Chapter 4

4.0 DEVELOPMENT OF ECONOMICAL VOLUME BATCHED CONCRETE MIXES FOR GRADES 25 &30 CONCRETES

4.1 General

In BS 8110 : Part1 : 1985, the improved durability of concrete was achieved by using mixes with higher strength such as grades 25 and 30. However, volume batched nominal mix of 1:2:4 (20 mm) is still used in many construction sites in Sri Lanka. This could be an undesirable situation which should be corrected with both short term and long term solutions. In this chapter, a cost effective short term solution is suggested to obtain grades 25 and 30 concretes based on a detailed experimental programme.

4.2 The objectives and the methodology

The main objective of the study presented in this chapter is to develop economical volume batched concrete mixes that could be used to obtain grade 25 and 30 concretes.

In order to achieve the above objective, the following methodology was adopted.

1. The possibility of improving the compressive strength of concrete by changing the cement content was investigated experimentally.

2. A detailed cost study was carried out to determine the cost increments associated with the proposed mixes when compared with 1:2:4 volume batched concrete. The cost saving relative to the currently recommended grade 25 and 30 mixes were also determined.

4.3 The experimental investigation

The coarse and fine aggregate used in Sri Lanka has a bulk density of about 1500-1600 kg/m^3. The solid density is about 2600-2700 kg/m^3. The water cement ratio used with 1:2:4 (20mm) volume batched concrete is about 0.55. Thus, it is possible to convert the 1:2:4 (20mm) volume batched proportion to weigh batched ratios with reasonable values for densities. This exercise was carried out with bulk densities of 1400 kg/m^3, 1550 kg/m^3, 1500 kg/m^3 for cement, sand and 20 mm aggregates respectively. The values used for solid densities were 3150 kg/m^3, 2650 kg/m^3 and 2600 kg/m^3, respectively (Shacklock, 1974). This indicates that the cement content per m^3 of concrete is about 310 kg/m^3 with 1:2:4 (20mm) volume batched concrete. This is well above the minimum cement content specified in BS 8110 : Part 1 : 1985.

A similar calculation for 1:1.5:3 (20mm) concrete indicates a cement content of about 375 kg/m^3. The cement content for 1:1:2 (20 mm) mix is about 485 kg/m^3. This indicates a quite high usage of cement associated with the mixes recommended for grade 25 and 30 volume batched concretes. Therefore, it is prudent to develop alternative mixes that achieves the required strength with lesser amount of cement.

When alternative mixes are suggested, it is essential to make them practically adoptable. One of the key features of all volume batched concrete is that the ratio between the coarse and fine aggregates was maintained as 2. This is for the practical purposes so that the same batching boxes could be used for fine and coarse aggregates. The extra strength of such mixes were then obtained by changing the cement content. However, the increase in cement content appears to be quite high.

It was reported by Shacklock (1974) that with a given set of materials and water cement ratio, the strength of concrete tends to increase as the aggregate to cement ratio decreases. Thus, increasing the cement content could be considered as a strategy for increasing the concrete strength. Therefore, in the present study the attention was placed to obtain an increase in strength by increasing the cement content by a lesser degree. For example, the cement content was increased by 10%, 20%, 30%. Such an increase in cement content is practically possible at sites since it is possible to make an extra gauge box of 10%, 20%, 30% the volume depending on the grade of concrete required.

4.3.1 The concrete mixes used for the study

The mix proportions used for the study are given in Table 4.1. It can be seen that only the cement content is increased as a percentage of the volume.

Identification	Mix proportion	% increase in cement
Mix No: 1	1:2:4	-
Mix No: 2	1.1:2:4	10%
Mix No: 3	1.2:2:4	20%
Mix No: 4	1.3:2:4	30%

Table 4.1: The concrete mixes used for the study

4.3.2 The method used for concrete cubes

For all the mix proportions, it was decided to ensure the workability remain the same. For most of the tasks where volume batching is used, a workability indicated by a slump of 50 – 60 mm would be sufficient. Since the water cement ratio that gives such a slump is not known, it is achieved in the following manner.

The constituent materials were initially fed to a tilting drum mixer with a water cement ratio of 0.4. After proper mixing, the slump is measured. At this water cement ratio, the mix generally had almost zero slump. Then water was gradually sprinkled and then mixed to improve the workability. The slump was measured at suitable intervals. As soon as the slump reached 50-60 mm, the mix was used to cast concrete cubes. A 50 mm to 60 mm slump is reasonable enough for most of the concreting purposes with adequate vibration (Schacklock, 1974). The additional quantity of water added was used to calculate the water cement ratio.

From each mix, nine cubes were made. The cubes were also made using the standard method. The cube was filled in three layers. Each layer was given 35 blows with a 1.8 kg hammer. These were tested at the ages of 7 days, 28 days, and 60 days. Because of the time limitation, instead of doing 90 days compressive strength testing, 60 days test was done. The cubes were demoulded one day after casting. All the cubes were kept in a water bath until the testing, after demoulding.

In order to ensure that comparison of results would be acceptable, the following controls were used for all the cubes.

1. Same brand of cement was used for a given batch
2. The coarse and fine aggregates were the same (Coarse aggregate is well graded nominal size of 20mm to 5mm and fine aggregate is well graded medium type of aggregate according to BS 882: 1983. The detailed results can be found in Appendix B)
3. The same mixing method was used for all the cubes
4. The same experimental programme was repeated with the other brands of cement

4.4 Results of the experimental study

The results of the experimental programme are shown below with four brands of cements for the mixes given in Table 4.2 and 4.3. The detailed results can be found in Appendix C

	Water cement ratio			
Mix	Brand 1	Brand 2	Brand 3	Brand 4
Mix 1 (1:2:4)	0. 54	0. 57	0. 55	0. 57
Mix 2 (1.1:2:4)	0. 51	0. 56	0. 54	0. 55
Mix 3 (1.2:2:4)	0. 50	0. 54	0. 53	0. 53
Mix 4 (1.3:2:4)	0. 43	0. 53	0. 52	0. 51

Table 4.2: The water cement ratios for a constant workability (slump value of 50-60mm) for different brands of cements

Mix	Average compressive strength in N/mm^2											
	Brand 1			Brand 2			Brand 3			Brand 4		
	7 days	28 days	60 days	7 days	28 days	60 days	7 days	28 days	60 days	7 days	28 days	60 days
Mix1	20. 5	28. 9	32.0	19. 5	27. 7	29. 5	20. 1	28. 7	31. 7	18. 5	26. 1	29. 2
Mix2	24. 8	33. 8	37. 2	23. 6	32. 1	35. 3	24. 6	33. 6	37. 5	23. 5	32. 2	35. 2
Mix3	27. 0	37. 0	38. 7	25. 2	36. 2	39. 1	28. 5	38. 2	40. 2	26. 3	36. 2	38. 1
Mix4	29. 7	40. 9	41. 4	27. 2	38. 0	42. 1	30. 1	42. 1	43. 1	28. 1	38. 7	40. 7

Table 4.3: The average compressive strength of concrete at 7 days, 28 days and 60 days for different brands of cements

	The average compressive strength for all cements in N/mm^2		
Mix	7 days	28 days	60 days
Mix 1 (1:2:4)	19. 6	27. 8	30. 6
Mix 2 (1.1:2:4)	24. 1	32. 9	36. 3
Mix 3 (1.2:2:4)	26. 8	36. 9	39. 0
Mix 4 (1.3:2:4)	28. 8	39. 9	41. 7

Table 4.4: The average compressive strength at 7 days, 28 days and 60 days

Four brands of popular cements were used as there could be variations in the cement properties from brand to brand. Under normal conditions adopted in Sri Lanka, a standard deviation of about 8 is usually used for concrete mixes. This gives a current margin of about 13 N/mm^2. This means, when Grade 20 concrete is needed, under laboratory conditions, a strength of about 33 N/mm^2 should be obtained as the mean strength.

However, it is stated that this current margin could be reduced by about 3.5 N/mm^2 when nine cubes were tested (Barnbrook et el.(1975)). Thus, the current margin required for the results given in Table 4.4 could be considered as 10 N/mm^2 since those are the averages values obtained for 12 cubes.

The results in Table 4.4 indicates that the use of Mix No: 3, which has 20% extra cement, could give a current margin in excess of 10 N/mm^2 for Grade 25 concrete at 28 days. Thus, Mix No: 3 could be sufficient for Grade 25 concrete. Similarly, Mix No: 4 could be recommended for Grade 30 concrete. It should be noted that these two mixes have given higher current margin than that obtained for 1:2:4 (20mm) nominal mix. It has given only about 7. 8 N/mm^2 for Grade 20 concrete.

It should be noted that all these results were obtained with strictly controlled constant workability (A slump value of 50 - 60 mm). However, at site conditions, it is difficult to expect such strictly controlled situations. Therefore, it is prudent to check the strength with higher slump values such as those giving collapse. Therefore, another set of experiments were carried out by increasing the slump until collapse only with Brands 3 and 4. The results of these experiments are in Table 4.5.

	Average compressive strength in N/mm^2 for almost collapse slump					
Mix	Brand 3		Brand 4		Average	
	28 days	60 days	28 days	60 days	28 days	60 days
Mix 1 (1:2:4)	19. 7	21. 4	23. 0	23. 7	21. 4	22. 6
Mix 2 (1.1:2:4)	24. 2	25. 7	24. 7	26. 2	24. 4	26.0
Mix 3 (1.2:2:4)	28. 4	32. 8	29. 1	32. 4	28. 8	32. 6
Mix 4 (1.3:2:4)	31. 7	33. 3	33. 2	33. 6	32. 5	33. 4

Table 4.5: The average compressive strength of concrete at 28 days and 60 days for very high workability (Almost collapse slump)

Even with collapse slump, Mix No:3, which has 20% extra cement has given a strength of 28.8 N/mm^2. Mix No: 4 has given a strength of 32.5 N/mm^2. The water cement ratio for these mixes were above 0.7. This indicates that even under adverse conditions, these mixes could give a sufficient strength.

4.5 The cost study

Since the same mix is used with additional cement such as 10%, 20%, and 30%, the extra cost would be primarily due to the cost of cement. The all the other costs such as aggregates, water and labour would remain approximately the same.

For these mixes, the cement content was calculated by using the bulk and solid densities given in Section 3. These values are given in Table 4.6 with the likely extra cost per m^3 of concrete. The price of a 50 kg bag of cement was considered as Rs 370/=. The detailed calculations are given in Appendix D.

Mix	Cement content (kg)	Increase of cement (kg)	Extra cost Rs.(With respect to the cement)
Mix 1 (1:2:4)	310		
Mix 2 (1.1:2:4)	325	15	110/=
Mix 3 (1.2:2:4) Proposed Grade 25	350	40	295/=
Mix 4 (1.3:2:4) Proposed Grade 30	380	70	520/=

Table 4.6: The table showing cement content, increase in cement content and the extra cost for different concrete mixes proposed.

Mix	Cement content (kg)	Increase of cement (kg)	Extra cost Rs.	Cost savings (with respect to cement) with proposed mix per m^3
Grade 20 (1:2:4)	310	-	-	-
Grade 25 (1:1.5:3)	375	65	480/=	185/=
Grade 30 (1:1:2)	485	175	1295/=	775/=

Table 4.7: The Table showing cement content, increase of cement content and extra cost for the existing concrete mixes.

The comparison of Tables 4.6 and 4.7 indicates the likely cost increase for Grades 25 and 30 concretes with the proposed mix and those generally recommended. This clearly shows that there is a very good potential to adopt the proposed mixes immediately as a short term solution to improve the strength of concrete used in Sri Lankan construction industry. This would be extremely useful in many remote sites where it is not possible to obtain ready mix concrete. If bulking is considered, the existing Grade 20, Grade 25 and Grade 30 concrete require cement content of 360 kg, 435 kg and 560 kg per m^3 of concrete, respectively. The minimum cement content according to ICTAD specification (1988) for Grade 20, 25 and 30 respectively are 320 kg, 405 kg and 552 kg per m^3 of concrete, respectively.

However, when these volume batched concrete is used for higher strength concrete, the following precautions could be suggested based on the past research carried out in Sri Lanka:

1. The strength of concrete could be affected by the compaction effort. It is proposed by Chandrakeerthy et al. (1986) that the concrete should be compacted with either immersion or shutter vibrators. This suggestion should be applied for the proposed mixes since hand compaction could give much variability in strength due to poor compaction.

2. The strength of concrete and also the workability could be improved with well graded aggregates. Therefore, blending of 20 mm aggregates with small aggregates was recommended by Chandrakeerthy (1987). This could be achieved generally by blending 20 mm aggregates with 8 mm chips with a ratio of about 3:1.

3. The water cement ratio affects strength and durability as described by Dias (1994) with detailed experimental programme carried out using sorptvity of concrete. Therefore, the control of slump to the required level with slump cone test at the site will be quite useful as recommended by Chandrakeerthy (1987) with volume batched concrete. This will allow to vary the water content depending on the variation of moisture content in the aggregates such as that occur in rainy days.

4. It is advisable to select a suitable mixing time depending on the concrete mixer available at the site so that a concrete mix of uniform colour could be obtained. It was reported by Chandrakeerthy (1987) that improper mixing of concrete could create many problems such as low workability and honeycombs.

5. As reported by Dias (1994) that curing of concrete could affect the durability of concrete very much under Sri Lankan conditions. Therefore, adequate curing of concrete also should be given sufficient attention. It was reported by Chandrakeerthy (1987) that the volume batched concrete made under careful control at the site could reduce the variability of strength.

Therefore, it could be suggested that the volume batched concrete mixes suggested based on this experimental study should be used with extra quality control measures identified by the past research work.

4.6 Summary

It is shown that volume batched Grade 20 concrete has been used at many construction sites in Sri Lanka, although BS 8110: Part 1: 1985 recommends higher grades. Therefore, it is useful to develop cost effective nominal mixes that could be adopted at least short term. It is shown that the nominal mixes presently adopted in Sri Lanka for Grades 25 and 30 concretes use quite high amount of cement and could be considered as expensive for many projects. These values are approximately 375 kg/m^3 and 485 kg/m^3.

The detailed experimental programme carried out has revealed the following:

1. It is possible to use 1:2:4 (20 mm) volume batched concrete with 20% and 30% extra cement to obtain Grade 25 and 30 concretes, respectively.

2. It is prudent to use a reasonable quantity of water so that the slump will remain in 50 to 60 mm range. However, even with higher water cement ratios also, the above mixes gave sufficient strength.

3. The approximate cement content in the proposed mixes for Grade 25 and 30 are 350 kg/m^3 and 380 kg/m^3, respectively. However, the cement content of the existing mixes for the Grades 25 and 30 concrete are 375 kg/m^3 and 485 kg/m^3, respectively. This indicates a saving of 25 kg/m^3 and 105 kg/m^3 of cement. Thus, there would be cost saving of about Rs 185/= per m^3 and Rs 775/= per m^3 of concrete.

4. The cement contents for Grades 20, 25, 30 could be approximately given as 310, 350 and 380 kg/m^3. Therefore, the proposed mixes will cost about Rs 295/= and Rs 520/= per m^3 than Grade 20 concrete. Since the cost of 1m^3 of Grade 20 concrete is about Rs 4500/=, these increases will be in the range of 6% and 11% for Grade 25 and 30 concretes, respectively. Since Grade 25 concrete is generally recommended in Sri Lanka, there is a very high possibility for adopting the proposed mix for Grade 25 at many construction sites. If higher Grade such as 30 is specified, the proposed mix with 30% extra cement could be used. When even higher grades are specified, it is advisable to use weigh batching since it would need grater quality control.