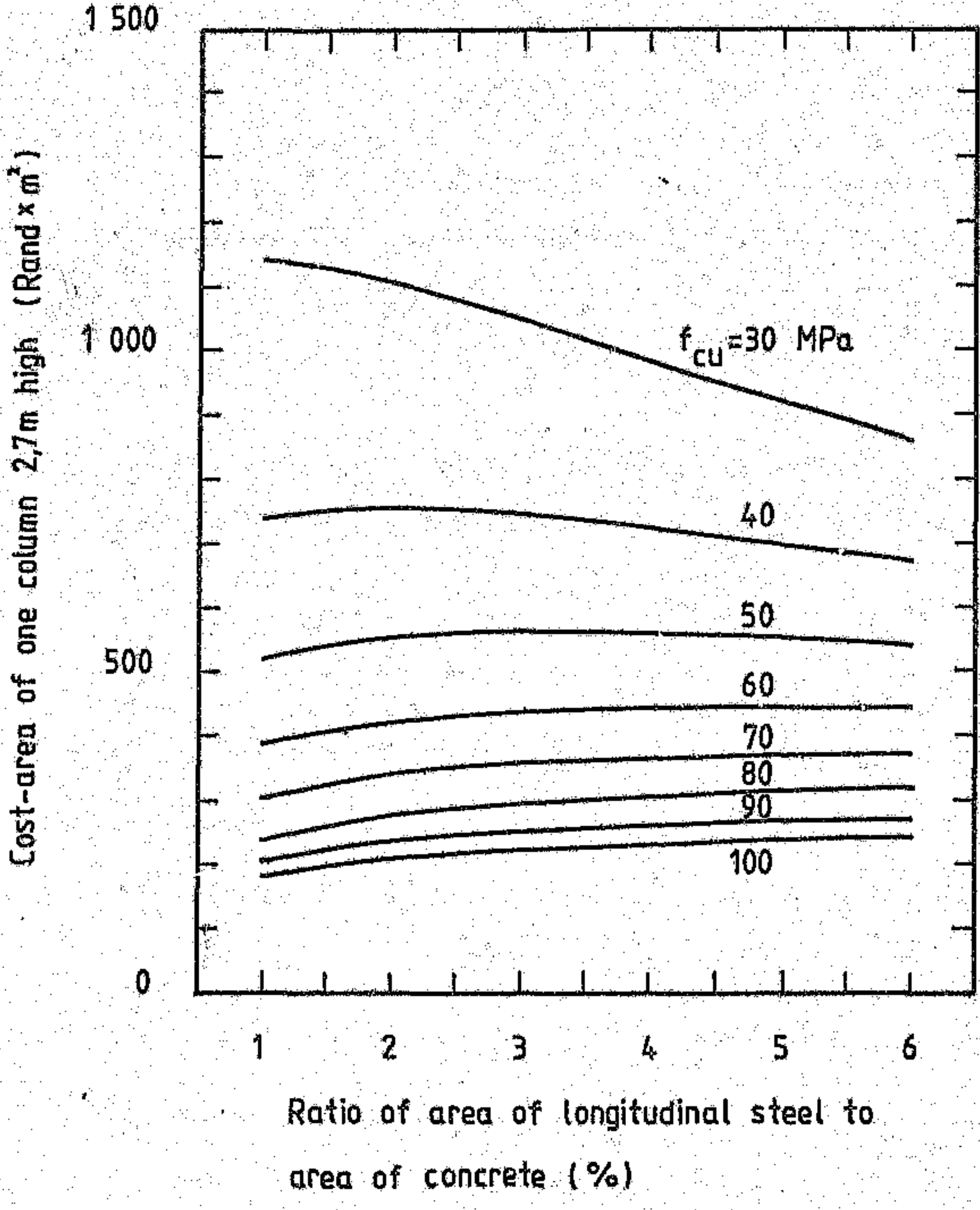

FIGURE 11.2: Cost-area of one hypothetical column using local materials; based on February 1991 prices

Cost–areas of the columns shown in Appendices A11.4 to A11.11 are calculated in Appendix A11.12 and shown in graphic form in Figure 11.2. As can be seen in the figure:

- Cost–area is less sensitive than building cost to the ratio of steel area.

- Overall range of cost–area for the columns considered is proportionately much greater than for building cost: the ratios for highest value to lowest value are approximately 6,3 for cost–area and 3,0 for building cost.

- At lower concrete strengths (30 and 40 MPa) high steel percentages are more favourable than low steel percentages. At higher concrete strengths (60 to 100 MPa) low steel percentages are more favourable than high steel percentages. At 50–MPa concrete strength the influence of steel percentage is negligible.

- A combination of high concrete strength (in this case 100 MPa) and low steel percentage is economically the most favourable although the difference in cost–area between 90–MPa and 100–MPa concrete is small.

11.2.5 Conclusion

The example shows the economic benefits of using high–strength concrete for columns. The concept of cost–area is useful in assessing the economic effects of concrete strength, steel percentage and column size. Whether building cost or cost–area is used as a criterion, the benefits resulting from increasing concrete strength are subject to diminishing returns. In practice therefore it would be preferable to keep concrete characteristic strengths to not more than 70 to 80 MPa while experience in the use of high–strength concrete is gained.

11.3 Cost of elements in general

A cost analysis of columns is given in section 11.2.

Because of the many variables involved, a generally valid cost analysis of elements such as beams and slabs is not practicable.

However, considering structures in general, high-strength concrete may offer the benefits of reduced dead load and reduced cross-sectional dimensions. How significant such benefits would be would depend on the nature of the structure. In the case of precast elements for example, the use of high-strength concrete could make it possible to produce larger elements requiring fewer connections.

High-strength concrete should be considered and evaluated as a material for structures or structural elements with constraints on mass or size. The evaluation should consider technical aspects and cost implications.

12. CONCLUSION

The thesis is based on information obtained from the literature, laboratory investigations, discussions with specialists in various fields and some deductive reasoning. While many of the findings were not unexpected, there were some surprises. In several instances laboratory findings were not in agreement with statements made in the technical literature.

Important aspects of the work and essential findings are discussed below.

12.1 Workability of fresh concrete

The workability of conventional concrete is dominated by aggregate characteristics. As cement content is increased, the workability of the paste plays an increasingly significant role in influencing the workability of the concrete.

The inclusion of a highly effective superplasticizing admixture is essential for the practicable manufacture, handling and placing of high-strength concrete. In unplasticized concrete made to a given slump, increased cement contents result in concretes with very high water contents. Such concretes are also extremely sticky and would be impossible to work with in practice. On the other hand, superplasticized concrete made to a given slump shows constant or decreasing water requirement with increased cement content up to a cement:water ratio of about 4. Such concretes consequently exhibit an extremely efficient use of cement. If any single factor can be said to make it possible to make, and practicable to use, high-strength concrete it is the availability of effective superplasticizers.

Various types of commercially available superplasticizer were tested. By far the most effective was one based on sulphonated naphthalene formaldehyde.

Rheological properties of superplasticized concretes differ from those of unplasticized concretes. Superplasticized concretes tend to be less cohesive, more viscous and less thixotropic than unplasticized concretes. These features could mean that techniques used for handling and placing conventional concrete would ideally need to be modified for high-strength concrete.

12.2 Mix proportioning

Mix proportioning is essentially a process of determining optimum stone content in order to achieve good workability of the fresh concrete and selecting an appropriate cement:water ratio to ensure the required strength of the hardened concrete. Methods used for proportioning conventional concrete do not work satisfactorily for high-strength concrete. This is because of the combination of low water content and high cement content associated with high-strength concrete mixes.

A method, based on the concepts of aggregate packing capacity and mortar hydraulic radius, and on empirical findings, was developed for the proportioning of high-strength concrete mixes. The method was extensively tested by being used to proportion mixes for all of the various investigations done. It is believed that the method caters for aggregates of any type, particle shape or grading. The methodology on which the development of the method is based also makes it possible to develop charts or formulae for slump requirements different from the slump used for the investigation.

12.3 The effect of high cement:water ratios on the hydration of cement

The hydration of cement is a function of the chemical and mineralogical properties of the cement and on relative volumes of the participating substances and products of hydration.

Because proportions of oxides used for the manufacture of modern portland cements are kept within narrow limits and the manufacturing process is so tightly controlled, hydration properties of different cements do not differ significantly.

On the other hand, relative volumes of cement and water in the fresh paste are determined by cement:water ratio which can vary within a wide range.

Hydrate can form only if sufficient space is available for its formation. If the available space is used up before all the cement has been hydrated, hydration ceases. On the other hand, if more than enough space is available for hydration and water is available, the cement, if fine enough, can hydrate completely and water-filled capillaries are left in the hydrate matrix. The concept of cement-saturation is introduced to describe a paste of which the ratio of cement to water is such that the products of hydration will exactly fill the available space when the cement is completely hydrated. Although cement:water ratio for cement-saturation cannot be precisely determined, cement-saturation is a condition which effectively separates pastes into two types with fundamentally different properties.

Cement-undersaturated pastes are those in which complete hydration is theoretically possible and capillary pores are present after complete hydration. The properties of such pastes in the hardened state are significantly influenced by the volume fraction and distribution of capillary pores. An increase in cement:water ratio has the effect of reducing the capillary porosity with a consequent increase in strength, elastic stiffness and impermeability.

Cement-oversaturated pastes are those in which there is insufficient space available for complete hydration. The hardened paste therefore contains unhydrated cement – the cores of cement particles – but does not contain capillary pores. The properties of such pastes in the hardened state are therefore not influenced by capillary porosity. An increase in cement:water ratio has the effect of merely increasing the fraction of unhydrated cement and intuitively should not result in an increase in paste strength. The strength of concretes made with cement-oversaturated pastes does however show an increase in strength with an increase in cement:water ratio. It is suggested that such differences in strength are caused by differences in interface or boundary conditions and not by changes in porosity. The behaviour of cement-oversaturated concretes with regard to strength and movement properties is discussed further in sections 12.4 and 12.5 respectively.

It can be shown by calculation that pastes with a cement:water ratio of higher than about 1.8 to 2 have to imbibe water if potential hydration is to be achieved; the original mixing water is insufficient. High-strength concretes would almost without exception have cement:water ratios in excess of 2. It is therefore essential that high-strength concretes should be cured by making additional water available at the surface of the element for as long as possible.

12.4 Strength of concrete

Strengths of structural concrete have increased steadily during the twentieth century. Conventional concrete has changed from a material with a compressive strength of about 20 MPa to one with a range of 25 to 40 MPa, with 30-MPa concrete probably the most commonly used. In parallel with this development, and starting during the sixties, "high-strength" concrete has developed from a material with a cube strength of about 50 MPa to the highest recorded strength used in a structure of about 150 MPa in 1987. While such high strengths are very unusual when seen in the context of the construction industry as a whole, it is significant that they are not merely laboratory curiosities but have been used for actual construction.

The factors which fundamentally influence the strength of concrete are paste strength, aggregate strength and paste-aggregate interface strength; their relative importance differs according to the strength of concrete. Aggregate strength becomes increasingly important as concrete strength increases.

High-strength concrete can also be divided into two categories. The boundary line between these categories is the cement:water ratio for cement-saturation.

As explained above, cement-undersaturated hardened pastes are characterized by theoretically complete hydration and the presence of capillary pores. When cement:water ratio is increased the volume of hydrate increases and capillary porosity decreases; paste strength consequently increases.

Cement–oversaturated hardened pastes are characterized by incomplete hydration and the absence of capillary pores. An increase in cement:water ratio has the effect of increasing the volume fraction of unhydrated cement; it does not increase paste strength by reducing porosity. On the other hand concrete strength increases with an increase in cement:water ratio. This increase in strength is caused by the increased fraction of unhydrated cement fragments which displace true aggregates and act as aggregates. Because the bond between hydrate and unhydrated cement is superior to the bond between hydrate and aggregate, overall interface strength is improved and concrete strength improves. Increases in concrete strengths effected in this way are small compared with increases to cement–undersaturated mixes as a result of a given addition of cement. Cement–oversaturated mixes are therefore a relatively inefficient use of cement.

The effects of various factors on compressive strength were investigated. These were stone size and packing capacity; blends of portland cement and various cement extenders; various rapid–hardening portland cements; the use of condensed silica fume; and various aggregate types. All materials used for the investigation were available in South Africa through ordinary commercial channels. In order to make rational comparisons of performance, the concept of "cement–efficiency factor" (CEF) is introduced. CEF is a measure of the strength developed at a given age by unit quantity of cement (or cement plus extender) and is expressed in units of MPa per 100 kg of cement per cubic metre of concrete.

The investigation into the effect of stone size showed that, using local aggregates, fairly large stone (26,5–mm nominal size) and blends of 26,5–mm and 6,7–mm were the most efficient with regard to strength. This is contrary to the generally held view expressed in the literature. A simple model was therefore developed in order to attempt to explain the difference in performance between large and small stone sizes.

In a series of tests done with a single rapid–hardening portland cement (RHPC) blended with various cement extenders, it was found that RHPC and condensed silica fume and RHPC on its own gave the highest strengths. Blends of ground granulated blastfurnace slag and fly ash performed relatively poorly and are not considered to be worth using in high-strength concrete. Condensed silica fume (CSF) showed the highest CEFs at lower cement:water ratios while RHPC on its own was the best performer at high ratios.

A comparison of different RHPCs showed significantly different performances in terms of both strength and CEF. It is important therefore that the proportioning of high-strength concrete should be based on tests done with the specific cement to be used. Preferably, several different RHPCs should be tested and the cement giving the best performance selected for the project.

The mechanisms by which condensed silica fume enhances strength were investigated. The "fine-filler effect" appears to be a satisfactory explanation for the physical mechanism. It was found that condensed silica fume produced significant improvements to CEF at the lowest cement:water ratio in the test series. Compared with RHPC on its own, the CSF blend was superior in cement-undersaturated mixes and RHPC was superior in cement-oversaturated mixes. Nevertheless, because the pozzolanic reaction does not consume water, CSF concretes do have the advantage of requiring less additional water for curing.

The performance of various South African aggregate types was compared. Of the geological types tested: andesite, dolerite, dolomite, granite and quartzite; only the first three gave acceptable results. At the higher cement:water ratios, andesite, dolerite and one of the dolomites gave the highest strengths but the dolomite consistently gave the highest CEFs. Concrete strengths did not show a strong correlation with direct or indirect indicators of rock strength. The very large differences in performance between different aggregate types emphasizes the importance of testing with specific materials and the selection of the best available aggregate.

Splitting-tensile and flexural strengths were investigated and it was found that both were higher than predicted by formulae from the literature although generally not by a wide margin. Predictive formulae appear to give realistic to conservative values.

It is generally accepted that the aspect ratio of a specimen used for compressive-strength testing influences strength: slender specimens tend to fail at smaller loads than squat specimens made with the same concrete. In tests done to find out the effect of high concrete strength on the aspect-ratio effect, it was found that strength had no influence. The significance of this finding is that the relation between cube strength and the strength of concrete in a more slender form in a structural element does not need to be modified when designing a structure in high-strength concrete. Converseley, standard specimen shape for testing for strength can be used for high-strength concrete.

Based on an analysis of some eighty strength tests it was found that the average within-batch variation of cube strengths did not change in a strength range of 60 to 120 MPa. The implication of this finding is that the criterion, in the SABS test method, for validity of a test does not need to be changed for high-strength concrete.

Tests carried out in the course of the investigations discussed above showed that it was possible, using commercially available cements, cement extenders, aggregates and admixtures and normal recommended admixture dosages, to produce concretes with 28- and 56-day cube strengths of 117 and 127 MPa respectively. Assuming a margin of 12 MPa, these strengths are equivalent to characteristic strengths of 105 and 115 MPa respectively.

Cement-efficiency factors of 26 and 30 MPa/100 kg cement/m^3 were achieved at 28 and 56 days respectively. These results compared favourably with values reported in the literature.

In a given set of mixes, it must not be assumed that highest strength and best CEF are achieved by the same mix. And for a given combination of materials, highest strength and maximum CEF do not occur at the same cement:water ratio. Highest strength is normally achieved at the highest cement:water ratio used while the highest CEF normally occurs at or about the cement:water ratio for cement-saturation.

Whether a concrete mix made of given materials should be proportioned for highest possible strength or for maximum CEF would depend on the specific application and on economic factors.

12.5 Movement properties

Modulus of elasticity, creep and shrinkage were investigated with three different aggregate types and across a wide range of cement:water ratio. It was found that the cement:water ratio for cement–saturation effectively formed a boundary between concretes with different characteristics in terms of modulus of elasticity, and creep. For cement–undersaturated mixes, an increase in cement:water ratio resulted in an increase in strength, an increase in modulus of elasticity and a decrease in specific creep. For cement–oversaturated mixes, an increase in cement:water ratio resulted in a relatively small increase in strength and virtually no difference in modulus of elasticity or specific creep. It is suggested that this difference in behaviour can be explained by the fact that properties of cement–undersaturated mixes are dominated by capillary porosity while the properties of cement–oversaturated mixes, which have no capillary pores, are dominated by aggregate–paste interfaces. Cement–oversaturated mixes are in this respect analogous to steel: strength is determined by the properties of crystal boundaries and steels of different strengths have the same modulus of elasticity.

Shrinkage did not show any clear pattern, relative to cement:water ratio or to water content. Generally though, shrinkage decreased with increasing cement:water ratio possibly because of reduced water content and greater impermeability which would tend to impede the escape of moisture.

Based on analyses of 180–day results, shrinkage, elastic and creep strains for concretes subjected to 0,4 times characteristic strength were calculated for characteristic strengths from 40 to 100 MPa. Shrinkage strain remained virtually constant, elastic strain increased linearly with increasing strength while creep strain reached a maximum at a strength of 70 MPa. Maximum total strain varied from 1 500 microstrain to 2 000 microstrain.

Movement-related properties of a concrete proposed for use in a structure should be determined by tests done on specific materials and according to a regime which replicates as closely as possible conditions expected in the field.

12.6 Durability

Because of the high cement:water ratios used in high-strength concrete, it is extremely impermeable and is therefore as resistant as concrete can be to the ingress of substances into the concrete. With the exception of alkali silica reaction, all chemically destructive mechanisms involve ingress. High-strength concrete can therefore be regarded as ultra-durable in the spectrum of concretes although there is doubt expressed in the literature as to the resistance of high-strength concretes to damage by freeze-thaw cycles.

12.7 Economic Implications

When one considers that the development of high-strength concrete has been driven mainly by economic forces, it is clear that cost is the ultimate criterion by which the usefulness of the material will be judged.

Based on mixes used for another part of the investigation, prices of concrete materials and bill-of-quantity concrete rates, the cost of a hypothetical column was calculated for various characteristic concrete strengths and reinforcement ratios. It was found, as expected, that the most economical column consisted of the strongest concrete with the least steel. The law of diminishing returns applied however: there was little to be gained by increasing concrete strength from 90 MPa to 100 MPa. But cost was extremely sensitive to steel:concrete ratio.

The above analysis does not address the question of floor space occupied, and thus rendered unusable, by the column. To rectify this shortcoming, the concept of "cost-area" was developed. Cost-area is defined as the product of the cost per column and the plan area of the column. Using the concept of cost-area, a further analysis showed that while the lowest cost-area was achieved with the strongest concrete and the least steel, cost-area was generally fairly insensitive to steel:concrete ratio.

Significantly, overall range of cost–area was more than twice the overall range of cost when taking the ratio of highest value to lowest value.

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APPENDIX A5.1: MIXES MADE WITH VARIOUS SIZES OF STONE AND WITHOUT ADMIXTURES

Table A5.1

Stone : 13,2–mm dolomite
Sand : Dolomite crusher
Cement : RHPC type "L"
Slump : Approximately 75 mm

	C/W	2,0	2,3	2,6	2,9	3,25
Quantities per m^3 of concrete (kg)	Water	223	227	235	245	289
	Cement	446	522	611	710	940
	Sand	877	763	597	396	0
	Stone	950	985	1 050	1 135	1 200

Table A5.2

Stone : 19–mm dolomite
Sand : Dolomite crusher
Cement : RHPC type "L"
Slump : Approximately 75 mm

	C/W	2,0	2,3	2,6	2,9	3,27
Quantities per m^3 of concrete (kg)	Water	201	213	230	248	284
	Cement	402	490	598	719	923
	Sand	821	678	504	314	0
	Stone	1 110	1 140	1 170	1 200	1 230

Table A5.3

Stone : 26,5-mm dolomite
Sand : Dolomite crusher
Cement : RHPC type "L"
Slump : Approximately 75 mm

	C/W	2,0	2,3	2,6	2,9	3,27
Quantities per m³ of concrete (kg)	Water	192	199	220	245	279
	Cement	384	458	572	710	914
	Sand	798	703	531	317	0
	Stone	1 175	1 185	1 195	1 215	1 250

Table A5.4

Stone : 75 % 26,5-mm dolomite and
25 % 6,7-mm dolomite
Sand : Dolomite crusher
Cement : RHPC type "L"
Slump : Approximately 75 mm

	C/W	2,0	2,3	2,6	2,9	3,17
Quantities per m³ of concrete (kg)	Water	198	196	210	232	258
	Cement	396	451	546	673	818
	Sand	647	588	439	234	0
	Stone	1 300	1 315	1 345	1 370	1 400

Table A5.5

Stone : 13,2–mm dolomite
Sand : Dolomite crusher
Cement : RHPC type "J"
Slump : Approximately 75 mm

	C/W	2,0	2,3	2,6	2,9	3,25
Quantities per m^3 of concrete (kg)	Water	215	215	220	236	289
	Cement	430	495	572	684	940
	Sand	914	832	699	484	0
	Stone	950	975	1 025	1 095	1 200

APPENDIX A8.1: MIXES MADE WITH VARIOUS SIZES OF STONE: PROPORTIONS, STRENGTHS AND CEFs

Table A8.1.1 Results of mixes using 13,2-mm stone

Stone	13,2-mm andesite
Sand	Andesite crusher
Cement	RHPC type "R"
Admixture	SNF powder type "C"
Slump	Approximately 75 mm

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water	190	185	185	180	170
	Cement	380	444	518	576	612
	Sand	1 200	1 141	1 067	1 004	969
	Stone	810	825	830	855	885
	Admixture	3,5	4,1	4,8	5,3	5,6
Age 7 days	Cube strength (MPa)	46	59	72	82	91
	CEF (MPa/100 kg cement/m³)	12,1	13,3	13,9	14,2	14,9
Age 28 days	Cube strength (MPa)	58	74	88	98	104
	CEF (MPa/100 kg cement/m³)	15,3	16,7	17,0	17,0	17,0

Table A8.1.2 Results of mixes using 19–mm stone

Stone	19–mm andesite
Sand	Andesite crusher
Cement	RHPC type "R"
Admixture	SNF powder type "C"
Slump	Approximately 75 mm

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water	170	170	170	170	170
	Cement	340	408	476	544	612
	Sand	1 163	1 094	1 021	953	855
	Stone	950	950	960	965	1 000
	Admixture	3,1	3,8	4,4	5,0	5,6
Age 7 days	Cube strength (MPa)	49	61	75	83	91
	CEF (MPa/100 kg cement/m^3)	14,4	15,0	15,8	15,3	14,9
Age 28 days	Cube strength (MPa)	60	73	88	101	104
	CEF (MPa/100 kg cement/m^3)	17,6	17,9	18,5	18,6	17,0

Table A8.1.3 **Results of mixes using 26,5-mm stone**

Stone	26,5–mm andesite
Sand	Andesite crusher
Cement	RHPC Type "R"
Admixture	SNF powder type "C"
Slump	Approximately 75 mm

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water	170	160	160	160	155
	Cement	340	384	448	512	558
	Sand	1 077	1 061	996	932	894
	Stone	1 030	1 035	1 040	1 045	1 055
	Admixture	3,1	3,5	4,1	4,7	5,1
Age 7 days	Cube strength (MPa)	50	65	76	85	95
	CEF (MPa/100 kg cement/m^3)	14,7	16,9	17,0	16,6	17,0
Age 28 days	Cube strength (MPa)	63	79	95	101	104
	CEF (MPa/100 kg cement/m^3)	18,5	20,6	21,2	19,7	18,6

Table A8.1.4 **Results of mixes using 26,5–mm and 6,7–mm stone**

Stone	80/20 blend of 26,5–mm andesite and 6,7–mm andesite
Sand	Andesite crusher
Cement	RHPC type "R"
Admixture	SNF powder type "C"
Slump	Approximately 75 mm

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water	175	165	165	165	165
	Cement	350	396	462	528	594
	Sand	1 023	995	924	853	767
	Stone	1 060	1 075	1 085	1 095	1 115
	Admixture	3,2	3,6	4,3	4,9	5,5
Age 7 days	Cube strength (MPa)	50	66	78	87	96
	CEF (MPa/100 kg cement/m^3)	14,3	16,7	16,9	16,5	16,2
Age 28 days	Cube strength (MPa)	60	78	95	98	108
	CEF (MPa/100 kg cement/m^3)	17,1	19,7	20,6	18,6	18,2

APPENDIX A8.2 MIXES MADE WITH RHPC AND VARIOUS CEMENT EXTENDERS: PROPORTIONS, STRENGTH AND CEFs

Table A8.2.1: Mixes and results: RHPC only

Stone	75 % 26,5–mm dolomite 25 % 6,7–mm dolomite
Sand	Dolomite crusher
Cement	RHPC
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water	145	140	135	130	130
	RHPC	290	336	378	416	468
	Sand	1 025	999	966	936	865
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	5,8	6,7	7,6	8,3	9,4
Age 7 days	Cube strength (MPa)	58	67	79*	83	92
	CEF (MPa/100 kg cement/m^3)	20,0	19,9	20,9*	20,0	19,7
Age 28 days	Cube strength (MPa)	66	81	94	103	107
	CEF (MPa/100 kg cement/m^3)	22,8	24,1	24,9	24,8	22,9
Age 56 days	Cube strength (MPa)		89	102	112	119
	CEF (MPa/100 kg cement/m^3)		26,5	27,0	26,9	25,4

* Anomalous result – too high

Table A8.2.2: Mixes and results: 5 % CSF

Stone	75 % 26,5-mm dolomite 25 % 6,7-mm dolomite
Sand	Dolomite crusher
Cement	95 % RHPC 5 % CSF
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water	150	145	140	140	140
	RHPC	285	331	372	426	479
	CSF	15	17	20	22	25
	Sand	996	966	931	870	795
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	6,0	7,0	7,8	9,0	10,1
Age 7 days	Cube strength (MPa)	59	73	82	89	96
	CEF (MPa/100 kg cement/m³)	19,7	21,0	20,9	19,9	19,0
Age 28 days	Cube strength (MPa)	77*	90	99	106	106
	CEF (MPa/100 kg cement/m³)	25,7	25,9	25,3	23,7	21,0
Age 56 days	Cube strength (MPa)		104	107	113	124
	CEF (MPa/100 kg cement/m³)		29,9	27,3	25,2	24,6

* 27 days

Table A8.2.3 Mixes and results: 10 % CSF

Stone	75 % 26,5–mm dolomite 25 % 6,7–mm dolomite
Sand	Dolomite crusher
Cement	90 % RHPC 10 % CSF
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6	5,0
Quantities per m³ of concrete (kg)	Water (total)	155	150	150	140	140	195⊡
	RHPC	279	324	378	403	454	878
	CSF	31	36	42	45	50	97
	Sand	966	934	869	861	784	0
	Stone	1 165	1 165	1 175	1 185	1 210	1 400
	Admixture (ℓ)	6,2	7,2	8,4	9,0	10,1	19,5
Age 7 days	Cube strength (MPa)	54	70	82	91	95	109
	CEF (MPa/100 kg cement/m³)	17,4	19,4	19,5	20,3	18,8	11,2
Age 28 days	Cube strength (MPa)	77☆	93	102	112	120◊	117
	CEF (MPa/100 kg cement/m³)	24,8	25,8	24,3	25,0	23,8	12,0
Age 56 days	Cube strength (MPa)		101	109	119	125	
	CEF (MPa/100 kg cement/m³)		28,0	25,9	26,6	25,3	

⊡ Slump 130 m ☆ 27 days ◊ Result not valid, range of three strengths > 15 % of average

Table A8.2.4: **Mixes and results: FA**

Stone	75 % 26,5-mm dolomite
	25 % 6,7-mm dolomite
Sand	Dolomite crusher
Cement	85 % RHPC
	15 % FA
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6	5,2□
Quantities per m^3 of concrete (kg)	Water (total)	140	135	135	135	135	190
	RHPC	238	275	321	367	413	835
	FA	42	49	57	65	73	147
	Sand	1 069	1 041	980	920	848	0
	Stone	1 130	1 130	1 140	1 150	1 170	1 400
	Admixture (ℓ)	5,6	6,5	7,6	8,6	9,7	19,7
Age 7 days	Cube strength (MPa)	48	60	71	79	90	96
	CEF (MPa/100 kg cement/m^3)	17,1	18,5	18,8	18,3	18,5	9,8
Age 28 days	Cube strength (MPa)	60	74	88	91	98	98*
	CEF (MPa/100 kg cement/m^3)	21,4	22,8	23,3	21,1	20,2	10,0
Age 56 days	Cube strength (MPa)	70	88	99	101◊	111	116☆
	CEF (MPa/100 kg cement/m^3)	25,0	27,2	26,2	23,4	22,8	11,8

□ Slump 200 mm
* Average of two cubes, range > 15 % of average
☆ Average of two cubes, range = 8 % of average
◊ Average of two cubes

Table A8.2.5: Mixes and results: GGBS

Stone	75 % 26,5-mm dolomite 25 % 6,7-mm dolomite
Sand	Dolomite crusher
Cement	75 % RHPC 25 % GGBS
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water (total)	140	135	135	135	135
	RHPC	210	243	284	324	364
	GGBS	70	81	94	108	122
	Sand	1 062	1 036	976	918	848
	Stone	1 145	1 145	1 155	1 165	1 185
	Admixture (ℓ)	5,6	6,5	7,6	8,6	9,7
Age 7 days	Cube strength (MPa)	51	62	72	84	91
	CEF (MPa/100 kg cement/m^3)	18,2	19,1	19,0	19,4	18,7
Age 28 days	Cube strength (MPa)	66	81	92	99☆	102◊ ☆
	CEF (MPa/100 kg cement/m^3)	23,6	25,0	24,3	22,9	21,0
Age 56 days	Cube strength (MPa)	69	84	96	104	107
	CEF (MPa/100 kg cement/m^3)	24,6	25,9	25,4	24,1	22,0

☆ Three cubes in set tested on two different machines
◊ Range > 15 % of average

APPENDIX A8.3: MIXES MADE WITH VARIOUS RHPCs: PROPORTIONS, STRENGTHS AND CEFs

Table A8.3.1: Mixes and results: cement "H"

Stone	75 % 26,5-mm dolomite
	25 % 6,7-mm dolomite
Sand	Dolomite crusher
Cement	RHPC type "H"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water (total)	145	140	135	140	145
	Cement	290	336	378	448	522
	Sand	1 026	999	966	880	774
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	5,8	6,7	7,6	9,0	10,4
Age 7 days	Cube strength (MPa)	57	69	77	85	90
	CEF (MPa/100 kg cement/m^3)	19,7	20,5	20,4	19,0	17,2
Age 28 days	Cube strength (MPa)	68*	83*	91*	96	101
	CEF (MPa/100 kg cement/m^3)	23,4	24,7	24,1	21,4	19,4
Age 56 days	Cube strength (MPa)	71	89	96	100	105
	CEF (Mpa/100 kg cement/m^3)	24,5	26,5	25,4	22,3	20,1

* 29 days

APPENDIX A8.3: MIXES MADE WITH VARIOUS RHPCs: PROPORTIONS, STRENGTHS AND CEFs

Table A8.3.1: Mixes and results: cement "H"

Stone	75 % 26,5-mm dolomite 25 % 6,7-mm dolomite
Sand	Dolomite crusher
Cement	RHPC type "H"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water (total)	145	140	135	140	145
	Cement	290	336	378	448	522
	Sand	1 026	999	966	880	774
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	5,8	6,7	7,6	9,0	10,4
Age 7 days	Cube strength (MPa)	57	69	77	85	90
	CEF (MPa/100 kg cement/m^3)	19,7	20,5	20,4	19,0	17,2
Age 28 days	Cube strength (MPa)	68*	83*	91*	96	101
	CEF (MPa/100 kg cement/m^3)	23,4	24,7	24,1	21,4	19,4
Age 56 days	Cube strength (MPa)	71	89	96	100	105
	CEF (Mpa/100 kg cement/m^3)	24,5	26,5	25,4	22,3	20,1

* 29 days

APPENDIX A8.3: MIXES MADE WITH VARIOUS RHPCs: PROPORTIONS, STRENGTHS AND CEFs

Table A8.3.1: Mixes and results: cement "H"

Stone	75 % 26,5–mm dolomite
	25 % 6,7–mm dolomite
Sand	Dolomite crusher
Cement	RHPC type "H"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water (total)	145	140	135	140	145
	Cement	290	336	378	448	522
	Sand	1 026	999	966	880	774
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	5,8	6,7	7,6	9,0	10,4
Age 7 days	Cube strength (MPa)	57	69	77	85	90
	CEF (MPa/100 kg cement/m^3)	19,7	20,5	20,4	19,0	17,2
Age 28 days	Cube strength (MPa)	68*	83*	91*	96	101
	CEF (MPa/100 kg cement/m^3)	23,4	24,7	24,1	21,4	19,4
Age 56 days	Cube strength (MPa)	71	89	96	100	105
	CEF (Mpa/100 kg cement/m^3)	24,5	26,5	25,4	22,3	20,1

* 29 days

Table A8.3.2: Mixes and results: cement "J"

Stone	75 % 26,5–mm dolomite 25 % 6,7–mm dolomite
Sand	Dolomite crusher
Cement	RHPC type "J"
Slump	Approximately 75 mm
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water (total)	145	140	135	130	130
	Cement	290	336	378	416	468
	Sand	1 025	999	966	936	865
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	5,8	6,7	7,6	8,3	9,4
Age 7 days	Cube strength (MPa)	58	67	79*	83	92
	CEF (MPa/100 kg cement/m³)	20,0	19,9	20,9	20,0	19,7
Age 28 days	Cube strength (MPa)	66	81	94	103	107
	CEF (MPa/100 kg cement/m³)	22,8	24,1	24,9	24,8	22,9
Age 56 days	Cube strength (MPa)		89	101	112	119
	CEF (MPa/100 kg cement/m³)		26,5	27,0	26,9	25,4

* Anomalous result – too high

Table A8.3.3: **Mixes and results: cement "L"**

Stone	75 % 26,5–mm dolomite 25 % 6,7–mm dolomite
Sand	Dolomite crusher
Cement	RHPC type "L"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water (total)	150	145	145	145	140
	Cement	300	348	406	464	504
	Sand	1 025	974	912	851	805
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	6,0	7,0	8,1	9,3	10,1
Ag[illegible]ays	Cube strength (MPa)	58	73	82	91	96
	CEF (MPa/100 kg cement/m³)	19,3	21,0	20,2	19,6	19,0
Age 28 days	Cube strength (MPa)	67	85	94	103	113
	CEF (MPa/100 kg cement/m³)	22,3	24,4	23,2	22,2	22,4
Age 56 days	Cube strength (MPa)	71	92	103	107	113
	CEF (MPa/100 kg cement/m³)	23,7	26,4	25,[illegible]	23,1	22,4

Table A8.3.4: Mixes and results: cement "R"

Stone	75 % 26,5–mm dolomite
	25 % 6,7–mm dolomite
Sand	Dolomite crusher
Cement	RHPC type "R"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water (total)	150	145	135	135	135
	Cement	300	348	378	432	486
	Sand	1 002	974	966	907	835
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	6,0	7,0	7,6	8,6	9,7
Age 7 days	Cube strength (MPa)	50	64	79	87	94
	CEF (MPa/100 kg cement/m³)	16,7	18,4	20,9	20,1	19,3
Age 28 days	Cube strength (MPa)	64	75	94	102	111
	CEF (MPa/100 kg cement/m³)	21,3	21,6	24,9	23,6	22,8
Age 56 days	Cube strength (MPa)	67	84	100	109	121
	CEF (MPa/100 kg cement/"3'	22,3	24,1	26,5	25,2	24,9

Table A8.3.5: **Mixes and results: cement "U"**

Stone	75 % 26,5–mm dolomite
	25 % 6,7–mm dolomite
Sand	Dolomite crusher sand
Cement	RHPC type "U"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water (total)	150	145	145	145	145
	Cement	300	348	406	464	522
	Sand	1 025	974	912	851	774
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	6,0	7,0	8,1	9,3	10,4
Age 7 days	Cube strength (MPa)	58	74	84	94	101
	OEF (MPa/100 kg cement/m^3)	19,3	21,3	20,7	20,3	19,4
Age 28 days	Cube strength (MPa)	71	88	105	110	112
	CEF (MPa/100 kg cement/m^3)	23,7	25,3	25,9	23,7	21,5
Age 56 days	Cube strength (MPa)	77	94	101	112	116
	CEF (MPa/100 kg cement/m^3)	25,7	27,0	24,9	24,1	22,2

Table A8.3.6: Mixes and results: cement "D"

Stone	75 % 26,5–mm dolomite 25 % 6,7–mm dolomite
Sand	Dolomite crusher sand
Cement	RHPC type "D"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water (total)	150	145	140	140	140
	Cement	300	348	392	458	504
	Sand	1 002	974	939	879	805
	Stone	1 165	1 165	1 175	1 185	1 210
	Admixture (ℓ)	6,0	7,0	7,8	9,0	10,8
Age 7 days	Cube strength (MPa)	57	70	86	92	98
	CEF (MPa/100 kg cement/m³)	19,0	20,1	21,9	20,5	19,4
Age 28 days	Cube strength (MPa)	68	86	96	108	113
	CEF (MPa/100 kg cement/m³)	22,7	24,7	24,5	24,0	22,0
Age 56 days	Cube strength (MPa)	73	89	102	109	114
	CEF (MPa/100 kg cement/ᵐ3)	24,3	25,6	26,0	24,3	22,6

APPENDIX A8.4: COMPARISON OF VARIOUS AGGREGATE TYPES: EFFECT ON COMPRESSIVE STRENGTH

Table A8.4.1: Sieve analyses and densities of aggregates

	SABS sieve (mm)	Dolomite ex Olifantsfontein			Granite ex Jukskei			Andesite ex Elkenhof		
		26,5-mm stone	6,7-mm stone	Crusher sand	26,5-mm stone	6,7-mm stone	Crusher sand	26,5-mm stone	6,7-mm stone	Crusher sand
Percentage passing	37,5	100			100					
	26,5	99			92			100		
	19,0	37			3			14		
	13,2	4			2			1		
	9,5	2	100		1	100		1	100	
	6,7	1	82		1	79	100	1	99	100
	4,75	1	38	100	1	42	99	1	59	99
	2,36	1	1	77	1	5	75	1	2	71
	1,18			47		1	51		1	46
	0,60			30		1	32		1	30
	0,30			21		1	17		1	21
	0,15			16		1	8		1	15
	0,075	0,4	0,3	13,8	0,4	0,6	3,9	0,5	0,8	12,2
Fineness modulus		7,59	5,61	3,08	7,94	5,5	3,19	7,83	5,36	3,18
Relative density		2,88	2,88	2,85	2,66	2,66	2,63	2,93	2,93	2,90
Bulk density	Loose				1 260	1 255	1 525	1 435	1 405	1 540
Bulk density	Compacted	1 660	1 530	1 855	1 445	1 395	1 685	1 530	1 630	1 675
Packing capacity (% solids in compacted state)		57,6	53,1	65,1	54,3	51,3	64,1	52,2	55,6	57,8

Table A8.4.1: (continued)

	SABS sieve (mm)	Dolomite ex Daleside			Quartzite ex Ferro				Dolerite ex Rooikraal		
		26,5–mm stone	6,7–mm stone	Crusher sand	26,5–mm stone	6,7–mm stone	Washed crusher sand	Unwashed crusher sand	26,5–mm Stone	6,7–mm stone	Crusher sand
Percentage passing	37,5	100			100				100		
	26,5	95			97				95		
	19,0	5			24				16		
	13,2				1				2		
	9,5		100	100		100	100		2	100	
	6,7		99	99		71	99	100	1	98	
	4,75		57	96		19	95	98	1	55	100
	2,36		4	58		1	63	76		4	76
	1,18		3	32		1	44	51		1	48
	0,60		3	20		1	32	40		1	32
	0,30		3	15		1	22	29		1	23
	0,15		2	12			12	20		1	15
	0,075	0,2	2,3	9,5	0,2	0,4	5,1	13,0	0,7	0,6	8,5
Fineness modulus		7,95	5,29	3,68	7,76	5,77	3,33	2,85	7,80	5,37	3,06
Relative density		2,86	2,86	2,84	2,66	2,66	2,64	2,64	3,04	3,04	3,06
Bulk density	Loose	1 405	1 380	1 680	1 295	1 375	1 530	1 565	1 515	1 475	1 750
Bulk density	Compacted	1 545	1 525	1 920	1 450	1 540	1 680	1 720	1 640	1 635	1 935
Packing capacity (% solids in compacted state)		54,0	53,3	67,6	54,5	57,9	63,6	65,2	53,9	53,8	63,2

Table A8.4.2: Particle–size distribution of fine material in crusher sands

	Particle size (micron)	Dolomite ex Olifants–fontein	Granite ex Jukskei	Andasite ex Elkenhof	Dolomite ex Daleside	Quartzite ex Ferro (washed)	Quartzite ex Ferro (unwashed)	Dolerite ex Roolkraal
Percentage of total sand sample smaller than stated size	74		5,3					
	73					5,4		
	69						11,8	
	66			7,0				5,0
	64	10,7			7,7			
	32					1,2		
	31		2,2					
	30						6,9	
	29							1,0
	28			5,5	5,1			
	27	7,8						
	14		1,5			1,0	4,0	
	13	4,7		3,9	3,5			0,9
	7			3,0		0,9	3,2	
	6,5	3,0			2,4			0,8
	3,6					0,7		
	3,5		1,4				1,6	
	3,3							0,5
	3,2	1,9			1,6			
	3,0			2,0				
	2,6		1,1			0,4		
	2,5	1,6						
	2,4							0,4
	2,3			1,7	1,3			
	2,1						1,5	
	1,6					0,2		
	1,5		0,6					0,2
	1,4	1,0		1,1	1,0			
	1,0						0,8	

Table A8.4.3: Aggregate-crushing values for various stone samples

Rock type	ACV (%) Stone size (mm) 26,5	6,7
Dolomite ex Olifantsfontein	23,0	
		34,5
Granite ex Jukskei	24,1	
		37,4
Andesite ex Elkenhof	11,4	
		20,1
Dolomite ex Daleside	23,1	
		28,8
Quartzite ex Ferro	19,8	
		29,4
Dolerite ex Rooikraal	15,7	
		27,7

Table A8.4.4: Strength characteristics of certain aggrega[illegible]es[8.14]

Aggregate	Unconfined compressive strength (MPa)	10 % FACT (kN)
Dolomite ex Olifantsfontein	212 – 396	220 – 240
Granite ex Jukskei	242 – 275	120 – 190
Andesite ex Elkenhof	516 – 538	440 – 475
Quartzite ex Ferro	Not given but quartzite in general is 105 – 394	160 – 310
Dolerite (generally)	160 – 410	180 – 450

Table A8.4.5: Compacted bulk densities of stone blends

Percentage in blend		Compacted bulk density (kg/m³) and [% increase compared with 100 % 26,5-mm stone]					
26,5-mm stone	6,7-mm stone	Dolomite ex. Olifants.	Granite	Andesite	Dolomite ex Daleside	Quartzite	Dolerite
100	0	1 645 [0]	1 470 [0]	1 550 [0]	1 585 [0]	1 520 [0]	1 640 [0]
89	11	1 650 [0]	1 560 [6]	1 660 [7]	1 665 [5]	1 560 [3]	1 730 [5]
81	19	1 805[10]	1 635 [11]	1 780 [15]	1 765 [11]	1 625 [7]	1 800 [10]
74	26	1 850[12]	1 665 [13]	1 800 [16]	1 800 [14]	1 660 [9]	1 900 [16]
68	32	1 805[10]	1 670 [14]	1 785 [15]	1 830 [15]	1 660 [9]	1 870 [14]
62,5	37,5	1 780 [8]	1 665 [13]	1 760 [14]	1 830 [15]	1 660 [9]	1 900 [16]
58	42					1 645 [8]	1 890 [15]
54	46						1 900 [16]
51	49						1 890 [15]
48	52						1 850 [13]
45	55						1 840 [12]

Table A8.4.6: **Mixes and results: Dolomite ex Olifantsfontein**

Stone	75 % 26,5–mm 25 % 6,7–mm
Sand	Crusher
Cement	RHPC type "J"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water Cement Sand Stone Admixture (ℓ)	145 290 1 025 1 165 5,8	140 336 999 1 165 6,7	135 378 966 1 175 7,6	130 416 936 1 185 8,3	130 468 865 1 210 9,4
Age 7 days	Cube strength (MPa)	58	67	79*	83	92
	CEF (MPa/100 kg cement/m³)	20,0	19,9	20,9*	20,0	19,7
Age 28 days	Cube strength (MPa)	66	81	94	103	107
	CEF (MPa/100 kg cement/m³)	22,8	24,1	24,9	24,8	22,9
Age 56 days	Cube strength (MPa)		89	101	112	119
	CEF (MPa/100 kg cement/m³)		26,5	27,0	26,9	25,4

* Anomalous result – too high

Table A8.4.7: **Mixes and results: Granite**

Stone	70 % 26,5-mm 25 % 6,7-mm
Sand	Crusher
Cement	RHPC type "J"
Admixture	SNF

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water (total)	160	155	145	140	135
	Cement	320	372	406	448	486
	Sand	903	874	867	830	798
	Stone	1 055	1 055	1 060	1 075	1 090
	Admixture (ℓ)	6,4	7,4	8,1	9,0	9,7
Age 7 days	Cube strength (MPa)	49	65	77	86	95
	CEF (MPa/100 kg cement/m³)	15,3	17,5	19,0	19,2	19,5
Age 28 days	Cube strength (MPa)	59	76	86	96	98
	CEF (MPa/100 kg cement/m³)	18,4	20,4	21,2	21,4	20,2
Age 56 days	Cube strength (MPa)	64	81	94	96	105
	CEF (MPa/100 kg cement/m³)	20,0	21,8	23,2	21,4	21,6

Table A8.4.8: Mix and results: Andesite

Stone	75 % 26,5–mm
	25 % 6,7–mm
Sand	Crusher
Cement	RHPC type "J"
Admixture	SNF type "C".

	C/W	2,0	2,4	2,8	3,2	3,6	5,34▸
Quantities per m3 of concrete (kg)	Water (total)	160	155	155	150	150	192
	Cement (RHPC)	320	372	434	480	540	1 026
	Sand	1 023	990	929	887	830	0
	Stone	1 135	1 135	1 140	1 155	1 175	1 430
	Admixture	6,4	7,4	8,7	9,6	10,8	20,5
Age 7 days	Cube strength (MPa)	58	77* 71•	89* 82•	91	99	118
	CEF (MPa/100 kg cement/m^3)	18,1	20,7* 19,1•	20,5* 18,9•	19,0	18,3	11,5
Age 28 days	Cube strength (MPa)	68	101	101	109	116	130
	CEF (MPa/100 kg cement/m^3)	21,2	23,4	23,3	22,7	21,5	12,7
Age 56 days	Cube strength (MPa)	74	104	104	112	117◊	132
	CEF (MPa/100 kg cement/m^3)	23,1	28,3	24,0	23,3	21,7	12,9

* Age 8 days
• Interpolated from cube curve
◊ Average of 2 cubes
▸ Mix roughly equivalent to C/W = R_o in section 2.4

Table A8.4.9: **Mixes and results: Dolomite ex Daleside**

Stone	65 % 26,5–mm 35 % 6,7–mm
Sand	Crusher
Cement	RHPC type "J"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water (total)	155	150	145	140	140
	Cement	310	360	406	448	504
	Sand	1 087	1 057	1 026	980	906
	Stone	1 045	1 045	1 050	1 070	1 095
	Admixture (ℓ)	6,2	7,2	8,1	9,0	10,8
Age 7 days	Cube strength (MPa)	55	68	80	86	97
	CEF (MPa/100 kg cement/m³)	17,7	18,9	19,7	19,1	19,2
Age 28 days	Cube strength (MPa)	66	80	91	101	106
	CEF (MPa/100 kg cement/m³)	21,3	22,2	22,4	22,5	21,0
Age 56 days	Cube strength (MPa)	70	82	94	103	112
	CEF (MPa/100 kg cement/m³)	22,6	22,8	23,2	23,0	22,2

Table A8.4.10: Mixes and results: Quartzite with washed sand

Stone	70 % 26,5–mm
	30 % 6,7–mm
Sand	Washed crusher
Cement	RHPC type "J"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water (total)	155	150	145	135	135
	Cement	310	360	406	432	486
	Sand	972	960	925	920	855
	Stone	995	995	1 060	1 015	1 035
	Admixture (ℓ)	6,2	7,2	8,1	8,6	9,7
Age 7 days	Cube strength (MPa)	49	62	74	84	94
	CEF (MPa/100 kg cement/m^3)	15,8	17,2	18,2	19,4	19,3
Age 28 days	Cube strength (MPa)	60	71	86	97	106
	CEF (MPa/100 kg cement/m^3)	19,4	19,7	21,2	22,5	21,8
Age 56 days	Cube strength (MPa)	64	77	87	100	*
	CEF (MPa/100 kg cement/m^3)	20,6	21,4	21,4	23,1	

* Press faulty

Table A8.4.11: Mixes and results: Quartzite with unwashed sand

Stone	70 % 26,5–mm 30 % 6,7–mm
Sand	Unwashed crusher
Cement	RHPC type "J"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m³ of concrete (kg)	Water (total)	150	145	140	140	140
	Cement	300	348	392	448	504
	Sand	925	898	875	814	758
	Stone	1 080	1 080	1 080	1 095	1 105
	Admixture (ℓ)	6,0	7,8	7,8	9,0	10,8
Age 7 days	Cube strength (MPa)	52	66	73	82	84
	CEF (MPa/100 kg cement/m³)	14,9	19,0	18,6	18,3	16,7
Age 28 days	Cube strength (MPa)	64	74	80	97	100
	CEF (MPa/100 kg cement/m³)	21,3	21,3	20,4	21,6	19,8
Age 56 days	Cube strength (MPa)	66	82	88	99	102
	CEF (MPa/100 kg cement/m³)	22,0	23,6	22,4	22,1	20,2

Table A8.4.12: Mixes and results: Dolerite

Stone	65 % 26,5–mm 35 % 6,7–mm
Sand	Crusher
Cement	RHPC type "J"
Admixture	SNF type "C"

	C/W	2,0	2,4	2,8	3,2	3,6
Quantities per m^3 of concrete (kg)	Water (total)	160	155	155	150	145
	Cement	320	372	434	480	522
	Sand	1 022	987	922	879	838
	Stone	1 235	1 235	1 240	1 255	1 270
	Admixture (ℓ)	6,4	7,4	8,7	9,6	10,4
Age 7 days	Cube strength (MPa)	51	64	78	94	102
	CEF (MPa/100 kg cement/m^3)	15,9	17,2	18,0	19,6	19,5
Age 28 days	Cube strength (MPa)	66	77	94	109	117
	CEF (MPa/100 kg cement/m^3)	20,6	20,7	21,7	22,7	22,4
Age 56 days	Cube strength (MPa)	69	87	99	117	128
	CEF (MPa/100 kg cement/m^3)	21,6	23,4	22,8	24,4	24,5

Table A8.4.13: Packing capacity of aggregates and water requirement at two C/W values

Rock type	Packing capacity (% solid volume in compacted state)			Water requirement (ℓ/m³)	
	Optimum stone blend	Sand	Average stone blend & sand	C/W = 2,0	C/W = 3,6
Dolomite ex Olifantsfontein	64,2	69,1	66,6	145	130
Granite	62,4	64,1	63,2	160	135
Andesite	61,1	57,8	59,4	160	150
Dolomite ex Daleside	63,3	67,6	65,4	155	140
Quartzite (washed sand)	60,9	63,6	62,2	155	135
Quartzite (unwashed sand)	60,9	65,2	63,0	150	140
Dolerite	62,5	63,2	62,8	160	145

Table A8.4.14: Aggregate-crushing values and 56-day cube strengths at C/W = 2,0 and 3,6

	ACV (%)			56-day cube strength (MPa)	
Rock Type	(A) 26,5-mm stone	(B) 6,7-mm stone	Average* of (A) & (B)	C/W = 2,0	C/W = 3,6
Dolomite ex Olifantsfontein	23,0	34,5	28,8	73 (est.)	119
Granite	24,1	37,4	30,8	64	105
Andesite	11,4	20,1	15,8	74	117
Dolomite ex Daleside	23,1	28,8	26,0	70	112
Quartzite (washed sand)	19,8	29,4	24,6	64	108 (est.)
Quartzite (unwashed sand)	19,8	29,4	24,6	66	102
Dolerite	15,7	27,7	21,7	69	128

* While the blends are not 50:50, a weighted average according to blend proportions is not justified as it would not take the sand into account

APPENDIX A8.5: COMPARISON OF THREE AGGREGATE TYPES: EFFECT ON TENSILE STRENGTH

Table A8.5.1 Gradings and densities of aggregates used in section 4.7

	SABS sieve size (mm)	Dolerite ex Roolkraal			Andesite ex Eikenhof			Dolomite ex Olifantsfontein		
		26,5-mm stone	6,7-mm stone	Crusher sand	26,5-mm stone	6,7-mm stone	Crusher sand	26,5-mm stone	6,7-mm stone	Crusher sand
Percentage passing	37,5	100						100		
	26,5	93			100			99		
	19,0	4			6			32		
	13,2	1	100		1			1		
	9,5	1	99		1	100			100	
	6,7	1	73	100	1	98	100		82	
	4,75	1	36	99	1	60	99		38	100
	2,36	1	8	76	1	5	72		1	77
	1,18		4	46		2	45			47
	0,60		3	31		2	29			30
	0,30		3	20		2	20			21
	0,15		3	13		2	14			16
	0,075	0,7	2,5	7,5	0,6	1,6	11,2	0,2	0,3	13,8
Fineness modulus		7,93	5,44	3,12	7,91	5,28	3,21	7,68	5,61	3,08
Relative density		2,98	2,98	2,97	2,93	2,93	2,90	2,88	2,88	2,85
Bulk density	Loose	1 480	1 445	1 570	1 470	1 480	1 595	1 450	–	1 600
	Compacted	1 620	1 590	1 760	1 565	1 620	1 79	1 575	1 530	1 855
Packing capacity (% solids in compacted state)		54,4	52,3	59,3	53,4	55,3	62,0	54,7	53,1	65,1

Table A8.5.2: Results of Mix 1 : C/W = 2,0

Material	Quantity per m³ (kg)
Water	170
Cement	340
26,5-mm dolomite stone	705
6,7-mm dolomite stone	380
Dolomite crusher sand	983
Admixture	6,8 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	63 MPa	2,5 %
Splitting-tensile strength	4,5 MPa	7,6 %
Flexural strength	–	–

Slump : 130 mm Mix size : 10 ℓ

Table A8.5.3: Results of Mix 2 : C/W = 2,0

Material	Quantity per m³ (kg)
Water	165
Cement	330
26,5-mm dolomite stone	730
6,7-mm dolomite stone	395
Dolomite crusher sand	967
Admixture	6,6 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	57 MPa	0,9 %
Splitting-tensile strength	–	–
Flexural strength	7,3 MPa	13,5 %

Slump : 130 mm Mix size : 20 ℓ

Table A8.5.4 **Results of Mix 3: C/W = 2,8**

Material	Quantity per m^3 (kg)
Water	140
Cement	392
26,5–mm dolomite stone	735
6,7–mm dolomite stone	400
Dolomite crusher sand	972
Admixture	7,8 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	90 MPa	1,9 %
Splitting–tensile strength	5,6 MPa	2,6 %
Flexural strength	–	–

Slump : 25 mm Mix size : 10 ℓ

Table A8.5.5: **Results of Mix 4 : C/W = 2,8**

Material	Quantity per m^3 (kg)
Water	145
Cement	406
26,5–mm dolomite stone	735
6,7–mm dolomite stone	400
Dolomite crusher sand	945
Admixture	8,1 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	84 MPa	5,1 %
Splitting–tensile strength	–	–
Flexural strength	8,3 MPa	2,1 %

Slump : 150 mm Mix size : 20 ℓ

Table A8.5.6 **Results of Mix 5 : C/W = 3,6**

Material	Quantity per m³ (kg)
Water	140
Cement	504
26,5–mm dolomite stone	750
6,7–mm dolomite stone	400
Dolomite crusher sand	856
Admixture	10,1 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	101 MPa	4,3 %
Splitting-tensile strength	7,0 MPa	7,5 %
Flexural strength	–	–

Slump : 75 mm Mix size : 10 ℓ

Table A8.5.7 **Results of Mix 6 : C/W = 3,6**

Material	Quantity per m³ (kg)
Water	140
Cement	504
26,5–mm dolomite stone	750
6,7–mm dolomite stone	400
Dolomite crusher sand	856
Admixture	10,1 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	104 MPa	4,2 %
Splitting-tensile strength	–	–
Flexural strength	12,3 MPa	8,7 %

Slump : 150 mm Mix size : 20 ℓ

Table A8.5.8 Results of Mix 7 : C/W = 2,0

Material	Quantity per m³ (kg)
Water	165
Cement	330
26,5–mm andesite stone	740
6,7–mm andesite stone	400
Andesite crusher sand	988
Admixture	6,6 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	62 MPa	0,4 %
Splitting–tensile strength	5,1 MPa	2,9 %
Flexural strength	–	–

Slump : 40 mm Mix size : 10 ℓ

Table A8.5.9 Results of Mix 8 : C/W = 2,0

Material	Quantity per m³ (kg)
Water	165
Cement	330
26,5–mm andesite stone	740
6,7–mm andesite stone	400
Andesite crusher sand	988
Admixture	6,6 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	64 MPa	0,2 %
Splitting–tensile strength	–	–
Flexural strength	7,5 MPa	3,4 %

Slump : 160 mm Mix size : 20 ℓ

Table A8.5.10 Results of Mix 9 : C/W = 2,8

Material	Quantity per m^3 (kg)
Water	150
Cement	420
26,5–mm andesite stone	745
6,7–mm andesite stone	400
Andesite crusher sand	944
Admixture	8,2 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	94 MPa	1,0 %
Splitting–tensile strength	6,7 MPa	3,8 %
Flexural strength	8,7 MPa	14,6 %

Slump : 150 mm Mix size : 24 ℓ

Table A8.5.11 Results of Mix 10 : C/W = 3,6

Material	Quantity per m^3 (kg)
Water	145
Cement	522
26,5–mm andesite stone	760
6,7–mm andesite stone	410
Andesite crusher sand	839

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	110 MPa	0,6 %
Splitting–tensile strength	6,2 MPa	6,0 %
Flexural strength	11,6 MPa	7,0 %

Admixture	10,4 ℓ

Slump : 50 mm Mix size : 24 ℓ

Table A8.5.12 Results of Mix 11 : C/W = 2,0

Material	Quantity per m³ (kg)
Water	167
Cement	335
26,5–mm dolerite stone	723
6,7–mm dolerite stone	389
Dolerite crusher sand	1 054
Admixture	6,7 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	58 MPa	1,6 %
Splitting–tensile strength	5,3 MPa	4,8 %
Flexural strength	6,7 MPa	14,7 %

Slump : 15 mm Mix size : 24 ℓ

Table A8.5.13 Results of Mix 12 : C/W = 2,8

Material	Quantity per m³ (kg)
Water	167
Cement	470
26,5–mm dolerite stone (Sample 30)	737
6,7–mm dolerite stone	397

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	86 MPa	4,7 %
Splitting–tensile strength	7,1 MPa	10,6 %
Flexural strength	7,7 MPa	6,1 %

Dolerite crusher sand	905
Admixture	9,4 ℓ

Slump : 30 mm Mix size : 24 ℓ

Table A8.5.14 Results of Mix 13 : C/W = 3,6

Material	Quantity per m^3 (kg)
Water	165
Cement	594
26,5-mm dolerite stone	765
6,7-mm dolerite stone	415
Dolerite crusher sand	742
Admixture	11,9 ℓ

Measured property	Value (average of three measurements)	Coefficient of variation of three measurements
Compressive strength	104 MPa	6,9 %
Splitting-tensile strength	6,1 MPa	16,0 %
Flexural strength	9,4 MPa	7,8 %

Slump : 140 mm Mix size : 24 ℓ

APPENDIX A9.1

DETAILS OF MIXES USED FOR INITIAL DETERMINATIONS OF MODULUS OF ELASTICITY, CREEP AND SHRINKAGE

Aggregate type	C/W	Cement (kg)	Water (kg)	Stone		Sand (kg)	Admixture*
				26,5 mm (kg)	6,7 mm (kg)		
Dolomite	2,0	300	150	695	370	1 096	6,0 ℓ
	2,66	389	146	695	372	1 024	7,8 ℓ
	3,6	540	150	715	383	853	4,9 kg
Andesite	2,0	[illegible]	160	740	395	1 017	6,4 ℓ
	2,8	420	150	745	400	944	8,4 ℓ
	3,5	563	161	745	400	790	4,3 kg
Dolerite	2,0	350	175	750	405	968	7,0 ℓ
	2,8	476	170	755	410	854	9,5 ℓ
	3,6	576	160	775	415	764	4,5 kg

* Sulphonated naphthaler[illegible]ldehyde type "C". Where values are expressed in litres the admixture was in liquid form, dosed [illegible]per 100 kg cement. Where values are given in kilograms the admixture was in powder form dose[illegible],92 kg per 100 kg cement. Dosages of liquid and powder admixture were equiv[illegible]nt.

APPENDIX A9.2

CHARACTERISTICS OF RHPC USED FOR MIXES MADE FOR INVESTIGATION DESCRIBED IN SECTION 9.1.2

Oxide contents according to manufacturer's analysis

Oxide	Content percentage
SiO_2	21,82
$A1_2O_3$	3,92
Fe_2O_3	3,14
Mn_2O_3	0,49
TiO_2	0,41
CaO	63,75
MgO	3,38
P_2O_5	0
SO_3	2,33
K_2O	0,51
Na_2O	0,11
Free CaO	1,00
TOTAL	99,8

Percentage contents of compounds according to Bogue (see section 7.2) are:

C_3S = 4,07 x % CaO –7,60 x % SiO_2 –6,72 x % $A1_2O_3$ –1,43 x % Fe_2O_3 –2,85 x % SO_3 = 56,3 %

C_2S = 2,87 x % SiO_2 –0,754 x % C_3S = 20,1 %

C_3A = 2,65 x % Al_2O_3 –1,69 x Fe_2O_3 = 5,1 %

C_4AF = 3,04 x % Fe_2O_3 = 9,5 %
Total = 91,0 %

∴ other compounds = 9,0 %.

APPENDIX A9.3 MIXES USED IN SECTION 9.1.2 AND 9.1.3: PROPORTIONS OF CONCRETE WHEN MIXED AND AT MATURITY

C/W		2,0	2,2	2,4	2,6	2,8	3,0	3,2	3,4	3,6
Per m³ when mixed (kg)	Water	170	170	165	165	160	160	160	160	160
	Cement	340	374	396	429	448	480	512	544	576
	Sand	1 154	1 125	1 094	1 084	1 076	1 041	1 002	963	917
	19–mm Stone	950	950	950	955	960	965	975	985	1 000
	SNF	3,13	3,44	3,64	3,95	4,12	4,42	4,71	5,00	5,30
Calculated volumetric proportions of mature concrete	Aggregate	0,723	0,712	0,709	0,698	0,697	0,687	0,677	0,666	0,656
	Hydrated cement paste (gel)	0,243	0,268	0,284	0,297	0,288	0,288	0,288	0,288	0,288
	Unhydrated cement	0	0	0	0,005	0,015	0,025	0,035	0,046	0,056
	Capillary pores	0,034	0,020	0,007	0	0	0	0	0	0
Gel:space* ratio		0,877	0,930	0,976	1,00	1,00	1,00	1,00	1,00	1,00

* Volume of gel is calculated volume of hydrated cement paste. Space is volume of cement able to hydrate plus volume of water at mixing stage.

APPENDIX A9.4

RESULTS OF CREEP AND SHRINKAGE TESTS ON CONCRETES MADE WITH THREE DIFFERENT TYPES OF AGGREGATE

Table A9.4.1

Rock type	Dolomite
C/W	2,0
28–day cube strength	59 MPa
Preload stress on specimen	0,94 MPa
Sustained stress on specimen	11,98 MPa
Secant modulus	45,2 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	244	0	0	0	0	0
1	349	67	38	0,14	3,1	185
3	381	89	49	0,18	4,0	238
7	437	86	107	0,40	9,0	529
14	515	129	142	0,54	11,9	700
28	609	164	201	0,76	16,8	961
180	859	287	327	1,24	27,3	1 612

Table A9.4.2

Rock type	Dolomite
C/W	2,66
28-day cube strength	84 MPa
Preload stress on specimen	0,93 MPa
Sustained stress on specimen	16,03 MPa
Secant modulus	53,1 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	284	0	0	0	0	0
1	357	40	32	0,11	2,0	169
3	437	67	86	0,28	5,4	450
7	504	72	148	0,49	9,2	773
14	631	118	228	0,76	14,2	1 195
28	706	131	290	0,96	18,1	1 519
180	1 009	290	435	1,44	27,1	2 278

Table A9.4.3

Rock type	Dolomite
C/W	3,6
28–day cube strength	99 MPa
Preload stress on specimen	0,89 MPa
Sustained stress on specimen	19,98 MPa
Secant modulus	51,9 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	368	0	0	0	0	0
1	440	–13	86	0,22	4,3	425
3	523	16	140	0,36	7,0	691
7	598	75	156	0,40	7,8	771
14	727	123	236	0,61	11,8	1 170
28	792	115	309	0,80	15,4	1 529
180	1 130	263	499	1,30	25,0	2 473

Table A9.4.4

Rock type	Andesite
C/W	2,0
28-day cube strength	64 MPa
Preload stress on specimen	0,94 MPa
Sustained stress on specimen	11,98 MPa
Secant modulus	47,3 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	233	0	0	0	0	0
1	376	83	59	0,23	4,9	315
3	502	140	129	0,51	10,8	688
7	572	145	193	0,76	16,1	1 032
14	690	223	233	0,92	19,5	1 247
28	786	258	295	1,17	24,6	1 577
180	1 087	529	325	1,28	27,1	1 735

Table A9.4.5

Rock type	Andesite
C/W	2,8
28–day cube strength	93 MPa
Preload stress on specimen	0,93 MPa
Sustained stress on specimen	16,03 MPa
Secant modulus	52,6 GPA

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	287	0	0	0	0	0
1	381	24	70	0,23	4,4	405
3	462	54	121	0,40	7,5	701
7	555	94	174	0,57	10,9	1 012
14	682	150	244	0,80	15,2	1 417
28	775	228	260	0,85	16,2	1 510
180	1 130	373	470	1,54	29,3	2 725

Table A9.4.6

Rock type	Andesite
C/W	3,5
28–day cube strength	102 MPa
Preload stress on specimen	0,89 MPa
Sustained stress on specimen	19,98 MPa
Secant modulus	46,5 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	411	0	0	0	0	0
1	502	13	78	0,18	3,90	397
3	588	72	105	0,24	5,24	534
7	698	150	137	0,32	6,85	699
14	810	207	193	0,45	9,67	986
28	872	207	462	1,07	23,10	2 356
180	1 189	207	572	1,33	28,61	2 918

Note: Creep and shrinkage results shown in this table are considered unreliable because of zero shrinkage indicated between 14 and 180 days.

Table A9.4.7

Rock type	Dolerite
C/W	2,0
28–day cube strength	59 MPa
Preload stress on specimen	0,92 MPa
Sustained stress on specimen	12,01 MPa
Secant modulus	46,5 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	239	0	0	0	0	0
1	333	43	51	0,20	4,2	250
3	413	81	94	0,36	7,8	461
7	488	105	145	0,56	12,0	712
14	596	164	193	0,75	16,1	949
28	706	225	241	0,93	20,1	1 186
180	1 135	472	424	1,64	35,3	2 082

Table A9.4.8

Rock type	Dolerite
C/W	2,8
28–day cube strength	93 MPa
Preload stress on specimen	0,94 MPa
Sustained stress on specimen	16,06 MPa
Secant modulus	50,3 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	301	0	0	0	0	0
1	405	59	46	0,14	2,8	264
3	504	99	105	0,33	6,5	606
7	596	145	150	0,47	9,4	870
14	738	191	247	0,77	15,4	1 429
28	845	220	325	1,02	20,2	1 880
180	1 202	341	561	1,76	34,9	3 247

Table A9.4.9

Rock type	Dolerite
C/W	3,6
28–day cube strength	106 MPa
Preload stress on specimen	0,89 MPa
Sustained stress on specimen	19,98 MPa
Secant modulus	50,1 GPa

Age from time of loading (days)	Total cumulative strain (Microstrain)	Shrinkage cumulative strain (Microstrain)	Creep cumulative strain (Microstrain)	Creep factor	Specific creep (Microstrain per MPa)	Creep strain per unit stress:strength ratio (Microstrain)
0	0	0	0	0	0	0
0	381	0	0	0	0	0
1	470	43	46	0,11	2,3	242
3	564	94	89	0,22	4,4	470
7	692	153	158	0,40	7,9	840
14	821	223	217	0,54	10,9	1 153
28	883	[illegible]	274	0,69	13,7	1 452
180	1 218	376	462	1,16	23,1	2 449

APPENDIX A9.5

RESULTS OF STRENGTH, CREEP AND SHRINKAGE TESTS ON CONCRETES MADE WITH ANDESITE AGGREGATE

Cement:water ratio	Cube strength (MPa)		Secant[1] modulus of elasticity (GPa)	At 180 days test age				
	At 28 days	At 56 days		Drying shrinkage (Microstrain)	Creep[2] strain (Microstrain)	Specific creep (Microstrain/MPa)	Creep[2] factor	Creep strain per unit stress:strength ratio (Microstrain) [3]
1,8	53	59	44,8	397	636	45,3	2,03	2 500
2,0	61	67	45,9	394	591	42,1	1,93	2 640
2,2	70	76	44,1	419	544	38,7	1,71	2 760
2,4	80	85	49,4	422	444	31,6	1,56	2 520
2,6	83	86	49,3	383	449	31,9	1,58	2 570
2,8	94	101	57,2	390	415	29,5	1,69	2 790
3,0	98	106	52,3	390	299	21,2	1,11	2 110
3,2	104	113	58,1	357	303	21,5	1,25	2 280
3,4	106	114	59,4	341	279	19,8	1,18	2 120
3,6	110	111	59,4	295	293	20,8	1,24	2 170

(1) At 56 days concrete age (2) Sustained stress of 15 MPa (3) Strength at 56 days

APPENDIX A9.6

CALCULATED STRAINS OF CONCRETES MADE WITH ANDESITE AGGREGATE

Characteristic strength (MPa)	40	50	60	70	80	90	100
C/W(1)	1,75	1,90	2,05	2,33	2,62	2,95	3,60
Specific creep (Microstrain/ MPa)	46,5	43,5	41	36	30,5	23	21
Shrinkage strain (Microstrain)	390	400	410	415	400	380	290
Modulus of elasticity (GPa)	46	47	48	50	53	54	54
Applied stress (MPa)(2)	16	20	24	28	32	36	40
Creep strain(3) (Microstrain)	744	870	984	1 008	976	828	840
Elastic strain (Microstrain)	348	425	500	560	603	667	740
Total strain (shrinkage + creep + elastic)	1 480	1 700	1 890	1 980	1 980	1 880	1 870
Predicted 30-year creep strain(4) according to reference 9.6 (Microstrain)	760	940	1 100	1 230	1 330	1 470	1 630
Predicted final creep based on measured creep(5)	1 240	1 450	1 640	1 680	1 630	1 380	1 400

(1) See section 11.2.2
(2) 0,40 x characteristic strength
(3) At 180 days loading
(4) Final creep strain = $\dfrac{\text{stress x creep factor}}{\text{modulus of elasticity at time of loading}}$
creep factor = 2,2 from reference 9.6
(5) Creep at 6 months assumed to be 60 % of final creep[9.6]

APPENDIX A11.1

PROPORTIONS OF MIXES DERIVED FROM ANALYSES OF FIGURE 9.4 AND APPENDIX A9.3

Average strength (MPa)	40	50	60	70	80	90	100	110
Characteristic strength (MPa)	30	40	50	60	70	80	90	100
C/W	1,62	1,75	1,90	2,05	2,33	2,62	2,95	3,60
Water (kg/m³)	170	170	170	170	165	165	160	160
Cement (kg/m³)	275	298	323	348	384	432	472	576
19-mm stone (kg/m³)	950	950	950	950	950	955	965	1 000
Sand (kg/m³)	1 210	1 190	1 165	1 145	1 125	1 075	1 045	910
Admixture (kg/m³)	2,53	2,74	2,97	3,20	3,53	3,97	4,34	5,30

APPENDIX A11.2

CALCULATED MATERIAL COSTS OF CONCRETE MIXES BASED ON PROPORTIONS SHOWN IN APPENDIX A11.1

Characteristic strength at 28 days (MPa)		30	40	50	60	70	80	90	100
Material cost per m³	Cement @ R0,22 /kg	60,50	65,56	71,06	76,56	84,48	95,04	103,84	126,72
	Stone @ R0,037/kg	35,15	35,15	35,15	35,15	35,15	35,34	35,70	37,00
	Sand @ R0,027/kg	32,67	32,13	31,46	30,92	30,38	29,02	28,22	24,57
	Admixture @ R10,33/kg	26,13	28,30	30,68	33,06	36,46	41,01	44,83	54,75
	Total	154,45	161,14	168,35	175,69	186,47	200,41	212,59	248,04

APPENDIX A11.3

CALCULATION OF RATES FOR CONCRETE OF VARIOUS CHARACTERISTIC STRENGTHS

Characteristic strength at 28 days (MPa)	30	40	50	60	70	80	90	100
Material costs (Rand)	154,45	161,14	168,35	175,69	186,47	200,41	212,59	243,04
Labour & plant costs for mixing, transporting, placing, etc. (Rand)	42,00	42,00	42,00	42,00	42,00	42,00	42,00	42,00
Total costs (Rand)	196,45	203,14	210,35	217,69	228,47	242,41	254,59	285,04
Profit @ 12 %	23,57	24,38	25,24	26,12	27,42	29,09	30,55	34,20
Rate per m^3 (Rand)	220,80	227,50	235,60	243,80	255,90	271,50	285,10	319,20

APPENDIX A11.4

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 30 MPa

$$A_c = \frac{13,8}{12,0 + 273,3p} \quad (m^2)$$

p	0,01	0.02	0,03	0,04	0,05	0,06
A_c (m^2)	0,937	0,790	0,683	0,602	0,538	0,486
$A_c + A_{sc}$ (m^2)	0,946	0,806	0,703	0,626	0,565	0,5[illegible]5
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,973	0,898	0,839	0,791	0,752	0,718
Volume of concrete (m^3)	2,529	2,133	1,844	1,625	1,453	1,312
Area of formwork (m^2)	10,508	9,698	9,061	8,543	8,122	7,754
Mass of steel (kg)	218	365	469	546	604	649
Cost of concrete* (Rand)	556	469	406	358	320	289
Cost of formwork* (Rand)	252	233	217	205	195	186
Cost of steel* (Rand)	403	675	868	1 010	1 117	1 201
Total cost (Rand)	1 211	1 377	1 491	1 573	1 632	1 676

* To nearest whole Rand

APPENDIX A11.5

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 40 MPa

$$A_c = \frac{13{,}8}{16{,}0 + 273{,}3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,737	0,643	0,570	0,512	0,465	0,426
$A_c + A_{sc}$ (m^2)	0,744	0,656	0,587	0,532	0,488	0,452
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,863	0,810	0,766	0,730	0,699	0,672
Volume of concrete (m^3)	1,990	1,736	1,539	1,382	1,256	1,150
Area of formwork (m^2)	9,320	8,748	8,273	7,884	7,549	7,258
Mass of steel (kg)	172	298	391	464	522	569
Cost of concrete* (Rand)	453	395	350	314	286	262
Cost of formwork* (Rand)	224	210	199	189	181	174
Cost of steel* (Rand)	318	551	723	858	966	1 053
Total cost (Rand)	995	1 156	1 272	1 361	1 433	1 489

* To nearest whole Rand

APPENDIX A11.6

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 50 MPa

$$A_c = \frac{13,8}{20 + 273,3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,607	0,542	0,489	0,446	0,410	0,379
$A_c + A_{sc}$ (m^2)	0,613	0,553	0,504	0,464	0,430	0,402
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,783	0,744	0,710	0,681	0,656	0,634
Volume of concrete (m^3)	1,639	1,463	1,320	1,204	1,107	1,023
Area of formwork (m^2)	8,456	8,035	7,668	7,355	7,085	6,847
Mass of steel (kg)	142	251	336	404	460	506
Cost of concrete* (Rand)	386	345	311	284	261	241
Cost of formwork* (Rand)	203	193	184	177	170	164
Cost of steel* (Rand)	263	464	622	747	851	936
Total cost (Rand)	852	1 002	1 117	1 208	1 282	1 341

* To nearest whole Rand

APPENDIX A11.7

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 60 MPa

$$A_c = \frac{13,8}{24 + 273,3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,516	0,468	0,429	0,395	0,366	0,342
$A_c + A_{sc}$ (m^2)	0,521	0,477	0,442	0,411	0,384	0,363
$b = \sqrt{(A_c + A'_{sc})}$ (m)	0,722	0,691	0,665	0,641	0,620	0,602
Volume of concrete (m^3)	1,393	1,264	1,158	1,066	0,988	0,923
Area of formwork (m^2)	7,798	7,463	7,182	6,923	6,696	6,502
Mass of steel (kg)	120	216	295	358	411	457
Cost of concrete* (Rand)	340	308	282	260	241	225
Cost of formwork* (Rand)	187	179	172	166	161	156
Cost of steel* (Rand)	222	400	546	662	760	845
Total cost (Rand)	749	887	1 000	1 088	1 162	1 226

* To nearest whole Rand

APPENDIX A11.8

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 70 MPa

$$A_c = \frac{13,8}{28 + 273,3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,449	0,412	0,381	0,354	0,331	0,311
$A_c + A_{sc}$ (m^2)	0,453	0,420	0,392	0,368	0,348	0,330
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,673	0,648	0,626	0,607	0,590	0,574
Volume of concrete (m^3)	1,212	1,112	1,029	0,956	0,894	0,840
Area of formwork (m^2)	7,268	6,999	6,761	6,556	6,372	6,199
Mass of steel (kg)	104	191	261	321	372	415
Cost of concrete* (Rand)	310	285	263	245	229	215
Cost of formwork* (Rand)	174	168	162	157	153	149
Cost of steel* (Rand)	192	353	483	594	688	768
Total cost (Rand)	676	806	908	996	1 070	1 132

* To nearest whole Rand

APPENDIX A11.8

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 70 MPa

$$A_c = \frac{13,8}{28 + 273,3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,449	0,412	0,381	0,354	0,331	0,311
$A_c + A_{sc}$ (m^2)	0,453	0,420	0,392	0,368	0,348	0,330
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,673	0,648	0,626	0,607	0,590	0,574
Volume of concrete (m^3)	1,212	1,112	1,029	0,956	0,894	0,840
Area of formwork (m^2)	7,268	6,999	6,761	6,556	6,372	6,199
Mass of steel (kg)	104	191	261	321	372	415
Cost of concrete* (Rand)	310	285	263	245	229	215
Cost of formwork* (Rand)	174	168	162	157	153	149
Cost of steel* (Rand)	192	353	483	594	688	768
Total cost (Rand)	676	806	908	996	1 070	1 132

* To nearest whole Rand

APPENDIX A11.9

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 80 MPa

$$A_c = \frac{13{,}8}{32 + 273{,}3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,397	0,368	0,343	0,321	0,302	0,285
$A_c + A_{sc}$ (m^2)	0,383	0,375	0,353	0,334	0,317	0,302
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,619	0,613	0,594	0,578	0,563	0,550
Volume of concrete (m^3)	1,072	0,994	0,926	0,867	0,815	0,770
Area of formwork (m^2)	6,685	6,620	6,415	6,242	6,080	5,940
Mass of steel (kg)	92	170	235	291	339	380
Cost of concrete* (Rand)	291	270	251	235	221	209
Cost of formwork* (Rand)	160	159	154	150	146	143
Cost of steel* (Rand)	170	314	435	538	627	703
Total cost (Rand)	621	743	840	923	994	1 055

* To nearest whole Rand

APPENDIX A11.10

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 90 MPa

$$A_c = \frac{13{,}8}{36 + 273{,}3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,356	0,332	0,312	0,294	0,277	0,263
$A_c + A_{sc}$ (m^2)	0,360	0,339	0,321	0,306	0,291	0,279
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,600	0,582	0,567	0,553	0,539	0,528
Volume of concrete (m^3)	0,961	0,896	0,842	0,794	0,748	0,710
Area of formwork (m^2)	6,480	6,286	6,124	5,972	5,821	5,702
Mass of steel (kg)	82	154	214	266	312	351
Cost of concrete* (Rand)	274	255	240	226	213	202
Cost of formwork* (Rand)	155	151	147	143	140	137
Cost of steel* (Rand)	152	285	396	492	577	649
Total cost (Rand)	581	691	783	861	930	988

* To nearest whole Rand

APPENDIX A11.11

CALCULATIONS OF QUANTITIES AND COSTS FOR ONE COLUMN 2,7 m HIGH; f_{cu} AT 28 DAYS = 100 MPa

$$A_c = \frac{13,8}{40 + 273,3p} \quad (m^2)$$

p	0,01	0,02	0,03	0,04	0,05	0,06
A_c (m^2)	0,323	0,306	0,286	0,271	0,257	0,245
$A_c + A_{sc}$ (m^2)	0,326	0,312	0,295	0,282	0,270	0,260
$b = \sqrt{(A_c + A_{sc})}$ (m)	0,571	0,559	0,543	0,531	0,519	0,510
Volume of concrete (m^3)	0,872	0,826	0,772	0,732	0,694	0,662
Area of formwork (m^2)	6,167	6,037	5,864	5,735	5,605	5,508
Mass of steel (kg)	75	142	197	246	288	328
Cost of concrete* (Rand)	278	264	246	234	222	211
Cost of formwork* (Rand)	148	145	141	138	135	132
Cost of steel* (Rand)	139	263	364	455	533	607
Total cost (Rand)	565	672	751	827	890	950

* To nearest whole Rand

APPENDIX A11.12

COST–AREA FOR ONE COLUMN 2,7 m HIGH

p f_{cu} (MPa)	0,01	0,02	0,03	0,04	0,05	0,06
30	1 146	1 110	1 048	985	922	863
40	740	758	747	724	699	673
50	522	554	563	560	551	539
60	390	423	442	447	446	445
70	306	339	356	367	372	374
80	238	279	297	308	315	319
90	209	234	251	263	271	276
100	184	210	222	233	240	247

Cost–area = Cost x overall cross–sectional area of column (Rand x m^2)