

Evaluation of the penetration depth of sealing plastic concrete walls in the clay core of earth dams.

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Abstract: Using of plastic concrete for construction of cutoff wall is known as a method to reduce and control of seepage which has been developed in recent three decades. Plastic concrete cutoff wall is suggested when a dam is constructed on an alluvial foundation with high permeability. In these conditions, a proper material is the one that can carry high stresses of wall, Moreover, this material with its adjacent soils should deflect without failure and losing sealant of wall. In other words, deformability modulus of this material should be similar to adjacent foundation. Low permeability, plastic behavior and high flexibility are most important specifications of plastic concrete. In order to accelerate of dam construction, in first step, an embankment should be constructed up to a specified height and then plastic concrete cutoff wall would be constructed from the same height. If height of embankment is increased the construction time will decrease. In this thesis and in order to find a maximum critical height for embankment, effect of different factors have been investigated by using PLAXIS code such as penetration depth of cutoff wall into clayey core and changing of mechanical specifications of clayey core, alluvial foundation, plastic concrete cutoff wall and different properties of interface element. All models have been analyzed with and without interface element.

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1. Introduction

The role of dykes following the dams is to prolong the water path in order to reduce the destructive pressure of drainage, hydraulic gradient and total Debbie. One of the sealing methods is the usage of a sealing plastic concrete. This type of walls contains high deformability, low permeability and compressive strength proportional to the applied pressure and their application in shedding soils, feeble and saturated lands, and fine - grained soils and also to repair the dam clay core is more cost effective than other methods. Plastic concrete is composed of cement, bentonite, stone materials and water. Due to the imposed deformation, the sealing wall should be able to stand the deformations without getting cracked and open joints between the panels. The best solution is to choose materials with plasticity characteristics similar to the surrounding soil. Based on Bulletin ICOLD1985, if the elasticity coefficient changes of surrounding soil be less than sealing depth, the coefficient elasticity of plastic concrete should be 4 to 5 times of surrounding soil to arise a compatible circumstance in the alluvial foundation. Several methods are introduced for determining the plastic concrete mixing design which is mainly based on the experimental diagrams. Plastic concrete properties and the interactions of sealing wall and surrounding soil are studied by several individuals. Shahbazian Ahari and colleagues (1378) conducted the numerical

modeling of Karkheh dam using CA2 software to study the static interaction of dam, the foundation and the plastic concrete sealing wall. They used parametric analysis on the sealing wall model of dam to evaluate various factors such as the elasticity coefficient, the plastic concrete resistance, the properties of wall and foundation joint, the properties of foundation and the dam clay core and the procedures of the attachment of wall to the dam core and its effects on the stress and strain of sealing wall. The results showed that the amount of strains is most critical at the end phase of sealing wall construction. Large amount of difference between the strain of sealing wall within the clay core and the amount of the strain of adjacent wall indicates a severe wall slip into the core and the occurring of nailing in the core. One of the interesting results from these analyses is the occurrence of plastic strain almost in all levels of the wall. Also it was observed that with the increase of wall penetration into the clay core, additional strains in the wall where is into the foundation and especially in the foundation adjacent to clay core will be raised. Karim Nia and Shah Karami (2000) investigated the behavior of water in homogeneous and inhomogeneous sealing walls. They also conducted the modeling of Karkheh dam on the inhomogeneous foundation and then compared the results with the same model, but on the homogeneous foundation. The results of analysis on the homogeneous foundation show that if the elasticity

coefficient of foundation and sealing wall be close to each other, the stress and strain of wall is adjusted and acceptable. Mirqasmi and colleagues (1380) studied the characteristics of plastic concrete used in Karkheh dam and the impact of various factors on the properties of plastic concrete. Experimental results were evaluated on over 150 plastic concrete mix designs. These studies show that the plastics concrete with less resistance has more plasticity, and it is impossible to increase plasticity without reducing the resistance. In the study of Sadrkarimi and colleagues (1381) on the sealing wall of Arasbaran dam, the pattern of stress distribution, the deformation and the interaction of the plastic concrete sealing wall and the land of adjacent foundation during the performance of dam, was performed using two methods of elastic and viscoelastic and by ANSYS software. The results show that firstly, the amount of absorbed strain by the sealing wall considerably conform to the ratio of bentonite to the cement and also concrete friction angle between the plastic concrete and the adjacent soil. Secondly, with regard to the viscoelastic behavior of plastic concrete, it can be seen that even after developing the dam and over time, the plastic concrete extends the deformation and the absorbed strain by the wall gradually transfer to the adjacent soil. Sadrkarimi and colleagues (1383) attempted to analyze the viscoelastic of the plastic concrete sealing wall in earthen dam due to the changes of reservoir water surface. In this study, a case from the geometric and mechanical properties of Arasbaran Dam in East Azarbaijan province was used for modeling in PLAXIS software. In this study, the interaction angle between sealing wall and adjacent soil on the stress distribution and the deformations of the plastic concrete sealing wall and soil subsidence during the dam developing and its services were studied. The obtained results show that firstly, due to the compressive stresses transfer of adjacent soil, by increasing the wall depth, the compressive stresses show increasing trend that this process is highly influenced by the angle of interaction between the wall and adjacent soil. Secondly, the creep behavior of plastic concrete causes that the wall subsidence to be continued even after the dam development. The obtained results also show that due to the creep behavior, the time is needed that the wall transfer and the soil to reach a coordination and by the plastic deformation, the wall transfer will never return to the primary site. Ghanbari and colleagues (2008) presented the hydro-mechanical behavior of the attachment systems of sealing wall to the clay core. The difference between the clay core rigidity and the sealing wall causes the stress concentration at the union which led to increasing the deformation in this region. To reduce the hydraulic gradient and the stress

concentration in this region, six different unions were studied. Finally, with regard to the leakage and stress - strain analyzes, it was concluded that union systems including a plastic concrete cap on the boundary between the foundation and the dam body is the best and the union system including a plastic concrete cover and a clay levee is the most inappropriate system for the union area. As was observed, various researchers have studied the interaction of the plastic concrete sealing wall and alluvial foundation, while the penetration amount of the sealing wall in the clay core, which sometimes is applied to reduce the flow concentration in the union area and sometimes to accelerate the operation of dams, are less studies. In this study, this issue is investigated by using the general cross-sectional of an earthen dam and the reasonable parameters.

2 - Numerical Modeling

In some dam projects in order to accelerate the implementation of the dam, first the dam embankment is performed to a certain level, and then the plastic concrete sealing wall through the clay core to the alluvium and the bedrock will be implemented from the desired level.

Given that the implementation speed of embankment can be high, whatever the embankment depth be greater, the project implementation will be accelerated. The major objective of this study is to obtain the maximum critical height of the embankment of dam body with regard to the properties of sealing wall and its surrounding areas.

This issue is investigated using PLAXIS software (2000), and the effect of the changes of various factors such as the penetration depth of sealing wall into the core dam and the resistance properties of the plastic concrete materials of sealing wall and also the changes of interface element properties were studied.

2-1 geometry and Limited element Network

In Figure 1, the two-dimensional model of earthen dam and its foundation can be seen. The dam has a height of 80 meters which is built on alluvial soil with a depth of 40 meters. The dam shell has an upstream and a downstream slope of %2 horizontal to a vertical and the dam core has an upstream and a downstream slope of 0/25 horizontal to a vertical.

The final height of dam reservoir is considered 70 meters from the alluvial bed and the width of dam crests is considered 10 meters. To sealing the alluvial foundation, the plastic concrete sealing wall with the width of one meter was used in the total height of alluvial foundation which the wall penetration depth into the clay core is variable in various models. All points will be studied on the three cross sections of AA, BB and CC. AA section is passed on the symmetry line of section and within the sealing wall, while the BB section is depicted across the depth of

alluvial foundation. CC is depicted in transverse across the level of 10 m above the foundation.

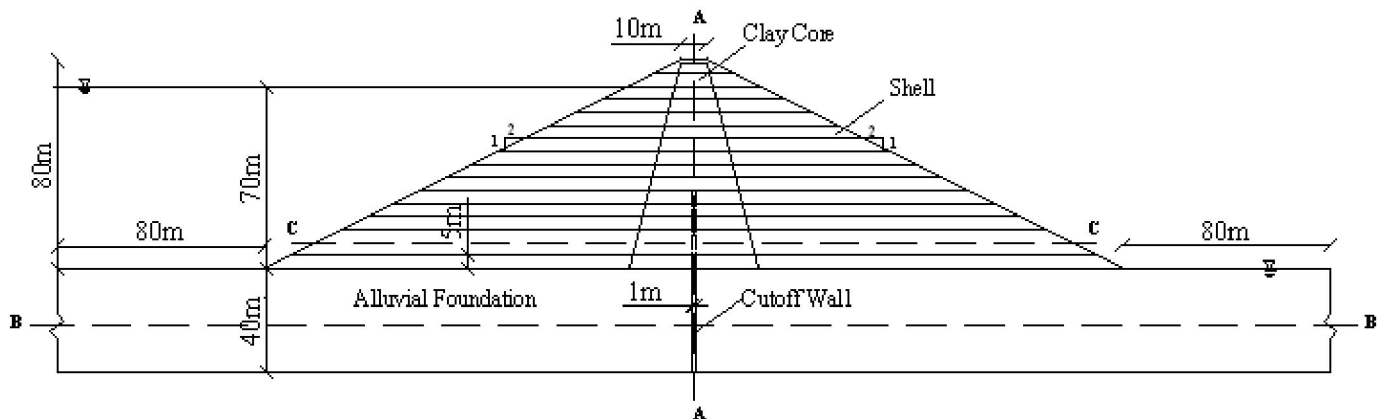


Figure 1 Cross-sections selected for modeling

As can be seen, the Levee body of dam should be built on an alluvial land. Consequently, the land is considered as the initial stress of model. With regard to the total height of levee body which is 80 meters, with assuming 5 meter layers, 16 layers are defined to complete the analysis. During the analysis, a computational phase is defined as plastic phase (Plastic) per each 5 layers which the load is actually exerted on it and the pore water pressure of dam increases due to loading. A consolidation phase is defined per each plastic phase to reduce the pore water pressure at each stage. In each model, given the circumstances, the height of sealing wall is specified and the sealing wall is placed in one of the phases. For example, if the penetration depth of sealing wall in the core dam be 5 meters, first 5 meter layer as the plastic and then the consolidation phase is defined. In these conditions, in the site of sealing wall, still there aren't materials related to the alluvial foundation and the clay core. In the next phase and while the height of the levee is 5 meters, inactive only the material related to the foundation and the core in desired site for the plastic concrete sealing wall, and instead of that, the material properties of the plastic concrete sealing wall will be assigned to the desired location. The rest of the embankment layers are defined as 5 meter layers to finally reach the height of 80 meters or the location of dam crest. The total period of the construction of dam levee body development is considered 5/2 years.

After the dam development, the dewatering step of dam reservoir is modeled to the height of 70 meters. Dewatering will be done in three steps which in the first step is dewatered to the height of 20 m and in the next step to the height of 30 to finally reach the total height of 70 meters, to complete the dewatering step of dam. The total duration of dewatering is assumed 6 months and dewatering process is

performed in 2 months. After filling the dam reservoir, it is turn to analyze in the exploiting conditions or in the stable leak state. The long-term consolidation of dam body is performed which is defined with assumption of 10 year duration. It should be noted that in addition to the investigation of the effect of sealing wall penetration into the core, the measuring sensitivity on the resistance properties of the plastic concrete materials of sealing wall and also the properties of interface are performed. Limited element network in prepared model is in accordance with figure (2). As can be seen in figure, due to the increase in the pore water pressure in the dam core and also the presence of the sealing wall at different heights, the elements network is considered in this part more detailed than elsewhere.

15 - Node triangular elements in the limited element network of desired model and standard boundary conditions in program were used for the boundary of model.

2-2 - Behavioral model and material properties

In order to modeling of dam and the penetration depth impact of the plastic concrete of sealing wall in clay core, the behavioral model of Moher - Coulomb was used. In PLAXIS software, this behavioral model in section is as non-associated flow rule and acts in tensile rupture as associated flow rule. Specifications of the materials used in the modeling of earthen dams is according to Table 1: γ_d dry density, γ_t wet density, C attachment coefficient, ϕ Friction angle, E elasticity coefficient, ν Poisson's ratio, σ_t Tensile resistance and κ permeability coefficient. The Poisson's ratio for the clay materials of core and plastic concrete is assumed 0.35 and for the alluvial materials and the membrane is assumed 0.3.

Table (1) Specifications of materials used in the modeling of earthen dam

K m/s	σ_t	E	ϕ Deg	c	γ_t	γ_d	SOIL
							Unit
$K_x = 10^{-9}$ $K_y = 10^{-9}$	5	10^4	26	10	19	18	Core
$K_x = 10^{-5}$ $K_y = 10^{-5}$	0	7×10^4	42	1	22	20	Shell
$K_x = 10^{-5}$ $K_y = 10^{-5}$	0	4×10^4	38	1	22	20	Alluvial Foundation
$K_x = 10^{-5}$ $K_y = 10^{-5}$	200	2×10^6	35	400	24	23	Plastic Concrete

3 – Investigation of the penetration rate effect of the plastic concrete sealing wall in the clay core

In this section, the penetration depth effect of the plastic concrete sealing wall in the clay core is studied. In first model, it is assumed that the sealing wall is located in total height of the foundation and is not penetrated the wall of water into the core. In the next model the wall penetration depth is assumed 5 m till the end phase of first layer and in the next model the wall penetration depth is enhanced to two layers, namely the penetration depth reaches 10 m and this procedure continues until the penetration depth of 50 m. According to figure (3), increase in penetration depth leads to decrease in effective vertical stress at the wall within the dam foundation. Due to the rigidity difference between clay and plastic concrete materials, stress concentration occurs at the top of wall, which leads to a sudden increase in effective vertical stress at the wall and the core. It is obvious that with the increase of the penetration depth of sealing wall in clay core, the vertical stress rate at dam axis where the sealing wall is located increases. It has been found at height of 40 m.

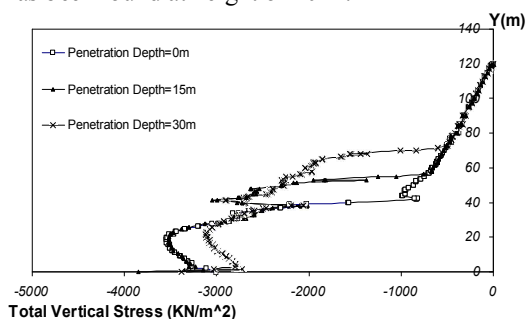


Figure 3 the effect of penetration depth on the distribution of total vertical stress at end phase of development in section AA.

Due to the difference between the properties of clay and plastics concrete materials, a sudden increase occurs in the volume strain rate in the interface of clay core and wall. Increase in the

penetration depth causes the increases of the volume strain in the wall located in the foundation, gets stable in all three steps of the end phase of development, dewatering and seepage, which is shown in figure 4 as an example. Increase in the wall penetration depth cause further strength on adjacent wall and leads to increasing on the volume strain rate.

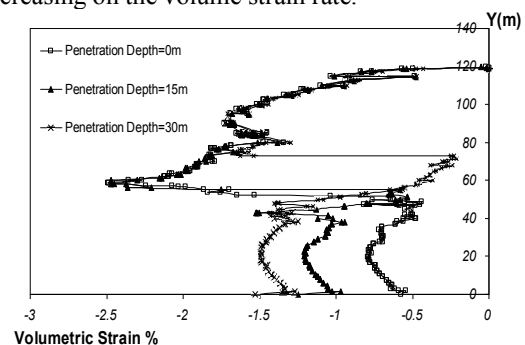


Figure (4) the effect of penetration depth on distribution of volume strain in dewatering step in section AA.

The point in section CC is that increase in the penetration depth leads to slightly decreasing in the horizontal shift in the end phase of development. This occurs due to the reverse arch phenomenon in the sealing wall.

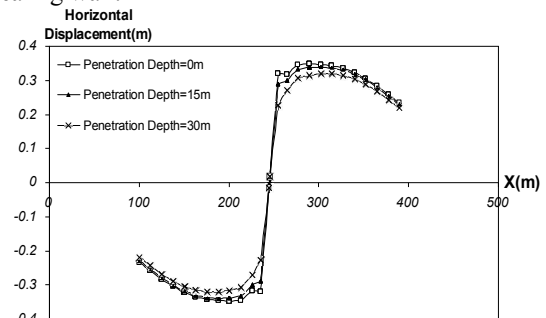


Figure (5) the investigation of penetration depth effects on the distribution of horizontal shift in the end phase of development in section CC.

3-1 - investigation of the penetration depth effects of the sealing wall on the strain at the top of wall.

In performed analysis, the most critical state of sealing wall was in the end phase of development. According to figure (6), in the end phase of dam development, increasing the penetration depth of sealing wall to 10 m leads to decreasing in the strain of its top, but when the depth exceeds 10 m, the strain rate at the top of sealing wall increases along with the increase of penetration depth.

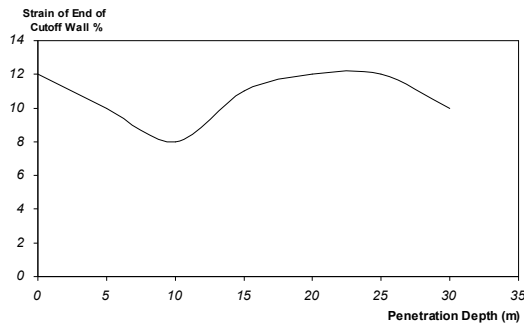


Figure (6) effect of the penetration depth on the strain at the top of wall in the end phase of development.

3-2 - Evaluation of the plastic parts of sealing wall.

In this section, the location of plastic formation points in the plastic concrete sealing wall is studied. For this purpose, push of Mohr - coulomb is drawn in the $p' - q'$ space regarding to the following relations: The effective stress along, which was studied, were also transformed to the main stress and was drawn in the $p' - q'$ space for different models. For this purpose the following equation is used:

Equation 2:

Rupture envelope and stress state in the height of the sealing wall of concrete plastic are

drown in three different situations of the wall in the clay core in figure (7).

As can be seen, at the end phase of development, the most critical state for the plastic formation of materials occurs, but in the dewatering and the steady leakage steps, the materials of sealing wall distance from the rupture envelop and the sealing wall stabilizes.

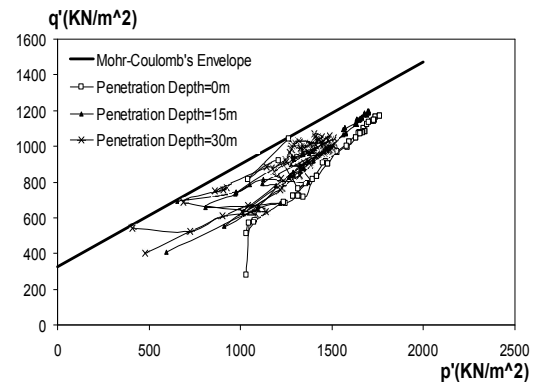


Figure (7) the position of stress and the rupture envelop of sealing wall for the penetration depth effect.

- a. the end phase of development,
- b. dewatering
- c. steady leakage

According to figure (8) prior to 10 m penetration depth of the sealing wall into the core, plastic points won't occur, but afterwards the plastic points are seen at the height of the wall. With increasing on the penetration depth of sealing wall in the clay core, the plastic parts amounts in the wall increases. Also, because the foundation is relatively stronger in comparison with clay core, in none of the penetration depth, the sealing wall in alluvium is transformed to the plastic.

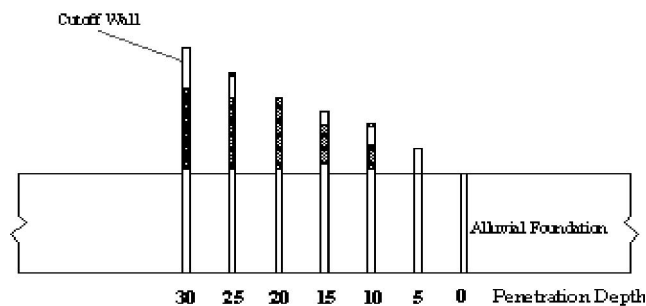


Figure (8) the range of plastic parts in the sealing wall at the end phase of development and different penetration depths

4- Measuring sensitivity on plastic concrete specifications

In order to investigate the sensitivity of plastic concrete parameters in response to exerted forces, three types of sealing wall with parameters presented in table (2) will be discussed.

Table (2), the plastic concrete parameters in three states of weak, moderate, strong.

Elasticity Modulus kg/cm^2	Friction Angle Deg	Cohesion kg/cm^2	Plastic concrete
800	30	1	Low Strength
2000	35	4	Medium Strength
10000	38	8	High Strength

The analysis performed showed that with increasing the resistance and elasticity coefficient of sealing wall, less strain will occur in the sealing wall in both foundation and core. For example, a volumetric strain along the height of the sealing wall which has a penetration depth of 15 m in the clay core is as figure (9). As can be seen, increase in the plastic concrete strength, leads to reducing the volume strain diagrams in all the three stages.

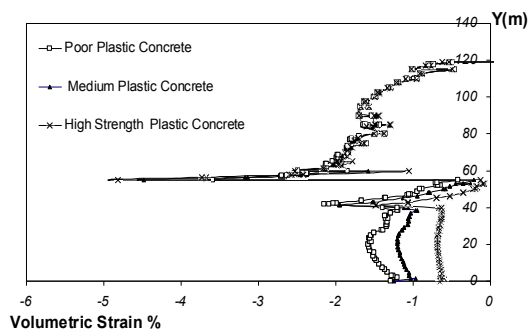


Figure (9) the effect of plastic concrete specification changes on the distribution of volume strain in the sealing wall with depth of 15 m in dewatering phase

The analysis shows that increase in resistance and elasticity coefficient causes more strain in the sealing wall in both foundation and clay core. As an example, the vertical strain occurred in the height containing the penetration depth of 15 m in clay core, is in accordance with figure (10). As shown in this figure, strengthen the plastic concrete leads to dramatic increase in total vertical strain graph in dewatering phase. This is due to the fact that increase in the rigidity of plastic concrete increases the further strain absorption.

4-1- investigation of specifications changes of plastic concrete materials on plastic points

With regard to the fact that the most concrete points are created in the end phase of development, the results presented in the end phase of development are studied. The push rupture of q' - p' regarding the mechanical specification changes of plastic concrete

sealing wall at the end phase of development for the steady penetration depth of 15 is shown in figure (11). With accordance to this figure, a separate rupture is drawn for all three weak, moderate and strong plastic, but as shown in figure (12), the plastic points are created in all three states.

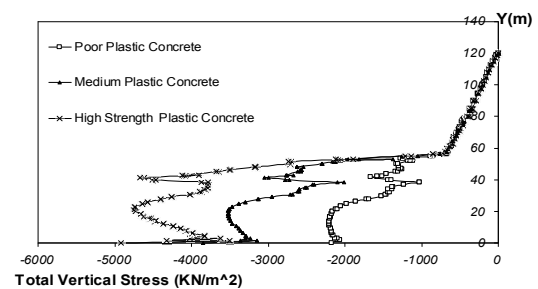


Figure (10) specification changes effect of plastic concrete on the distribution of total vertical strain in the sealing wall with depth of 15 m in dewatering phase.

As shown in figure (12) when the plastic concrete is strengthened, the plastic range shift toward the foundation. The weaker plastic concrete also contains less plastic points, because it has undergone less stress and distance from push rupture.

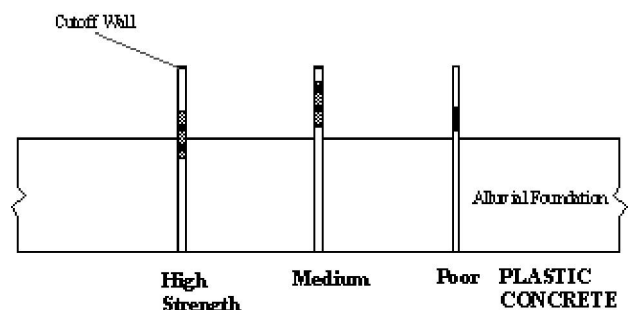


Figure (11) specifications effect of plastic concrete on plastic points range formed in sealing wall in the end phase of development in the depth of 15 m

5- The effects of interface element on the interaction of plastic concrete wall and surrounding soil

In all models, the existence or the lack of interface element was studied. This element is used to investigate the probable slip between wall and soil. In cases where the interface element is located in the model, the resistance coefficient of $R_{inter} = 0.75$ is used. This factor is the ration of wall and foundation interface to the soil resistance. The trend observed in the results is similar to the previous case, if the effect of interface element be applied, but the quantities are changes.

To study the changes, the measuring sensitivity is done, in order to study the effect of wall penetration into the core and the changes of plastic concrete specifications in the presence of interface.

For example, two graphs observed in the previous section, is mentioned below regarding to the interface:

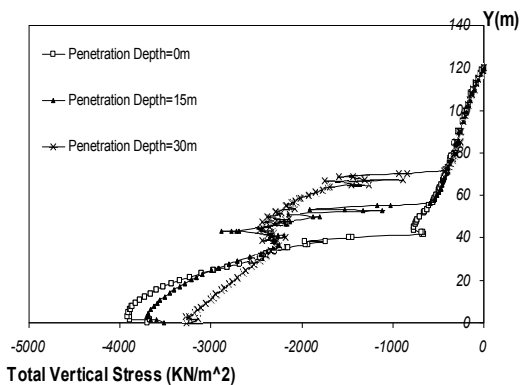


Figure (12) the effect of penetration depth on the distribution of total vertical stress in the end phase of development.

Table (3) the resistance reduction coefficient parameter of interface element in three states of weak, moderate and strong.

Magnitude	R_{inter}
0.5	Weak Interface
0.75	Medium Interface
0.95	Strong Interface

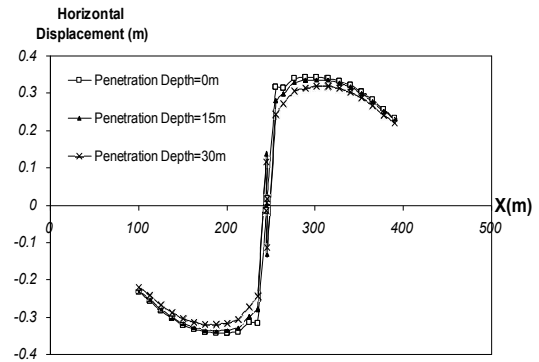


Figure (13) the effect of penetration depth on the distribution of horizontal shift in the end phase of development.

As was mentioned, increase in the penetration depth of the sealing wall to height of 10 m leads to decreasing the strain at the top of wall, but when the depth exceeds 10 meters, strains at the top of sealing wall increases along with the increase of penetration depth. This is the same for the case of interface element application but the strain values are much more in the model containing the interface element. In figure (15) it is shown the comparison of stain at top of the wall with the penetration depth in the both states of presence or absence of interface element. In case of interface presence, the plastic range formed in the sealing wall was almost the same as the previous corresponding states, but some discontinuities are generated in the plastic range.

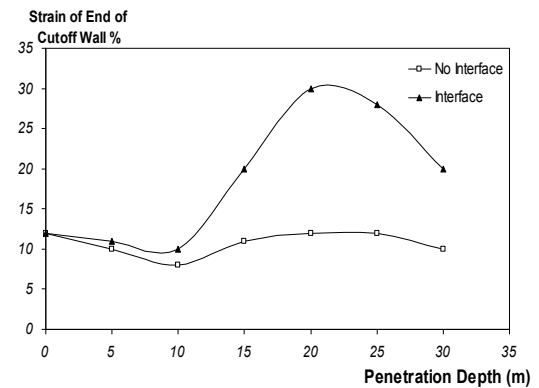


Figure (14) the effect of penetration depth on the strain at the top of wall in the end phase of development.

5-1 measuring the sensitivity on the specifications of interface element

In the section, the measuring interface on the resistance reduction coefficient (R_{inter}) of interface element is performed, which is shown in the following table.

In this section, the graphs are studied in the penetration depth of 15 m. As expected, with decrease in R_{inter} coefficient, the possibility of soil slip at sealing wall increases, and consequently the horizontal shift in three states of the end phase of development, dewatering, steady leak, and the vertical shift in the end phase of development increase. Decrease in R_{inter} leads to decreasing in the effective vertical and total strain, since while force shifts, due to decrease in shear resistance of interface, the occurred slip and strain shift lessen, which is shown in figure (17).

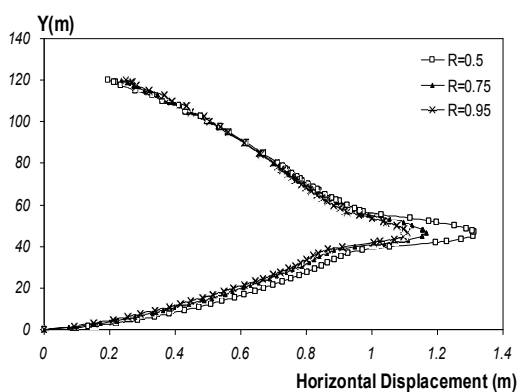


Figure (15) R_{inter} coefficient effect on the distribution of horizontal shift in the steady leak state at section AA.

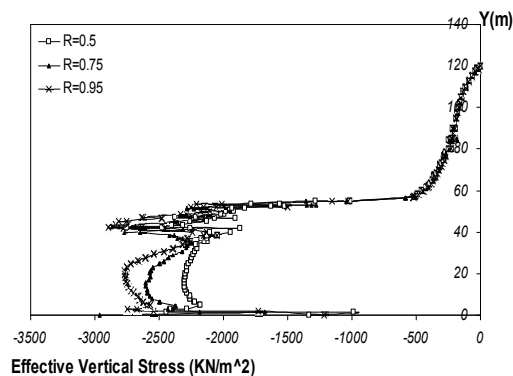


Figure (16) R_{inter} coefficient effect on the distribution of vertical strain in the steady leak state at section AA.

5-2- investigation of the R_{inter} coefficient changes on plastic points

In this chapter, the push rupture of q' - p' with regard to R_{inter} coefficient changes in the end phase of development are studied. These graphs for the

penetration depth of 15 m are shown in figure (18) and figure (19). As observed, several points in the sealing wall is converted to plastic form which indicates that the end phase of development is very critical, and with increase in R_{inter} coefficient, the plastic ranges decrease and it shows that if the sealing wall contains an appropriate attachment with surrounding soil, it will be less damaged.

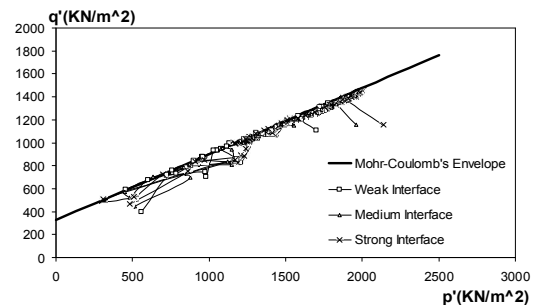


Figure (17) Push rupture for the effect of R_{inter} coefficient changes in the end phase of development.

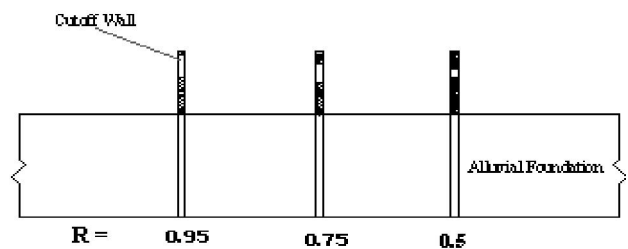


Figure (18) the effect of R_{inter} coefficient changes on the plastic points ranges formed in the sealing wall in the end phase of development at the depth of 15 m

6- Conclusion

In this article, an earthen dam with clay core, alluvial foundation and plastic concrete sealing wall with specified dimensions was modeled as two dimensional using PLAXIS limited elements program and the penetration effect of plastic concrete sealing wall and its attachment with surrounding soil by the interaction of concrete wall to the surrounding soil were studied. According to performed studies the following results are obtained:

- Increase in the penetration depth of sealing wall into the core leads to increasing in maximum horizontal shift and the volume strain of plastic concrete sealing wall.
- Increase in the penetration depth of sealing wall into the core leads to decreasing in the total

vertical shift and the vertical strain of sealing wall in alluvial foundation.

- In the end phase of development, till the penetration depth of 5 m into the core, no plastic points were detected, but after the depth of 10 m, plastic points were appeared in the wall. Indeed, regarding the dimensions and parameters considered in this article, the penetration depth of 10 is known as maximum penetration depth.
- The End-phase development is the most critical phase in the formation of plastic parts.
- Increase in the penetration depth into the core to the depth of 10 m leads to decreasing the strain at the top of wall, but when the depth exceed 10 m, the strain values at the top of wall decreases along with the penetration depth increase
- Increase in the interface shear resistance of wall and surrounding soil leads to decreasing the maximum horizontal shift of wall and increasing the effective and total vertical strain in the wall into the foundation. In presence of interface element in the end phase of development, the plastic points are appeared from the penetration depth of zero.
- Consequently, the penetration depth of sealing wall in the clay core may not be somewhat more and in present study regarding the presented parameters, the embankment of dam body on the alluvial foundation might be continued to the depth of 10 m, and then the plastic concrete sealing wall to be applied. Of course, the penetration rate could be change in different similar designs.
- However, to measure the optimum penetration in embankment operation, numerical analyses with actual specifications are need.

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