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Practical method for mix design of cement-based grout

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Abstract

Cement-based grout is made of mixed water and cement, which is sometimes also added with sand and admixtures. It is commonly used for soil improvement, for repairing the damages on concrete and masonry, or for the construction of preplaced-aggregate concrete. Currently there are hardly any available practical methods which can be used to carry out the grout mix design. The practical method to carry out cement-based grout mix designs suggested in this paper is based on some graphics and or empirical equations, which are derived from regression analyses of laboratory test results data to simplify the mix design process.

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Keywords: flowability, flow cone test, gradation, grout, mix design, gradation, water-cement ratio

1. Introduction

Cement-based grout is made of mixed water and cement, which is sometimes also added with sand and admixtures. It is commonly used for soil improvement, such as dam curtain walls using jet grouting methods [1-5], for masonry wall crack repairs [6], or for preplaced-aggregate concrete applications [7-12].

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In the application the grout is placed by using injection methods, with pressure or by its own weight only. Therefore it is necessary for the grout to have adequate flowability so that the injection process can be easily carried out; additionally, it is also necessary for the grout to have adequate mechanical properties such as compressive and tensile strengths. However, currently there are hardly any available practical mix design methods of cement-based grout. Commonly the grout mix design is carried out by trial-and-error in laboratories. Meanwhile, a variety of grout mix is needed to satisfy the required physical and mechanical properties. For instance, high flowable neat grout or paste grout that contains only a mix of water and cement is needed for injection into small cracks so that the grout can easily penetrate them. For wide cracks on the other hand, the mortar grout mix with coarser sand is preferable to minimize the cost and the shrinkage.

Therefore, it is important to develop a practical method of grout mix design that can be easily used and adapted on-site as will be discussed in this paper. The suggested practical mix design is based on empirical equations found from regression analyses of laboratory test results where the grout flowability was measured using standard flow cone methods, based on ASTM-C939 [13].

Nomenclature

f'_m	grout compressive strength
F_c	correction factor
G_c	specific gravity of cement
G_s	specific gravity of sand
G_w	specific gravity of water
s	volumetric portion of sand
V_c	the need of cement volume per cubic meter
V_{cc}	the corrected need of cement volume per cubic meter
V_s	the need of sand volume per cubic meter
V_{sc}	the corrected need of sand volume per cubic meter
V_w	the need of water volume per cubic meter
V_{wc}	the corrected need of water volume per cubic meter
w	volumetric portion of water
W_c	the need of cement weight per cubic meter
W_{cc}	the corrected need of cement weight per cubic meter
W_s	the need of sand weight per cubic meter
W_{sc}	the corrected need of sand weight per cubic meter
W_w	the need of water weight per cubic meter
W_{wc}	the corrected need of water weight per cubic meter
w/c	water-cement ratio in weight
w/c_{min}	minimum water-cement ratio in weight that still satisfy the flow cone test
γ_c	unit weight of cement
γ_s	unit weight of sand
γ_w	unit weight of water

2. Literatures review

2.1. Studies of grout mix

Cement-based grout mix design is commonly carried out based on volumetric ratio to avoid unpractical on-site weighting procedures [1]. The range of the volumetric ratio between water and cement is around 6 : 1 to 0.6 : 1 for common applications. If sand is to be used as filler, the weight ratio of sand to cement is normally not more than 2. To modify the grout performance, normally admixtures are used, e.g. accelerators to speed up the hydration process, retarders to prolong the hydration process, fluidifiers to increase the flowability, water reducers to reduce the applied water, and expanding admixtures to compensate the shrinkage. The volume of the resulted grout can be estimated from the absolute volume of each material used in the mix. For instance, the absolute volume of a bag of cement of 94 pounds is around 0.478 cubic feet, which is sometimes taken as 0.5 cubic feet for simplicity.

Kuisi et.al [4] suggested three different mix designs of cement-based grout for curtain wall applications (as can be seen in Table 1) named as GIN, backfilling, and Sleeve. All of the mixes are without sand where each has a water-cement ratio *w/c* of 1.00, 0.40, and 3.64 respectively. It can be seen that the sleeve has the highest water-cement ratio so that it will have the most flowable mix compare to the GIN and backfilling mixes that have lower water-cement ratios. To increase the GIN flowability, the mix is added with an admixture. Meanwhile, the back filling is left to be a thick mix, as it is used as a grout to seal up the bore holes.

For the application in soil improvement, the cement-based grout mix is recommended to utilize well graded sand [3]. The volumetric ratio of cement : sand of 1 : 2 can be used as long as the sand passes a 1.20 mm sieve, with the amount of sand that passes 0.15 mm is above 15%. The application of sand in the mix is to increase the grout compressive strength. He also mentions that the application of coarser sand will cause segregation except when more fine sand is added or by adding mineral admixtures such as fly ash. The amount of water to be used in the mix can be determined using the volume or weight ratio. For practical reasons the volumetric water-cement ratio is more preferable, which is between 4 : 1 to 0.75.

Table 1. Grout mix type for under dam curtain wall application [4].

Grout name	Grout mix per m^3			
	Water (Liter)	Cement (kg)	Bentonite (kg)	Admixture (Liter)
GIN	750	750	18	20
Backfilling	560	1400	-	-
Sleeve	910	250	25	-

Cement-based grout mix is also used in the construction of preplaced-aggregate concrete, also known as prepacked concrete or grouted concrete [7, 8, 14, 11]. Moreover a preplaced-aggregate concrete method is used if it is impossible to apply the normal concrete method, such as in cases of underwater concreting [10], fiber concrete with a very high content of fiber [12], or high density steel slot concrete [15]. In these cases admixtures may be required.

In the study of cement-based grout for preplaced-aggregate concrete application, Awal [7] used several varieties of grout mix with or without admixtures. He used three different cement : sand weight ratios, namely 1 : 1, 1 : 1.5, and 1 : 2 with various water-cement ratios using the same sand gradation. In general it was found that the application of more sand in the mix will reduce material cost but will also reduce the grout flowability. A higher water-cement ratio is required if more sand is used in the mix to maintain the grout flowability. For instance the 1 : 2 mix must have a water-cement ratio of 0.65 to pass the flow cone test, meanwhile the 1 : 1.5 and 1 : 1 mixes only need water-cement ratios of 0.52 and 0.50 respectively.

2.2. Gradation of Sand

In the application on cement-based mixes such as concrete or mortar, the sand gradation is normally divided into four categories or gradation zones [16] as shown in Table 2, i.e. coarse or zone I, rather coarse or zone II, rather fine or zone III, and fine or zone IV. The graphics of the average percentage passing of Table 2 is shown in Fig. 1.

2.3. Grout Flowability

As mentioned above, grout must have adequate flowability. One method to measure its flowability for its application in preplaced-aggregate concrete is by using a flow cone test according to ASTM-C939 [13]. The grout is considered to have adequate flowability if its 1725 ml efflux time is 35 seconds or less. It is noted here that the efflux time for pure water is 8 seconds. Therefore the ideal efflux time for grout lies between 8 seconds to 35 seconds, where higher efflux time means lower flowability.

Table 2. Sand gradation category based on percentage passing [16].

Sieve size (mm)	Percentage passing			
	Coarse (I)	Rather Coarse (II)	Rather Fine (III)	Fine (IV)
10	100	100	100	100
4.8	90-100	90-100	90-100	95-100
2.4	60-95	75-100	85-100	95-100
1.2	30-70	55-90	75-100	90-100
0.6	15-34	35-59	60-79	80-100
0.3	5-20	8-30	12-40	15-50
0.15	0-10	0-10	0-10	0-15

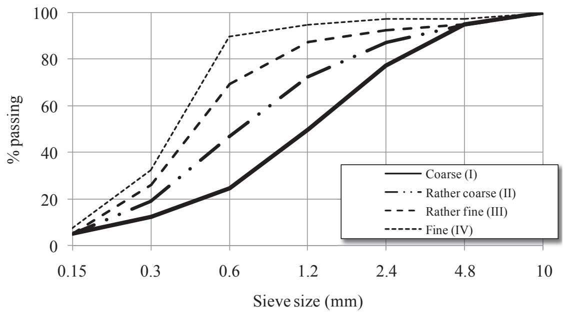

Fig.1. Sand gradation category based on average percentage passing.

3. Theory background

The mix design of grout can be calculated based on the absolute volume of each material using determined water, cement, and sand volumetric or weight proportion. If the volumetric ratio of cement : sand : water is 1 : s : w is determined, for example, then according to the absolute volume method the following equation must be satisfied.

$$\frac{V_c \gamma_c}{G_c \gamma_w} + \frac{s V_c \gamma_s}{G_s \gamma_w} + \frac{w V_c \gamma_w}{G_w \gamma_w} = 1 \tag{1}$$

where G_c = specific gravity of cement, G_s = specific gravity of sand, G_w = specific gravity of water, s = volumetric portion of sand, w= volumetric portion of water, γ_c = unit weight of cement, γ_s = unit weight of sand, and γ_w = unit weight of water.

If the water-cement ratio in weight w/c is determined rather than the volumetric ratio, Eq. 1 then becomes

$$\frac{V_c \gamma_c}{G_c \gamma_w} + \frac{s V_c \gamma_s}{G_s \gamma_w} + \frac{w / c V_c \gamma_c}{G_w \gamma_w} = 1 \tag{2}$$

The need of cement volume per cubic meter V_c can be easily found from Eq. 1 or 2 because V_c is the only unknown variable in the equations. Once the variable V_c is known, the other materials' volume can also be found using the determined proportion, in this case the need of sand $V_s = sV_c$ and $V_w = wV_c$ for the water. For more consistent measurement of materials the need of material volume can also be changed to the weight by multiplying each material volume with its unit weight. Therefore the weight of cement, sand, and water will be $W_c = V_c\gamma_c$, $W_s = V_s\gamma_s$, and $W_w = V_w\gamma_w$ respectively.

4. Research method

There were three materials used in this research: water, cement, and sand. All of them were local materials that can be easily found around Yogyakarta. The main equipment used were a grout mixer, a flow cone apparatus, 50 mm cube grout molds, and a compressive test machine of Avery-Denison with the capacity of 200 kN.

Four categories of sand gradation based on the average value of Table 2 (shown in Fig. 1) ware used for the grout mix: fine, rather fine, rather coarse, and coarse. Four different volumetric cement : sand ratios were studied, being 1 : 0, 1 : 0.5, 1 : 1.0, 1 : 1.5 and 1 : 2.0, where grout with volumetric ratio of 1 : 0 means grout without sand and is named neat grout or paste grout, while the others are called mortar grout.

The condition of sand used for the grout mix was oven-dry and the water-cement ratio of each mix was found by trial-and-error to find the minimum water-cement ratio that still satisfies the flow cone test. In the trial-and-error process the increment or decrement of the water-cement ratio was 0.05. When the minimum water-cement ratio of each grout mix that satisfies the flow cone test was found, the grout was then poured into the 50 mm cube mold to make compressive test specimens. The compressive test of each grout mix was carried out on the age of 7 days and 28 days. The variables of grout mix and the number of specimens are shown in Table 3.

Table 3. Variable of the grout mix and the number of specimen of compressive test.

No	Sand gradation	Volumetric ratio Cement	:	Sand	Minimum *w/c*	No of specimen	Compressive test
1	Fine	1	:	0.50	To be found	4	7 days
						4	28 days
2		1	:	1.00		4	7 days
						4	28 days
3		1	:	1.50		4	7 days
						4	28 days
4		1	:	2.00		4	7 days
						4	28 days
5	Rather fine	1	:	0.50	To be found	4	7 days
						4	28 days
6		1	:	1.00		4	7 days
						4	28 days
7		1	:	1.50		4	7 days
						4	28 days
8		1	:	2.00		4	7 days
						4	28 days
9	Rather coarse	1	:	0.50	To be found	4	7 days
						4	28 days
10		1	:	1.00		4	7 days
						4	28 days
11		1	:	1.50		4	7 days
						4	28 days
12		1	:	2.00		4	7 days
						4	28 days
13	Coarse	1	:	0.50	To be found	4	7 days
						4	28 days
14		1	:	1.00		4	7 days
						4	28 days
15		1	:	1.50		4	7 days
						4	28 days
16		1	:	2.00		4	7 days
						4	28 days

After the water-cement ratio has been determined, the grout mix design of each proportion can be calculated using Eq. 2. Note that the grout mix proportion was discharged from further tests and analyses if no water-cement ratio could satisfy the flow cone test. Using the test results of the flow cone test, grout mix design, compressive test at 7 days and at 28 days, the correlation between volumetric ratio of sand to cement, which is expressed as the ratio of sand to cement *s/c,* can be drawn. Then using regression analysis, empirical equations of their correlations can be found and used for practical mix design procedures.

5. Results and discussion

5.1. Physical properties of materials

The physical properties of materials used in the grout mix are as follows:

a. unit weight and specific gravity of water are γ_w = 1000 kg/m^3 and G_w = 1,
b. unit weight and specific gravity of cement are γ_c = 1250 kg/m^3 and G_c = 3.15,
c. unit weight and specific gravity of sand are γ_s = 1637 kg/m^3 and G_s = 2.71.

5.2. Correlation between s/c and w/c_{min}

Table 4 shows the minimum water-cement ratio w/c_{min} that can still be used to satisfy the flow cone test for various volumetric ratios of cement to sand and sand gradation. It can be seen that the sand gradation category has less influence to the required minimum water-cement ratio w/c_{min} that can still be used to satisfy the flow cone test than the cement : sand ratio. If the correlation of cement : sand volumetric ratio, expressed as the volumetric ratio of sand to cement *s/c*, and minimum water-cement ratio w/c_{min} for all results regardless of the sand gradation category is plotted as shown in Fig. 3, the following trends can be found. Note that some inconsistent data are discharged from regression analyses.

a. The minimum water-cement ratio w/c_{min} that satisfies the flow cone test increases with the increase of *s/c*.
b. For the rather coarse sand gradation category the maximum *s/c* that can be used to satisfy flow cone test is 1.5 while that of the coarse sand is only 1.0.
c. From regression analysis shown in Fig. 2 the minimum water-cement ratio w/c_{min} can be found using Eq. 3.

$$w/c_{\min} = 0.072\left(\frac{s}{c}\right)^2 + 0.045\left(\frac{s}{c}\right) + 0.45 \quad (3)$$

Table 4 Minimum waer-cement ratio w/c_{min} of grout to satisfy flow cone test.

Sand grading	Cement :	Min. water-cement
Fine	1 : 0.5	0.50
	1 : 1.0	0.55
	1 : 1.5	0.65
	1 : 2.0	0.80
Rather fine	1 : 0.5	0.50
	1 : 1.0	0.55
	1 : 1.5	0.65
	1 : 2.0	0.70
Rather coarse	1 : 0.5	0.50
	1 : 1.0	0.55
	1 : 1.5	0.65
	1 : 2.0	*
Coarse	1 : 0.5	0.50
	1 : 1.0	0.55
	1 : 1.5	*
	1 : 2.0	*

Note: * does not pass flow cone test

5.3. Correlation between s/c and f'm

The correlation between *s/c* and grout compressive strength f'_m at 7 days age and at 28 days age are shown in Fig. 3 and 4, which show the following tendencies:

a. grout compressive strength depends on *s/c*. Note that the higher the *s/c*, the higher w/c_{min} of the mix to satisfy flow cone test as shown in Fig. 2,
b. for rather coarse sand gradation category, the maximum *s/c* that can be used is 1.5 and 1.0 for coarse sand,
c. from regression analysis shown in Fig. 3 and 4, Eqs. 4 and 5 can be found and be used to predict the grout compressive strength at 7 and 28 days' age.

$$f'_m \text{ at 7 days} = -9.09\left(\frac{s}{c}\right)^2 + 9.461\left(\frac{s}{c}\right) + 31.03 \tag{4}$$

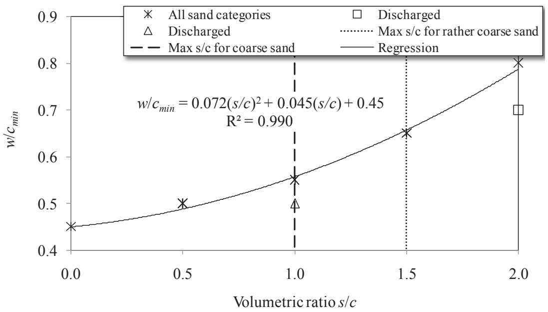

Fig. 2. Correlation between *s/c* and w/c_{min}.

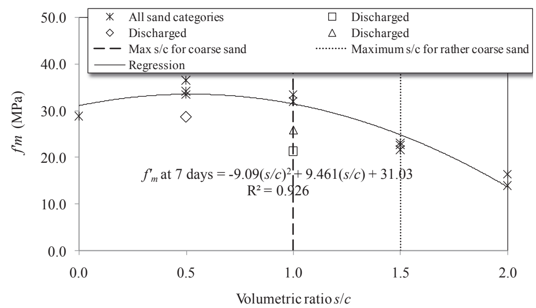

Fig. 3. Correlation between *s/c* and f'_m at 7 days.

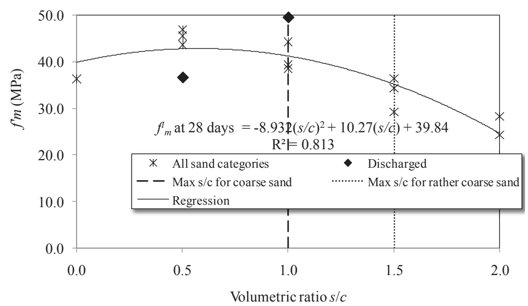

Fig. 4. Correlation between *s/c* and f'_m at 28 days.

$$f_m^{'} \text{ at } 28 \text{ days} = -8.932\left(\frac{s}{c}\right)^2 + 10.27\left(\frac{s}{c}\right) + 39.84 \tag{5}$$

5.4. Correlation between s/c and V_w

Correlation between *s/c* and the need of water per cubic meter V_w is shown if Fig. 5 which indicates the following tendencies:

a. the need of water in the grout mix decreases as the *s/c* value increases,
b. from regression analysis shown in Fig. 5, Eq. 6 can be found and used to calculate the need of water volume per cubic meter of grout mix.

$$V_w = 0.063\left(\frac{s}{c}\right)^2 - 0.231\left(\frac{s}{c}\right) + 0.58 \tag{6}$$

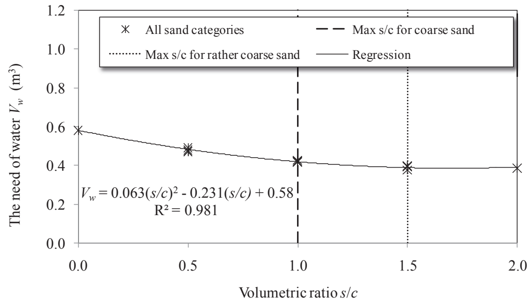

Fig. 5. Correlation between s/c and the need of water per cubic meter.

5.5. Proposed Grout Mix Design Procedure

Using the empirical equations found from regression analyses discussed above, the following practical procedure to carry out grout mix design is suggested.

a. Determine the appropriate *s/c* value to be used for the grout mix by considering the purpose of the grout application and the requirement of compressive strength at 7 or 28 days using Eq. 4 or 5.
b. Based on the selected *s/c*, determine the minimum water-cement ratio w/c_{min} to be applied using Eq. 3, and the need of water volume per cubic meter V_w using Eq. 6.
c. Calculate the need of cement weight W_c in kg using Eq. 7.

$$W_c = \frac{\gamma_w V_w}{w/c} \tag{7}$$

d. Calculate the need of cement volume V_c in m^3 by dividing Eq. 7 with the cement unit weight γ_c as shown in Eq. 8.

$$V_c = \frac{W_c}{\gamma_c} \tag{8}$$

e. Calculate the need of sand volume V_s in m^3 by multiplying V_c with *s/c* as expressed in Eq. 9.

$$V_s = V_c(s/c) \tag{9}$$

f. For better accuracy and for more consistent material proportions in every mix, the material quantity expressed in volume can be converted into weight, by multiplying each volume with its unit weight. Therefore the need of material in weight will be as follows: weight of water $W_w = \gamma_w V_w$, weight of cement $W_c = \gamma_c V_c$, and weight of sand $W_s = \gamma_s V_s$.
g. To get a more precise amount of material, the following correction factor F_c based on Eq. 1 can be found.

$$F_c = \frac{W_w}{G_w \gamma_w} + \frac{W_c}{G_c \gamma_w} + \frac{W_s}{G_s \gamma_w} \tag{10}$$

h. Using Eq. 10 the more exact calculation of each material needed in volume or in weight can be found as follows: $V_{wc} = V_w/F_c$ or $W_{wc} = W_w/F_c$ for water, $V_{cc} = V_c/F_c$ or $W_{cc} = W_c/F_c$ for cement, and $V_{sc} = V_s/F_c$ or $W_{sc} = W_s/F_c$ for sand.

It is important to note here that the used sand in this research was in oven-dry condition. On site, the condition of sand commonly is not in oven-dry condition so that more water will be present in the mix if Eq. 6 is used. Therefore the need of water in the mix expressed in Eq. 6 might be reduced by the amount of sand moisture content. Otherwise the mix will have less efflux time but might have less compressive strength as the mix has higher w/c due additional water content from the sand. Moreover, if the used materials have different mechanical or chemical properties, the suggested equations may give different predictions. Some adjustments might be required, or the user may carry out personalized laboratory tests and use the results to derive more appropriate empirical equations as discussed above.

5.6. Example

The physical properties of materials to be used in the grout mix are, for instance γ_w = 1000 kg/m^3, γ_c = 1250 kg/m^3, γ_s = 1600 kg/m^3, G_w = 1.0, G_c = 3.15, G_s = 2.6. Step-by-step procedure of the grout mix design is carried out as follows.

a. The value of s/c is, for instance, determined to be 0.75.
b. Using Eq. 3, the minimum water-cement ratio can be found as w/c = 0.52.
c. Using Eq. 4 and 5, the estimated compressive strength of the grout at 7 and at 28 days will be 33.0 MPa and 42.5 MPa respectively.
d. Using Eq. 6, the need of water can be found as V_w = 0.44 m^3.
e. Using Eq. 7, the need of cement in weight can be found as W_c= 843.47 kg.
f. Using Eqs. 8 and 9, the volume of cement and sand can be calculated to be V_c = 0.67 m^3 and V_s = 0.51 m^3 respectively.
g. The need of materials in volume calculated above can be converted into weight as follows: $W_w = V_w \gamma_w$ = 442.19 kg, $W_c = V_c \gamma_c$ = 843.47 kg, and $W_s = V_s \gamma_s$ = 809.73 kg.
h. Using Eq. 10, the correction factor can be found as F_c = 1.02.
i. Using the correction factor F_c, the more precise calculation of each material needed in volume or in weight can then be calculated as follows: $V_{wc} = V_w/F_c$ = 0.43 m^3, $V_{cc} = V_c/F_c$ = 0.66 m^3, $V_{sc} = V_s/F_c$ = 0.50 m^3, $W_{wc} = W_w/F_c$ = 432.93 kg, $W_{cc} = W_c/F_c$ = 825.80 kg, $W_{sc} = W_s/F_c$ = 792.77 kg.

6. Conclusions

Using some empirical equations based on regression analyses of laboratory test results, a practical procedure for grout mix design is proposed where the following tendencies are noted.

a. A higher minimum water-cement ratio w/c_{min} is required for a higher sand-cement ratio s/c to satisfy the flow cone test.
b. The maximum s/c that can be used to satisfy the flow cone test is 1.5 for rather coarse or Zone II sand gradation category, and is only 1.0 for coarse or Zone I sand gradation category.
c. In any case it is suggested that the value of s/c be not more than 2.0.
d. The grout compressive strength depends on the value of s/c.
e. If physical or chemical properties of the materials differ with the ones used in this research, it is suggested that the empirical equations shall be based on regression analyses from personal laboratory test results.

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References

[1] EM 1110-2-3506, Engineering and Design Grouting Technology, Department of U.S. Army Corps of Engineers, Washington, DC 20314-1000, 1984.
[2] A.M. El-Kelesh, and T. Matsui, Compaction Grouting and Soil Compressibility, Proceedings of The Twelfth (2002) International Offshore and Polar Engineering Conference Kitakyushu, Japan, May 26–31, 2002, 2002.
[3] J.P. Guyer, Introduction to Soil Grouting, Continuing Education and Development, Inc., 9 Greyride Farm Court Stony Point, NY 10980, 2009.
[4] M.A. Kuisi, A.E. Naqa, F. Shaqour, Improvement of Dam Foundation Using Grouting Intensity Number (GIN) Technique at Tannur Dam Site, South Jordan, Volume 10, Bundle A, The Electronic Journal of Geotechnical Engineering, 2005.
[5] F. Tuncdemir, Theoretical and Practical Aspects of Compaction Grouting, Teknik Dergi Vol. 18, No. 1 January 2007, pp: 4069-4080, 2007.
[6] Khairil, Evaluation and Strengthening of Heritage Buildings in Kepatihan Complex Yogyakarta, Master Thesis, Postgraduate Programme of Civil and Environmental Engineering Department, Faculty of Engineering Gadjah Mada University, 2010.
[7] A.S.M.A. Awal, Manufacture and Properties of Prepacked Aggregate Concrete, Master Thesis, Department of Civil Engineering, University of Melborne, Australia, 1984.
[8] ACI 304.1 R-92, Guide for the Use of Preplaced Aggregate Concrete for Structural and Mass Concrete Applications, ACI Committee 304, 1997.
[9] I.R. Bayer, Use of Preplaced Aggregate Concrete for Mass Concrete Application, Master Thesis, the Graduate School of Natural and Applied Sciences of Middle East Technical University, 2004.
[10] I. Satyarno, Design and Supervision of Hydro Power System Construction, Monthly Report, Department of Public Work, Yogyakarta Special District, 2005.`
[11] UFGS-03372, Preplaced-Aggregate Concrete, Division 03-Concrete, Section 03 37 00, Unified Facilities Guide Specification, 2006.
[12] S.Randa, Mechanical Properties of Steel Fiber Concrete with Preplaced Aggregate Concrete Construction Method, Master Thesis, Postgraduate Program of Civil and Environmental Engineering Department, Faculty of Engineering Gadjah Mada University, 2013.
[13] ASTM-C939. Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method), American Standard of Testing Materials.
[15] A. Alhadi, The Application of Steel Slot for High Density Concrete for Gamma Ray Shield, Master Thesis, Postgraduate Program of Civil Engineering Department, Faculty of Engineering Gadjah Mada University, 2006.
[16] N.K. Raju, Design of Concrete Mixes, CBS Publisher & Distributors, 485, Jain Bhawan, Bhola Math Nagar Shandra, Delhi-110032, India, 1983.