Evaluation of bond strength in Roller Compacted Concrete under various normal pressures

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Abstract

The construction of dams using Roller Compacted Concrete (RCC) is a relatively new technology, which has rapidly developed in recent years. To increase the safety factor in designing the various horizontal construction joints in RCC dams, an experimental research using interlayer cement grout has been carried out to improve the bond strength. A device with the ability of exerting the normal pressure in the direct shear method has been designed and used. 144 tests were carried out to assess the effect of interlayer cement grout along with exerting the normal pressure. The tests include different proportions of water to cement of the interlayer grout (0.5, 0.75, 1) and different values of normal pressure (0, 5, 10, 15 kg/cm^2) in the ages of 7, 28 and 90 days. The results indicate that the use of interlayer cement grout in the range of the normal pressure exerted gives higher bond strength compared to the state of no grout. By reducing the ratio of water to cement of the grout, the bond strength increases.
Keywords: Roller Compacted Concrete, horizontal construction joint, interlayer cement grout, bond strength, normal pressure.

1 Introduction

The RCC dams are built in relatively thin layers, with a thickness of approximately 30 centimeters placed, spread and compacted over each other; therefore a large number of horizontal joints are formed in the dam. The quality of the concrete at the joint surface is of great importance to ensure the integration of layers. But in practice, this surface has a lower quality compared to the concrete mass; and a lower tensile and shear strength and a higher permeability is expected [1].

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The shear strength is a function of cohesion and angle of internal friction. The minimum shear properties occur at the horizontal construction joints between the lifts of RCC. Generally, the shear strength of the joint is dependent upon the amount of cement used in the RCC mixture, grading and quality of aggregates, amount of compaction of each layer, existing conditions of each layer surface (including weather conditions, construction conditions, and etc), layer age, improvement of layer surface by adding bedding mixture and index of maturity or curing. A large range of the bond strength depends on the RCC mixture and above named factors. As a general range, the cohesion can be taken between 0.1 and 2.5 MPa and the angle of friction between 30 and 65 degrees [2].

Although the normal pressure varies from one point to another in dam height, but the experimental researches and the bond (shear) strength determination are mostly carried out in the absence of normal pressure. The shear strength parameters stated in the technical data, are based on coring studies and joint tests on specimens taken from the dam built or being built. In this research, the influence of different normal pressures on the bond (shear) strength of RCC construction joints is studied using common laboratory specimens and by using interlayer cement grout.

2 RCC materials

2.1 Cement

The heat generation control is of great importance in selecting the cement type. Heat generation is typically controlled by using pozzolans and slags, therefore Portland cements including Type I, Π and V can be used [3]. In the present research, exports cement Type I of the Isfahan cement factory was used with the chemical analysis given in Table 1. The quantities of C_3S, C_2S, C_3A, C_4AF and insoluble residue in this cement are respectively 46.13, 27.38, 9.61, 9.98 and 0.44%.

Table 1: Chemical analysis of the cement used in the RCC mix design (%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
21.68	5.72	3.28	63.53	1.75	1.63	0.2	0.52

2.2 Pozzolans

Ninety percent of the dams built until 1998 contain some kind of additional material such as slag or pozzolan, and in only 10 percent of the cases, the cement has been used individually to make RCC [3]. To replace a portion of the cement by pozzolan (25%) a natural pozzolan powder was used in the RCC mix design. The chemical analysis is given in Table 2.

Table 2: Chemical analysis of natural pozzolan (%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
57.35	18.2	5	6.23	1.45	1.93	3.5	1.72

2.3 Aggregates

Considering that the aggregates fill 75 to 85% of the RCC volume [4], Their properties are an effective factor on fresh and hardened RCC. The gravel is crushed river aggregates with a maximum size of 25.4 millimeters in accordance with ASTM C33, and the sand is natural sand with 4.2% of the material passing No. 200 sieve (non-plastic) in accordance with ASTM C33. The gravel/sand ratio in the RCC mix design is 55 to 45. The grading of the coarse and fine aggregates is given in Table 3.

Table 3: Grading of the aggregates (Gravel and sand) in the RCC mix design.

Coarse Agg.	Agg. size (mm)	19.0	12.5	9.5	4.75	2.36	1.18
	Passing Percent	92.3	52.1	28.2	1.3	0.0	0.0
Fine Agg.	Agg. size (mm)	4.75	2.36	1.18	0.6	0.3	0.15
	Passing Percent	96.5	87.1	66.9	42.8	27.7	12.2

Table 4: Mix design specifications (in one cubic meter).

Weight of mix material (kg/m^3)				
Water	Aggregates		Cementitious material	
	Gravel	Sand	Cement	Pozzolan
137	1161	950	139	35

3 Tests program

The above materials, cubic RCC specimens with 15x15x15 cm dimensions were made using the optimum mix design [5] given in Table 4. The specimens were made in two layers and each layer was compacted for 15 seconds using the electric vibrating hammer (ASTM C1435).

The specimens are cured and protected by common laboratory methods to carry out shear strength tests at the ages of 7, 28 and 90 days.

The tests carried out include different proportions of water to cement of interlayer grout (0.5, 0.75, 1) and different values of normal pressure (0, 5, 10, and 15 kg/cm^2).

3.1 Test method for determining the bond strength

Considering that the construction joint can be referred to as an imposed crack (failure), for determination of the RCC bond strength according to previous researches [6], a device with a similar mechanism to the soil direct shear apparatus was designed and used. The RCC specimen was placed in the frame (figure1). The frame consists of a fixed plate and a moving plate. The normal pressure is exerted according to the mechanical theory of high strength bolts and by tightening the bolts on the moving plate. The device was then placed under the pressure jack (with the pressure being exerted in the same direction as the contraction joint). Finally, two sliding plates were placed tangent to the joint and on opposite sides of it. By exerting the pressure on the jack, shear failure would occur at the joint (figure 2).

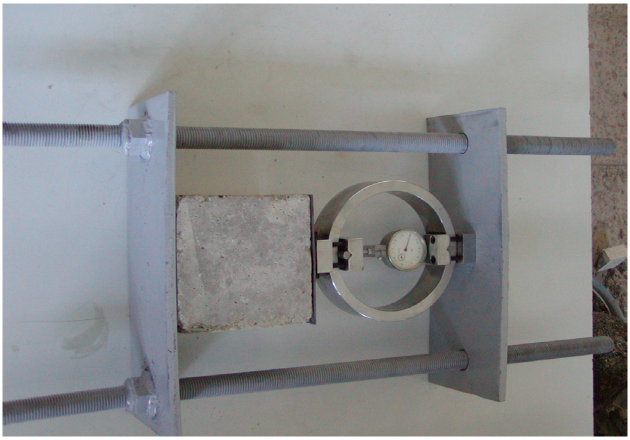

Figure 1: Device for exerting normal pressure to the RCC specimen.

4 Analysis of results

4.1 Bond strength at different ages

In Table 5, the average results of the bond strength determination at the ages of 7, 28 and 90 days (each test done at least 3 times) are given with the specifications of the specimen (interlayer grout) and also test along (4 values of normal pressure).

The variations of bond strength versus normal pressure for different values of proportion of the interlayer grout are shown in figures 3, 4 and 5 (for different ages of specimens). Any test where no grout is used has the least bond strength, and where the w/c ratio is equal to 0.5 the most bond strength is obtained. By decreasing the w/c ratio, the bond strength increases. This matter can be observed more significantly in the diagrams of figure 4 (at the age of 28).

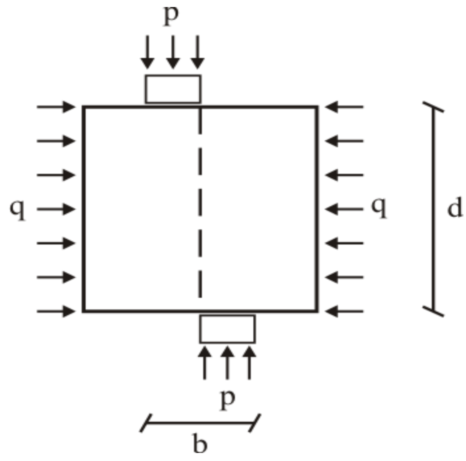

Figure 2: Exertion of normal and shear forces.

Table 5: Average results of RCC bond strength at the ages of 7, 28 and 90 days.

Age (days)	w/c ratio	Bond strength [τ] (kg/cm^2)			
		Normal pressure σ= 0 kg/cm^2	Normal pressure σ= 5 kg/cm^2	Normal pressure σ= 10 kg/cm^2	Normal pressure σ= 15 kg/cm^2
7	No grout	16	20.9	22.2	26.7
	1	17.2	19	24.45	25.9
	0.75	17.6	23	24.15	28.3
	0.5	19.4	20.3	25.2	28.6
28	No grout	21.8	23.1	30.4	31.1
	1	23.6	25.8	31.9	33.2
	0.75	23.3	29.8	30.1	35.4
	0.5	24	30.8	32.1	35.4
90	No grout	25.4	27.1	34.6	35.1
	1	25.3	30.9	35.6	36.1
	0.75	27.4	28.4	35.0	37.9
	0.5	28.5	28.8	33.5	39.2

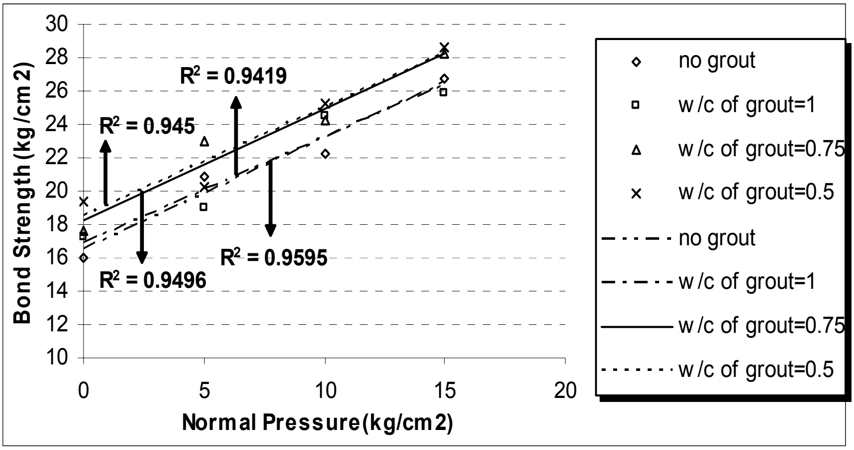

Figure 3: Bond strength versus normal pressure diagram at the age of 7 days, comparing different proportions of w/c.

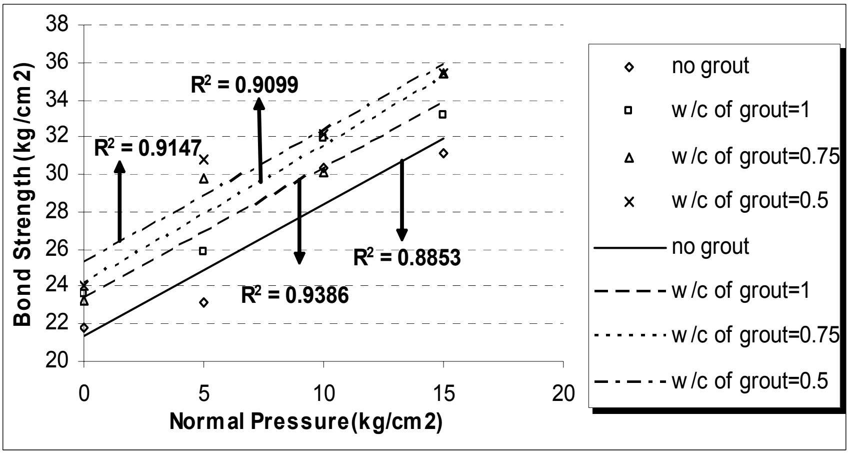

Figure 4: Bond strength versus normal pressure diagram at the age of 28 days, comparing different proportions of w/c.

The RCC shear strength parameters which include the interlayer cohesion (C) and the angle of interlayer friction (φ) have been derived for each age and each proportion of w/c. The results are given in table 6.

4.2 Effect of specimen age on the bond strength

For all normal pressure values and proportions of w/c, on average, the 7-day bond strength is approximately 77.7% of the 28-day bond strength. Also, the 90-

day bond strength has an increase of 10.1% compared to the 28-day bond strength (figure 6).

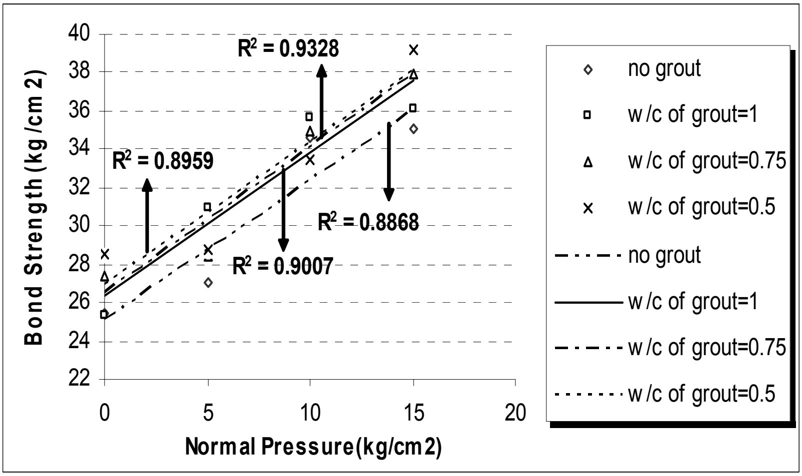

Figure 5: Bond strength versus normal pressure diagram at the age of 90 days, comparing different proportions of w/c.

Table 6: RCC shear strength parameters (C, φ).

Specimen Age (days)	w/c ratio	Interlayer Cohesion, kg/cm ^{2}	Interlayer friction angle
7	No grout	16.44	33.7
	0.5	18.51	32.96
	0.75	18.28	33.58
	1	16.87	32.41
28	No grout	21.32	35.14
	0.5	25.25	35.4
	0.75	24.16	36.2
	1	23.39	34.9
90	No grout	25.06	36.2
	0.5	26.98	36.4
	0.75	26.46	37.3
	1	26.41	36.6

4.3 Effect of w/c ratio of interlayer grout and specimen age on shear strength parameters

The interlayer cohesion is intact with the bond strength, resulting that the maximum and minimum cohesion occur at w/c=0.5 and state of no grout used, respectively (figure 7). The angle of interlayer friction has no specific trend, and its maximum and minimum values occur at w/c=0.75 and w/c=1.0, respectively (figure 8).

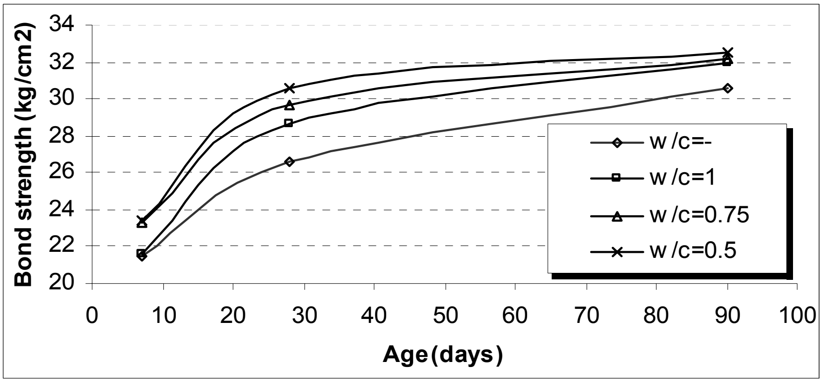

Figure 6: Bond strength versus age curves for different proportions of w/c.

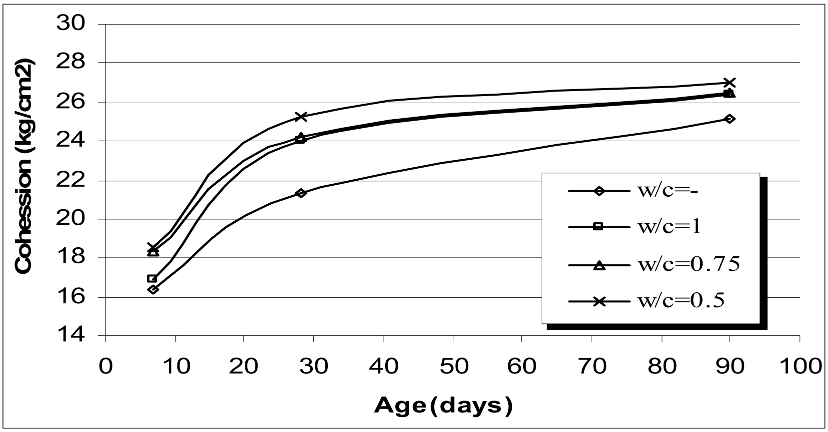

Figure 7: Cohesion versus age curves for different proportions of w/c.

5 Conclusions

In this research, a device with the ability of exerting the normal pressure was designed to assess the RCC bond strength. The analysis of the overall results obtained from the optimum mix design, different w/c ratios (0.5, 0.75, and 1) and different values of normal pressure (0, 5, 10 and 15 kg/cm^2) at the ages of 7, 28 and 90 days gives the following conclusions:

The Mohr coulomb equation [$\tau = C + \sigma \tan \varphi$] has regressed the bond strength versus normal pressure for each proportion of w/c and also for the state of no grout used, along with the high correlation coefficients derived from above.

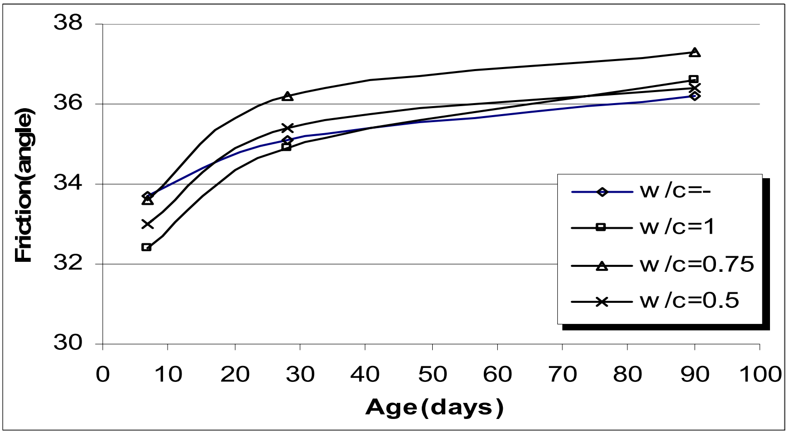

Figure 8: Angle of friction versus age curves for different proportions of w/c.

The minimum bond strength was obtained in the tests where no grout was used, and where the interlayer grout is used, the bond strength would decrease whilst the w/c ratio is increased.

The variation of the interlayer cohesion including all proportions of w/c and also the state of no grout used is intact with the variation of the bond strength, whereas the angle of interlayer friction does not follow any special pattern.

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