European Online Journal of Natural and Social Sciences 2015; www.european-science.com
Vol.3, No.3 Special Issue on New Trends in Architecture, Civil Engineering, and Urban Studies
ISSN 1805-3602

Implementation of dam wall by plastic concrete to control water seepage under soil dams structure

Farzad Hatami[1], Hassan Gogonani[2], Taghiyan Masoud[2]
[1]Assistant Professor, Amirkabir University of Technology, Tehran, Iran; [2]Master students, Construction Management of Amirkabir University of Technology, Tehran, Iran

Abstract

If there is no proper control, escape of stored water behind the soil dam by dam foundation can cause serious problems for the dam. The most problems arecaused by increased water output gradient that causes soil particles floating in the dam heel and thus, resulting in the movement of the soil particles. To control the seepage of dam foundation methods should be applied to reduce water leakage. One method to reducing the leakage of foundation is drilling trenches in dam foundation and then filling it with plastic concrete materials.

Introduction

Plastic concrete is material with low resistance (less than normal concrete) and has higher ductility than normal concrete. Low water-cement ratio is often used in plastic concrete. Plastic concrete in addition to high ability to deformation and low permeability (Soroush, and Mojtahedi, 2002) has proportional shear strength to applied pressure.

Seepage control under the dam foundation is done in different ways. Earth layers' material in location of dam foundation, the importance of dam and available executing technology are effective factors in selecting the leakage control methods.

Injection membrane, shield waterproof, upstream covering and watertight wall are of the main and conventional methods of seepage control of dam foundations.

Waterproof walls have characteristics such as high flexibility, low permeability and compression resistance proportion to applied pressure and thus, are used in areas where the foundation is weak and permeability is high. Sealing walls' construction steps include the construction of guide wall and work platform, trenches drilling, adding drilling mud to walls stability and finally, fill it with suitable materials.

The filling materials can be aggregated and mixed with bentonite clay, mixed cement and bentonite as flowing clay or plastic concrete (Saghiri, 2011).

Plastic concrete strength is much less than normal concrete with high ductility and low permeability. Plastic concrete is an appropriate material in delta regions with poor soil that needs sealing walls to be flexible and have sufficient strength to withstand stresses of dam loading to control seepage of dam foundation .

Background of study

Nearly 50 years pass of concrete and bentonite combination to make waterproof dams walls. Meanwhile, it has been also common more than 20 years that mixing cement and bentonite is widely used in Europe, North America and Japan. Also, the use of plastic concrete dam has increased significantly in Iran due to the expanding of sealants industry since 1991 and by arrival of drilling machine of waterproof wall (Hydroferez).

What is the plastic concrete?

Plastic concrete is obtained by mixing water, cement, sand and bentonite (Ajorloo).

What is bentonite?

Bentonite is a kind of clay that guarantees impermeable and being doughy of plastic concrete.

As the agent of creating appropriate formation, sustainable fresh plastic concrete of sticking aspect is used to prevent detached stone grains in the plastic concrete (Websites Company Arjan Pey).

Figure 1: Bentonite bags and stirring device (Malaksour)

What is the difference between plastic concrete and normal concrete?

- Less elasticity coefficient than normal concrete
- Increase of concrete plasticity
- Decrease the compressive strength
- Most frequently used in non-permeable curtains

Plastic concrete characteristics

As mentioned, plastic concrete has much less resistance than conventional concrete, high formability and low permeability. Ingredients of plastic concrete are cement, aggregate and bentonite slurry. In addition to these materials, some additional materials may be used to repair its properties (Company's website of Faraz Pey Malekan).

Application of plastic concrete

- **Seepage control under the dam**

Creating a watertight wall around a site and water drain from the excavation site to construct desired structure.

Prevent the spread of contamination (industrial wastewater, water weeds, etc.) in groundwater.

Around the site, as a suitable damping factor of mechanical vibrations of projects

The main application of plastic concrete is in watertight wall under soil and gravel dams (Sabir Company Website).

The material properties and plastic concrete mix design

In choice of materials in the plastic concrete, mix design affects various factors such as desired permeability, site conditions, access to materials in location, effective economic and executive aspects.

Plastic concrete made from these materials

Bentonite slurry: Role of this material is to suspension particles of cement and sand during operation, increasing ductility and holding low permeability. To provide maximum flexibility in

plastic concrete more water should be used in mix design. This leads to instability of fresh concrete (cement, aggregates detachment). Bentonite is added as a stabilization agent to meanwhile homogenization of fresh concrete and increases its final ductility and keeps its permeability at the acceptable level in order to be used in watertight walls. Bentonite causes to the separation of components of plastic concrete and thus, grains and particles absorb water better after separation. In addition, the mixing has more homogenous texture and more appropriate processed. In case of high quality, slurry of 2 to 12% bentonite and in case of low quality slurry of 12 to 25% bentonite is used (Mansouri, 2001).

Cement: Cement is splicer of plastic concrete components. If the amount of bentonite used in mix design to be little, some amount of cement is deposited and if more bentonite to be used in mix design, it causes design to be non-economic and causes problems in handling concrete. Therefore, in a proper mix design low cement content is considered to prevent sedimentation. In low ratios of 0.1 <C / W <0.3 according to the type of cement is guaranteed adhesion and mechanical strength of plastic concrete. Adding the cement increases compressive strength and critical hydraulic gradient and reduces permeability of plastic concrete (Mojtahedi, 2010).

The aggregate: It forms approximately 50% of final volume of concrete. This amount of sand prevents continuous hang together of particles and therefore, reduces its deformability. Whatever aggregate to be larger and more difficult, plastic concrete resistance is higher. The maximum size of coarse aggregate is usually limited to 20 mm. Gradation curve should be continuous and should not fine matter. If the fine colloidal material to be high, then the amount of bentonite should be reduced (Soroush and Mojtahedi, 2002).

Additives: Additives are factors of better operating and efficiency of concrete during construction and implementation.

Major additives

Soda: Soda or sodium carbonate (Na2CO) increases the rate of sedimentation of suspended solids in the concrete. Therefore, in projects that speed of watertight wall implementation is high can use this material to speed up solid particles sedimentation and reduce the use of plastic concrete setting time (Soroush and Mojtahedi, 2002).

Metal cellulose Carbohegzy (CMC): It is available in solid and dough forms and in concrete mix it is used as a paste or slurry solution of 10% to 12%. If we want that final mix viscosity to be low or moderate, we can use this material.

Retarders: These substances are used to delay setting time of concrete cast when difficulties occur in concrete. In general, retarders cause to reduce creep and shrinkage of plastic concrete. Their use may be limited to 2.0% to 2% of total volume of plastic concrete. Usually, the super plasticizers are used to retard the setting time of concrete and increase efficiency. The use of these materials may also reduce cracking walls (11).

The recommended mix design ICOLD

The average value of materials for constructing 1cubic meter of plastic concrete, is as follows:

Bentonite slurry: 500 ~ 400 ml

Cement: 200 ~ 100 kg/f

Fine grained sand Materials: less than 1,500 kg/f

Weak grained sand Materials: less than 1300 kg/f

Specific weight of above materials will be mentioned between 1800 to 2100 kg/f per cubic meter (Mansouri).

Efficiency

Plastic concrete should have high efficiency and fluency that the fresh concrete enters through the tube into the semester and can easily flew into previous concrete that has already been poured and moved it by its pressure and movement to up. High efficiency is one of the most important characteristics of a good plastic concrete, but on the other hand, this concrete should not be placed under the separation of grains. By limiting the maximum aggregate size, concrete performance can be raised by using rounded corners and creating air bulbs. Simple criteria to check the efficiency of plastic concrete is measuring its slump that should be between 100 and 200 mm (Brenner, Roshanzamir, and Abed, 2003).

Compressive strength

Sealing plastic concrete walls require little resistance because the force on the walls is not very significant. However, this resistance should be able to save the lateral tensions of soil surrounding during operation and during dam operation. On the other hand, in order to obtain materials that have high deformation lowest possible pressure resistance should be selected. Thus, the compressive strength needed for such walls are often between 10 ~ 30 kgf / cm2 but by observance formation principles of ductility for wall, its resistance can be increased to 40 kgf / cm2 (2).

Factors affecting the level of resistance

Water to cement ratio (C / W): Whatever water to cement ratio to be increased, the compressive strength of plastic concrete will be more.

Cement Type: Performance of various cements depends on amount of C / W and is a function of these parameters. In terms of being fixed C / W, using molten metal slag cement instead of portland cement will increase plastic concrete strength from 50% to 100%.

Ratio, size and type of aggregate: By increasing the ratio of aggregate materials in plastic concrete of mix design, the compressive strength of plastic will increase too. Continuity and high gradation of aggregate (Cu) increases the compressive strength. Difficulty and sharp corners of aggregate increase the compressive strength.

If the compressive strength of plastic concrete to be high, it has not been optimum deformability against enforcement and is cracked and broken at low strain. For example, in an earthquake the possibility of wall cracking will increase. Also, if we have interruptions in secondary panels' execution, it cause difficulty in initial drilling concrete panels (Mojtahedi, 2010).

Deformability

Major deformations that occur to sealing walls

Deformations caused by dam depression under its own weight.

Deformations caused by depression and edema of Dam Foundation.

Vertical and horizontal deformation due to applied loads during execution (depending on construction method) and applied loads during operation period (loads caused by first tank watering and then alternating loads relevant to using tank).

Vertical and horizontal deformation due to earthquake loads, explosion and loads of dust around the sealing wall.

Due to the imposed deformation mentioned above, sealing wall should be able to tolerate these deformation without picking up, expansion joint sealing between panels or in any way reduce the incurred withstand.

For this purpose, elements are needed that can withstand applied deformation without failure or damage. The best solution is the choice of materials which its formation properties are very similar to surrounding soil.

Experience has proved that if modulus of elasticity of surrounding soil changes to a depth of sealing wall, low (homogeneous soils) elasticity modulus of plastic concrete should be at least 4 to 5 times of the surrounding soil until its deformation to be suitable.

Deformability and resistance are depending on each other to the large extent and all factors that have an influence on one of them, influence another as well. Increasing factors of plastic concrete compressive strength will reduce its deformability (Mansouri, 2001).

Permeability

The main purpose of sealing wall construction is reducing the leaks in a dam site. Overall, permeability of sealing wall depends on intrinsic properties of the constituent materials (normal concrete, plastic concrete, etc.), discontinuities (cracks, seams opening) and how to connect to low permeability layer (flooring stone).

Factors affecting the permeability of plastic concrete

Water to cement ratio (C / W): permeability is decreased by increasing the ratio of cement to water.

The colloidal agent amount: For constant water to cement ratio, an increasing in the proportion of bentonite, increases the permeability of coefficient at least to 10 times.

The effect of additional materials ratio: Addition of ingredients is always lead to a reduction in permeability.

Aggregate: In the practice, adding aggregate has no effect on permeability.

Drying: Loss of water causes the concentration of bentonite and cement, and decreases permeability (Mojtahedi).

Abrasion resistance

Plastic concrete should be resistant against abrasion. Wear resistance and compressive strength are directly related. Whatever the compressive strength to be higher, wear resistance also becomes higher. Plastic concrete during pinhole test is resistant against abrasive wear if the following conditions exist:

Its final compressive strength to be reached at least to 20.35 kgf / cm.

Its Hydraulic gradient to be not more than 30.

Durability

Plastic concrete durability depends on two factors of sealing and resistance. Plastic concrete strength like normal concrete increases with time. Over time, permeability tends to becoming low. This is caused by closing pores of the soil by fine-grained material.

Studying the reasons and factors affecting the formation of bentonite fissures in sealing walls

Dam walls are built to control the leak against the flow and set in foundation and according to soil conditions and are made in different types of fluid clay, structure concrete, plastic concrete, etc.

Panel method of implementation is one of implementation of wall panels by replacing the fluid clay. In this method, unavoidable seams are created between the primary and secondary panels which are decussated among the primary panels. These seams contain bentonite materials which in secondary panels in drilling time are attached to concrete on primary panels and secondary panels concrete cannot completely move it. In this study, to identify the factors and parameters that affect

the thickness of formed clot on primary plastic concrete panels, a laboratory apparatus were designed and numerous tests were performed. In addition, to reduce the joint thickness, following guidelines have been suggested:

- Prevention of the effects of pollution, especially pollution of cement and calcium ions by using additives such as sodium bicarbonate and reducing overlapping the panels and the plastic concrete cement amount to reduce the amount of released calcium.
- The use of bentonite clay with the appropriate specifications
- Using plastic concrete with appropriate method of concrete and efficiency
- Using suitable polymers to create thin layers of cake.
- Using proper strong brushes and proper washing to clean concrete and bentonite layer attached to the primary panels concrete before concreting the secondary panels.
- Shortening the time between drilling and secondary panels concreting
- Reducing suction forces of unsaturated rocks by injecting additional water to the drilling area (Mojtahedi, 2010).

How to build plastic concrete

Experiments have shown that it can affect the production method of plastic concrete to its properties. Construction of plastic concrete is done in a particular batching. Desired batching is consists of following equipment.

- Separating the storage silos of cement and bentonite
- Combining the mixer of bentonite powder and water
- Bentonite slurry tank
- Gauge systems, weighing, mixing, pumps, pipes and so on.

Figure 2: Mixer of bentonite powder mixture

To produce plastic concrete, first, the bentonite should be added to water during the rapid mixer and mix to be stirred between 3 to 5 minutes rapidly. Then the resulting mixture should be maintained and rested for at least 24 hours in the storage tank to absorb water and swelling bentonite slurry be done well. During this period, the mixture is stirred constantly. Then, cement should be added to Bentonite slurry and finally, aggregates are added to the mix (Soroush and Mojtahedi, 2002).

Figure 3: Bentonite slurry tank for 24 hours

Quality control of plastic concrete

Plastic concrete quality because of the role play of these materials is especially important. For this reason, the material properties required for the manufacture of concrete, fresh plastic concrete properties and finally, the hard plastic concrete should be precisely controlled (Haji Ghasemi, 1997).

A-Control and materials inspection

Materials which needed to make the plastic concrete such as bentonite, cement and additives should be controlled regularly in workshop laboratory.

Bentonite: Bentonite quality should be guaranteed by the manufacturer and do necessary control over every delivery.

Cement: Tests of bending strength and compressive on 7 and 28 and 90 days cement have to be done in the laboratory and curves have to be plotted (ASTM C150).

Additives: The effect of lubricants and retarders on making plastic concrete samples should be analyzed and controlled.

Consuming water: Consuming water should be free of any harmful chemical compounds, such as sulfates, carbonates, and chlorides. Often, rivers' water, wells and springs are suitable for it. Using impure water has risk of creating bentonite curdle in the slurry and reduces its viscosity. Therefore, analysis of the used water is necessary. Analysis is consist of hydrogen ions concentration, sulfate, chloride, calcium nitrate and magnesium in the water (Haji Ghasemi, 1997).

B - Bentonite Slurry Control

Density: Regular inspection control density reveals 10 possibility of control and evaluation of any unusual changes in weighing and mixing or any mistakes in the system. In conventional conditions, bentonite slurry density is set in the range of 1.1 ~ 1.25 kgf / cm2.

Viscosity (by Marsh funnel): Marsh density is the measurement of a certain volume of liquid time passing through Marsh funnel that has certain dimensions and weights and specified dimensions output hole. Marsh bentonite mud density is done in pond and before concrete production. Proper range of Marsh density is usually between 40 and 50 seconds.

Launch: Launch slurry coefficient is the ratio of the volume of water that collect after a certain time on the surface of the slurry, in addition to the initial slurry volume. This coefficient according to the technical specifications should not exceed a certain amount (ibid).

C - Quality control of fresh plastic concrete

Performance control: As previously mentioned, the high-performance for plastic concrete has specific importance. Since the plastic concrete cannot be compacted by vibration in the trenches, to obtain a mixed with the ability of self-compacting and self - leveler, the efficiency of concrete should be enough. To control the plastic concrete efficiency, common slump test is used. Based on obtained experiences, the slump amount between 100 to 220 mm has been accepted for plastic concrete.

Density Control: Plastic concrete density is lower than ordinary concrete. Usually fresh plastic concrete density is about 1700 ~ 2300 kgf / cm3. New plastic concrete density control system provides the possibility of weighing and mixing materials systems evaluation.

Temperature control: In plastic concrete the effect of ambient temperature is lower than other types of concrete because this concrete is executed in the basement. In addition, the presence of bentonite and relatively low cement ratio in the mix design is effective at low hydration temperature than normal concrete. These factors are effective in reducing plastic concrete temperature limitations. But since the temperature rise is effective in reducing the concrete slump, therefore, some limitations should be applied to its temperature. Usually plastic concrete temperature should not exceed 30 ° C.

Uniformity Control: The uniformity of plastic concrete should be controlled at each stage of construction. The components have to mix together in a way that was completely uniform. Construction method is effective in uniformity.

Setting time control: Setting time is controlled to ensure proper functioning of plastic concrete in concreting time (Haji Ghasemi, 1997).

D- The quality control of hardened plastic concrete

After curing samples of fresh plastic concrete, following tests will done for quality control of hardened plastic concrete. These tests are done to determine the compressive strength, elasticity modulus and permeability of plastic concrete (Haji Ghasemi, 1997).

Uniaxial compressive strength test

The purpose of this test is to measure sample bearing by defined geometry and dimensions. By measuring simple compressive strength, modulus of elasticity can also be calculated. Usually compressive strength of samples is determined at 7 and 28 and even 90 days. Testing machine by keeping constant the strain rate applys force on sample surface (The test is a strain control). In this test, always sample surface puts caps to avoid stress concentration around the middle axial of sample (ibid).

A - Axial compressive strength of three axial test

The purpose of this test is to determine the angle of internal friction and adhesion of plastic concrete materials. This test can be done in two methods:

Tests on consolidated undrained samples (CU Test): this experiment is one of the best tests that in terms of the theory is the same of sealing wall conditions.

Tests on non-consolidated and non-undrained samples (UU Test) (ibid).

B - Permeability Test

The purpose of this test is to determine the permeability of plastic concrete sample. In this experiment, the under pressure water is applied to the surface of saturated plastic concrete. To create a one-dimensional of cylindrical plastic concrete sample, its side is covered by a sealing material such as asphalt. Therefore, the pressurized water enters to the sample from one side, and only from opposite side can leave (ibid).

C - Erosion tests

This test is known as pinhole test which is to determine the amount of water seepage under different gradients of the holes created in the sample at a certain and pre-determined time. As previously mentioned, a plastic concrete tested by pinhole test is resistant to abrasion when its compressive strength is at least 0.35 kgf / cm2 and its hydraulic gradient is not more than 30 (Haji Ghasemi, 1997).

Some interesting and important results

By increasing the cement

- For every 10% increasing, the cement is added about 50% to uniaxial compressive strength and up to 15% to the maximum principal tension.
- Uniaxial MOE (module of elasticity) for every10% increasing, increases 4% to 5% and three axial modulus increases between 20% and 50%.

The coefficient of adhesion (C) for every 10%, increases in internal friction angle from 50% to 73% and 1.5% respectively.

By increasing the grade of bentonite

- Increasing the permeability
- Uniaxial compressive strength about 12% and three axial compressive strength is reduced to 60%
- Uniaxial MOE to 36% and three axial modulus is reduced to 60%

Coefficient of adhesion to 14% and friction angle is decreased to 6%

Comprehensive pressure increasing

- Compressive strength increasing
- Increasing the modulus of elasticity
- Reducing permeability coefficient
- Increasing the ductility

Increasing the sample age

- Increasing the compressive strength in range of 25% to 60%
- Increasing the modulus of elasticity in the range of 30% to 60%
- Increasing viscosity coefficient in the range of 40% to 70%
- Reducing internal friction angle in the range of 3% to 7% (Saghiri)

Discussion and Conclusion

Materials forming Plastic concrete include bentonite, cement, aggregates and water which in terms of the type and mixing ratio have a direct effect on its properties. Therefore, to provide low permeability, ductility and proper resistance for plastic concrete, we should refer to a good mix design.

Bentonite slurry is as a stabilizer actor to prevent the separation of aggregates and cement. By increasing cement to water ratio, compressive strength will increase and its deformability and permeability will decrease. Increasing aggregate ratio in the mix design leads to the increase of the compressive strength and reduction of the ductility. But adding the aggregate ratio has no effect on permeability. Also, sharp corners, material hardness and continuity of grading curve aggregate lead to the enhancement of the compressive strength of plastic concrete.

New technology in the construction of the dam wall

Drilling with Hydroferez machine

Another method to drilling watertight dam walls, is drilling by Hydroferez machine. In this drilling method, drilling and unloading materials are done simultaneously and unloading materials

from drilling by a pump out by a large pump named Amasco with capacity of 300 cubic meters per hour from Barrett inside to out and transfer to Dysendr machine to purification (Websites of Company Cacagrandegroup.com).

Figure 4: Dysender machine

In Dysender machine by two large and small sieve machine, coarse and fine-grained materials are separated from clay bentonite and the isolated and excavated materials clay (bentonite slurry) is pumped back into Barrett and by this action we have substantially consumption savings of bentonite. After removing the excavated materials from Dysender machine, they are shipped to another place by loaders and trucks (ibid).

Figure 5: Bentonite slurry pumping to drilling location

But, in the drilling method with Hydroferez machine, after putting the machine at Barrett place for drilling, drilling and unloading materials from drilling are simultaneously and continuously done and there is no need to Hydroferez to get out of Barrett for draining and entering to Barrett to continue drilling. This act prevents provocation and creates tension on the walls of the Barrett stop and in comparison with the previous method, has lower concrete volume and as following has much lower concrete volume than drilling by Grap.

Another advantage of this drilling by machine compared with drilling method by Grap is that in drilling methods by Hydroferez machine because of being fully automatic, hydraulically there is no need to hitting for drilling, but in drilling method by Grap because it just mechanically works, for drilling need to hit the Barrett floor, and the strike would shake Barrett and causes to Barrett loss, enhancement of the volume of drilling and the subsequent increase in the volume of concreting (ibid).

Figure 6: Hydroferez machine image

Figure 7: Part of Hydroferez machine that drill by its rotational movements

Drilling Speed

Drilling speed and drilling accuracy, according to that Hydro-ferez machine is equipped to an inclinometer, Barrett deviation will be fully controllable but in drilling method by Grap machine, because the perform method is mechanical, there is Barrett deviation possibility and also drilling speed is less than Hydroferez drilling speed (ibid).

Concreting method

Concreting by this new drilling method has no difference from Grap machine drilling and is performed by pipe-term as mentioned above, in other words, the difference between the two methods is only in drilling method (ibid).

References

Ajorloo, A.M. (2008). Experimental investigation of the mechanical behavior of plastic concrete in triaxial stress conditions, Shahid Abbaspour University of Technology.

Brenner, P., Roshanzamir, I., & Abed, J. (2003). Design of cofferdams, Technical report, Ostour dam and Hydropower Plant Project.

Company's website of Faraz Pey Malekan

Haji Ghasemi, A.A. (1997). The permissible hydraulic gradient plastic concrete, Master Thesis, Department of Civil Engineering, Faculty of Engineering - Tehran University

Mansouri, K. (2001). Review and provide practical guidance on the use of plastic concrete dam grout curtain, MT.

Mansouri, M.T. (2007). Investigating and providing practical guidance on the use of plastic concrete curtain, MA thesis, Tarbiat Modarres University

Mojtahedi, M.A. (2010). Plastic concrete walls of a dam gates upstream cofferdam and dawn locks and power, MS of Geo Technique

Sabir Company Website

Saghiri, N. (2011). The study of the mechanical behavior of plastic concrete (concrete bentonite) and modeling its behavior, MS Thesis of engineering faculty of University of Tabriz.

Soroush, M., & Mojtahedi, A.F. (2002). General design and implementation of plastic concrete sealing wall in the foundation of dams, dams designed to address specific issues and special proceedings of the workshop and its affiliated organizations, Isfahan University of Technology.

Watertight cutoff wall (2003). Final revised method statement, Ostour dam and Hydropower Plant Project.

Websites Company Arjan Pey.