concrete mixes according to American Institute Standards (ACI method) [2],[3]:**

The American concrete institute recommends a method of mix design considering the most economical use of available materials to produce concrete of a desirable workability and strength. The design tables incorporating the basic relationships between the parameters are useful in selecting optimum combinations of the ingredients of non air-entrained or air-entrained concrete mixes. The standards apply primarily to concrete of average density, with the consistency varying from "extremely dry" without any slump to "flowing" when the slump is of the order of 150 to 175 mm.

This method recommends a suitable degree of workability for concrete in the form of slump depending upon the type of construction and the maximum sizes of aggregate varying from 10 mm to 150 mm, suitable for different situations. The ACI. method utilizes the fact that for a given maximum size of aggregate, water content in kilograms per cubic meter determines the workability of the mix, largely independently of the mix proportions. This is in contrast to the method of road note No.4, where the water/cement ratio is directly determined from the desired strength considerations, almost independtly of the size and type of aggregate.

The determination of the quantity of coarse aggregate in the mix is based on the assumption that the optimum ratio of the bulk volume of the coarse aggregate to the total volume of concrete depends only on the maximum size of aggregate and on the grading of the fine aggregate. The shape factor of the aggregate is automatically taken into account in the determination of the bulk density. The water/cement ratio is selected based on the strength and durability requirements. Knowing the volumes of water, coarse aggregate, and cement, the quantity of fine aggregate required is determined by the absolute volume method, allowing for the quantity of air-entrained in the mix. The final proportions should be established by actual trial and necessary required for the field mixes.

2. The Current British Method (D.O.E) [4]:

The current British method of concrete mix design has been produced to replace that in Road Note No. 4, which has been one of the methods often used in the United Kingdom. The latter method was applicable to concrete for many purposes, although with its title and production by the Road Research Laboratory, it could be considered that the method was specifically for road surfaces .The present revised method of mix design is applicable to concrete for most purposes.

This method is restricted to designing concrete mixes for workability and strength using Portland cements complying with BS 12 or BS 4027[6,7] and natural aggregate complying with BS 882[8] or coarse air-cooled slag complying with BS 1047. It does not deal with special cements or special concrete such as lightweight aggregate concrete.

This method follows broadly similar principles to those used in Road Note No. 4. It is divided into three parts. Part one gives the background information which is required to understand the mix design process and contains all the basic information in the form of tables and graphs for the application of the method to most concrete designed for compressive strength. A standardized form has been developed for use with this method, and a number of worked examples are given.

3. Design of concrete mixes based on surface and angularity index of aggregate (Murdock Method) [1]:

In the design of concrete mixes, the grading of the coarse and fine aggregate is an important factor since it affects the resulting workability. The quantity of water required to produce a given workability depends largely on the surface area of the aggregates. The surface area per unit weight of the material is termed as "specific surface" and this is an indirect measure of the aggregate grading. The specific surface increases with a reduction in the size of material so that fine sand contributes very much more to the surface area than does the coarse aggregate. The workability of a mix is therefore influenced more by the finer fractions than the coarser particles of the aggregate.

Specific surface gives somewhat misleading picture of the workability to be expected and to overcome this difficulty, Murdock has suggested the use of surface index, which is an empirical number, related to the specific surface of the particles with more weightage assigned to the coarser material.

The total surface index (f_s) of a mixture of aggregates is calculated by multiplying the percentage weight of material retained on each sieve and the corresponding surface index and to their sum is added a constant of 330 and the result is divided by 1000.

The specific surface varies with different types of aggregate due to variations in the angularity. The angularity index (f_a) depends upon the grading of coarse and fine aggregate, angularity number and the relative proportion of coarse and fine aggregates in the final mix. For single sized aggregate, the angularity index (f_a) can be expressed in the form,

$$f_a = 11.05 - \frac{15W}{VG}$$

Where

W=weight of single size aggregate in gms, compacted in a cylinder of known volume .

G= specific gravity of aggregate particles.

V= volume of the cylinder (ml).

The angularity index of combined aggregate is determined by combining the angularity index for each single size in proportion to the amount present in the mixture. Crushed stones have a higher angularity index than the irregular and rounded gravels.

4. Basic (Owen's) Method [5]:

Most specifications for concrete are based, either on limiting the proportions or strength or on some other method of assessment. The basic mix method relies on the classification of the chosen or available materials and results of standard tests and tables are provided for the immediate selection of the first trial mix.

Adjustment is usually necessary to the first trial mix to suit the particular materials before basic mix is obtained. Other mixes linked to the Basic mix are then required to produce the test data for the mix chart. This chart, when completed, provides the information from which the batch quantities of material are selected to satisfy the particular requirements.

Procedure of Selections of the Basic Mix

1. The maximum size of coarse aggregate, grading zone of fine aggregate and the grading type of coarse aggregate are determined in advance.
2. The first trial mix is selected using the suitable table from the set of given tables. Adjustments are made for:
    a) Specific gravity of cement and aggregate,
    b) Moisture condition of aggregate;

The above adjustment are made since the tables are based on specific gravity of cement, which equals (3.1) and for aggregate (fine and coarse), that equals (2.6) and is based on aggregate in saturated surface dry condition.

3. The first trial mix is batched to check the workability of fresh concrete. Correction is made, if necessary, for faults in workability or cohesion.
4. Tests for workability and density are made; corrections are made, if necessary, to obtain the basic mix.
5. Mix chart is then prepared as shown hereafter* . The cement and fine aggregate ranges are applied but water and coarse aggregate remain constant.
6. Test specimens are made with the two or more levels of cement content within the limiting range.
7. From the mix chart, the suitable mix is chosen to satisfy the requirements.

*** Mix Design Chart**

Maximum Aggregate Size:20mm, Aggregate Type: Quartzite, workability- medium

<table>
<tr><td colspan="4">Workability slump mm</td><td>85</td><td>75</td><td>75</td><td>75</td><td>75</td><td>50</td><td>25</td></tr>
<tr><td colspan="4">Free W/C ratio</td><td>0.93</td><td>0.74</td><td>0.62</td><td>0.53</td><td>0.46</td><td>0.41</td><td>0.37</td></tr>
<tr><td colspan="4">Water Liters / m^3</td><td>185</td><td>185</td><td>185</td><td>185</td><td>185</td><td>185</td><td>185</td></tr>
<tr><td rowspan="4">kg/m^3</td><td colspan="3">Cement (OP)</td><td>200</td><td>250</td><td>300</td><td>350</td><td>400</td><td>450</td><td>500</td></tr>
<tr><td rowspan="3">Aggregate</td><td colspan="2">Fine Zone 3/4</td><td>630</td><td>590</td><td>550</td><td>510</td><td>470</td><td>430</td><td>390</td></tr>
<tr><td rowspan="2">Coarse</td><td>10 mm</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td><td>400</td></tr>
<tr><td>20 mm</td><td>950</td><td>950</td><td>950</td><td>950</td><td>950</td><td>950</td><td>950</td></tr>
</table>

Materials Used

1. Cement: Locally manufactured cement by Badoosh factory in accordance
   With IQS No. 5-1980 is used throughout this research, table(1)gives some of the cement physical properties .

2. Fine aggregate: medium (river) sand is used in accordance with B.S. 882-1999.[8] as shown by table(2) .
3. Coarse aggregate: rounded river gravel of 20 mm max aggregate size in accordance with B.S. 882-1999 is used throughout this research, table(3) shows the sieve analysis of the used gravel .
4. Water: ordinary tap (drinking) water was used throughout the work of present investigation.
5. Additives: no additives are used whatsoever.

Table(1) physical properties of cement used

	Results	Specifications
Fineness Blain	2630 cm^2/g	≤ 2300 cm^2/g
Initial setting time	132 min	≤ 45 min
Final setting time	3:45	≥ 10 hrs
Compressive	3 day	≤ 15

strength MPa	18.5	
	7 day 29.5	≤ 23.0

Table(2) sieve analysis of fine aggregate .

Sieve size (mm)	% passing	Specification BS 882-1992
10.0	100	100
5.0	100	89 – 100
2.36	88	60 – 100
1.18	75	30 – 100
600 µm	65	15 – 100
300 µm	29	5 – 70
150 µm	6	0 - 15

Table(3) sieve analysis of coarse aggregate 20 mm maximum aggregate size

Sieve size (mm)	% passing	Specification BS 882-1992
37.5	100	100
20.0	100	90 – 100
14.0	75	40 – 80
10.0	35	30 – 60
5.0	--	0 – 10
2.36	--	--

Test Procedure

Four mixes were designed by each of the four methods mentioned earlier at the four levels of compressive strength considered i.e. 20, 30, 35, and 40 MPa bringing the number of designed mixes to sixteen. Three 100 mm× 100 mm× 100 mm cubes/mix (two layers of fresh concrete and not less than 25 strokes per layer) were cured and tested according to BS

1881 parts 108, 111, and 116 [9] bringing the total number of tested specimens to (48). All specimens were tested at the age of 28 days.

Discussion of Results

At a strength level of (say) 30 MPa, Examining Figs (1-5), together with table (4) the test results indicated the followings.

1. Cement Content: The Basic method required the minimum cement content of 250 kg/m^3 while an increase of 10%, 28%, and 60%is noticed in Murdock, D.O.E., and ACI respectively . This is clear from Fig.(1), It is further substantiated by the highest A/C ratio of the concrete designed by the Basic method indicating a lean mix (c=250 kg/m^3), while contrary to that ACI mix is the richest (c=400 kg/m^3). This is due to the fact that the Basic method depends mainly on the fine material i.e. cement and sand as the primary influencing parameters, while in the ACI method the cement content influencing factors are the water demand of the mix and w/c ratio.
2. Sand Content: again and as expected the Basic method required the minimum sand content of 590 kg/m^3, while Murdock, ACI, and D.O.E. registered an increase of 56%, 37%, and 13% respectively. This is obvious from Fig.(2).Also the Basic method has a high G/S coefficient that is the ratio of weight of gravel to that of sand, this ratio averaged 2.29 as compared to 1.19 and 1.10 for ACI and Murdock respectively, From practical point of view mixes of high G/S ratios exceeding 2.2 (in this case 2.29) might segregate hence the use of powerful vibrators is essential during casting of concrete.
3. Gravel Content: At the present level of 30 MPa from Fig.(3) the ACI method needed only 964 kg/m^3 which is the least of the four considered methods, and as a reminder, the gravel content in the ACI method is a function of sand fineness modulus and the maximum aggregate size. The Basic method required an increase(in the gravel content) of 40% followed by 26% and 5% by D.O.E. and Murdock respectively, the reason for the high percentage of the Basic method (1350 kg/m^3 gravel content) is the philosophy of this method by considering a somewhat high gravel and water contents of 1350 kg/m^3 and 185 kg/m^3 respectively (for the given workability of a medium range as this case i.e. a slump of 75-100 mm) as shown by the enclosed chart given previously .

4. w/c Ratio: Fig.(4) indicates that the same level of 30 MPa compressive strength was attained at w/c ratios of 0.52, 0.60, 0.61, and 0.74 (based on S.S.D condition) for ACI, Murdock, D.O.E., and the Basic methods respectively. This seems to be quite reasonable for many reasons, one reason is given by the D.O.E. method whereby a reference mix using O.P.C. with a w/c of 0.5 gave a 40 MPa compressive strength at 28 days while at a w/c of 0.61 a 30 MPa compressive strength is reached (of the present investigation), the other reason being the dependence of the Basic method on the fine materials hence increasing the mix total surface area ultimately leading to a high water demand 185 kg/m^3 coupled with the lowest cement 250 kg/m^{3}thus the highest w/c ratio of 0.74.
5. A/C Ratio: In good agreement with the cement and aggregate contents previously discussed and examining Fig.(5) ACI seems to give the richest mix, while that of the Basic is the leanest, Murdock method also gave a somewhat lean mix which is expected since Murdock relies in his method on aggregate grading, both fine and coarse aggregate in terms of the surface and angularity index.

Table (4) Main Investigated Concrete Mix Parameters (at 30 MPa Strength Level)

Method	Mix weights (kg/m^3) and proportions				W/C ratio *	A/C ratio **	G/S ratio ***	Unit Weight kg/m^3
	Cement	Sand	Gravel	Water				
ACI	400 **1**	808 **2.02**	964 **2.41**	207 **0.52**	0.52	4.43	1.19	2379
D.O.E	320 **1**	665 **2.08**	1210 **3.78**	195 **0.61**	0.61	5.86	1.82	2390
Murdock	275 **1**	918 **3.34**	1010 **3.67**	165 **0.60**	0.60	7.00	1.10	2368
Basic	250 **1**	590 **2.36**	1350 **5.40**	185 **0.74**	0.74	7.76	2.29	2375

*By weight based on S.S.D

**By weight

***weight of gravel/sand

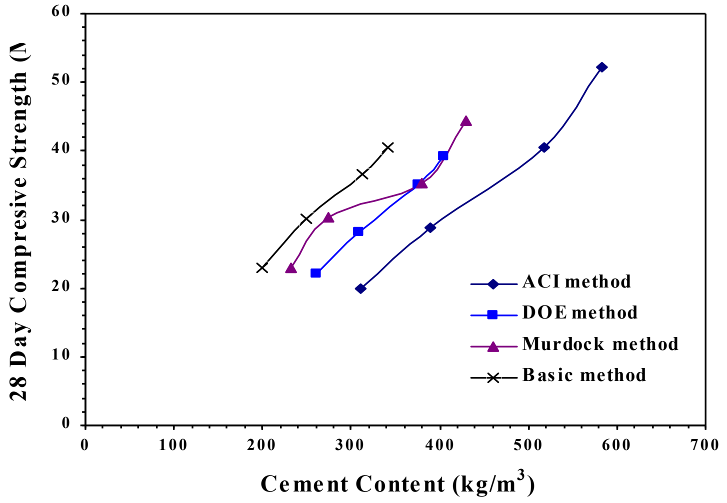
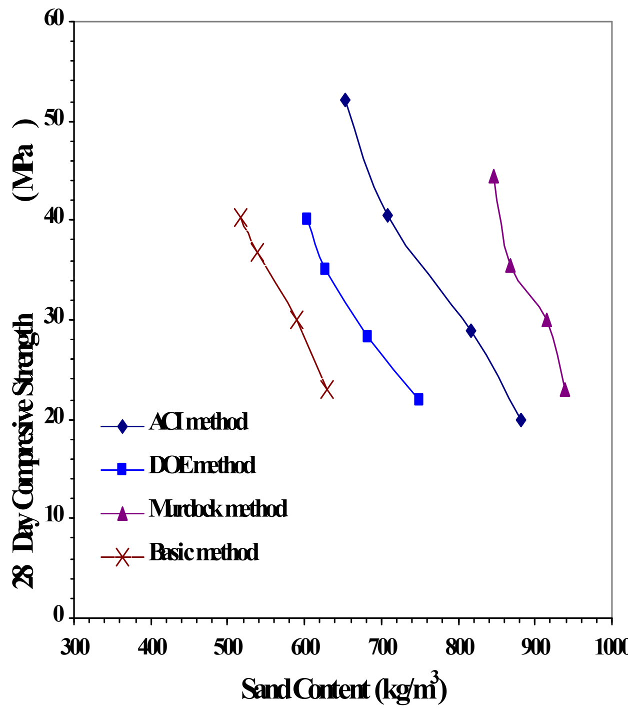


Fig. (1) Relation between 28 day cube compressive strength and cement content of the mix.



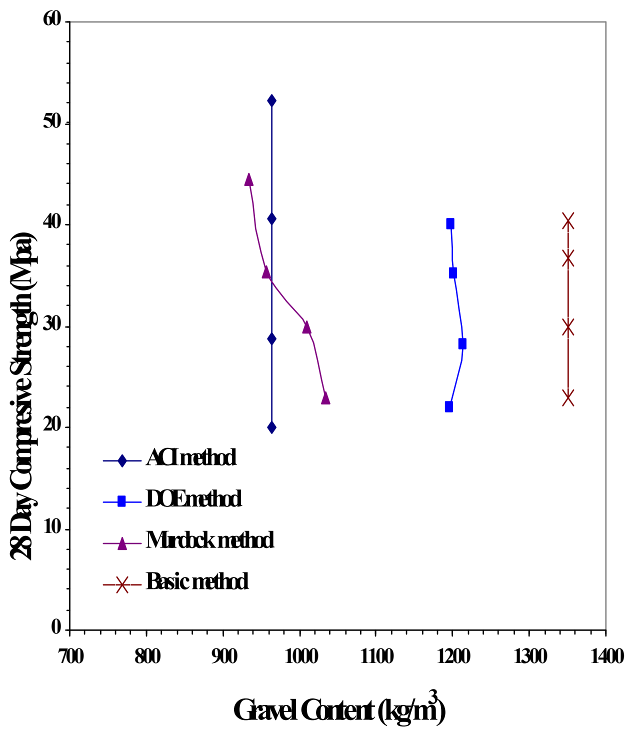


Fig. (2)Relation between 28 day cube compressive strength and sand content of the mix.

Fig. (3) Relation between 28 day cube compressive strength and gravel content of the mix.

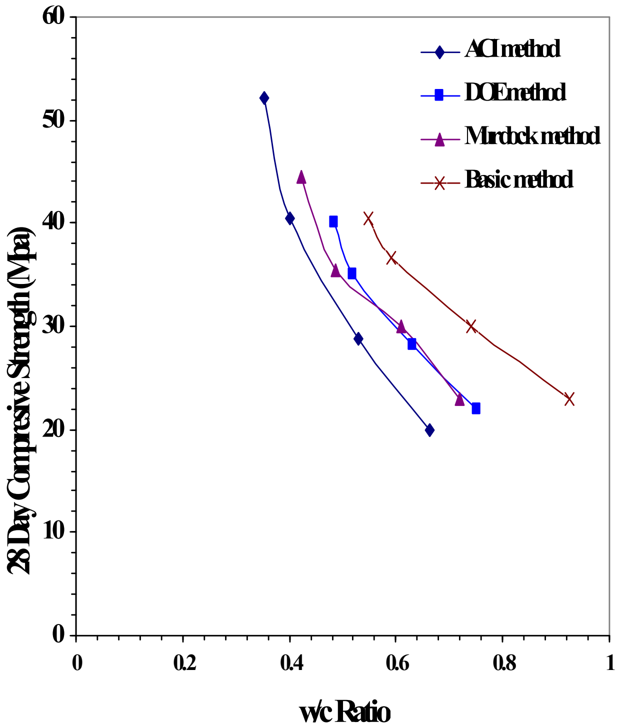


Fig. (4)Relation between 28 day cube compressive strength and w/c ratio of the mix

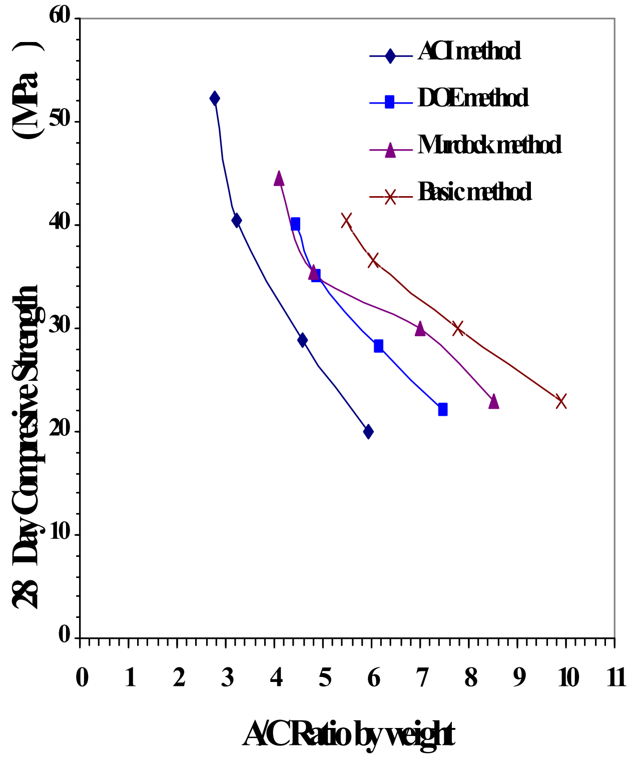


Fig. (5)Relation between 28 day cube compressive strength and A/C ratio of the mix

Conclusions

The results of the present investigation may point out to the following conclusions:-

1- All the four methods of mix design seem to have selected the appropriate influencing parameter in other words the influencing parameters have materialized and justified their inclusion , as an example minimum cement content for the Basic method, on the other hand maximum cement content for the ACI method.

2- The unit weight of fresh contents looks like being independent of the different selected influencing parameters all calculated values of unit weight is almost the same (in the region of 2378 kg/m3)
3- The G/S that is the weight of gravel kg/m^3 to that of sand kg/m^3 is highest for the Basic method (G/S=2.29) which is expected and matches the selection of a somewhat high gravel content this however indicates a tendency for such mix to segregate during placing therefore powerful vibrators must be used in such situations .
4- From Table (5), cost wise the mix designed by ACI method at 30 MPa and (at the given workability) is the most expensive one, on the other extreme end the mix designed by Basic method is the cheapest , by a difference of 65 % .

Table (5) Cost/ m^3 in I.D (at 30 MPa Strength Level)

Method	*Cost I.D./m^3 of Concrete
ACI	115850
D.O.E.	100295
Murdock	94015
Basic	86685

*to nearest five I.D

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