DESIGN OF ROLLER COMPACTED CONCRETE MIXES FOR ROAD PAVEMENTS

T.C. Ekneligoda, S. M. A. Nanayakkara,
Department of Civil Engineering, University of Moratuwa.

DESIGN OF ROLLER COMPACTED CONCRETE MIXES FOR ROAD PAVEMENTS

T.C. Ekneligoda, S. M. A. Nanayakkara,
Department of Civil Engineering, University of Moratuwa.

ABSTRACT

This paper presents some guidelines to carry out mix design for Roller Compacted Concrete (RCC). In order to propose a mix design method for RCC, an experimental investigation was carried out to study the properties of RCC such as wet density and flexural strength under different cement contents. A new test method was proposed to measure the wet density of RCC considering the action of a vibrating roller. The test results of wet density show that the behaviour of RCC is similar to soil with respect to optimum density. And also it was found that the flexural strength depends not only on the water cement ratio but also on the cement content. An approximate relationship was obtained for the flexural strength combining the water cement ratio and cement content.

INTRODUCTION

In Sri Lanka as well as other countries, most of the road pavements are designed as flexible pavements and constructed using bituminous materials. Flexible pavements are popular in the third world countries mainly due to its low initial cost. But the durability of the surface and the long-term performance of the flexible pavements are very poor and require continuous maintenance consuming a large sum of money. Therefore most countries are deviating from flexible pavements to rigid pavements. Where rigid pavements are concerned, there are three types of pavements known as conventional concrete pavements, reinforced concrete pavements and roller compacted concrete pavements [1]. Out of these three, the Roller Compacted Concrete (RCC) yields the lowest cost [2]. The popularity of RCC is due to some other advantages too. One of them is that it does not require any special machinery, and equipment that is used for construction of conventional road pavements can be used. Another important advantage is that an RCC pavement can be opened to traffic once its compaction has been finished. But there is no specified mix design available for RCC covering both strength and surface finish. An experimental investigation was carried out to study the properties of RCC, especially flexural strength and wet density, in order to propose a mix design procedure.

EXPERIMENTAL INVESTIGATION

Any mix proportion for Roller Compacted Concrete is expected to fulfill the following five basic requirements [3].

1. It must achieve the specific strength.
2. It must contain sufficient water to allow the ingredients to hydrate fully.
3. It must have sufficiently stiff consistency such that the material will not collapse under the action of roller after placing.
4. It must have high resistance against segregation.

5. The mix proportions must be such that when compacted and cured the resulting pavement will have a durable, i.e. abrasion-resistant, surface.

Since the available mix design methods such as DoE method [4] for normal concrete cannot be directly used to achieve these basic requirements, experimental investigations were carried out to formulate a mix design method for RCC.

Particle size distribution is very important to obtain a dense compacted mass specially for low slump concrete mixes. It is common practice to use both maximum sized 20mm and 37.5mm graded aggregate for RCC [5]. Based on the research carried out by Road Development Authority in Sri Lanka [6] the recommended grading for 20mm combined (without cement) aggregate is shown in Figure 1. Similar grading for combined aggregate is specified by the French Authority [7]. The fineness modulus of this combined grading curve lies between 5.0 to 7.0.

In order to produce the grading curve of combined aggregate within the recommended limits fine and coarse aggregate were mixed to the ratio of 43% to 57% respectively and obtained grading A shown in the figure 1. The required grading of coarse aggregate was obtained by blending 20mm single size and 10mm single size to the ratio of 3:2.

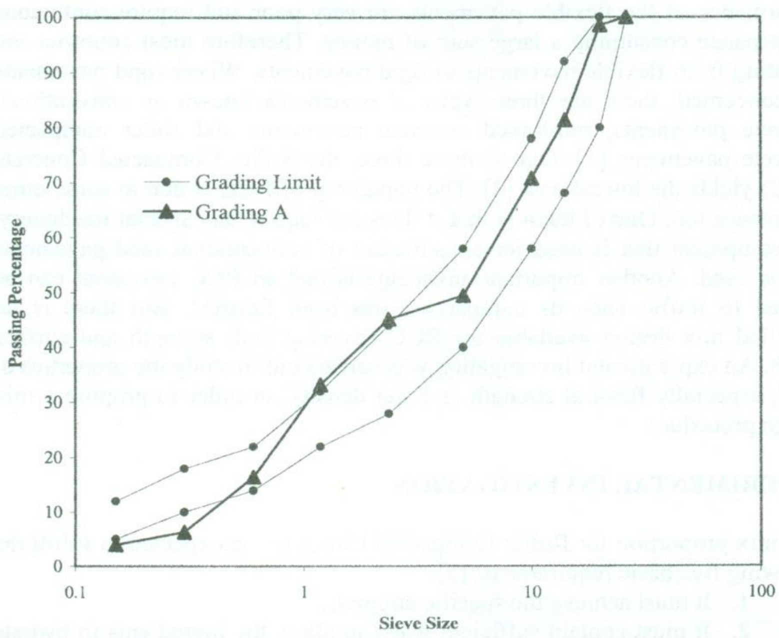


Figure 1: Combined grading curve for 20mm aggregates

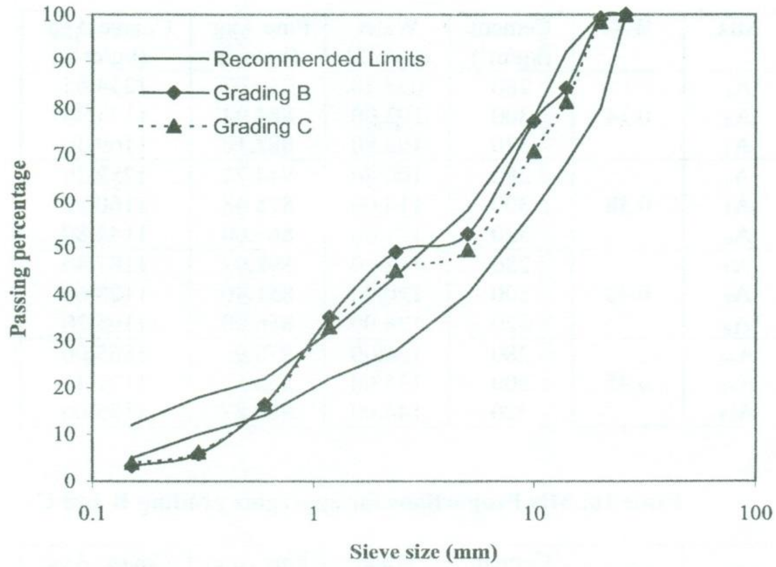


Figure 2: Particle size distribution of two aggregates samples B and C

In order to study the effect of grading curve of combined aggregate, a few trials were carried out with two more gradings, grading B and C outside the recommended limits as shown in the Figure 2.

The maximum size of the aggregate also plays a key role in low slump concrete mixes. The required effort to compact the low slump concrete will increase with the increase of particle size; this may result in reduction of flexural strength. Therefore maximum size of 20mm coarse aggregate which satisfies the grading limits shown in the Figure 1 was used for the entire test series.

It was decided to use one brand of cement for the entire series of the test to avoid any variation in quality of cement [8]. The cement quantity was varied from 280kg/m^3 to 320kg/m^3.

For each cement content, the water quantity was varied in such a manner that w/c varies from 0.34 to 0.45. Adopted mix proportions are given in Table 1(a) and Table 1(b).

Table 1a: Mix Proportions

Mix	W/C	Cement (kg/m^3)	Water (kg/m3)	Fine Agg: (kg/m^3)	Coarse Agg: (kg/m^3)
A_1		280	095.20	930.97	1234.05
A_2	0.34	300	102.00	884.94	1173.06
A_3		320	108.80	882.10	1169.30
A_4		280	106.40	944.72	1252.29
A_5	0.38	300	114.00	875.48	1160.51
A_6		320	121.60	863.60	1144.80
A_7		280	112.00	898.92	1187.40
A_8	0.40	300	120.00	851.40	1128.60
A_9		320	128.00	856.00	1195.20
A_{10}		280	126.00	878.92	1165.00
A_{11}	0.45	300	135.00	853.55	1131.41
A_{12}		320	144.00	886.87	1175.00

Table 1b: **Mix Proportions for aggregate grading B and C**

Mix	W/C	Cement (kg/m^3)	Water (kg/m3)	Fine Agg: (kg/m^3)	Coarse Agg: (kg/m^3)
A		300	114.00	875.48	1160.51
B	0.38	300	114.00	977.28	1058.45
C		300	114.00	875.48	1160.51*

* The Coarse aggregate of mix C was obtained by blending 20mm and 10mm single size aggregate to the ratio of 1 to 1.

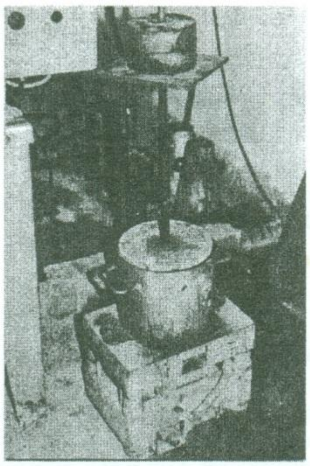
For each mix, the density of fresh concrete and the flexural strength at 28 days were measured.

Test Results

Wet Density

In order to obtain the density of concrete under the expected degree of compaction under vibratory rollers, a test method was developed by modifying the conventional V-B test apparatus. The transparent plate of the V-B apparatus was replaced with a steel plate and a loading arrangement was connected to this steel plate as shown in Figure 3. The load can be applied according to the applied stress due to the static weight of the roller. Based on the weight of a typical vibratory roller, 15kg was used in this apparatus to produce a pressure of 3.31×10^{-3} N/mm^2 on the concrete. Even though the amplitude of the vibrating table of the V-B apparatus is not the same as the vibrating roller, this method was expected to produce more realistic results than the conventional methods such as the Marshal method [5] to obtain wet density of RCC. The test procedure can be given as follows.

Initially the cylindrical container is filled with concrete to the top level in one layer. Then the required weight is applied to the top plate and is vibrated until no further compaction is possible. This condition can be confirmed by monitoring the reduction of depth of concrete in the cylinder. After measuring the final settlement of the steel plate from its initial position, the density can be calculated.



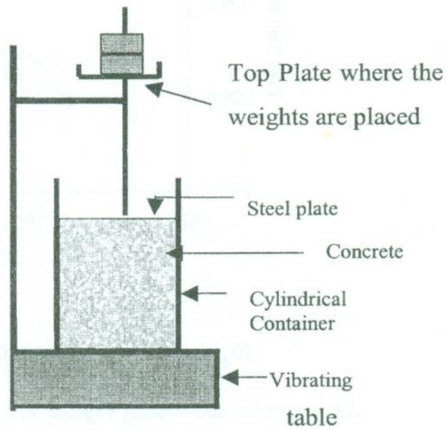


Figure 3: Modified V-B apparatus to measure the wet density

For each mix two tests were carried out and results are given in Table 2 and shown in Figure 4.

Table 2: Density of fresh concrete

W/C	Wet Density (kg/m^3) Cement Content (kg)		
	280	300	320
0.34	2195 *(2185, 2205)*	2225 *(2230, 2220)*	2319 *(2320,2318)*
0.38	2224 *(2228, 2221)*	2350 *(2365, 2335)*	2450 *(2450)*
0.40	2125 *(2120, 2130)*	2390 *(2390)*	2348 (2350,2346)
0.45	--	2346 *(2348, 2344)*	2374 *(2380, 2368)*

*Italic values represent the wet density of each test mix

When the wet density results of C-320 are analyzed it can be shown that the result with W/C=0.4 is a odd figure. Hence this result was not considered when plotting the graph between wet density and water content.

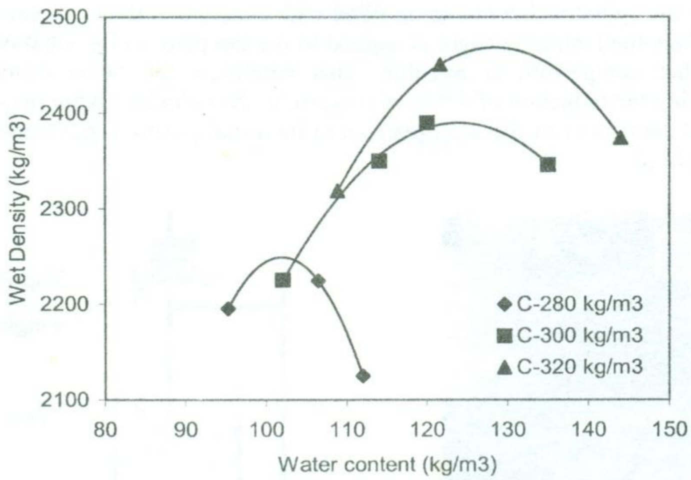


Figure 4: Variation of wet density with Water content

As it can be seen from Figure 4, for each cement content, there is an optimum water content at which highest density of fresh concrete can be achieved. This behaviour indicates that the concrete mix proportions with low water contents behave similarly to soil as far as compaction is concerned. Figure 5 shows that this optimum w/c ratio varies with the cement content and at high cement content variation of optimum w/c is not significant. In the case of RCC, it is important to achieve the maximum compaction in order to obtain good surface finish.

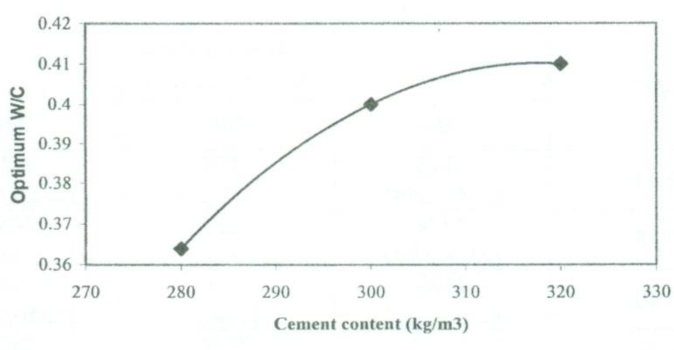


Figure 5: Optimum W/C vs. Cement content.

The calculated air content for each mix based on densities of individual material and measured wet density is given in the Table 3. It can be seen that the variation of air content with w/c for a given cement content is not significant.

Table 3 : The air content

W/C	Air Content (%)		
	Cement Content (kg)		
	280	300	320
0.34	13.0, 14.0	10.0, 9.0	8.0, 9.0
0.38	11.0,10.0	9.0, 8.0	5.0, --
0.40	12.0,13.0	7.0, --	4.0, 5.0
0.45	--	9.0,9.5	7.0, 8.0

As expected, the air content decreases with the increase of cement content indicating increase in density as shown in the Figure 6.

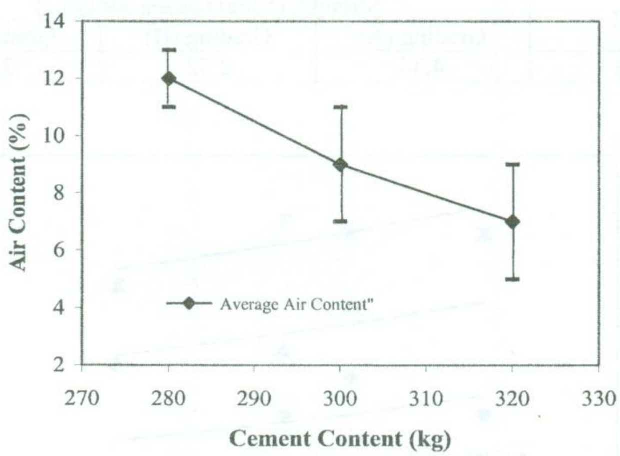


Figure 6 : The variation of air content with cement content

<u>Flexural strength</u>

Since flexural strength is the governing parameter in rigid pavement design, the flexural strength of each mix was measured. To measure the flexural strength, beams were cast using steel moulds of 150 mm x 150 mm x 750 mm [9]. In order to simulate the condition under the vibratory roller, a load of 36kg was applied to the concrete surface by using a steel beam during casting of these beams. After placing concrete in the steel mould, the steel beam was kept on the concrete and vibration was applied by using a vibratory table. For each mix two beams were cast and the results of 28- day flexural strength are given in Table 4 and 5.

W/C	Flexural Strength (MPa) ( )*		
	Cement Content (kg/m^3)		
	280	300	320
0.34	3.50 (3.16, 3.79)	3.40 (3.50, 3,30)	5.00 (4.95, 5.01)
0.38	3.80 (3.88, 3.72)	4.36 (4.36)	4.90 (4.9)
0.40	3.50 (3.49, 3.49)	4.01 (4.01, 4.01)	5.00 (5.01.5.00)
0.45	3.10 (2.90, 3.30)	4.00 (4.01, 4.00)	4.51 (4.38, 4.65)

*individual values

Table 5: 28- day Flexural strength of concrete with aggregate grading 'B' and 'C'

W/C	Strength (MPa) (cement 300 kg/m^3)		
	Grading (A)	Grading (B)	Grading (C)
0.38	4.36	2.52	2.92

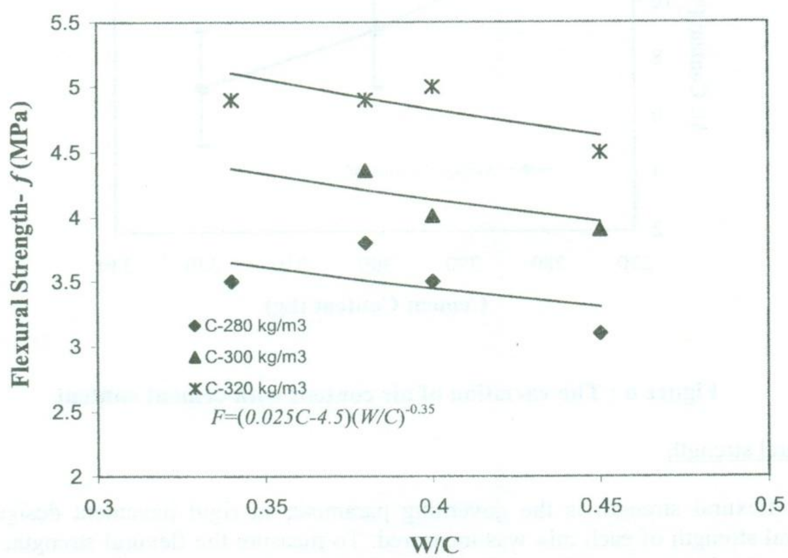


Figure 7 : Variation of Flexural strength with water cement ratio (w/c)

Flexural strength results obtained for different aggregate gradings (Table 5) show that the effect of combined aggregate grading on flexural strength is significant. These results confirm that the mix proportion with combined aggregate grading A, which is within the recommended limits, give better flexural strength.

As it can be seen in Figure 7, the flexural strength decreases with the increase of w/c and for the same w/c, flexural strength increases with the increase of cement content [10], [11]. However the result with C-300 and W/C =0.34 was disregarded as it is incomparable when compared to other results. This behavior is different to normal concrete mix proportions where strength mainly depends on w/c. According to the results obtained for 20mm aggregate, the relationship between flexural strength, water cement ratio and cement content can be expressed approximately as follows.

$$f = (0.025 \times C - 4.5) \times \left(\frac{W}{C}\right)^{-0.35}$$

where $\frac{W}{C}$ - water cement ratio

f - 28- day flexural strength(N/mm^2)
C- cement content (kg/m^3)

MIX DESIGN PROCEDURE

Based on the results obtained for the strength and wet density of concrete for the mix proportions tested, basic steps involved in the mix design procedure can be given as follows.

Step 1 - Selection of the appropriate water/cement ratio and cement content

The selected mix for RCC should give not only the required strength but also a satisfactory surface finish. Therefore the selection of w/c depends on both the strength and the surface finish. Based on the relationship established between flexural strength, w/c and cement content, for the selected cement content, w/c can be obtained for the required flexural strength according to Figure 7. If the optimum w/c for selected cement content based on compaction (Figure 5) is grater than the w/c obtained based on the flexural strength, the cement content should be increased until the optimum w/c for that cement content gives the required flexural strength. The flow chart for selection of proper w/c is shown in Figure 8.

Step 2 - Proportion of fine aggregate to coarse aggregate

Based on the recommended grading (Figure 1) for the combined aggregate the proportion of fine to coarse aggregate can be determined. According to the filling and packing theory [12], Roller Compacted Concrete should also have sufficient amount of mortar in order to fill the voids in coarse aggregate. Any surplus mortar will contribute towards easy compaction and better surface finish. Experimental investigations show that level of surface finish and strength required depends on the percentage of fines in the mix [13]. Since the surface finish depends on the shape of the fine aggregate it is advisable to do a few trials to determine the fine to coarse aggregate ratio.

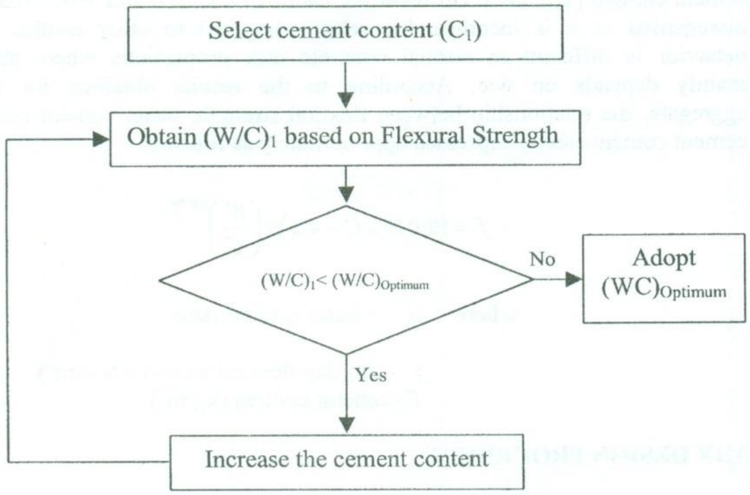


Figure 8: Selection of W/C and cement content

Step 3 - Sand content

Assuming an appropriate value for the air content (A) based on the Figure 6, the following equation can be written.

$$\frac{W}{1000} + \frac{C}{1000\rho_c} + \frac{S}{1000\rho_s} + \frac{G}{1000\rho_g} + A = 1$$

where W, C, S and G the weights of water , cement, sand and coarse aggregate respectively in kg/m^3

ρ_c, ρ_s, ρ_g the specific densities of cement, fine aggregate and coarse aggregate in kg/m^3.

Then the following equation can be derived for the sand content.

$$S = \frac{1000 - W - \dfrac{C}{\rho_C} - 1000A}{\dfrac{1}{\rho_s} + \dfrac{(1 - S_0)}{\rho_g S_0}}$$

Where S_o – Percentage of sand based on the total aggregate content calculated under step 2

Then the coarse aggregate content (G) can be calculated as follows

$$G = S\,\frac{1 - S_o}{S_o}$$

CONCLUSIONS

1. The combined aggregate grading has a significant effect on the flexural strength of zero slump concrete such as roller compacted concrete. A slight deviation from the recommended grading limits for combined aggregate can cause great reduction in flexural strength.
2. Wet density of roller compacted concrete depends on water content and cement content. For a given cement content, there is an optimum water content at which maximum density can be achieved. Since the surface finish of a road pavement is important, it is necessary to achieve maximum compaction of this kind of concrete.
3. The flexural strength of RCC depends not only on w/c, but also on cement content. An approximate relationship for the variation of flexural strength with w/c and cement content was developed.
4. Based on the relationships established using the experimental results a mix design method for RCC for road pavements was proposed. The proposed method gives guidelines to achieve required flexural strength and good surface finish for road pavements.

REFERENCES

[1] BRYAN, P., "Low Volume Concrete Roads", Cement and Concrete Institute Midrand, South Africa, 2000.

[2] MALLAWARACHCHIE, D. P., JAYALATH, J., and SENEVIRATNE, G. G. A., "Use of Roller Compacted Concrete in road and air port pavement construction is Sri Lanka", International Symposium on concrete roads, Lisbon, 1998

[3] HODGKNSON, J.R., "Design and Construction of Roller Compacted Concrete Pavements", Cement and Concrete Association of Australia, May, 1991.

[4] TEYCHENNE, D.C., FRANKLIN R.E, and ERNTROY H.C, "Design of Normal Concrete Mixes", Department of Environment, Building Research Establishment, 1998.

[5] HIROYUKI, T., "Status Report on Roller Compacted Concrete Pavements", Concrete Library of JSCE No 16, December, 1990

[6] MALLAWARACHCHI, D.P., NAGULESWARAN, A. and SILVA G.H.W., "Lessons Learnt form the construction of a few sections of roller compacted concrete for road pavements", International Symposium on concrete roads, Lisbon,1998

[7] CARLOS, J., and IRIAKI Z., "Roller Compacted Concrete Pavements in Basque country", International Symposium on Concrete Roads, Lisbon,1998 .

[8] NANAYAKKARA, S.M.A, "Prediction of Compressive Strength of Concrete", Symposium of Engineering Research Unit, University of Moratuwa, 2000.

[9] BS 1881/118, Method for determination of flexural strength, British Standard Institution, 1983.

[10] NEVILLE, A.M., and BROOKS J.J, "Concrete Technology", Longman, Singapore, 1990.

[11] SOROKA, I., "Concrete in hot environments", E & FN Spon, London, 1993.

[12] POWERS, T.C, "The Properties of Fresh Concrete", John Wiley and Son, New York, 1968.

[13] JAMESON, G.W, SHARP, K.G, and WARWICK R.A, "A Field Trial of the use of Roller Compacted Concrete in High Speed Traffic Applications", Australian Road Research Conference ,1990 International, February 1987, pp.25 – 29.