*Journal of Structural Engineering and Geotechnics,*
*5 (1), 39-47, Winter 2015*

# The Investigation of Effective Factors in the Removal of Bentonite Jelly from the Joints of Cut-off Wall Panels

Seyed Majdeddin Mir Mohammad Hosseini[*a], Abdolhossein Azadmanesh[b]

[a]*Prof. Amirkabir Univ. of Technology, Tehran- Iran*
[b]*Bsc. Civil Eng. Mahab Ghodss Consulting Eng. Co., Tehran- Iran*

Received 3 November 2014; Accepted 25 February 2015

**Abstract**

In the construction process of a plastic concrete cut-off wall, concreting is usually performed using the termie pipe method. In this method, concreting is performed from the lowest point in the excavated trench (containing the slurry) using a funnel and the pipe connected to it. The concrete poured in the funnel gradually settles in the panel through the termie pipe which is beneath the slurry and the end of the pipe has always been in the concrete. Because of its unit weight which is less than that of the concrete, the slurry goes up and the height of its column reduces. As the construction continues the length of the termie pipe is cut down so that the remaining operation is carried out more easily.
In this process there are three types of flows to be considered: concrete flow in the termie pipe, concrete flow in the panel and slurry flow in the panel.
Using the fundamentals of hydraulics, this paper tries to study the interactions among these fluids. It also examines the influential factors in removing the bentonite jelly in order to provide the plastic concrete with homogeneity and consistency (slump 22-16 cm) in primary and secondary panels of cut – off wall as a most reliable water tightening system in most dam foundations.

**Keywords**: Plastic Concrete, Cut-off-Wall, Primary Panel, Secondary Panel, Bentonite Jelly

## 1. Introduction

One of the concreting methods used in underwater environments or other fluids such as slurry which is used to provide the stability of excavated trenches in concreting the panels of cut-off walls – is concreting by the use of the termie pipe [1]. This method is based on piping inside the liquid (water or slurry which is usually used in excavating cut-off walls) and pouring concrete in the funnel above the pipe and filling the section of the panel from the bottom to the top. To prevent the concrete from being polluted, the end of the pipe is always placed in the fresh concrete. Employing the laws governing fluid mechanics [2] in concreting by the use of the termie method, we can consider and survey the following:

- Calculation of the acted shear force on the wall of the panel, which results from the concrete flow and its influence on cleaning the cake or coagulation of the remaining slurry from the walls, which will finally influence the quality of the joints of the primary and the secondary panels and the possibility of seepage from the joints.
- Investigating the influences of speed, pressure, concrete flow, and maintaining the needed conditions on which the principles of concreting by the use of the termie pipe is based, in other words maintaining the order of placement of the concrete in the panel
- Continuation of the movement of the old concrete. (the part of the concrete which is pushed upward by the new concrete)
- Those influences which may be used in practice in order to enhance the quality and conditions of concreting; keeping the concrete in the liquid state during the concreting process by using retarders, carrying on concreting for an optimal and suitable duration, and placing an optimal length of the pipe in the concrete.

Although acquiring an all-inclusive and thorough understanding of the aforesaid issue requires making hydraulic models and performing laboratory studies in a condition where the effective parameters and factors are under control, by the use of the laws of fluid mechanics

* Corresponding Author Email: mirh53@yahoo.com

and applying valid assumptions we will be able to present an analytical examination of this issue.

**2. Hydrostatics of Concerting**

In concreting with the termie pipe method, as long as pouring concrete in the funnel is stopped, the three phases of the slurry, the concrete in the termie pipe, and the concrete in the panel will have the chance to reach an equilibrium state. This state is named concrete hydrostatic balance. (Figure 1)

If the main parameters in Figure 1 are defined as follows:

$\gamma_c$ = unit weight of fresh plastic concrete
$\gamma_s$ = unit weight of slurry
$p_c$ = pressure of overburden at level 1 – 1
$p_s$ = pressure of slurry column at level 1 – 1
$h_1$ = height of the low level of slurry in the panel in proportion to the base level (on the guide wall)
$h_2$ = height of the concrete in the termie pipe in the panel at the time of the concreting balance, and
$h_3$ = the height of the top level of slurry in the panel in proportion to the base level (on the guide wall)

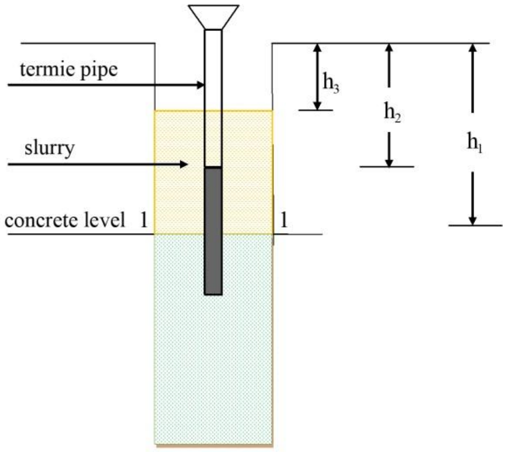



Figure 1- The static balance of the slurry and flow concrete

Balancing of pressure for the section of concrete at level 1 – 1 is as follows:

The pressure of slurry at level 1 – 1:

$$P_s = \gamma_s (h_1 - h_3)$$

The pressure of concrete at level 1 – 1:

$$P_c = \gamma_c (h_1 - h_2)$$

equaling these two equations: $P_c = P_s$

The hydrostatic balance equation (1) will be as follows:

$$\gamma_s (h_1 - h_3) = \gamma_c (h_1 - h_2) \quad \textbf{(1)}$$

If in measuring one of the panels of the cut-off wall with the below main parameters, by the use of equation 1 the unit weight of the plastic concrete will be calculated as follows:

$\gamma_s$ =1.02(gr/cm$^3$) $h_1$=40.50m $h_3$=0 $h_2$=18.8 m

$$\gamma_c = \frac{1.02(40.5 - 0)}{40.5 - 18.8} = 1.9 \qquad (gr./cm^3)$$

If the values measured based on the unit weight of the plastic concrete in actuality are considered, the obtained result is reasonable. From examining the above issue this conclusion can be drawn that the level of the concrete in the termie pipe (which itself is directly influenced by the unit weight and the height of the slurry) always comes to rest at a level higher than that of the concrete in the panel. This characteristic naturally reduces the tendency of separation of the concrete aggregates in falling down through the termie pipe. In the above example, the level of the concrete in the panel is 40.5 meters and the height of the falling of concrete in the termie pipe at the starting moment of the concreting is 18.8 meters.

**3. Hydrodynamics of Concerting Using the Termie Method**

Understanding the nature and course of the concrete flow [3] in a trench with limited dimensions is a prerequisite to exploring this topic. It is obvious that the geometric shape of the section, the speed and pressure of the flow, the number and distribution of the termie pipes, etc., play an important role in formation of the flow. In this regard, some experimental points are presented as shown in Figures 2 and 3. These Figures are prepared according to the sampling of the concreting operations by use of a termie pipe as well as color concrete. The color concrete has been used to indicate the placement of the concretes based on the order they have been poured.

The volume of plastic concrete, equal to one truck mixer, was poured in an oblong cube model of a cut-off wall panel with the dimensions of 2.1×0.6×0.6 meters. Concreting was performed in two ways [4] : a part of that was done with a truck mixer, concrete pump, and termie pipe and the speed of concreting was constant, and the other part was done with a bucket which was used to carry and pour concrete gravitationally.

The way the concrete lay in the model was conducive to surprising results in comparison to the reality. It is noticed that using the truck mixer, concrete pump, and termie pipe the speed of pouring is constant and disturbance is less than the other way (Figure 2). Mixings have mostly occurred in carrying and pouring concrete with the bucket, especially, in those cases in which concrete was poured with irregular speed (Figure 3) [2].

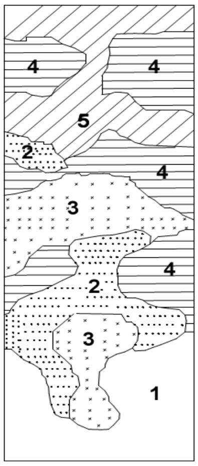



Figure 2- Rough Diagram of the Placement the Concrete in the Panel Data 1971 from Ikuta

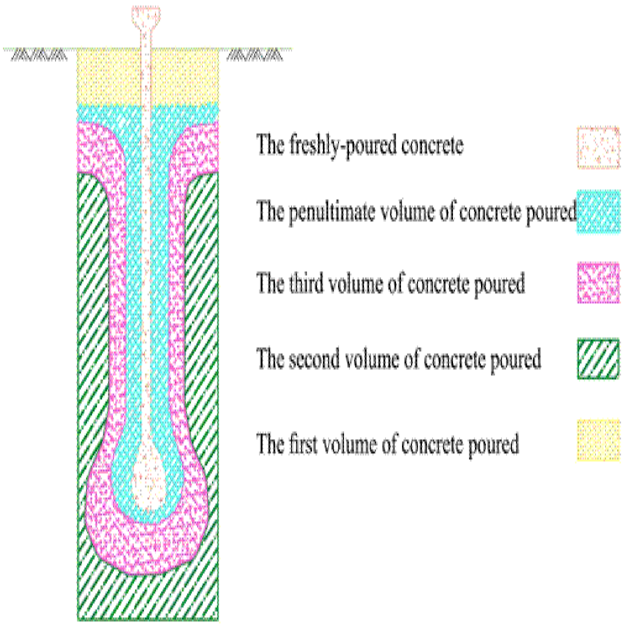



Figure 3- Concreting Section of the Modeled Panel using Color Concrete

Regarding the order in which the concrete volumes are lying, Figure (2) demonstrates a luminary flow in the panel. This Figure also shows how the flow cross-section in different stages of pouring concrete has decreased. Figure (3) indicates that the concrete flow in the panel is turbulent. In this state the placement of concrete volumes is disordered.
These Figures show two types of under-pressure concrete flows. It can be assumed that the concrete flow, based on Figure (2), is of luminary type, that is, the staged volumes or different volumes has slid and lain parallel over each other.
Seemingly as the section of the panel decreases or as the speed of the concreting increases, the possibility of turbulence in concrete flow is raised which, by itself, causes the orderliness of the concrete volumes poured to be disturbed Figure (3). Therefore, like the studies conducted by fluid mechanics researchers, such as Reynolds, on separating between these two flows, we can assume that introducing a number similar to Reynolds number can be effectual. The results of such studies are useful, because maintaining the conditions of luminary flow in the panel is more favorable than those of the turbulent flow and such conditions cannot be established unless the border of these two flows is comprehended. Further explanation in this regard will be provided below.

## 4. The Reasons Why Luminary Flow is Advantageous for Concerting Using the Termie Method

The possibility of pollution of the concretes adjacent to the slurry (old concrete) in luminary flow is smaller than that in turbulent flow. The form of movement of the concrete in the luminary flow leads to decrease in the perpendicular movements to the course of flow or, in a sense, decrease in the horizontal courses which result in the confinement of the slurry in the joints and causes pollution of the plastic concrete.
In this state the order in which the concrete volumes (the volume of a truck mixer) lie in the panel is subject to the orderliness of the pouring of volumes; on the basis of the order in which the concrete is poured, a special and orderly formation takes place. The placement order of concretes is advantageous in that the fresh concretes are always in motion and the old concretes either do not move or have little motion which help the setting-up of concrete to confront less disruption.
To dissect the concrete flow, initially, it can be assumed that the factors influencing the concrete flow are those which influence any other fluids such as water. These factors are as follows:

- Speed
- Viscosity
- Specific gravity
- Section type

It should be mentioned that in concrete flow the above factors are of more complex nature than those in a fluid like water.
Concrete is more compressible than water; it means that the changes in the unit weight of the plastic concrete resulting from the overburden and slurry, in comparison with its initial amount (in the method of concreting by the use of a termie pipe), will be more than the changes in the unit weight of water influenced by its overburden. There are other factors which make it more intricate:
- Setting-up of the concrete in the method of concreting using termie which causes instability in viscosity. Considering Figure (2), the placement order of concrete in the panel may give the impression that the cross-section of flow is decreased as any volume is poured. In this Figure, the cross-section for concrete volumes is gradually decreased from the first volume poured to the last one.
- Another factor, affecting the changes, is the length of the termie pipe placed in the concrete. This is because of the

required reductions made in the length of the termie pipe so as to ease the flow of the concrete. In other words, during concreting operations, the circumstances of concrete flow make the constancy of the speed of the concrete impossible because, on one hand, the length of the pipe in the concrete increases as the process is going on and, on the other hand, the length of the pipe is decreased so as to ease the flow of the concrete. Moreover, in the two-fluid flow of concrete and slurry with dissimilar unit weights (the unit weights of the plastic concrete and fresh slurry are 2 and 1.03 gr/ cubic centimeters respectively) the depth of the concrete is continually increasing and the height of the slurry column is decreasing.

- Roughness of boundaries and the difference in the boundaries of the secondary panels (in the secondary panels the longitudinal boundaries are of soil and the transverse ones are of plastic concrete) and presumably the role slurry coagulation or coating plays in reducing the roughness and finally in reducing the friction force, which exits between the concrete and the boundary, should all be taken into consideration.
- Heterogeneity (non-homogeneity) of the fluid of concrete is noteworthy. During concreting, The Presence of aggregates and setting-up of the concrete eliminate the homogeneity of the environment.

**5. Hydrodynamics of Concreting:**

Irrespective of all intricacies inherent in the concrete flow, one can, under certain circumstances, make use of the simplifying assumptions of the formulas common in the literature of fluid mechanics so as to obtain corrective factors based on pure and experimental mathematics and to compare them with the behavior of the fluid in reality.

A summary of these assumptions is as follows:

- It is assumed that the concrete flow from the end of the pipe pushes the whole mass of concrete on its top upwards and this movement occurs throughout the section. This assumption is in full agreement with the principles of concreting by the use of a termie pipe. Although there are some scientists who are in disagreement about this idea, the modeling, as shown Figure 2, confirms it.

Indeed, it seems that the mobile model is closer to reality. In other words, instead of assuming that the entire section of the concrete on top of the termie pipe is being pushed upwards, the movement of the concrete is assumed to be a defective conic movement in which the smaller base is situated near the exit of the termie pipe and the larger base, which form the entire section of the panel, is the upper level of the old concrete in the panel.

- regarding the fact that concreting in the panels of the cut-off wall is not a continuous process and as the aim of this paper is to find out the ways which are conducive to slow flow of concrete, to calculate the forces exerted on the concrete on an instantaneous basis, and also to determine their minimum and maximum, the concrete flow is assumed to be a discrete function, yet during pouring, a continuous flow with constant speed.
- Compressibility of concrete is disregarded. Experience has proved that plastic concrete does not compress well with ordinary tools such as vibrators. However, under conditions engendered by overburdens like slurry and weight the concrete undergoes compression and settlement. Of course the settlement takes place mainly due to chemical interactions resulting from absorption of calcium ions in concrete by bentonite. In this process, bentonite mostly acquires the chemical properties of calcic bentonite and this process together with dissipation of induced water is because of the change of the sodium bentonite into calcic bentonite and the drop in the plastic concrete.
- The flow of concrete is free and under the influence of gravity.
- Despite the dissimilarity in the boundaries of the secondary panels (the longitudinal and traverse boundaries are made of the soil and plastic concrete respectively) in terms of the influences of the slurry on the boundaries in conglomerate and concrete parts, we can consider the roughness along the separation boundaries as equal. If the longitudinal and traverse boundaries are made of clay and plastic concrete respectively, this assumption will be more accurate.

**6. Calculation of the Shear Force of Concrete over the Panel Boundaries**

According to Figure 4, we suppose there is a mass of concrete which is the length of L (a volume which is pushed upwards in the termie pipe by the concrete poured). Regarding the fact that the concrete flow in the pipe is influenced by the changes in the friction force and the weights of the concrete as well as the slurry (it is assumed that the length of the pipe is not decreased), the circumstances of the flow is always changing. Therefore, through the momentum equation the shear stress can be calculated.

$$W_c + (P_2 \times A) - (P_1 \times A) + F = \frac{\gamma_c}{g} Q(\beta_2 V_2 - \beta_1 V_1) \qquad (2)$$

In the above equation:

$W_c$ = the weight of concrete mass
$P_2$ = the pressure of slurry column
$P_1$ = the pressure of concrete column
$F$ = Friction force
$V_1$ & $V_2$ = the speed of the flow at Levels 1 and 2 respectively
$\beta_1$ & $\beta_2$ = the corrective factors of speed at Levels 1 and 2 respectively
$\gamma_s$ = the unit weight of slurry
$\gamma_c$ = the unit weight of concrete
$Q$ = discharge of flow
$A$ = the cross-section of the panel (we disregard the slight decrease produced by the termie pipe, with a 26 cm external diameter, in the cross section)

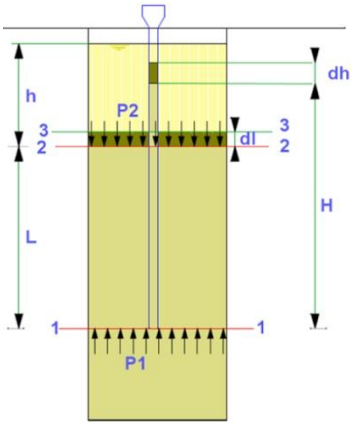



Figure 4- The Force of the Concrete and the Slurry Fluid in the Panel

Because of pumping, it is assumed that level of the slurry is fixed.
If at the moment after the start of concreting the height of the concrete in the panel is *dl* and the height of the concrete column in the termie pipe is d*h*, therefore equation (2) will be:

$$(W_c+\gamma_c\times A\times dl)+(P_2-dP_2)A-(P_1+dP_1)A+(F+dF)=0 \qquad (3)$$

$dP_2=\gamma_s\times dl$ changes in the slurry column
$dP_1=\gamma_c\times dh$ changes in the concrete pressure
$dF=(\tau$, shear stress$)\times(dl$, depth$)\times(X$, circumference of the panel$)$ = changes in the shear force
$dF=X\times\tau\times dl$
$W_c=\gamma_c\ L\times A$
$P_2=\gamma_s\times h$
$P_1=\gamma_c\times H$

With substitution in equation 3, differential equation of forces is concluded:

$$\gamma_c\times A(L+d\ell)+A\times\gamma_s(h-d\ell)-\gamma_c\times A(H+dh)+X\times\tau(L+d\ell)=0 \quad (4)$$

**7. Calculation of Shear Stress**
Now, with regard to Figure (4), the dynamic equilibrium state of equation (2) is looked at:

$$W_c+(P_2\times A)-(P_1\times A)+F={}^{\gamma_c}\!/_{g}\,Q(\beta_2V_2-\beta_1V_1) \qquad (2)$$

Because the speeds of the concrete and the slurry in the course of the flows of concrete from Level 1 – 1 to Level 2 – 2 in the panel are the same, therefore it can be concluded that:

$\beta_1=\beta_2$ and $V_1=V_2$

And equation (2) can be simplified as follows:

$$W_c+P_2A-P_1A+F=0 \qquad (5)$$

If the friction between the slurry and the boundaries of the panel is ignored, the value of F is related to the friction between the concrete and the boundaries of the panel. Using the equation between the stress of the boundary and friction to calculate the friction force of the old concrete in the panel with a length of L, it is possible to write:
The friction force

$$F=X\times\tau\times L \qquad (6)$$

$W_c=L\times A\times\gamma_c$ the weight of concrete

Based on equation (5):

$$F=A(P_1-P_2-L\times\gamma_c)$$

If we equate these two equations:

$$A(P_1-P_2-L\times\gamma_c)=X\times\tau\times L$$

The shear stress is obtained as follows:

$$\tau=\frac{A(P_1-P_2-L\times\gamma_c)}{X\times L} \qquad (7)$$

If the dimensions of the oblong panel are as follows:
a = width F= □×□ × *dl* d
b = length
A = Cross section
X = Circumference

Hence:

*X=2(a+b)* and *A=(a× b)*

The shear stress on the boundary engendered by the concrete, with regard to equation (7), is as follows:

$$\tau=\frac{ab(P_1-P_2-L\times\gamma_c)}{2L(a+b)} \qquad (8)$$

In general, the value of the shear stress ($\tau$) is a function of the average velocity, the dynamic coefficient of viscosity ($\mu$), density ($\rho$), hydraulic radius and roughness ($\varepsilon$) of the boundaries. In fluid mechanics, the below equation is given for all flows, including luminary and turbulent, with regard to the above components:

$$\tau=C_f\times\rho\frac{V^2}{2} \qquad (9)$$

If equations (8) and (9) are equated,

$$\tau = \frac{ab(P_1 - P_2 - L\times\gamma_c)}{2L(a+b)} = C_f \times \rho \frac{V^2}{2} \qquad (10)$$

Non-dimensional coefficient $C_f$ is obtainedexperimentally. Generally, all factors which increase shear stress help the cleaning of the boundaries by the old concrete. This state is effective on increasing the quality of the joints of the primary and secondary panels. With regard to the above equations, we can draw the following conclusions:

- The more the length of the concrete mass is from the end of the termie pipe, in other words, the more the length of the termie pipe is in the concrete, the less the shear stress will be.
- With the increase in the dimensions of the panel, the shear stress will decrease.
- With the increase in the pressure difference of the column of the top end of the termie pipe in relation to the slurry column $(P_1\text{-}P_2)=\Delta P$ the shear stress will increase.
- The less the unit weight of the slurry is, the more the shear stress will become.

**8. Calculation of Energy Loss**

To find the equation of energy loss, Bernoli's equation is used between Level 1 – 1 in the termie pipe and Level 2 – 2 which is the border between the slurry and the plastic concrete in the panel (Figure 5). The sections of the Figure are as follows:

Section 1 – 1: the level of the concrete in the termie pipe

Section 2 – 2: the border between the concrete and slurry level

Section 3 – 3: the end part of the termie pipe

$$(h_1 - h_2) + \frac{P_1}{\gamma_c} + \frac{V_1^2}{2g} = (h - h_2) + \frac{P_2}{\gamma_c} + \frac{V_2^2}{2g} + \Delta h \qquad (11)$$

Where:

$v_1$= the speed of concreting in the termie pipe

$v_2$= the speed of concreting in the panel

$p_1$= the pressure at the level of the concrete in the pipe

$p_2$= the pressure at the level of the concrete in the panel

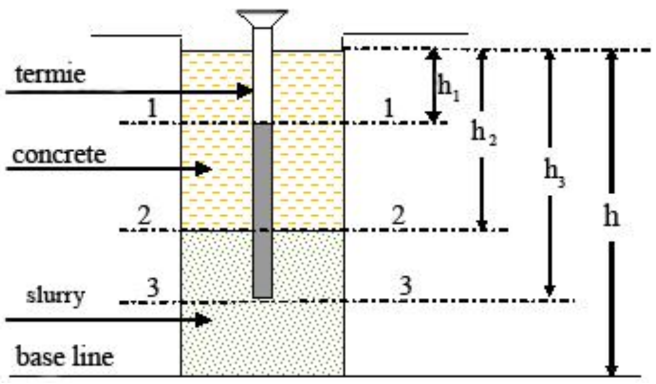



Figure 5- Calculation Circumstances of Energy Loss

With regard to the contact between cross-section 1 – 1 in the pipe and the air:

$P_1 = 0$

With regard to the balancing of pressure at cross-section 2 – 2, we may calculate the pressure for this cross-section based on the slurry column, hence:

$P_2 = h_2\,\gamma_s$

If these values are substituted in the above equation:

$$(h - h_1) + \frac{0}{\gamma_c} + \frac{V_1^2}{2g} = (h - h_2) + h_2\frac{\gamma_s}{\gamma_c} + \frac{V_2^2}{2g} + \Delta h$$

$$\Delta h = h_2\left(1 - \frac{\gamma_s}{\gamma_c}\right) + \frac{1}{2g}(V_1^2 - V_2^2) - h_1 \qquad (12)$$

The effective local loss resulting from the widening of the entry section of the flow from the pipe into the panel can be calculated from the following equation

$$\Delta h_1 = \frac{V_1^2}{2g}\left[\left(\frac{A_1}{A_2}\right) - 1\right]^2$$

In the above equation:

$A_1$ = the cross-section of the pipe

$A_2$ = the cross-section of the panel

By and large, two types of flow loss take place. One results from friction and the other is local loss owing to the change in the section of the flow ($\Delta h_1$). Therefore, the flow loss resulting from friction ($\Delta h_f$ ) is equal to:

$$\Delta h_f = \Delta h - \Delta h_1$$

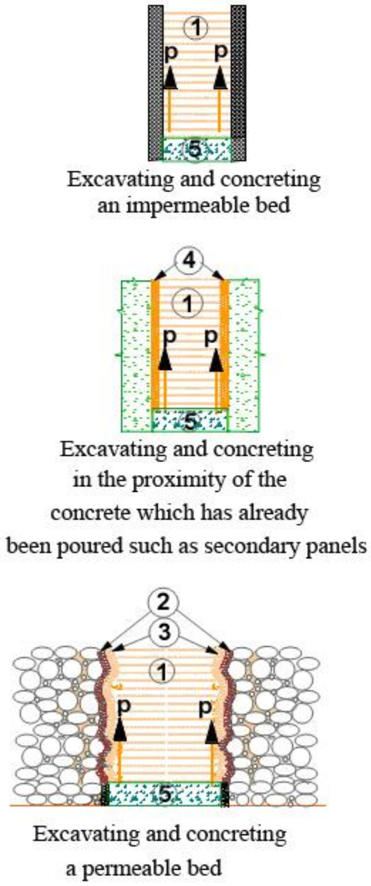
Considering the above formulas and equations and the inspections conducted, flow energy loss takes place under the following circumstances:

- With the increase in the height of the concrete on top of the termie pipe end, energy loss increases.
- With the increase in the slurry column $h_2$ or, in other words, in the lower depths of the concrete level in the panel, more energy loss takes place.
- With the increase in the speed of concreting in the termie pipe ($V_1$), energy loss increases.
- The increase in the speed of concrete in the panel ($V_2$) causes energy loss to decrease. This happens because the adjacent concretes make the cross-section of the panel smaller.
- With the decrease in the ratio of ($\gamma_s/\gamma_c$), energy loss increases.

**9. Studying Shear Stress of Concrete Flow, Resistance of Cake, and Coagulation of Slurry**

Depending on the adjacent layers, three states are predicted for the slurry in the panel:

1. the slurry comes to rest in the proximity of the less permeable layers such as clay
2. the slurry comes to rest in the proximity of the poured plastic concrete
3. the slurry comes to rest in the proximity of the permeable layers such as conglomerate




P: shear force exerted on the boundaries which results from the upward movement of the plastic concrete
1: slurry
2: bentonite cake
3: bentonite jelly
4: coagulated slurry resulting from its reactions with the adjacent concrete
5: concreting

Figure 6- Different States of slurry inside the excavated panels

The interaction between the plastic concrete and the slurry in each of the above states are as follows:

1. Boundary with low permeability such as clay: no cake is formed on the boundary or in case of forming, it would be very thin. However, concrete shear force F can easily clean the boundary.
2. Permeable boundary such as conglomerate: the cake is formed on the boundary and it takes the shape of the boundary. In addition to the cake, a jelly layer is also formed in the proximity of the cake; concrete can easily clean the jelly layer. However, the hard cake is not easily cleaned, especially in the voids, and it is possible that some parts of the cake remain untouched.
3. Boundary of plastic concrete: it is the most important case in the states of boundaries because of its influence on the quality of the joints and sealing at this kind of boundaries. In this state the slurry in the proximity of the concrete is coagulated with ion exchange. Cohesion of bentonite jelly and the boundary barely exceeds $5\times10^{-6}$ ($N/mm^2$) (equal to 0.50 $t/m^2$). The shear force of the concrete is several times bigger than jelly cohesion; therefore, removal of jelly by the concrete can easily be accomplished. This is evaluated in the case study below.

## 10. Case Study in a Panel

In concreting operations in a panel with the dimensions of 0.8×2.8 and depth of 75 meters, the concrete of each truck mixer of 6 cubic meters was poured in 2 minutes through a termie pipe with a diameter of 25 cm.

Friction, boundary stress, total energy, total and local energy loss are to be calculated for the following states:

Regarding the concreting circumstances, the position of the plastic concrete in the panel is as follows:
A) the level of the concrete at the depth of 40 meters
A – 1) 3 meters of the length of the termie pipe in the concrete
A – 2) 14 meters of the length of the termie pipe in the concrete
B) the level of the concrete at the depth of 20 meters and the position of the termie pipe is the same as the above two states.
In this example, it is assumed that the potential level of slurry in the panel is 0.50 meter lower than the guide wall. Other necessary information is given under the Figure7.

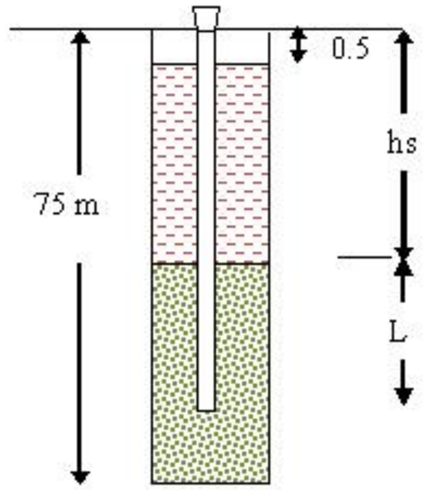



Figure 7- The excavated Panel under Study

The unit weights of the slurry and the plastic concrete are as follows:

$\gamma_s = 1.03\ (t/m^3)\ \ \&\ \ \gamma_c = 2\ (t/m^3)$

The main parameters are calculated firstly:

$F = A\,(P2 - P1 - L \times \gamma_c)$

$P2 = (L + h_s + 1)\gamma_c \qquad P_1 = (h_s - 0.5)\gamma_c \qquad H = (h_s + 1) - (h_s - 0.5)\times(\gamma_s/\gamma_c) + V_1^2/2g$

$V1 = (6)/(2 \times 60) = 0.05 \quad (m^3/\sec)$

$A1 = 3.14(0.25)/4 = 0.05\ \ (m^2)$

$A = 2.8 \times 0.8 = 2.24 \qquad (m^2)$

***Solution:***

**A1)**

$h_s = 40\,m \qquad L = 3\,m$

$P_1 = 1.03(40 - 0.5) = 40.7 \quad t/m^2$

$p_2 = 2(3 + 40 + 1) = 88 \qquad t/m^2$

$F = 2.24(88 - 40.7 - 3\times\ 2) = 92.5 \quad (t)$

$\tau = \dfrac{F}{2l(a+b)} = \dfrac{92.5}{2\times3(\ 2.80\ \ 0.8)} = 4.28 \qquad (t/m^2)$

$H = (40+1) - 39.5\ (1.03/2) + 0.05(\ 22 - 9.8) = 20.65 \quad (m)$

$\Delta h = [\dfrac{0.05^2}{2\times9.81}]\times[\dfrac{0.05}{2.24} - 1] = -2.49\times10^{-3}\ \ (m)$

**A2)**

$h_s = 40\ m \qquad L = 14\ m$

$P_1 = 1.03(\ 40 - 0.5) = 40.7 \quad (t/m^2)$

$P2 = 2(14 + 40 + 1) = 110 \quad (t/m^2)$

$F = 2.24(110 - 40.7 - 14\times2) = 92.5 \quad (t)$

$\tau = \dfrac{F}{2l(a+b)} = \dfrac{92.5}{14\times3(2.80+0.8)} = 0.918\ (t/m^2)$

$H = (40+1) - (39.5)\times(\dfrac{1.03}{2}) + (\dfrac{0.05}{2\times9.81}) = 20.65 \quad (m)$

**B1)**

$h_s = 20\ m \qquad L = 3\ m$

$P_1 = 1.03\times(20 - 0.5) = 20.1 \quad (t/m^2)$

$P_2 = 2\times(3 + 20 + 1) = 48 \quad (t/m^2)$

$F = 2.24\times(48 - 20.1 - 3\times2) = 49.1 \quad (t/m^2)$

$\tau = \dfrac{F}{2l(a+b)} = \dfrac{49.1}{3\times2(2.80+0.8)} = 2.27 \quad (t/m^2)$

$H = (20+1) - (20-0.5)\times(\dfrac{1.03}{2}) + (\dfrac{0.05}{2\times9.81}) = 11 \quad (m)$

**B2)**

$h_s = 20\ m \qquad L = 14\ m$

$P_1 = 1.03(20 - 0.5) = 20.1 \quad (t/m^2)$

$P_2 = 2\times(14 + 20 + 1) = 70 \quad (t/m^2)$

$F = 2.24\times(70 - 20.1 - 14\times2) = 49.1 \quad (t)$

$\tau = \dfrac{F}{2l(a+b)} = \dfrac{49.1}{14\times2(2.80+0.8)} = 0.48 \quad (t/m^2)$

$H = (20+1) - (20-0.5)(\dfrac{1.03}{2}) + (\dfrac{0.05^2}{2\times9.81}) = 11 \quad (m)$

Based on the performed calculations the states of the Bentonite jelly are summarized in the following table:

| The level of concrete in the panel in proportion to the level of the bed (m) | length of the termie pipe in the concrete (m) | shear stress of the boundary of the panel ($t/m^2$) | comparison between cohesion strength of the bentonite jelly and the boundary ($t/m^2$) | The possibility of the cleaning of bentonite jelly |
|---|---|---|---|---|
| 40 | 3 | 4.28 | > 0.50 | Yes |
| | 14 | 0.918 | > 0.50 | Yes |
| 20 | 3 | 2.27 | > 0.50 | Yes |
| | 14 | 0.48 | < 0.50 | No |

## 11. Summary and Conclusions

Taking into account the fact that accurate and coherent Performance of the cut-off wall panels as the main part of the water tightening system of body and foundation [5-6] of earth dams is of great sensitivity and importance, this paper investigates the effective factors causing discontinuity at the interface of the primary and the secondary panels in the form of bentonite jelly. The forces and stresses at the boundary of bi-fluid consisting of slurry and plastic concrete have been calculated and determined using the principles of hydrostatics and

Hydro dynamics. Since the nature and properties of the above fluids in this system are very complicated, a great effort has been attempted to modify the results using some empirical coefficients. Finally, as a case study a real type of executed panel of plastic concrete cut-off wall has been evaluated using the develop equation.

Some of the main results of the present study are as follows:

- With equal depths of concrete levels in concreting operations, the less the length of the pipe is in the concrete, the more the shear stress is exerted on the boundaries. This can help through cleaning the joints as much as possible which eventually enhances their quality.
- Assuming that the length of the pipe is the same (at the depths where the comparison is made), the more the concrete level is, the less the shear stress of the boundary will become. Using this we can predict that the quality of joints in lower depths are better than that of the upper levels. This is important because as the depth increases, the hydrostatic pressure of the concrete also increases and superior quality of the joints will decrease seepage of the cut-off wall in proportion to the increase of the hydrostatic pressure of the dam reservoir.
- The speed of concrete flow in the practical limit (pouring each 6 cubic meters truck mixer in 2 to 3 minutes) is not noticeably influential in head loss (H). However, it is probably influential in concrete flow and order.
- Local head loss in performance of plastic concrete cut-off wall is insignificant and therefore can be disregarded.

**12. References**

[1] Shadravan B., Azadmanesh A., et al., The Final Report on The cut-off Wall of Karkheh Embankment Dam-2002, Mahab Ghodss Eng. Company, Tehran Iran.

[2] Streeter V.L., Wylie E.B., Bedford K.W., "The Fluid Mechanics", McGraw-Hill, New York, 1909

[3] Streeter V.L., "Fluid Dynamics", McGraw-Hill, New York, 1948

[4] Technical Report on the Method Statement of cut-off Wall of Karkheh Embankment Dam, Sepasad. Eng.Co., Tehran-Iran, June 1996.

[5] Seepage Analyses for Complementary cut-off Wall of Karkheh Embankment Dam in the left bank, Iran Water & Power Resources Dev. Co. (I.W.P.C) Sept. 2004.

[6] Seepage Analyses for the Complementary cut-off Wall at the right bank, The Conglomerate Layer above Mudstone (t3), Iran Water & Power Resources Dev. Co. (I.W.P.C), Dec. 2004.