DEEP FOUNDATIONS: STUDY ON EFFECT OF DRILLING FLUIDS ON CONCRETE INTEGRITY

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ABSTRACT The installation of Bored Piles and Diaphragm Wall under slurry using tremie raises quality concerns on the integrity of concrete. It is vital to understand the effects on concrete integrity during concrete pouring process. This paper intends to unveil to what extent the compressive strength of the concrete pour is affected in contact with drilling fluid still. Another important angle of analysis proves whether the inclusion of solids particles of un-hydrated fluid could have impact on the concrete compressive strength. The testing comparing the response of concrete compressive strength when drilling fluid is included into the concrete mix altering the water/cement ratio by 5%, 20% and 30%. Comparative results are analysed between two different hydrated slurries namely sodium activated Bentonite and 3rd generation synthetic polymer.

Keywords: Bentonite, PolyMud®, concrete-slurry intermix

1. INTRODUCTION

Soil stabilization is the base for a successful deep foundation execution. The G3 System Slurry developed by Ground Engineering Operations (GEO), with its third generation polymer, namely PolyMud®, is an innovative and unique alternative to the mineral based slurries for soil stabilization, enhancing the quality and integrity of the underground foundation structures. It optimises the production rate of work progress and cost as well. At the same time, PolyMud® slurry is proven to be environmentally friendly.

Guaranteeing the maximum quality of the foundation elements according to the initial design is one of the most important objectives and a concern for the foundations contractors. In order to fulfil the project expectations in this aspect, any incident that could compromise the designed concrete integrity and capacity must be avoided.

GEO, has carry out its own research regarding effects on the concrete compression results if drilling fluid intermixes with fresh concrete while pouring. To shed light in this regard, GEO, in collaboration with CML (Concrete Materials Laboratory) Sdn. Bhd., carried out empiric tests that analyse this particular event from different perspectives, bringing up the corresponding results that will be studied and commented in this article.

The scope of this research is divided in two main goals:

- To evaluate if the compressive strength of the concrete is affected when concrete is in contact or partially contains drilling fluid in its composition.
- To evaluate if the compressive strength of the concrete is affected by the ratio of water/cement.

2. OBJECTIVE

Lab tests were carried out to prove effects on the concrete compressive characteristics if alterations were made in the composition of the concrete design mix. This composition alteration refers to the drilling fluid; those were PolyMud®, and Bentonite (GTC 4). In order to make a fair comparison, a control mix sample which batched according to the actual concrete mix design was also prepared and tested.

These tests replicate the actual scenario on field where the excavations were filled with stabilizing fluid before concrete is being poured. There are chances for the fresh concrete to be intermixed with the slurry, thus affecting the compressive strength of the concrete. This study is demonstrated through concrete cube tests to evaluate the changes in the concrete compressive strength when fresh concrete is intermixed with stabilization fluid.

Two different protocols were executed, with four different percentages in volume of drilling fluid in the mix (0% or control mix, 5%, 20% and 30%).

The purpose of mixing different percentages in volume of the drilling fluid with the concrete is to quantify their impact in the concrete's resistance.

In order to determine the effects on the concrete properties occurred, all samples were tested for compression resistance after 7 and 28 days of concrete hardening and results were collected for analysis and interpretation.

3. TEST METHODOLOGY

3.1 Materials used

The products involved in this test have been concrete, PolyMud® and Bentonite drilling fluids, with the following further specifications in the mix design:

3.2 Concrete

Table 1. Concrete Mix Design

SUMMARY CONCRETE MIX DESIGN			
Feature	***Value/Type***	***Unit***	***Observations***
Characteristic Strength	40	N/mm^2	At 28 days
Margin	8	N/mm^2	
Target Mean Strength	48	N/mm^2	
Summary			
Batch for one cubic metre of concrete	Value	Unit	Observations
Design Concrete Density	2355	kg	
Cementitious	465	kg	
Water	160	kg	
Fine Aggregate	780	kg	
Coarse Aggregate	950	kg	
Admixture	1400	ml	D45
	3950	ml	ADVA181

3.3 PolyMud® drilling fluid

Table 2. Parameters of Polymer drilling fluid

PolyMud® drilling fluid		
Feature	***Value/Type***	***Unit***
Water	1	m^3
PolyMud	1	kg
Mixing Time (under Air Agitation)	2	hours
Viscosity	50-60	seconds
Density	1.00	g/cm^3
pH	11	

3.4 Bentonite drilling fluid (GTC 4)

Table 3. Parameters of Bentonite drilling fluid

Bentonite drilling fluid		
Feature	***Value/Type***	***Unit***
Water	1	m^3
Sodium Bentonite	50	kg
Maturing Time	24	hours
Viscosity	34-42	seconds
Density	1.02 – 1.04	g/cm^3
pH	9	

3.5 Test Protocols

Two different protocols (Protocol 1 and Protocol 2) were carried out in order to evaluate the changes in concrete's compressive capacity when intermix with drilling fluids during pouring under different considerations.

Parallel to both protocols sample preparation, a control mix sample batched according to the design mix was also prepared in order to take it as a reference when load tests were executed.

3.6 Nomenclature in Tests

For data recording purposes, the different mixes and tests were named as follows:

- **TM1**: Control mix test specimens (concrete batched according to design mix)
- **TM2**: Test specimens with inclusion of PolyMud® drilling fluid
- **TM3**: Test specimens with inclusion of Bentonite drilling fluid
- **Test 1**: Compression test for TM1, TM2 and TM3 (7 and 28 days).

TM2 and TM3 will have **5%** of its water volume from the concrete mix design being replaced with **5%** of drilling fluid volume respectively.

- **Test 2**: Compression test for TM1, TM2 and TM3 (7 and 28 days).

TM2 and TM3 will have **20%** of its water volume from the concrete mix design being replaced with **20%** of drilling fluid volume respectively.

- **Test 3**: Compression test for TM1, TM2 and TM3 (7 and 28 days).

TM2 and TM3 will have **30%** of its water volume from the concrete mix design being replaced with **30%** of drilling fluid volume respectively.

- **Test 4**: Compression test for TM1, TM2 and TM3 (7 and 28 days).

TM2 and TM3 will include additional **5%** volume of water by respective drilling fluid.

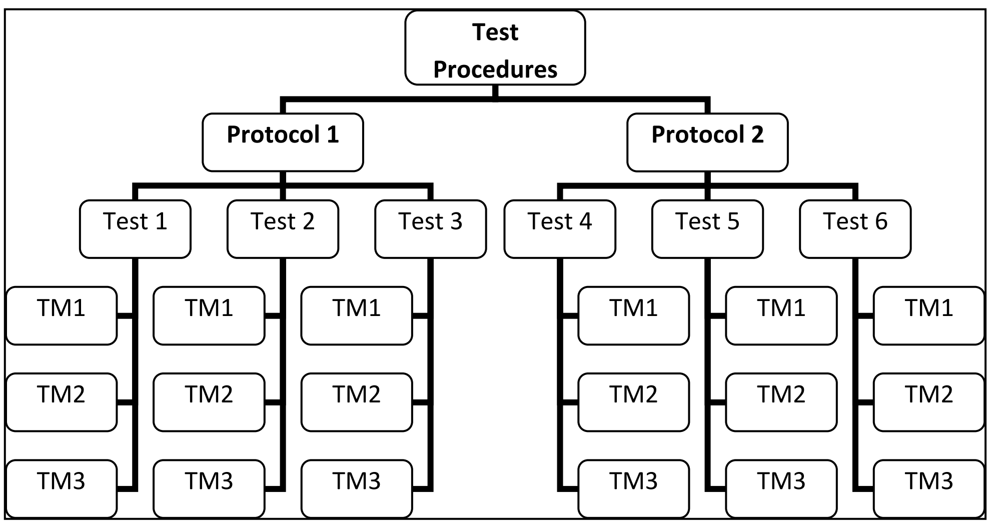
- **Test 5**: Compression test for TM1, TM2 and TM3 (7 and 28 days).

TM2 and TM3 will include additional **20%** volume of water by respective drilling fluid.

- **Test 6**: Compression test for TM1, TM2 and TM3 (7 and 28 days).

TM2 and TM3 will include additional **30%** volume of water by respective drilling fluid.

Chart 1. Test and sample grouping



3.7 PROTOCOL 1

3.7.1 General Description

All samples (except TM1) for Test 1, Test 2 and Test 3 were prepared according to Protocol 1. This includes sample preparation by removing certain amount of water (by percentage) from the concrete design mix and replacing it with same amount of drilling fluid.

Eighteen standard compression tests were conducted according to procedures specified in BS EN 12390-3:2002 (Excluding Cylinder Testing).

3.7.2 Test samples preparation

A volume of $0.3m^3$ of concrete was mixed for every batch according to the design mix. Concrete slump is measured and recorded for each batches.

For TM1 (control mix), the concrete was batched according to the design mix and concrete cubes with the dimension of 150mm x 150mm x150mm were produced.

3.7.3 PolyMud® drilling fluid

1 kg of PolyMud® was mixed in $1m^3$ of water in a tank and left for 2 hours continuously under air agitation to enhance the hydration process, until fluid parameters shown in Table 2 were achieved.

For TM2, there batches of concrete mix were batched according to the design mix leaving 5%, 20% or 30% of water volume and replacing them with PolyMud® drilling fluid respectively. 6 concrete cubes with dimension of 150mm x 150mm x150mm were produced for each batch.

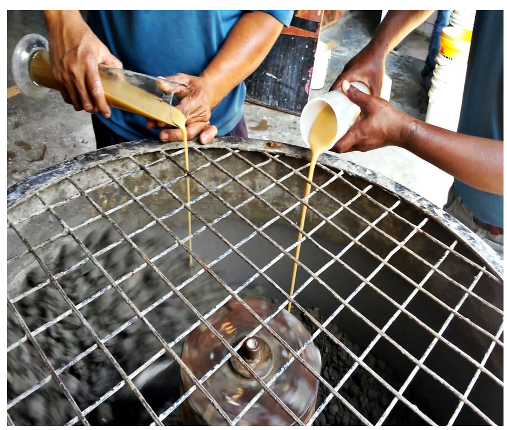
3.7.4 Bentonite drilling fluid (GTC 4)

50kg sodium activated Bentonite were mixed in $1m^3$ of bentonite mixer, being left maturing for 24 hours, until the slurry reached parameters specified in Table 3.

For TM3, there batches of concrete mix were batched according to the design mix leaving 5%, 20% or 30% of water volume and replacing them with Bentonite drilling fluid respectively. 6 concrete cubes with dimension of 150mm x 150mm x150mm were produced for each batch.

Figure 1a. Preparation of TM2 mix

Figure 1b. Preparation of TM3 mix



3.8 PROTOCOL 2

3.8.1 General Description

In this protocol, certain amount of drilling fluid (in percentage of water volume from the design mix) was added into the fresh concrete that had been batched according to the design mix. Test 4, Test 5 and Test 6 had been prepared according to Protocol 2.

Eighteen (18) standard compression tests were conducted according to procedures specified in BS EN 12390-3:2002 (Excluding Cylinder Testing).

3.8.2 Test samples preparation

The PolyMud® and Bentonite drilling fluid was prepared in the same procedure as Protocol 1.

For TM1 (control mix), the concrete was batched according to the design mix and concrete cubes with the dimension of 150mm x 150mm x150mm were produced.

For TM2, three batches of concrete mix were batched according to the design mix. Once the concrete was homogenously mixed in the mixer, PolyMud® drilling fluid was added into the fresh concrete with an equivalent amount of 5%, 20% or 30% of water volume. 6 concrete cubes with dimension of 150mm x 150mm x150mm were produced for each batch.

For TM3, three batches of concrete mix were batched according to the design mix. Once the concrete was homogenously mixed in the mixer, Bentonite drilling fluid was added into the fresh concrete with an equivalent amount of 5%, 20% or 30% of water volume. 6 concrete cubes with dimension of 150mm x 150mm x150mm were produced for each batch.

Concrete slump is measured and recorded.

4. COMPRESSIVE STRENGTH TESTING

4.1 Cubes

After preparing the corresponding concrete cube samples following the protocols described, the concrete is poured into the tightly fixed steel mould. The top surface of these cube samples were made even and smooth for accurate results in the compression strength test. After 24 hours these moulds are opened carefully and test cube samples are placed in a curing tank filled with water.

The cube samples have all the same sizes, cube shaped 150mm of width, length and height, cube weight ranging 8 ± 0.2kg and density 2340-2370 kg/m^3.

Figure 2a and 2b. Test 2 TM2 concrete collection and test cubes preparation

For each Test, 18 cubes were made, 6 for each type of mix (TM1, TM2 and TM3). Out of the 6 cubes group, 3 were tested at 7 days and the remaining 3 at 28days as shown in Table 4.

Table 4. Test cube samples

Test Number	% of additive used (TM2 & TM3)	Additive Replacing water volume	Additive added to water volume	TM1 cubes tested at 7days	TM1 cubes tested at 28days	TM2 cubes tested at 7days	TM2 cubes tested at 28days	TM3 cubes tested at 7days	TM3 cubes tested at 28days	Total cubes tested
1	5	✓		3	3	3	3	3	3	18
2	20	✓		3	3	3	3	3	3	18
3	30	✓		3	3	3	3	3	3	18
4	5		✓	3	3	3	3	3	3	18
5	20		✓	3	3	3	3	3	3	18
6	30		✓	3	3	3	3	3	3	18

5. TEST

After 7 and 28 days curing, the concrete cube samples are tested in a standard compression testing machine, as shown in Picture 5.

Load was applied gradually at a rate of 140 kg/cm^2 per minute until the cube sample fails. Compressive strength of concrete cube samples as described in the formula below.

$$\text{Compressive strength } (N/mm^2), \quad = \frac{W_f}{A_p} \qquad [1]$$

where,
W_f = Ultimate load in N
A_p = Plan area of cube sample in mm^2

The test results of each test protocols are collected and recorded. The concrete design mix was catered for characteristic strength of 40 N/mm^2 at 28days. The mean target strength is set for 48 N/mm^2.

Figure 3a and 3b. Cube compression test

6. RESULTS

The cube compression tests results both Protocol 1 and Protocol 2 for 7days and 28days curing process are shown in the Table 5 and Table 6 below:

Table 5. Results of Protocol 1

	Test Number	% of Slurry replacing water in concrete mix	Average Compressive strength (MPa)		Sample Type	Remarks
			7 days	28 days		
PROTOCOL 1	1	0%	49.9	67.4	TM1	Control Mix
		5%	47.8	56.2	TM2	PolyMud®
			51.1	70.8	TM3	Bentonite
	2	0%	44.3	60.8	TM1	Control Mix
		20%	45.3	60.7	TM2	PolyMud®
			44.9	62.3	TM3	Bentonite
	3	0%	40.5	51.9	TM1	Control Mix
		30%	44.6	60	TM2	PolyMud®
			37.9	59.3	TM3	Bentonite

Table 6. Results of Protocol 2

	Test Number	% of Slurry added to water in concrete mix	Compressive strength (MPa)		Sample Type	Remarks
			7 days	28 days		
PROTOCOL 2	4	0%	38.7	58.5	TM1	Control Mix
		5%	35.3	53.7	TM2	PolyMud®
			35.6	53.8	TM3	Bentonite
	5	0%	37.1	50.1	TM1	Control Mix
		20%	29.8	47.8	TM2	PolyMud®
			30.8	50.4	TM3	Bentonite
	6	0%	32.9	49.2	TM1	Control Mix
		30%	25.3	41.1	TM2	PolyMud®
			25.2	40.4	TM3	Bentonite

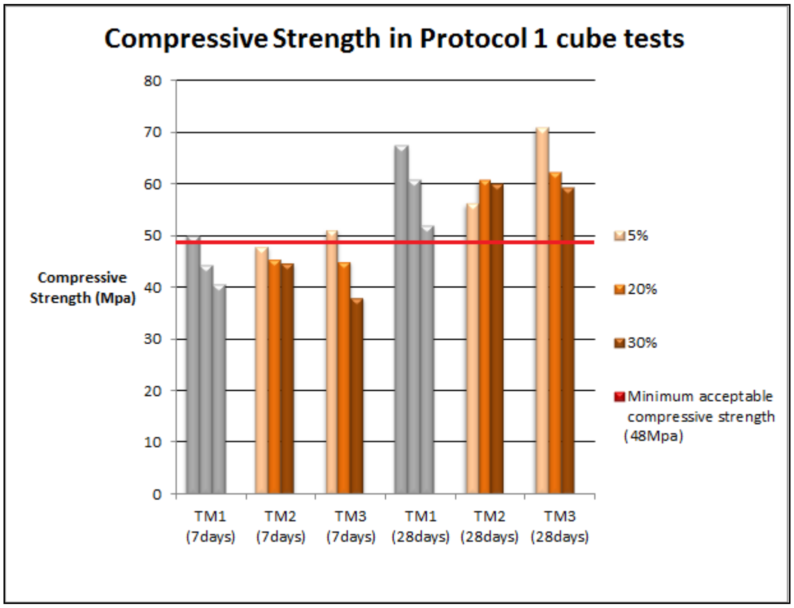
7. ANALYSIS

Based in the lab tests carried out above and the results obtained, the following conclusions can be drawn.

7.1 Protocol 1

Results of the compressive strength tests showed a consistent compressive strength development for the control mix (TM1) and the samples mixed with PolyMud® (TM2) and bentonite (TM3) slurries, for both 7 and 28 days tests.

Graph 1. Cube compressive strength according to Protocol 1



The Graph 1 above, shows all the samples widely accomplished to resist over the target mean strength at 28 days, set on 48MPa (40MPa Compressive strength + 8MPa Margin). This suggested that the inclusion of drilling fluid either PolyMud® or Bentonite even with the maximum amount of 30%, did not affects the characteristic strength of the concrete.

However, the results also show that the increase in percentage of Bentonite drilling fluid into concrete mix lowers the compressive strength gradually. This phenomenon most likely occurs as more foreign particles (Bentonite clay particles) available in the concrete fresh mix that affects the concrete cube compression strength.

It was interesting to understand that synthetic based PolyMud® did not have any significant effects on the concrete cube compression strength even at 30% of its inclusion. This shows that PolyMud® itself do not contain any element that weekend the concrete compression strength.

7.2 Protocol 2

Results of the cube compressive strength for Protocol 2 shows what is predicted. With the fact that drilling fluid either PolyMud® or Bentonite being added into the concrete lab mix, the design water/cement (w/c) ratio is being altered. Therefore, the cube compressive strength was decreased corresponding to the percentage of drilling fluid addition. Graph 2 below shows the relation between w/c ratios to the concrete compressive strength.

Graph 2. Relation between w/c ratio and Concrete Compressive Strength. Source: ***"28 days strength of concrete in 15 minutes", Kaushal Kishore, Materials Engineer, www.engineeringcivil.com***

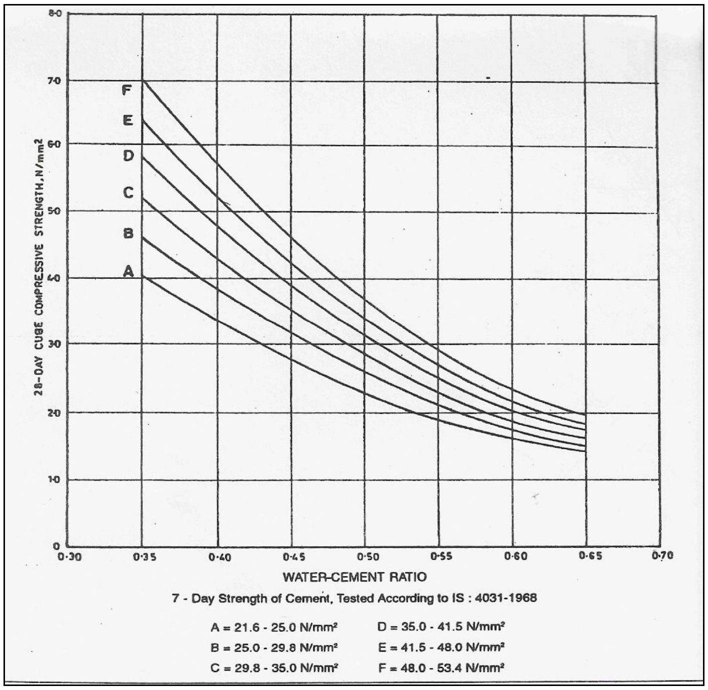
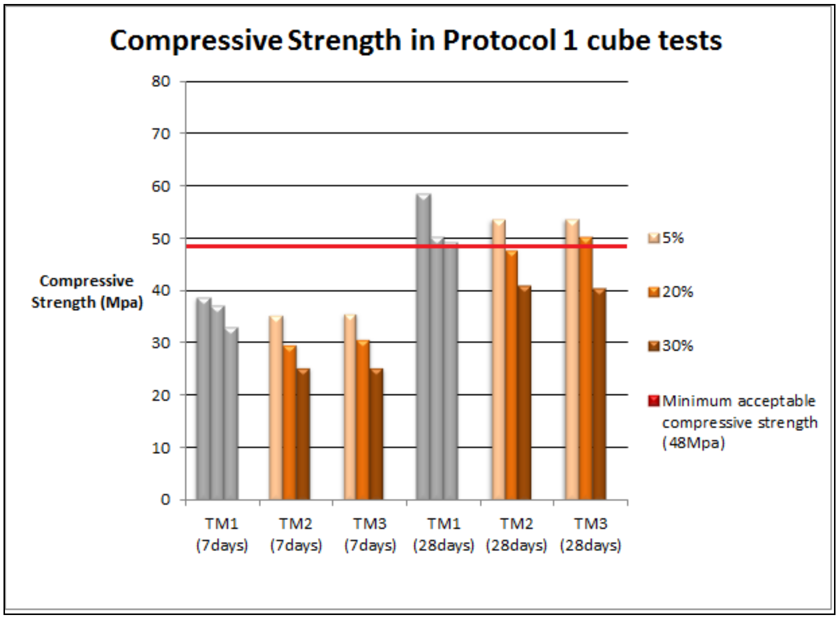


Table 7. W/C Ratio calculated for Protocol 2

Concrete mix with addition of drilling fluid (in %)	**W/C Ratio**
0% (Original Design Mix)	0.34
5%	0.36
20%	0.41
30%	0.44

Results for Protocol 2 were compared in the Graph 3 below.

Graph 3. Cube compressive strength according to Protocol 2



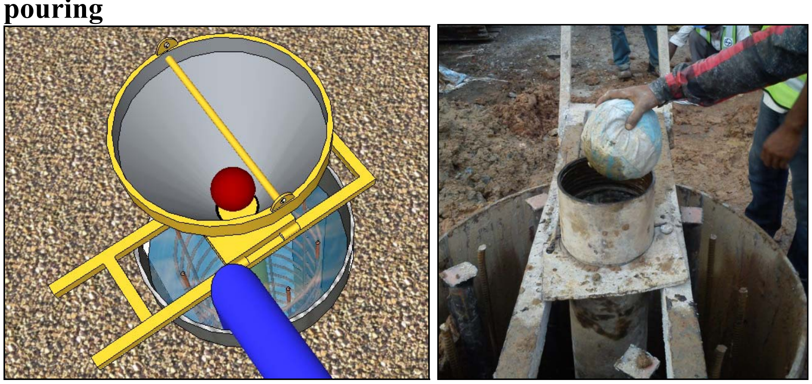
The samples containing additional 5% and 20% volume of drilling fluid accomplished to resist over or the target mean strength at 28 days, set on 48MPa

Test samples containing additional 30% of volume drilling fluid be it either PolyMud® of Bentonite in the mix failed the test hardly achieving values between 40 - 41 MPa of compressive strength at 28days, below the targeted mean strength. This is because the original w/c ratio has been altered due to introduction of foreign fluid into the concrete mix composition.

It is important to note in here, that any increase in intermix above 20% between concrete and drilling fluid, be it PolyMud® or Bentonite, affects the concrete compressive strength. This is very critical during concrete pouring process using tremie method for bored piles and diaphragm walls.

Important measures has to be taken to avoid intermixes of fresh concrete and drilling fluid to happen while pouring concrete such as placing concrete interface. Concrete interface has to be placed at the mouth of the tremie, so that the first concrete that is being discharge into do not have significant contact with the drilling fluid as shown in Picture 4a and 4b. Plastic ball is widely used as concrete separator due to its buoyancy.

Figure 4a and 4b: Inclusion of a concrete-slurry interface in the tremie pipe before concrete pouring



8. CONCLUSIONS

A maximum inclusion of at least 30% of foreign material, be it Bentonite or PolyMud® powder into the concrete mix, does not affect the compressive strength of the concrete itself.

If volume of water in w/c ratio is increased by 20% or more with drilling fluid (either Bentonite or PolyMud® slurry), the concrete's compressive strength is reduced. There is no significant impact in the concrete compressive strength if drilling fluid was added into the concrete mix up to 20% of water volume provided the mixture is homogenous. However, in the event of localized concentration of drilling fluid in the concrete mixture, may contribute to significant reduction in the concrete compressive strength. This has to be avoided during construction phase.

While Bentonite drilling fluid is being used widely for its specific swelling properties that forms permanent 'cake' along the excavation wall to provide greater stability, the quality of the concrete which is in contact with the slurry is exposed to compressive strength defects. PolyMud® slurry on the other hand, promotes the same stability achievements with unlikely affects the foundation element integrity when in contact with fresh concrete. Temporary 'membrane' which is formed along the excavation wall is also eliminated while concreting leaving a strong bond between the structure and the soil formation.

Further research is needed to understand about bonding strength between reinforcement steel bar and concrete when the reinforcement steel bar is in submerged in drilling fluid for a certain period of time.

Another interesting topic that requires further studies would be about development of skin friction between concrete pile and soil formation using Bentonite and PolyMud® drilling fluid.

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