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Designing concrete mixtures for strength, elastic modulus and fracture energy

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There are many methods for determining a concrete mix proportion when the compressive strength is the design criterion; however, there is much less information available when other criteria, such as the fracture energy or the elastic modulus, are specified. For these cases, a new mix design nomogram has been developed from well-established concrete relationships. The application of this method is demonstrated by an experimental programme which shows the influence of cement content, water-to-cement ratio and aggregate-to-cement ratio on the compressive strength, modulus of elasticity, splitting tensile strength, fracture energy, and characteristic length of concrete. Six concrete mixtures with different water-to-cement ratios and workabilities were studied. The mix design nomogram, besides being a tool for the practitioner, can also help the researcher in selecting the most adequate mix parameters for experimental and scientific purposes. It is noted that when studying the effect of mix parameters on the properties of concrete certain constraints should be used: for instance when varying the water-to-cement ratio, the workability of fresh concrete should be kept constant and vice versa.

NOMENCLATURE

E_c	Modulus of elasticity (GPa)
C	Cement content (kg m^{-3})
G_F	Fracture energy (N m^{-1})
f_c	Compressive strength (MPa)
f_t	Splitting tensile strength (MPa)
l_{ch}	Characteristic length (mm) given by EG_F/f_t^2
m	Aggregate-to-cement ratio, by weight (kg kg^{-1})
w/c	Water-to-cement ratio, by weight (kg kg^{-1})
k_1, k_2, k_3, k_4	Constants which depend on the materials used

1. INTRODUCTION

The fracture mechanics of concrete is entering a more mature stage where it can provide significant insight into the design of reinforced concrete. It has been particularly useful in the analysis of special structures such as large dams, wide-span bridges, prestressed pressure vessels, and unreinforced pipes. For this purpose it was necessary to establish suitable and reliable experimental methods to determine the fracture mechanics properties of concrete. Hillerborg [1] presented the theoretical basis of a method to determine the fracture energy G_F of concrete, which was later adopted by RILEM [2]. While researchers have been successful in the development of new test procedures to measure the fracture energy, strain softening and toughness of concrete [3–5], comparatively little has been done in developing methods of mix proportioning to obtain a given fracture mechanics property. It is not adequate to arbitrarily change the concrete composition and measure its resulting properties. A criterion for proportioning concrete is necessary for experimental research and practical applications, allowing the engineer to manage the mix proportioning and the concrete production. It is also useful to know how one particular concrete property can be obtained by using different materials and proportions. The designer can specify the property but the contractor must obtain it at minimum cost, by choosing the easiest and fastest method.

In this work, a mix design nomogram is introduced for the complete and fast prediction of the fresh and hardened concrete properties. The nomogram is based on three basic and classical concepts of mix design: 'Abrams' law' for hardened concrete, 'Lyse's law' for fresh concrete, and 'Molinari's law' for cement content. The first relationship was originally developed by Abrams [6] and generalized by Powers [7] for the compressive strength as a function of the water-to-cement ratio. Recent research has shown some limitations of this relationship for high-strength concrete where the strength

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of the aggregate and the aggregate–cement paste transition zone are important parameters. The work described here is limited to normal-weight, normal-strength concrete. The second relationship is based on the work of Lyse [8] who showed that when using the same concrete materials it is possible to obtain concretes with the same consistency by keeping constant the ratio between the volume of water and the volume of compacted fresh concrete. Using this rule it is possible to obtain fresh concretes with the same consistency but very different mix proportions and consequently different mechanical properties. Finally, the third relationship was formulated by Molinari [9, 10] who correlated the cement content with the aggregate-to-cement ratio. Once the trial mixes are performed, these three relationships are arranged in a graphical form which permits the determination of a mix proportion for a specified property.

To demonstrate the utility and the prediction capacity of the proposed methodology, experimental results from six different mix proportions using the same materials are presented. The following mechanical properties for the mixes were determined: compressive strength, splitting tensile strength, modulus of elasticity, fracture energy and characteristic length. This study points out that when studying the effect of the mix parameters on the properties of concrete certain constraints should be used. For instance when varying the water-to-cement ratio, the workability of fresh concrete should be kept constant and vice versa. Under these conditions the mix parameters may have different effects on the concrete properties; for example a decrease in cement content or an increase in aggregate content leads to an increase in the fracture energy for a constant water-to-cement ratio, and leads to a decrease in the fracture energy for a constant workability.

2. MIX DESIGN DIAGRAM

The concrete mixtures were obtained by using the mix design nomogram which combines three relationships developed for the properties of fresh and hardened concrete in one graph, as shown in Fig. 1. The mix design nomogram uses the following correlation:

1. *Abrams' law* correlates the concrete compressive strength with the water-to-cement ratio (by weight) for a determined level of cement hydration. Since the water-to-cement ratio is the most important variable in concrete, this relationship can also be extended to other properties such as modulus of elasticity, permeability and fracture energy. For a given workability, the equation which best fits this behaviour law is

$$f_c = \frac{k_1}{k_2^{w/c}}$$

where f_c = compressive strength (MPa), k_1, k_2 = constants which depend on the materials used and w/c = water-to-cement ratio, by weight.

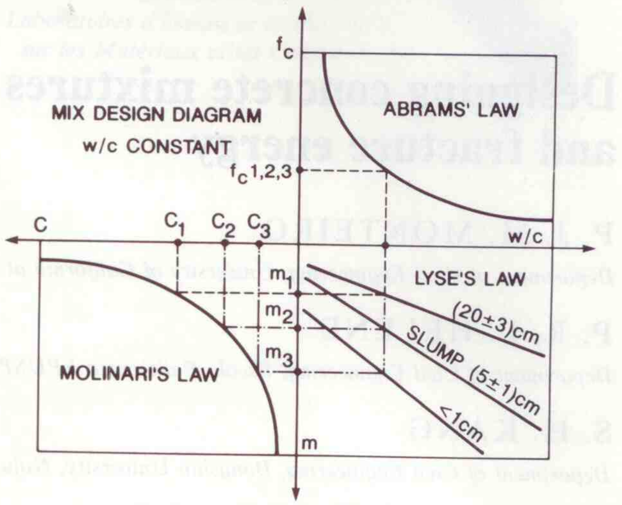

Fig. 1 Mix design nomogram for a given water-to-cement ratio. Compressive strength as the design criterion.

2. *Lyse's law* correlates the water/cement ratio with the ratio (fine + coarse aggregates)/cement (by weight). The equation that best fits this behaviour law is

$$m = k_3(w/c) + k_4$$

where m = aggregate/cement ratio by weight and k_3, k_4 = constants which depend on the materials used for a given workability.

3. *Molinari's law* correlates the cement content, C, and the aggregate-to-cement ratio, m. The equation that best fits this behaviour is

$$C = \frac{1000}{k_5 m + k_6}$$

where C = cement content (kg m^{-3}) and k_5, k_6 = constants which depend on the materials used.

Fig. 1 indicates that for a given water-to-cement ratio it is possible to have different mix proportions using the same materials and to obtain different properties of fresh and hardened concretes as exemplified in Table 1. The water-to-cement ratio is the most important variable in the concrete mix proportion and it can significantly change the properties of hardened concrete. To avoid its influence when studying the effect of other variables, such as cement content and aggregate-to-cement ratio, the

Table 1 Example of mix proportions for a given water-to-cement ratio

Consistency (slump) (cm)	Compressive strength (MPa)	Aggregate/ cement ratio (kg kg^{-1})	Cement content (kg m^{-3})
Fluid	f_c	Low	High
Plastic	f_c	Medium	Medium
Dry	f_c	High	Low

water-to-cement ratio should be kept constant. When the water-to-cement ratio is kept constant, any change in the concrete mix proportion causes a change in the consistency of the fresh concrete, modifying its slump as shown in Fig. 1 and Table 1.

To analyse the influence of the water-to-cement ratio on the properties of concrete, it is necessary to fix other variables such as the consistency of fresh concrete, cement content, or aggregate content. Producing concretes with the same cement content or the same aggregate content and different water-to-cement ratio means changing significantly the consistency of these concretes. If this option is taken, the experimental research will have the following limitations:

1. Practical difficulty in keeping the same quality of compaction for the different mixtures, if the energy of vibration to compact a fluid concrete is different from that necessary for the compaction of concrete with medium or dry consistency.
2. Reduction of the range of study because the different mixtures will quickly lose their consistency, making it very difficult to prepare the specimens, therefore requiring the use of admixtures and other methods which introduce new and unknown variables.
3. The experimental research may also face the risk of not representing the practical necessity of having adequate concretes for a given use. The workability is an important factor to be defined and maintained in the field, as function of the equipment available.

It is challenging to study in the laboratory the properties of concrete with an ample range and at the same time with relevance to the real field problems. It is therefore recommendable that the water-to-cement ratio should be modified by using the criterion of maintaining the same consistency of fresh concrete. Using this condition, the influence of water-to-cement ratio on the properties of hardened concrete can be studied without the influence of other variables. For a given consistency of fresh concrete, measured by the standard slump test, it is possible to have different concretes by changing the mix proportions as indicated in Fig. 2 and exemplified in Table 2.

For normal-strength concrete, the aggregate is stronger than both the matrix and the transition zone; therefore the strength of these two weaker phases, which is controlled by the water-to-cement ratio and degree of hydration, is the limiting parameter to the strength of concrete, as indicated in Fig. 1. The elastic modulus and fracture energy, however, are greatly influenced by other mix parameters, such volume of aggregate or cement content. This is reflected in Fig. 3, where instead of having only one curve in the first quadrant as in the case of Fig. 1, a series of curves associated with the existing volume fraction of the phases is necessary.

Table 2 Example of mix proportions for a given plastic consistency of fresh concrete

Water/ cement ratio ($kg\,kg^{-1}$)	Compressive strength (MPa)	Aggregate/ cement ratio ($kg\,kg^{-1}$)	Cement content ($kg\,m^{-3}$)
Low	High	Low	High
Medium	Medium	Medium	Medium
High	Low	High	Low

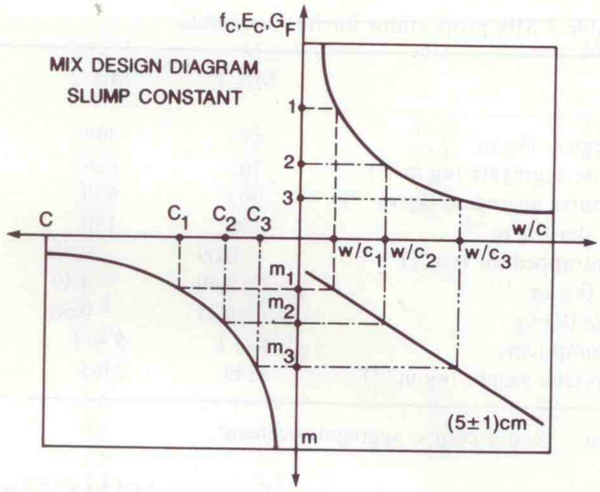

Fig. 2 Mix design nomogram for a given consistency of fresh concrete. Compressive strength as the design criterion.

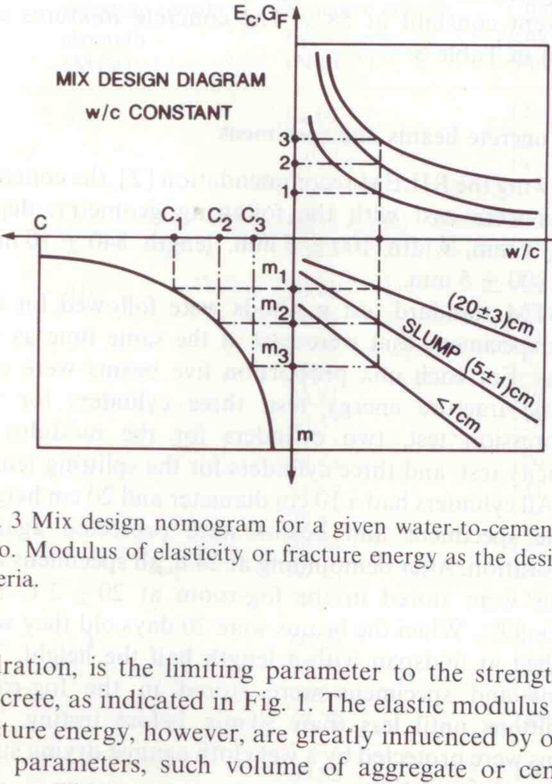

Fig. 3 Mix design nomogram for a given water-to-cement ratio. Modulus of elasticity or fracture energy as the design criteria.

3. EXPERIMENTAL PROGRAMME

3.1 Materials and mix proportions

ASTM Type I–II Portland cement was used. A natural sand meeting ASTM C 33 was employed as the fine aggregate with maximum size of 2.4 mm, fineness modulus of 3.1, bulk specific gravity of 2640 kg m^{-3} and water absorption of 1.45%.

Table 3 Mix proportions for fresh concrete

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Cement (kg m^{-3})	478	398	329	282	306	484
Fine aggregate (kg m^{-3})	765	866	929	976	1023	721
Coarse aggregate (kg m^{-3})	902	920	914	911	961	875
Water (kg m^{-3})	196	199	198	198	153	242
Entrapped air (vol%)	0.09	0.76	0.63	0.51	0.57	0.65
m (kg kg^{-1})[a]	3.49	4.49	5.59	6.69	6.50	3.30
w/c (kg kg^{-1})	0.41	0.50	0.60	0.70	0.50	0.50
Slump (cm)	5 ± 1	5 ± 1	5 ± 1	5 ± 1	<1	20 ± 3
Specific weight (kg m^{-3})	2339	2365	2355	2355	2429	2307

[a] m = (fine + coarse aggregate)/cement.

Natural siliceous river gravel meeting ASTM C 33 was used as the coarse aggregate with a maximum size of 9.5 mm, fineness modulus of 5.61, bulk specific gravity of 2680 kg m^{-3}, and water absorption of 0.34%.

For all the concrete mixtures the ratio (cement + fine aggregate)/(cement + fine aggregate + coarse aggregate) was kept constant at 58%. The concrete mixtures are shown in Table 3.

3.2 Concrete beams and specimens

Following the RILEM recommendation [2], the concrete beams were cast with the following geometry: depth 100 ± 5 mm, width 100 ± 5 mm, length 840 ± 10 mm, span 800 ± 5 mm.

ASTM standard test methods were followed for the other specimens that were cast at the same time as the beams. For each mix proportion five beams were cast for the fracture energy test, three cylinders for the compression test, two cylinders for the modulus of elasticity test, and three cylinders for the splitting tensile test. All cylinders had a 10 cm diameter and 20 cm height.

The specimens and beams were protected against evaporation. After demoulding at 24 h, all specimens and beams were stored in the fog-room at 20 ± 2°C and RH > 99%. When the beams were 20 days old they were notched at midspan with a length half the height. The beams and specimens were stored in the fog-room conditions until less than 30 min before testing. The beams were protected by a wet cloth against drying stress and crack formation.

3.3 Test methods

The modulus of elasticity was determined according to ASTM C 469, the compressive strength according to ASTM C 39 and the splitting tensile strength according to ASTM C 496. These tests were performed in a 1335 kN Baldwin universal testing machine, with a 241 kPa s^{-1} rate of loading.

A special compressometer fabricated in the U.C. Berkeley laboratory was used for reading the deformations in the modulus of elasticity test. Two linearly variable differential transformers (LVDTs) measured the deformations between the upper and lower rings, which were rigidly fastened to the cylinder specimens. The digital data were acquired using an IBM PC/AT and a Keithley System 500 data acquisition system. The average longitudinal deformations of the specimens were measured using two LVDTs in each position. The LVDTs were conditioned and the signal was amplified using a Daytronic 300D amplifier unit. The load was taken from the testing machine load cell and conditioned using a Daytronic 300D amplifier unit. The data acquisition software (DAS) program was used to acquire, reduce and plot the stress–strain data. The plot was displayed on an IBM enhanced graphic terminal, and printed out on an IBM printer. The data were sampled at 1 s intervals.

All beams were tested in three-point bending mode according to the RILEM recommendation. The beam test was performed in a 133 kN MTS servo-hydraulic universal testing machine, with an approximately constant rate of deflection, which was chosen so that the maximum load was reached within 30–60 s after the start of the test. The data were acquired by the IBM PC/AT system, and the data were sampled at 1 s intervals.

4. RESULTS AND DISCUSSION

Results for compressive strength, modulus of elasticity and splitting tensile strength at 28 days are presented in Table 4. Results for fracture energy G_F and characteristic length l_{ch} at 28 days are given in Table 5. The characteristic length (l_{ch}) was computed according to the expression $l_{ch} = EG_F/f_t^2$).

4.1 Influence of the water-to-cement ratio

The influence of the water-to-cement ratio on the concrete properties was determined by performing regression analysis on the experimental data. The most important relationships are the ones required to establish mix design nomograms such as the one presented in a conceptual format in Fig. 1. Mix design nomograms can be obtained by plotting the data from Tables 3, 4 and 5. In this work, they are established for the following properties: compressive strength (f_c), modulus of elasticity (E_c) and fracture energy (G_F). Fig. 4 shows the dependence of the

Table 4 Results for hardened concrete specimens at 28 days

	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Compressive strength (MPa)						
f_{c1}	53.4	47.2	38.0	26.5	48.5	47.6
f_{c2}	51.4	48.6	36.1	26.6	48.4	45.1
f_{c3}	54.1	47.2	36.2	25.6	48.2	47.4
f_c (average)	53.0	47.7	36.8	26.2	48.4	46.7
Modulus of elasticity (GPa)						
E_{c1}	27.58	25.51	24.96	23.31	28.06	23.37
E_{c2}	27.24	25.86	25.03	22.96	28.13	24.62
E_c (average)	27.41	25.69	25.00	23.14	28.10	24.00
Splitting tensile strength (MPa)						
f_{t1}	4.2	4.1	3.6	3.1	4.2	3.9
f_{t2}	4.8	3.9	4.0	3.4	3.8	3.9
f_{t3}	4.3	4.0	3.9	3.5	4.2	4.0
f_t (average)	4.4	4.0	3.8	3.3	4.1	3.9

Table 5 Fracture energy and characteristic length results

Mix No.	Water/cement ratio (kg kg^{-1})	Slump (cm)	Modulus of elasticity (GPa)	Splitting tensile strength (MPa)	Fracture energy, G_F (N m^{-1})	Characteristic length, l_{ch} (mm)
1	0.41	5 ± 1	27.41	4.4	98.69	140
					92.35	131
					93.33	132
					[a]	[a]
					96.11	136
Average					95.12	135
2	0.50	5 ± 1	25.69	4.0	89.45	144
					80.44	129
					88.05	141
					78.42	126
					86.51	139
Average					84.57	136
3	0.60	5 ± 1	25.00	3.8	74.54	129
					81.62	141
					79.87	138
					79.78	138
					80.42	139
Average					79.25	137
4	0.70	5 ± 1	23.14	3.3	69.29	147
					75.59	161
					66.01	140
					68.23	145
					[a]	[a]
Average					69.83	148
5	0.50	<1	28.10	4.1	91.64	153
					88.67	148
					[a]	[a]
					94.61	158
					[a]	[a]
Average					91.64	153
6	0.50	20 ± 3	24.00	3.9	81.12	128
					80.16	126
					84.26	133
					[a]	[a]
					85.42	135
Average					82.74	131

[a] Values not used because of technical problem during the test.

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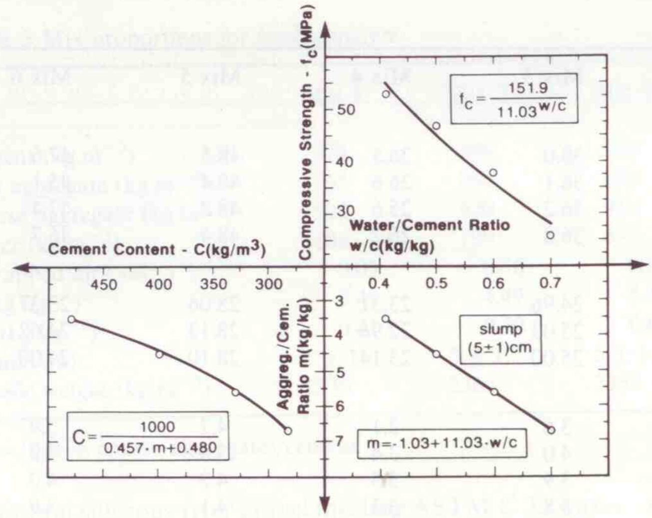

Fig. 4 Mix design nomogram for a given consistency of fresh concrete. Compressive strength as the design criterion.

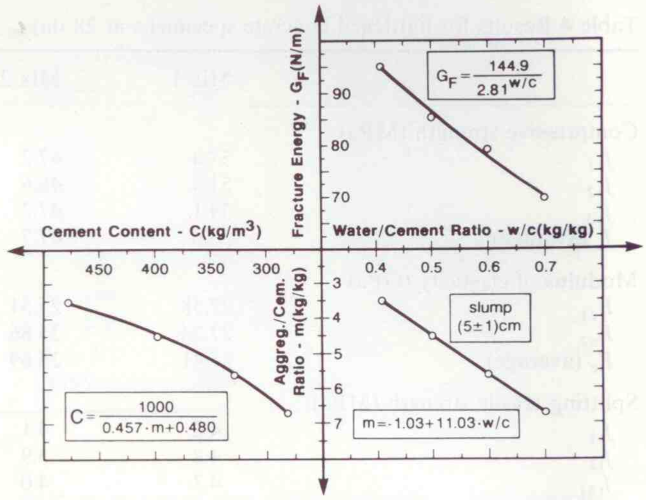

Fig. 6 Mix design nomogram for a given consistency of fresh concrete. Fracture energy as the design criterion.

compressive strength on the water-to-cement ratio, the aggregate-to-cement ratio and the cement content for a given consistency of the fresh concrete. Least-squares analysis shows a strong correlation among the variables when the equations presented in section 2 are used. Sometimes there is a tendency to propose new mathematical equations even when only limited experimental results are available. The authors believe that only when there is a large number of experimental results, at least 35, is a new formulation justified. In this experimental programme only six different mix proportions were used; therefore the behaviour laws previously described are used because they were based on thousands of different mix proportions.

Figs 5 and 6 show the mix design nomograms obtained when the modulus of elasticity and the fracture energy are selected as performance criteria for the case of a constant consistency of fresh concrete. Once the consistency is kept constant it is possible to easily observe how the water-to-cement ratio influences the concrete properties.

The comparative analysis of Figs 4, 5 and 6 shows the great influence of the water-to-cement ratio on the three properties studied. For example, even though mix 4 (Table 3) has the highest aggregate content it is the one that has the lower modulus of elasticity and the lowest fracture energy. This observation, apparently contradictory, is explained by the fact that both the modulus of elasticity and the fracture energy depend mainly on the strength of the matrix and its bond to the aggregate.

4.2 Influence of cement content

The influence of cement content on the mechanical properties of concrete was studied under two conditions: concrete with the same consistency and concrete with the same water-to-cement ratio. Figs 7–10 show the results for a constant consistency of fresh concrete equal to

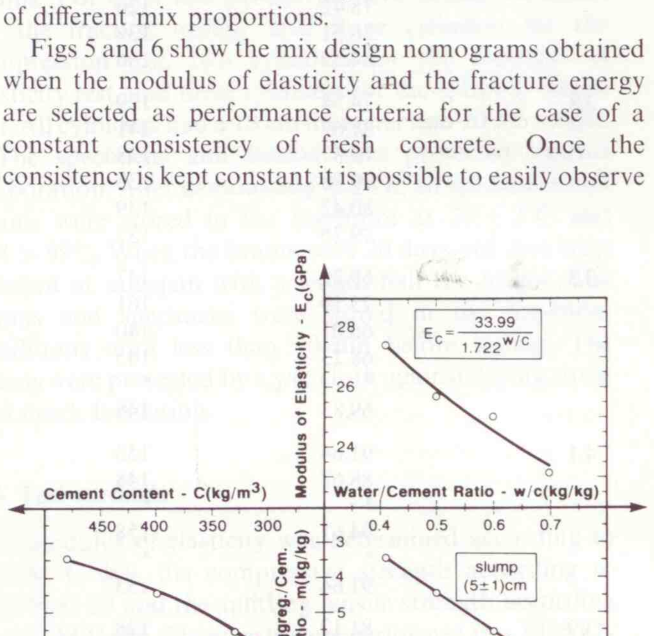

Fig. 5 Mix design nomogram for a given consistency of fresh concrete. Modulus of elasticity as the design criterion.

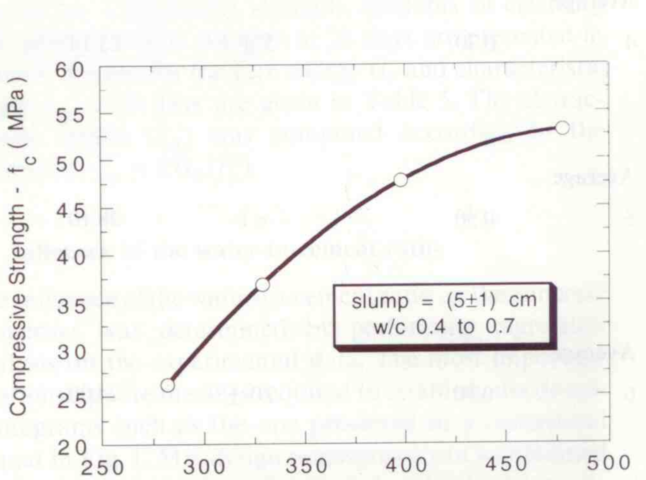

Fig. 7 Effect of cement content on the compressive strength for a constant consistency.

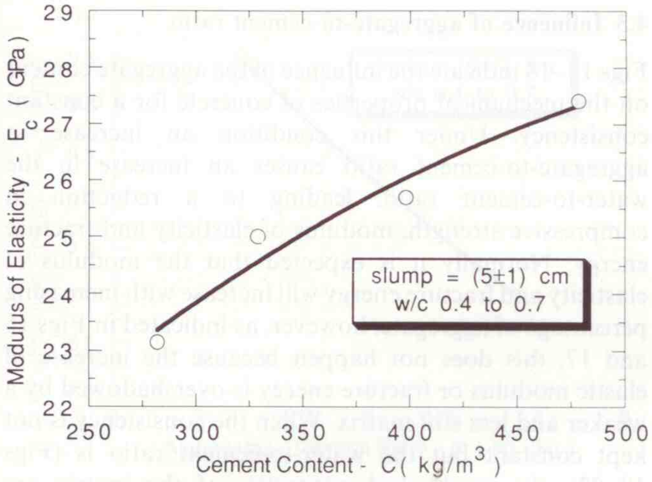

Fig. 8 Effect of cement content on the modulus of elasticity for a constant consistency.

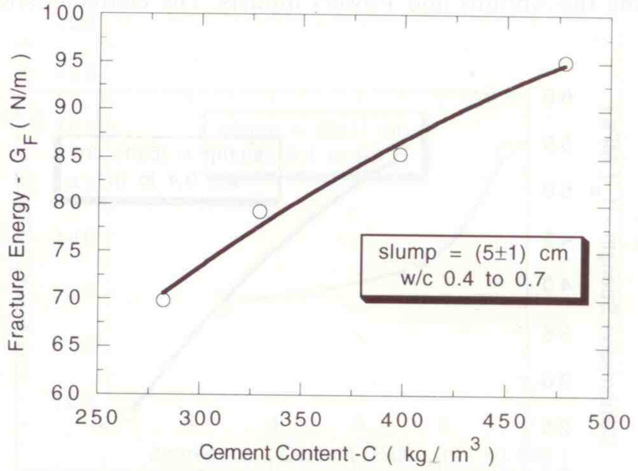

Fig. 9 Effect of cement content on the fracture energy for a constant consistency.

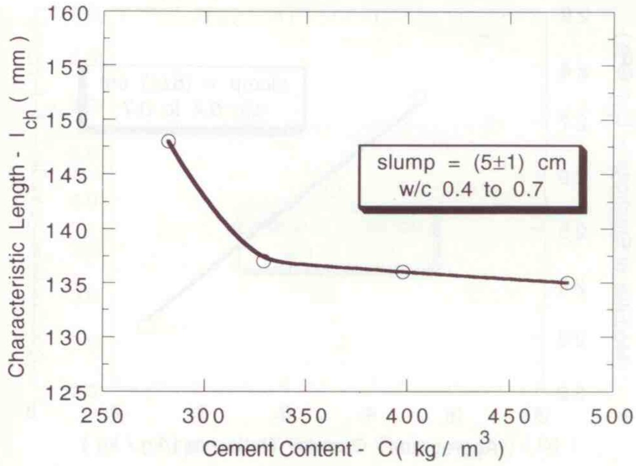

Fig. 10 Effect of cement content on the characteristic length for a constant consistency.

5 ± 1 cm slump. The compressive strength, modulus of elasticity and fracture energy increase with increasing cement content, as indicated in Figs 7 to 9. For a constant consistency, an increase in cement content requires a decrease in the water-to-cement ratio and therefore produces a stronger and stiffer matrix.

Figs 11–14 show the influence of the cement content on the mechanical properties of concrete for a water-to-cement ratio constant and equal to 0.50. It should be noted that under this condition the dependency of the compressive strength, modulus of elasticity and fracture energy on the cement content (Figs 11–13) is significantly different from that under condition of constant consistency (Figs 7–9). Fig. 11 indicates that for a constant water-to-cement ratio the compressive strength is basically independent of the cement content, as expected from the Abrams and Powers models. An increase in cement content results in a reduction in the

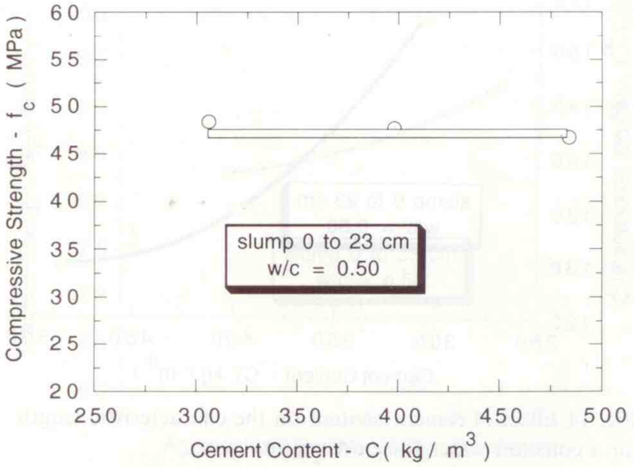

Fig. 11 Effect of cement content on the compressive strength for a constant water-to-cement ratio.

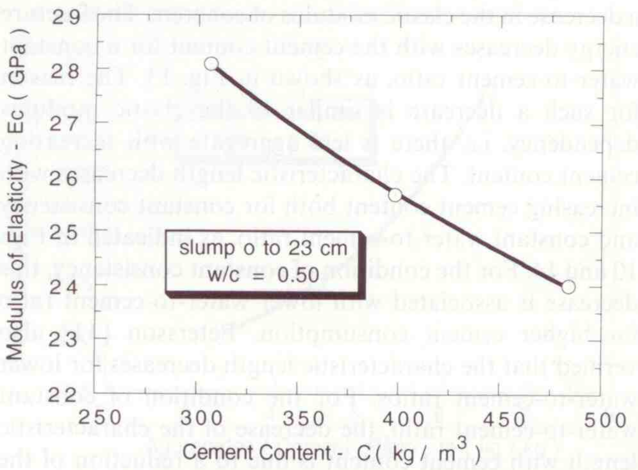

Fig. 12 Effect of cement content on the modulus of elasticity for a constant water-to-cement ratio.

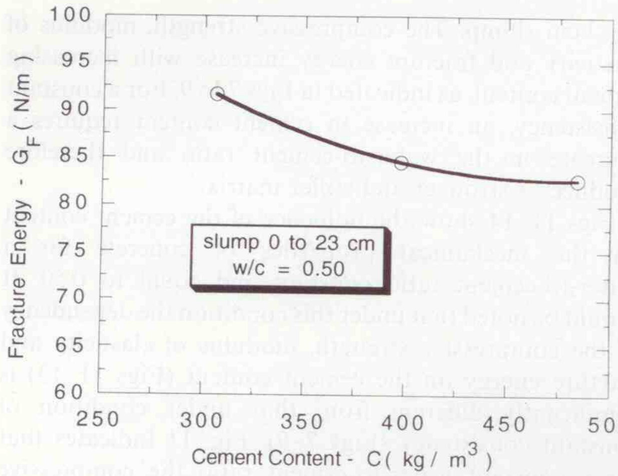

Fig. 13 Effect of cement content on the fracture energy for a constant water-to-cement ratio.

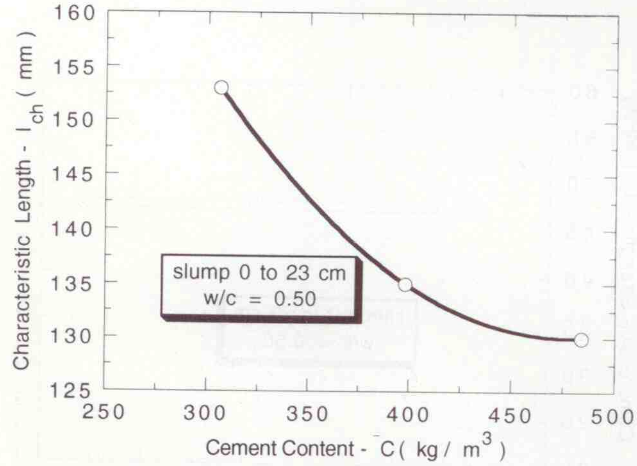

Fig. 14 Effect of cement content on the characteristic length for a constant water-to-cement ratio.

modulus of elasticity, as shown in Fig. 12. This result is expected because an increase in cement content leads to a reduction in the aggregate content, and since the aggregate has a higher modulus of elasticity than the cement paste, reducing the aggregate content would cause a decrease in the elastic modulus of concrete. The fracture energy decreases with the cement content for a constant water-to-cement ratio, as shown in Fig. 13. The reason for such a decrease is similar to the elastic modulus dependency, i.e. there is less aggregate with increasing cement content. The characteristic length decreases with increasing cement content both for constant consistency and constant water-to-cement ratio, as indicated in Figs 10 and 14. For the condition of constant consistency, this decrease is associated with lower water-to-cement ratio for higher cement consumption. Petersson [11] also verified that the characteristic length decreases for lower water-to-cement ratios. For the condition of constant water-to-cement ratio, the decrease of the characteristic length with cement content is due to a reduction of the amount of aggregate, therefore reducing the capacity for energy absorption.

4.3 Influence of aggregate-to-cement ratio

Figs 15–18 indicate the influence of the aggregate content on the mechanical properties of concrete for a constant consistency. Under this condition an increase in aggregate-to-cement ratio causes an increase in the water-to-cement ratio, leading to a reduction in compressive strength, modulus of elasticity and fracture energy. Normally it is expected that the modulus of elasticity and fracture energy will increase with increasing percentage of aggregate; however, as indicated in Figs 16 and 17, this does not happen because the increase of elastic modulus or fracture energy is overshadowed by a weaker and less stiff matrix. When the consistency is not kept constant but the water-to-cement ratio is (Figs 19–22), the mechanical properties of the matrix are approximately constant, so both the modulus of elasticity and fracture energy increase with higher contents of aggregate as shown in Figs 20 and 21. For a constant water-to-cement ratio, the compressive strength is not affected by the aggregate-to-cement ratio, again confirming the Abrams and Powers models. The characteristic

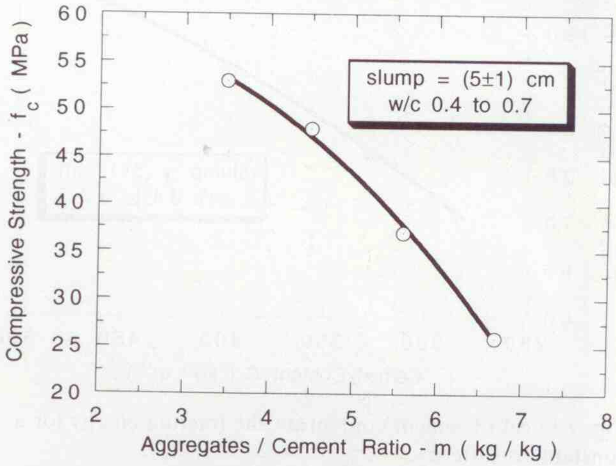

Fig. 15 Effect of aggregate-to-cement ratio on the compressive strength for a constant consistency.

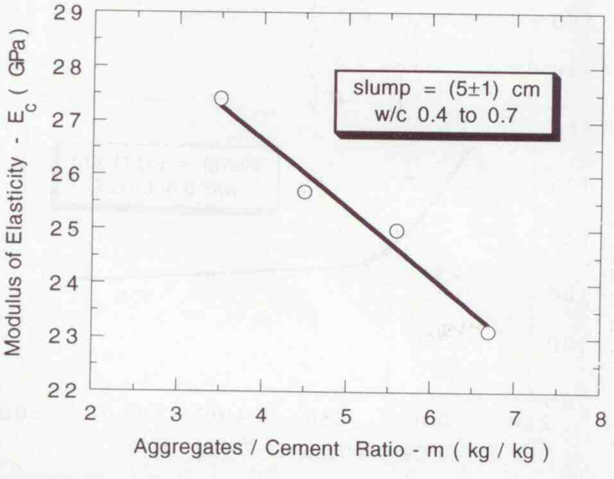

Fig. 16 Effect of aggregate-to-cement ratio on the modulus of elasticity for a constant consistency.

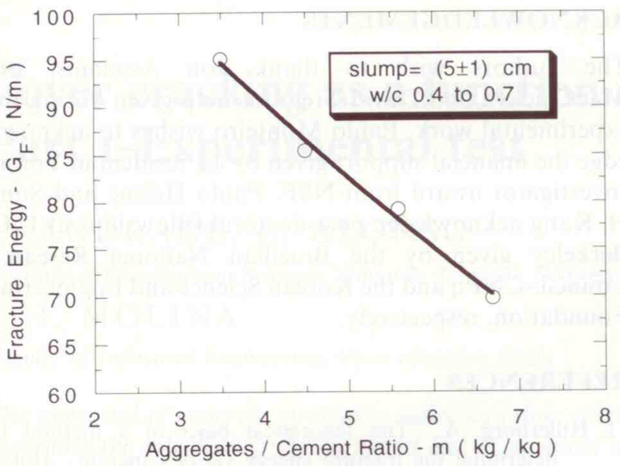

Fig. 17 Effect of aggregate-to-cement ratio on the fracture energy for a constant consistency.

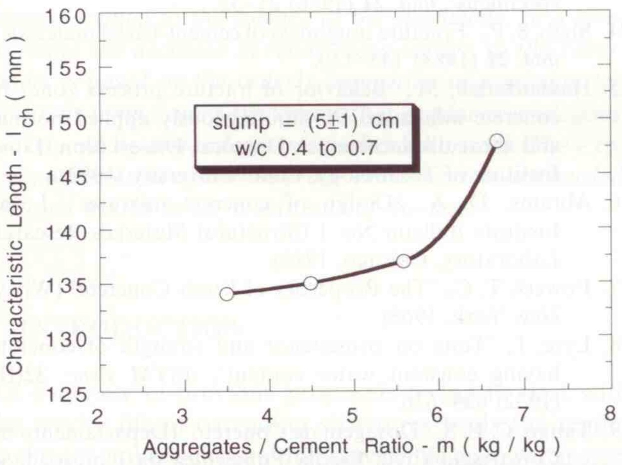

Fig. 18 Effect of aggregate-to-cement ratio on the characteristic length for a constant consistency.

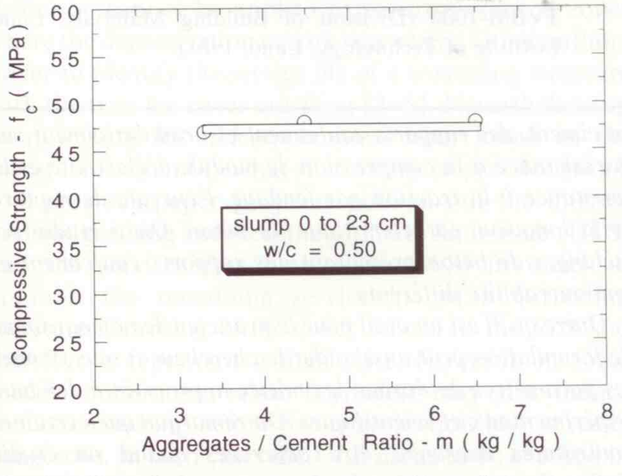

Fig. 19 Effect of aggregate-to-cement ratio on the compressive strength for a constant water-to-cement ratio.

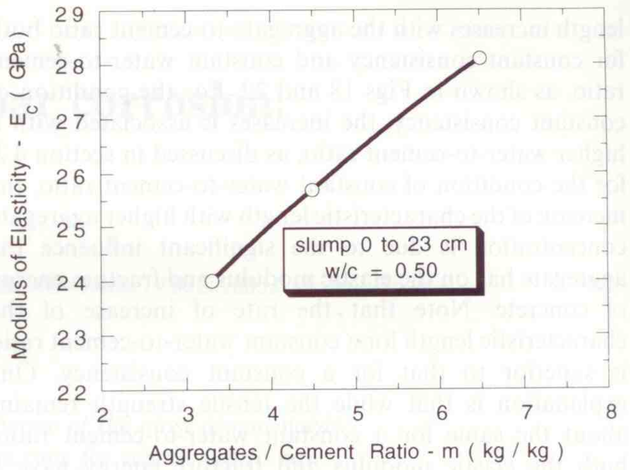

Fig. 20 Effect of aggregate-to-cement ratio on the modulus of elasticity for a constant water-to-cement ratio.

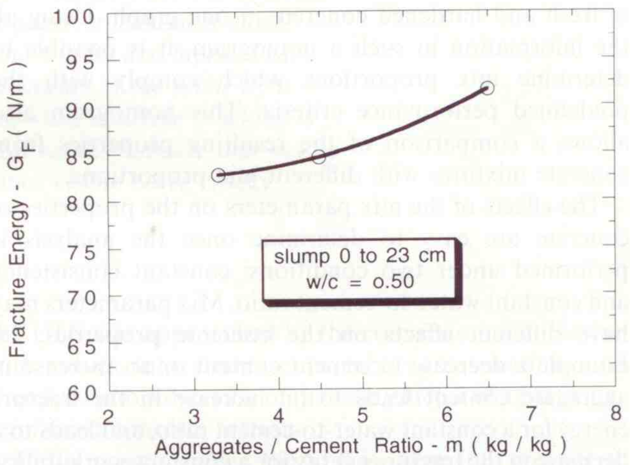

Fig. 21 Effect of aggregate-to-cement ratio on the fracture energy for a constant water-to-cement ratio.

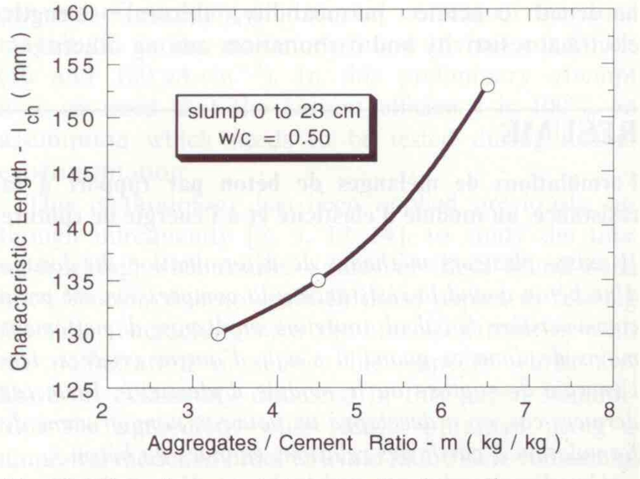

Fig. 22 Effect of aggregate-to-cement ratio on the characteristic length for a constant water-to-cement ratio.

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length increases with the aggregate-to-cement ratio both for constant consistency and constant water-to-cement ratio, as shown in Figs 18 and 22. For the condition of constant consistency, the increases is associated with a higher water-to-cement ratio, as discussed in section 4.2; for the condition of constant water-to-cement ratio, the increase of the characteristic length with higher aggregate concentration is due to the significant influence the aggregate has on the elastic modulus and fracture energy of concrete. Note that the rate of increase of the characteristic length for a constant water-to-cement ratio is superior to that for a constant consistency. One explanation is that while the tensile strength remains about the same for a constant water-to-cement ratio, both the elastic modulus and fracture energy have a significant increase and therefore increase the characteristic length.

5. CONCLUSIONS

A useful mix design nomogram can be obtained by combining three relationships dealing with the properties of fresh and hardened concrete in one graph. Using all the information in such a nomogram, it is possible to determine mix proportions which comply with the predefined performance criteria. This nomogram also allows a comparison of the resulting properties from concrete mixtures with different mix proportions.

The effects of the mix parameters on the properties of concrete are easy to determine once the analysis is performed under two conditions: constant consistency and constant water-to-cement ratio. Mix parameters may have different effects on the concrete properties; for example a decrease in cement content or an increase in aggregate content leads to an increase in the fracture energy for a constant water-to-cement ratio, and leads to a decrease in the fracture energy for a constant workability.

In this work special attention was given to the design of mixtures with given fracture mechanics properties and modulus of elasticity. The resulting mix design nomograms allow the precise determination of a concrete mixture for a specified fracture energy or modulus of elasticity. This approach can also be used for many properties of hardened concrete: permeability, flexural strength, electrical resistivity and carbonation, among others.

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RESUME

Formulations de mélanges de béton par rapport à la résistance, au module d'élasticité et à l'énergie de rupture

Il existe plusieurs méthodes de détermination du dosage d'un béton quand la résistance à la compression est prise comme critère de calcul; toutefois, on dispose de nettement moins de données quand il s'agit d'autres critères, tels l'énergie de rupture ou le module d'élasticité. Pour ces derniers cas, on a développé un nouveau nomogramme de formulation à partir des relations connues du béton.

L'application de cette méthode est démontrée par un programme expérimental qui montre l'influence de la teneur en ciment, des rapports eau/ciment et granulat/ciment sur la résistance à la compression, le module d'élasticité et la résistance à la traction par fendage, l'énergie de rupture et la longueur caractéristique du béton. On a étudié six mélanges de béton présentant des rapports eau/ciment et une ouvrabilité différents.

Outre qu'il est un outil pour le praticien, le nomogramme de formulation peut aussi aider le chercheur à sélectionner les paramètres de dosage les mieux appropriés à des buts expérimentaux et scientifiques. On remarque que certaines contraintes devraient être observées quand on étudie l'effet des paramètres de dosage sur les propriétés du béton.