Advantages of CMD's in CMD-Earthfill Composite Dams (Case Study: Dasht-e-Palang Dam)

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Abstract

When selecting a dam body type, a composite dam (Gravity-Embankment along the longitudinal axis) is sometimes the best solution. Special care should be taken while dealing with the contact interface in this type of dam. Generally, conventional gravity dams are built with vertical or near-vertical upstream face, which results in an insufficient cross-sectional area at the contact interface with an Embankment. Insufficiency of this area and vertical slope of gravity dams cause problems such as compromised water tightness at contact interface and separation of Embankment under dynamic loadings. A number of solutions have been proposed which could overcome this challenge. One of these solutions is the use of CMD technique, which results in a wider cross-sectional area and hence minimizes the mentioned problems.

In this paper, Dasht-e-Palang composite dam (which is under construction and located in the south of Iran) is investigated. In this study, a proper contact scheme is designed and applied to the system. This scheme is also optimized using 3D dynamic analysis. Two main results of this study are minimizing the separation of Earthfill-Gravity, and scrutiny 3D geometry effects of concrete upstream slope on the stability of Embankment.

Keywords: Composite Dam, CMD, Contact, RCC, 3D Analysis

1. INTRODUCTION

There are many dams constructed with different cross-section types along the longitudinal axis. They are called "Composite Dams". A study of the U.S. Bureau of Reclamation online database shows that over 40 dams in the U.S. are composite dams. Many papers and online databases list a large number of high composite dams constructed all over the world and it is seen that many of them are located at areas of high seismic risk.

The main branch of the composite type is a Rigid part which combined with an Embankment dam.Rigid section of the composite dam is mainly Conventional Concrete where nowadays it is mostly designed as an RCC type.This Rigid/Gravity part is generally used as a spillway or hydropower generation unit, which is combined by one or two Embankment wings.

The rigid or gravity part can be designed by the concept of Cemented Material Dam (CMD). CMD is a new generation of Gravity Dam that rationalizes the design, material and construction process. Available materials at site or near areas are prepared with a minimal process, mixed with cement in Batching Plants, transported to the dam, and after spreading, are compacted in layers like Roller Compacted Concrete. Generally, the material of the Dam body is called "Hardfill".

The main challenge in designing a composite dam is at the interface of Embankment and Rigid part that is called "Contact". The behavior of the Contact during a strong earthquake shaking is critical to the safety of a composite dam.

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CMD type has a wide cross-section area with a low deformation modulus. Therefore, it is possible to have a CMD (that is Rigid or Gravity dam) on a low strength rock foundation. This wide cross-section area has a geometry between a Concrete (RCC or Conventional) and an Embankment Dam. Therefore, it has more compatibility at the Contact of the Embankment and the rigid area.

In thispaper, the main advantage of this type of design is presented with a casestudy. The question to be answered is “How CMD type can modify the behavior ofthe contact region in the Dasht-e-Palang composite dam?”

2. General specification of the Dasht-e-Palang project

Dasht-e-Palang Dam is a reservoir dam for regulating 50MCM drinking and agricultural water per year. Based on water recourses management studies, a 56m high dam will supply all demands. The Dasht-e-Palang Dam is a composite of Gravity and Embankment type under construction at the south of Iran [1].

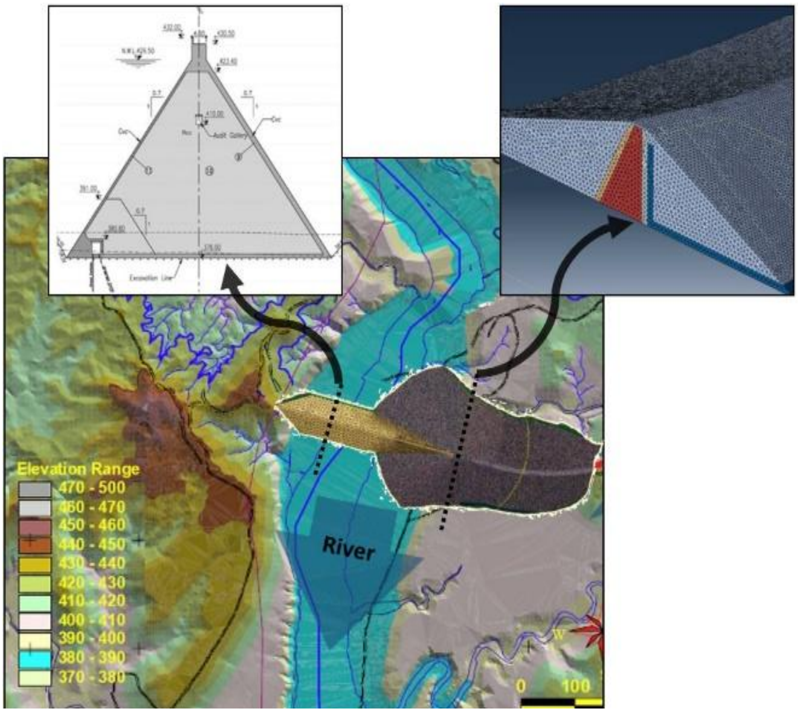

Figure 1. Dasht-e-Palang dam layout
(A composite of CMD &Embankment)

The general specifications of the dam are as follows:

- Rock foundation: very weak Siltstone and Sandstone
- Peak Maximum Flow of the river: 6000 CMS
- Maximum height: 56 m
- CMD part crest length: 350 m. Embankment part crest length: 680 m
- CMD part crest width: 4 m. Embankment part crest width: 8 m
- The upstream and downstream slope of the rigid part: 0.7h /1.0 v
- The upstream and downstream slope of the Embankment part: 2.5h / 1.0v
- Hardfill volume: 540,000 m3. CVC volume: 150,000 m3
- Embankment volume: 950,000 m3
- Spillway: ogee type on the dam body with a 160m width

3. Why a composite type is selected as the dam body?

All suitable locations for the dam axis were studied in the region, and based on Geology and Economical studies, the final axis is selected as shown in Fig.1. Construction materials limitation (especially lack of clay), high magnitudes of flood in construction phase (diversion system type), high magnitudes of flood in operation phase (spillway size) and low quality of bedrock leads to selection a composite type of dam as the optimum selection of the dam type.

In the first stage of dam body design, Embankment type (with Asphalt Core) is designed for Dasht-e-Palang site. Other concrete types (Arch, CVC, and RCC) were put aside because of the low strength parameters of the rock foundation.Although, in Embankment type, the high volume of floods has the main challenge in designing the construction stage (diversion system designing) and operation stage (spillway designing). In single Embankment variants (consisted of Asphalt Core Earthfill dam and Clay Core Earthfill dam), spillway designing at one abutment is the main challenge.On the right abutment, it is not possible to use a flip bucket structure as an energy dissipater, because it has a high risk of the erosion of the dam body at the downstream.Stilling basin design will cause a large amount of excavation that is not economical.On the left abutment, there is a long dry stream way where is downstream of the spillway. It has a low capacity for conveying floods and in many cases, it will cause backwatering and may damage Embankment toe.Therefore, constructing a spillway on a rigid dam body at the flood plain of the river is considered.In this manner, at the middle and right part of the longitudinal axis of the dam, a CMD type is designed which has a main function as a spillway.Another part of the dam (left part), is designed as Clay Core Earthfill dam [2].

4. VARIANTS IN DESIGNING OF THE CONTACT

The Embankment may separate or slip from rigid section during strong earthquakes. It allows water to inject along the upstream face of the Rigid dam. The repeated separation/attachment of Embankment/Rigid dam can result in a permanent gap due to the plastic Embankment deformation, internal erosion due to the water pumping action and finally it will cause the dam failure.

To overcome this phenomenon, three methods are at hand to designing the contact area:

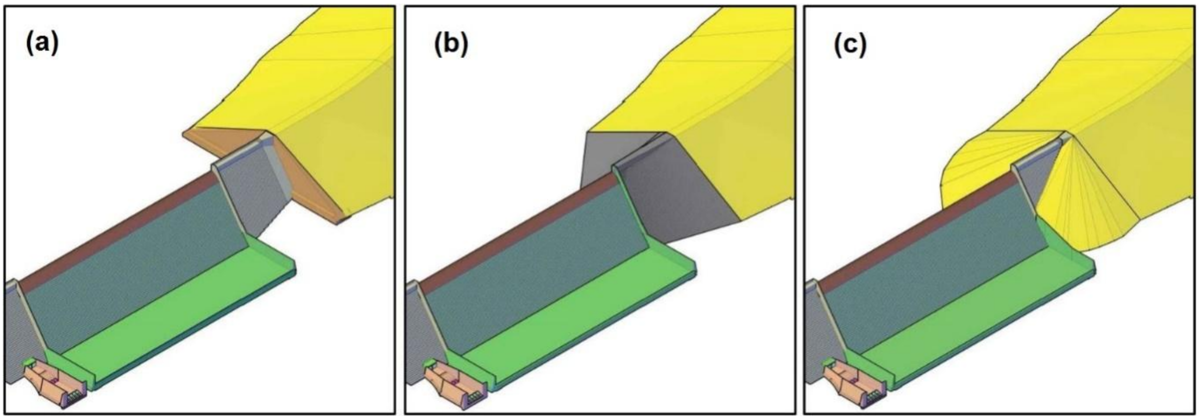

Figure 2. Three methods of transition designing from Rigid part to Embankment Part

(a) Designing a cantilever wall for retaining the Embankment part.

Because of the poor values of the rock foundation parameters, here it is not possible to have a conventional cantilever wall; therefore, this variant was lifted aside.

Figure 3. A sample of wall design method (Itapúa Dam)

(b) Designing a gravity transition (or Gravity wall) between Embankment and CMD parts.

In the conventional section of gravity dams, the transition between two parts is restricted of a narrow section in gravity part. Therefore, this type of contact is not used typically. The main reason is the cost of this method in comparison to the third method; therefore, this variant was also liftedaside.

(c) Designing the Embankment part as it wrapped around the CMD part.

This method is widely used all over the world and was selected in this project. The wide cross-section area of CMD and also low Modulus and frequencies of foundation resulted in more compatibility between Embankment and CMD parts in comparison to other combinations.

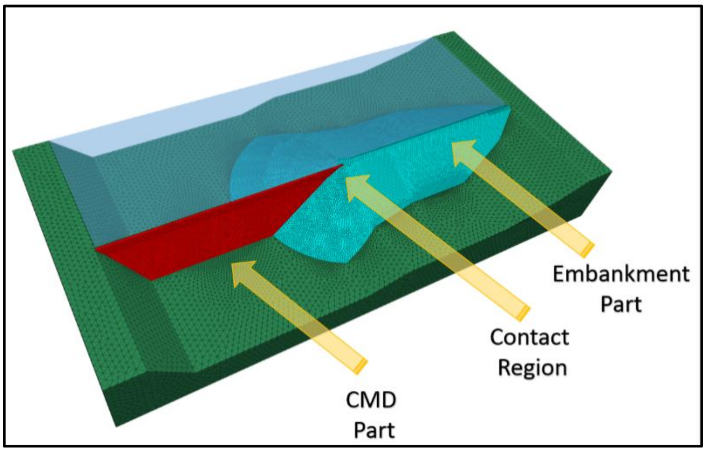

Figure 4. Wrap around method (Dasht-e-Palang Dam)

5. BASIC DESIGN OF CONTACT

At the first stages of design, the cross-section of CMD was decreased so that only the clay core of Embankment was laid on CMD part. In the perpendicular section of the dam body, the inclined plane of contact has two slopes. At the next stages of design, these modificationswere performed based on technical experiences and initial 2D analysis:

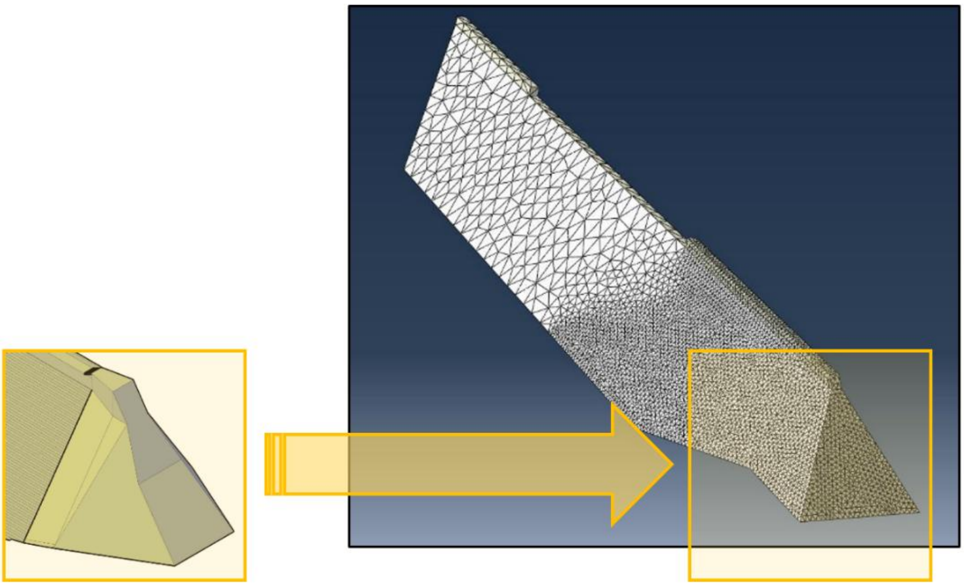

Figure 5. Corrections on the geometry of contact at Rigid part

The effect of the upstream interface slope angle has a significant effect on the interface separation and pressures along with the interface.

6. SELECTION AMONG PHYSICAL OR NUMERICAL MODELING

Many combined dams are modeled by centrifugal tests and then constructed and have a good performance all over the world [3]. Nowadays, due to developments in 3D numerical analysis, many combined dams are analyzed only with numerical analysis instead of centrifugal tests. It should be noted that physical tests only predict quality and conceptual behavior of contact area, whereasnumerical models have more advantages in these fields such as:

- Reducing the cost and time of modeling
- The Flexibility of the numerical model in modifying geometry and properties of materials
- Obtaining all desired output parameters in the model

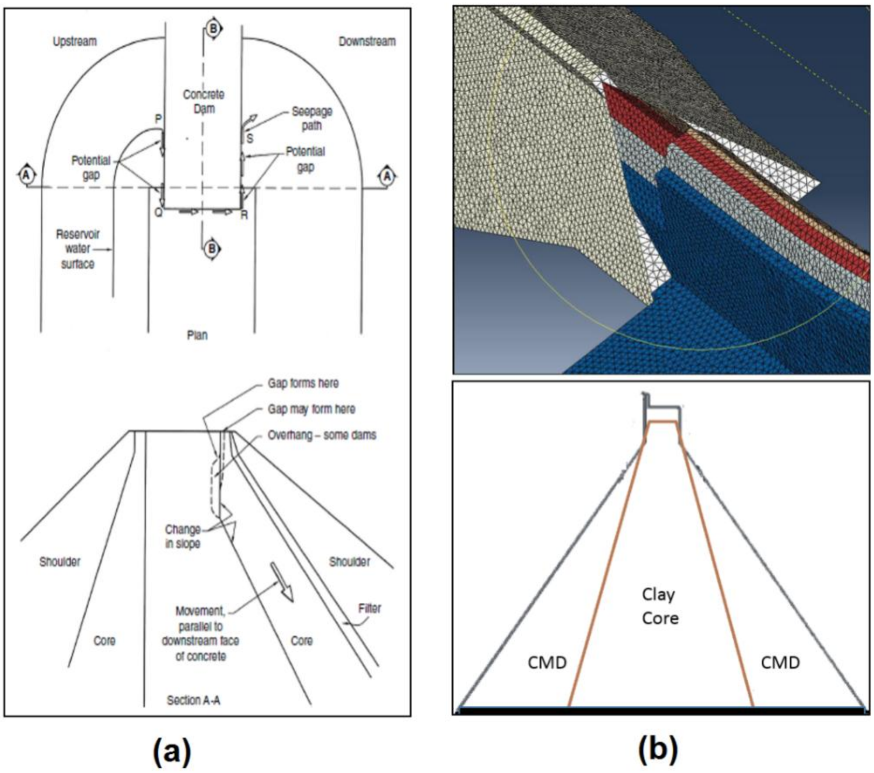

Figure 6. (a) Narrow area of RCC for supporting clay core
(b) Wide area of CMD for supporting clay core

7. 3DANALYSIS OF DASHT-E-PALANG COMBINED DAM

The behavior of the CMD part and Embankment part of composite dams at contact region (interface area) are not the same.Therefore, dynamic interaction between these two parts and the effect of it on the stability and on the dam water-tightness is very important, especially during and after an earthquake. It is possible to have a plastic deformation of soil after an earthquake and if this separation is wide, then it will cause piping and major failure of the Embankment part of the dam. Therefore, 3D dynamic analysis of contact was investigated in this project.

The analysis was performed by FLAC3D software [4]. About 1.5 Million pyramid elements were used to modeling foundation and dam body. CMDand Embankment parts were connected by interface elements. These elements can slide or separate or contact together in earthquake loading. The behavior model of Embankment part is Mohr-Coulomb Elastoplastic and for other parts is Linear-Elastic.

The bonding between CMD layers is generally less than the RCC layers due to low cement content, no treatment between successive layers, no need to bedding mortars between layers and finally more segregation compared to RCC. We can elicit that the layered behavior of the dam body under loadings should not be neglected. Layering behavior of CMD part has an important effect on the output results. One of the methods is to model the layers of the dam body one by one and considering their interfaces using the appropriate approach [5]&[6]. Although this method is more reliable than ignoring the multilayer properties of the materials, performing this complicated method is far more time-consuming and thus impractical, especially in dynamic loads. Another method is to find a way for the estimating of "3D modulus of dam body" whereas the estimation of the modulus of deformation must be sufficiently close to reality in order to give valid stress analysis results.

The strength properties of the CMD layers are reduced in the direction normal to the layers. Employing the mechanics of multilayered or composite materials, we can define an orthogonal material with two different moduli in two perpendicular directions. Mohammadian [7] proposed two methods for the better estimating of dam body modulus in CMD's using these concepts.

Comparing the stress results of a 2D analysis of CMD in two variants (first one with different horizontal and vertical values for E and the second one with equal decreased values for E in both directions) shows that variations are neglectable, therefore, the further 3D analysis was just performed by decreased E.

Boundary conditions were considered as Absorbent Free-Field boundaries to minimize the effect of boundary effect on the model.

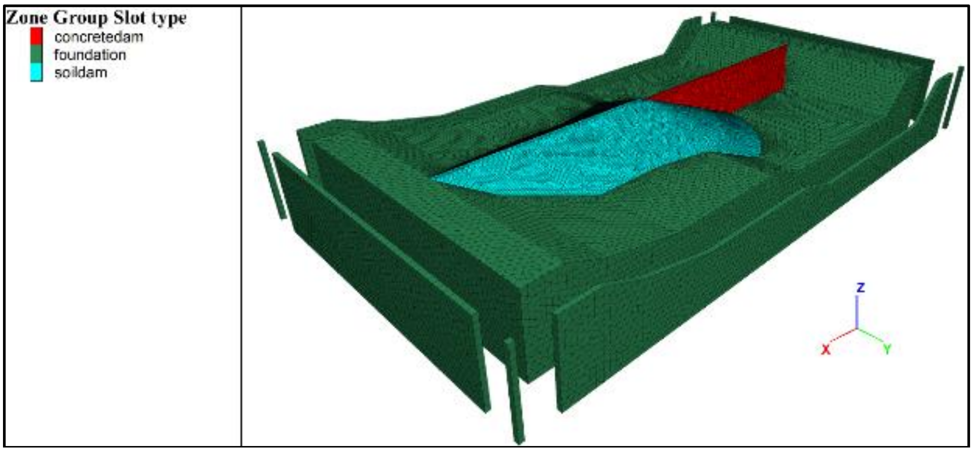

Figure 7. Absorbent Free-Field boundaries

Based on the Dasht-e-Palang seismic studies, the Peak Ground Accelerations are as follows:

DBL: 0.25g (horizontal) 0.15g (vertical)

MCL: 0.54g (horizontal) 0.40g (vertical)

After correction of baseline, filtration and scaling by peak acceleration, the records of Avaj, Baladeh and Zarand were used as DBL level and the records of Karebas, SanFernando and Northridge records were used as MCL level.

Hydrodynamic pressure of reservoir on dam body was inserted on the model by the Westergard added mass method.

Analysis:

Due to the high nonlinearity of the problem, the analysis was quite time-consuming. Five parts of the analysis were as follows:

1) 3D seepage analysis was performed as the prerequisite of other analysis.
2) Stability analysis of the dam was performed in Static and Pseudo-Static conditions.
3) Residual deformation of Embankment part was analyzed at the end of dynamic loadings.

4) deformations, strains, and stresses were calculated.
5) Dynamic interaction of CMDand earth-fill parts at contact is investigated.

Results:

1) The pore-pressure distribution was obtained.
2) The minimum safety factor of the critical sliding surface in the static condition was obtained as 1.9 and in the Pseudo-Static condition equal to 1.03. These surfaces are far apart of the contact area.

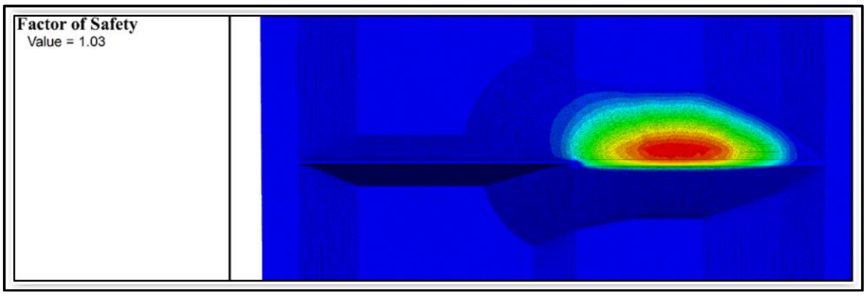

Figure 8. The minimum safety factor of the critical sliding surface in the Pseudo-Static condition

3) Residual deformation of the earth-fill dam in DBL level was limited to 25cm and in MCL level was not more than 120cm, which are acceptable. It is worthy to notice that residual deformations of the Embankment at contact region (where the Embankment is laid on the CMD) show more amounts but it will have no risk of overtopping on dam body because the Rigid CMD part will support the reservoir.

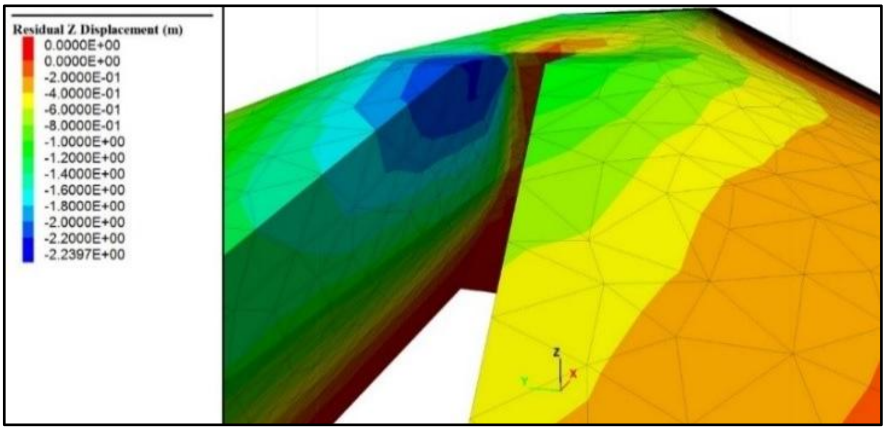

Figure 9. Residual deformation of the earth-fill dam (MCL, Karebas record)

4) Maximum deformations at CMD part at DBL and MCL levels are 5.5cm and 10.2cm respectively which are at the reasonable ranges. Maximum principal stresses in tension, compression and vertical lift separation are below the allowable stresses in all of the load combinations after omitting the partial concentration areas.
5) Evolution of residual separated contours and variations of normal dynamic stress on normal static stress between the Embankment and CMD parts on contact surfaces shows that normal stress loading on clay core bed is nowhere and no time equal to zero during earthquakes. This parameter shows that the clay core of Embankment part is settled on CMD part and has no separation during earthquakes and it reveals the major advantage of CMD-Embankment composite dams.

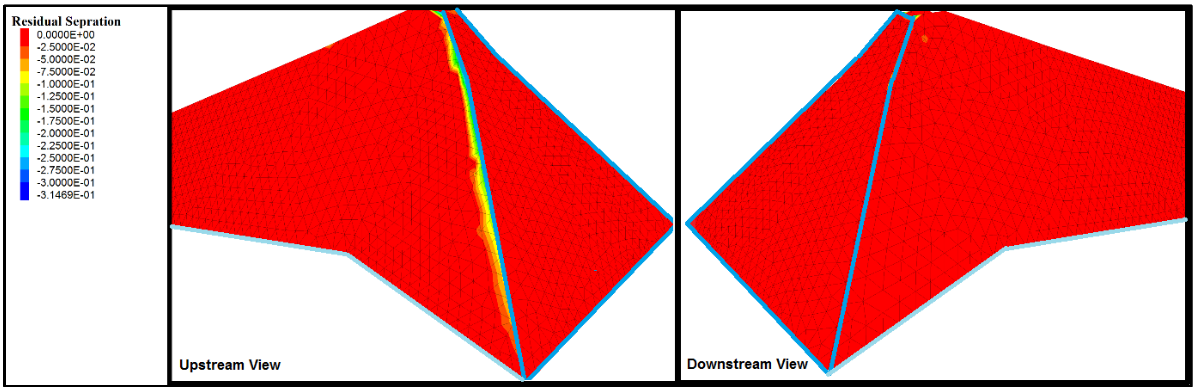

Figure 10. No Residual separationon clay core bed at MCL
(Some minor counters at edges are arises from modeling and are not real)

For better interaction between Embankment and CMD especially at high levels of the dam, based on the above analysis, these optimizations in the geometry of contact is concluded as follows:

- Deleting the vertical slope of CMD section at the crest.
- Designing an arena at the interface of Embankment and CMD sections to eliminate the differences between two crest levels.
- Designing fillets at all edges of contact especially where the filter and drains of Embankment meet the CMD.

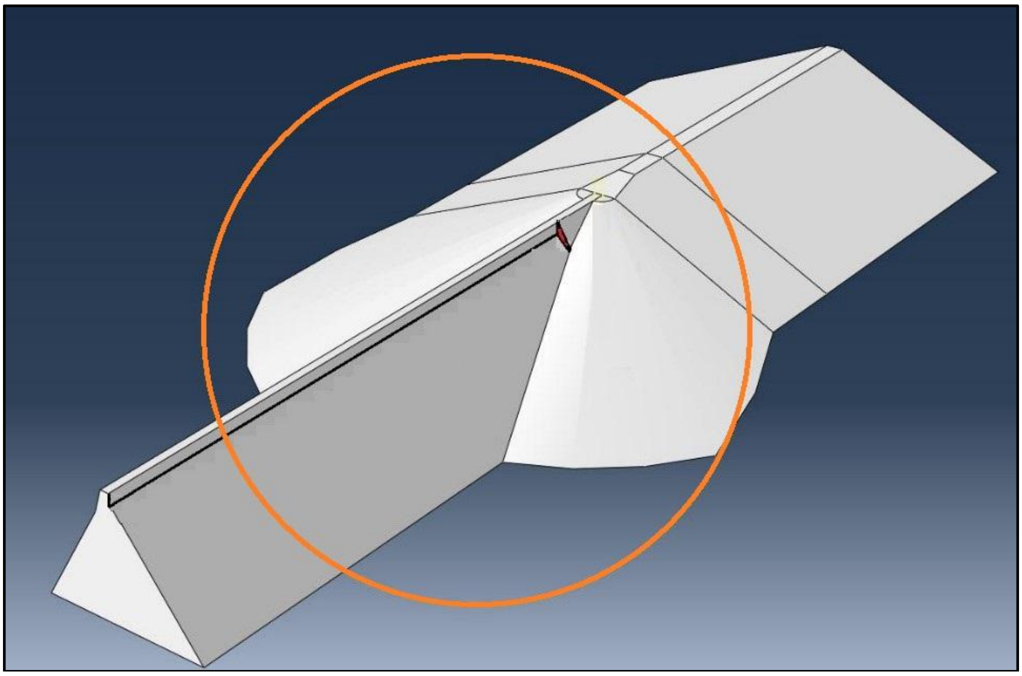

Figure 11. The optimized geometry of the contact area

8. Conclusions

Dasht-e-Palang Dam as a case of composite CMD-Embankment dam was modeled in this paper. Two main results of this study are:

- 3D geometry effects of CMD upstream slope (at the high levels of the dam) has the main effect on the stability of Embankment part.
- The separation of Embankment -Rigid Contact is minimized using CMD as the Rigid Part of the composite dam.

9. ACKNOWLEDGMENT

The work presented in this paper was supported by the Bushehr Regional Water Authority. The authors wish to thank A. Mohammadi from BRWA and A. Ghezel-Ayaghand A. Bolouri from ABFAN co.for their reviews and discussions.

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