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Relative Performance Evaluation of Asphaltic Concrete Core Embankment Dam and Clay Core Embankment Dam: By Plaxis Software Application

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Abstract: This paper investigates asphaltic concrete core embankment dam in relative to the clay core embankment dam so that it is vital from the perspective of safety and controlling seepage. Plaxis 8.5, finite element based software was employed for analysis of the dam and Geostudio 2012 for seepage analysis. Relatively the result of analysis shows that good result of safety factor has been found in asphalt concrete core dam with regard to the stability of the dam during steady-state condition and end of construction. During steady-state condition, the factor of safety computed for clay core dam was 1.466, and the dam fails to attain the minimum factor of safety recommended by USACE. But, under this similar condition stability analysis result of asphalt concrete core dam gave a good result of 1.661 which is found within the recommended range. Likewise, at the end of construction, the factor of safety computed for clay core dam was 1.553, but, under this loading condition (end of construction) stability analysis result of asphalt concrete core dam gave a good result of 1.600 which keeps the dam more stable. The seepage analysis result of asphaltic concrete core dam is also insignificant. Generally, application of asphalt concrete core in rock fill dam can fulfill the basic requirement and minimum factor of safety under all loading condition, and dam of such types is seepage free as it shown here and approved by many other researchers' extensive works.

Keywords: Asphaltic Concrete Core Embankment Dam, Clay Core Embankment Dam, Plaxis Software, Stability, Seepage

1. Introduction

Globally, everywhere over the world water requirements are not similar to its availability. Therefore, building a dam of any type is one of the simple concepts for fulfilling this water requirement. Accordingly, the asphaltic concrete core embankment dam is gaining its popularity as the advantages of this design become more apparent from the perspective of safety, economy, and controlling seepage [14]

Asphalt concrete has an excellent record of self-healing advantage when it suffers cracks so that it minimizes the seepage flow to the insignificant value when it serves as water barrier this is related to its viscoelastic properties [2] As well, Wang and Hoeg argued that the self-healing (self-sealing) ability of the asphalt concrete Core is provided due to its viscoelastic, plastic and ductile properties and this compensates for the problem of cracks developing in the core wall [6]

Asphalt concrete can be placed both by hand inside the formwork with the filter outside and it can also be placed and compacted by machine [3]. The former way of placing core is time-consuming and expensive, but usually necessary, to establish a horizontal base for the core paver. The documented history of asphalt concrete core embankment shows that the first embankment dam with a machine-compacted dense asphaltic concrete core, was built in Germany in 1962, and since 1970 almost only such cores, compacted in thin layers, have been used in large dams [2]

The documented site performance of asphaltic concrete core embankment dam, along with their high degree of water tightness, high deformability, and chemical inertness resulted in their more extensive application, especially in the last 30-35 years, following the engineering and fabrication of machinery for the simple placement and compaction of the asphalt mixture [2].

Countries like Austria, Germany, China, and Norway, among others, have built many of this type of dam over the last 50 years, and now other countries like Brazil and Canada are building their first ones. Similarly, great Ceres dam was the first asphalt concrete core embankment dam constructed in the continent of Africa, in South Africa by vieddekke contractor [5].

2. Method

The objective of the study is to examine the relative performance of asphalt concrete core and clay core embankment dam under different loading condition. The study has mainly used secondary data obtained from Oromia water work construction and design supervision for clay core embankment dam. The computer-based program, Geostudio 2012 and Plaxis 8.5 software were used in this study for the analysis of the dam. Seep/W was used to conduct seepage analysis, and Plaxis was used to conduct stability analysis of dam.

2.1. Plaxis Software

Plaxis is described as a finite element package for geotechnical analysis that can utilize both two-dimensional and three-dimensional analysis in determining the stability and deformation experienced by slopes [11]. PLAXIS is a finite element program, developed for the analysis of deformation, stability and ground water flow in geotechnical engineering. It uses different equation and models for the simulation of soils. The development of Plaxis begin in 1987 at Delft university of Technology as an initiative of the Dutch ministry for public works and water management [4]. Plaxis use various models for analysis of engineering structures (Linear elastic model, Mohr coulomb model, Jointed rock model, Hardening soil model, HS small model, Modified Cam-Clay model, Soft soil model, Soft soil creep model, and User defined Soil model) to simulates the behavior of soil and other continua [4].

2.1.1. Mohr Coulomb

For conducting slope stability analysis with the aid of Plaxis software, Mohr coulomb model was used in for the simulation of material behavior used in the dam. Mohr coulomb model is the most known model and it is used as a first approximation of soil behavior in general. The models utilize five parameters of the material, namely young's modulus, Poisson's ratio, cohesion, friction angle, and dilatancy angle [4].

2.1.2. Slope Stability Analysis

In the design of an embankment dam, it is important to consider not only the final stability but also the stability during each stage of construction. To achieve this, stability analysis of both dam has been checked at different stage of construction. To determine an appropriate factor of safety at each stage of construction, the Phi-c reduction[1] approach was utilized. This process involves the strength parameters $\tan\emptyset$ and c of the soil being reduced until the slope fails [4].

$$\text{safety factor}\left(\sum \text{Msf}\right) = \frac{c - \sigma\tan\emptyset}{c\prime - \sigma\tan\emptyset\prime} \tag{1}$$

Where, C and $\emptyset$, are input strength parameter and σ is actual normal stress component. The parameter c' and $\emptyset'$ are reduced strength parameter that is just large enough to maintain equilibrium. This principle is the basic methods of safety that can be used in Plaxis to calculate a global safety factor. In this approach, the cohesion and the tangent of the friction angle are reduced in the same proportion.

$$\sum \text{Msf} = \frac{\tan\emptyset}{\tan\emptyset\prime} = \frac{c}{c\prime} \tag{2}$$

Safety factor (∑Msf) of a given construction stage is expressed by plotting values of FoS against displacement at that particular construction stage or the second alternative of computing safety factor in Plaxis software is available under calculation information option of view menu of Plaxis output, in which one can directly access to safety factor (ΣMsf) of the corresponding current calculation [4].

2.2. Geostudio Software

Geo-studio is among the world wide used software for the analysis of engineering structure, and it is one of geotechnical program that can conduct analysis like stress strain, seepage, slope stability, dynamic analysis, and fast water drop in reservoir. This software has a number of package in it selves, SEEP/W for conducting seepage analysis (to quantify the amount of seepage water through embankment material), SLOPE/W for conducting slope stability of both manmade and natural slope, SIGMA/W for conducting deformation analysis, QUAKE/W, for conducting earthquake effect on the structure, and etc.

Seepage analysis: Steady-state seepage analysis is carried out to estimate the amount of seepage through the two[2] embankments dam section and foundation materials. The analysis is conducted using the state of the art finite element method based computer program. SEEP/W software is used here in this study to calculates the seep water that will pass through the material using partial differential equations shown below [9].

$$\frac{\partial}{\partial x}\left(kx * \frac{\partial H}{\partial x}\right) + \frac{\partial}{\partial y}\left(ky * \frac{\partial H}{\partial y}\right) = 0 \tag{3}$$

Where, kx, ky = Coefficients of permeability in (x, y) H = Total head of water.

1 Phi-c reduction is an option available in Plaxis software to compute safety factor

2 Two is used refer Asphalt concrete core and clay core embankment dam.

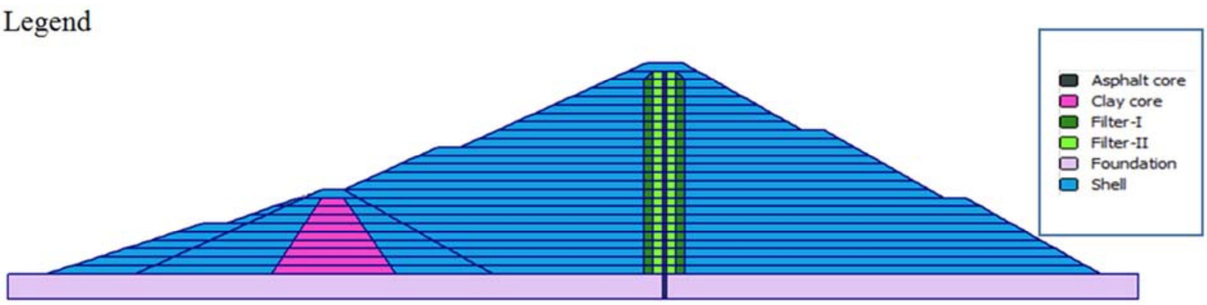

Figure 1. *Asphalt concrete core embankment dam with its materials (source: Plaxis Output).*

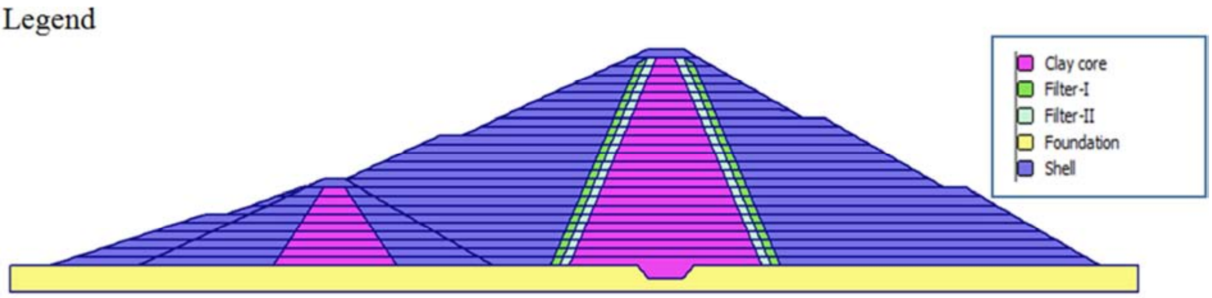

Figure 2. *Clay Core embankment dam with its materials (source: Plaxis Output).*

The upstream slope of the main dam is proposed as 2.0 H: 1V from cofferdam top to dam crest level and 2.5 H: 1V from cofferdam top to the stripped level below. The downstream slope is provided with a slope of 1.5H: 1V with 5.0 m wide berm at 10.0 m vertical height interval. The total height of the dam is 50 m.

Table 1. *Parameters used in analysis of dam.*

Materials	Permeability K(m/s)	γ_{sat}(KN/m^3)	γ_{unsat}(KN/m^3)	C(KN/m^2)	Φ(°)	E(KN/m^2)	References
Asphalt concrete core	$1x10^{-9}$	23.93	23.54	800	35	$2.6x10^5$	[8], [7]
Filter-I	$6.5x10^{-5}$	22.07	20.11	5	34	$4.0x10^4$	[10]
Filter-II	$5x10^{-5}$	21	20.6	5	34	$4.0x10^4$	[10]
Clay core	$1x10^{-8}$	18.5	18	26	27	49050	[10]
Shell(Rock fill)	$5x10^{-7}$	22	21.5	0	41	$5.4x10^4$	[10]
Foundation	$1x10^{-7}$	20	19.5	22	30	$2.0x10^6$	[10]

3. Result and Discussion

a. Result of Stability Analysis of the dam during construction

In the design of an embankment dam, it is important to consider not only the final stability but also the stability during each stage of construction. Thus, both dam has been analyzed by splitting into 25 stage of construction by 2 m depth. as shown in figure 3.

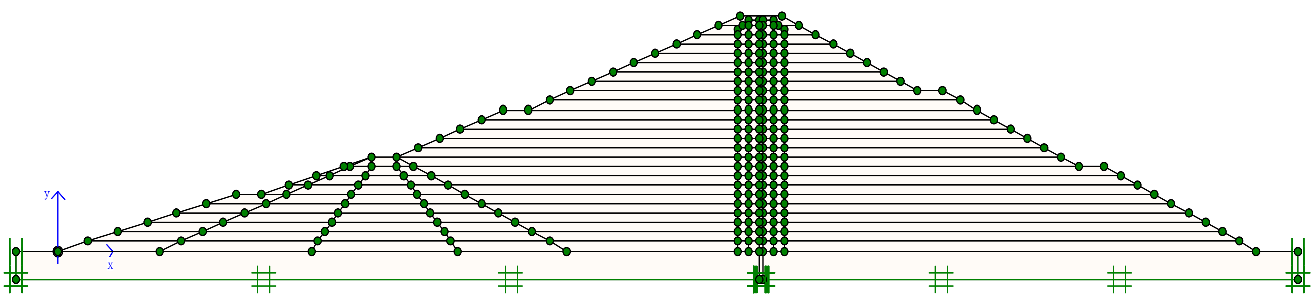

Figure 3. *Staging construction of the dam (Source: Plaxis output).*

The result of stability analysis for the last ten construction stage is selected and shown in figure 7 for ACCED. The result shows that use of asphalt concrete instead of clay core can equivalently fulfill the minimum factor of safety requirement recommended by USACE during construction.

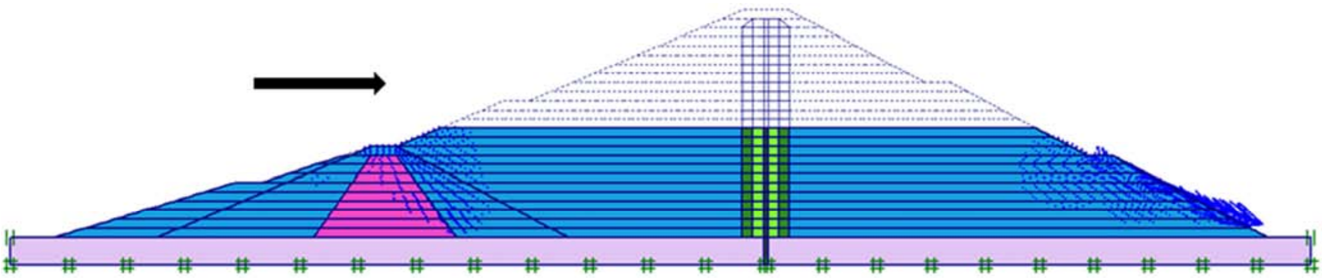

Figure 4. *Possible failure surface of the Asphalt concrete core embankment dam during construction (Source: Plaxis output).*

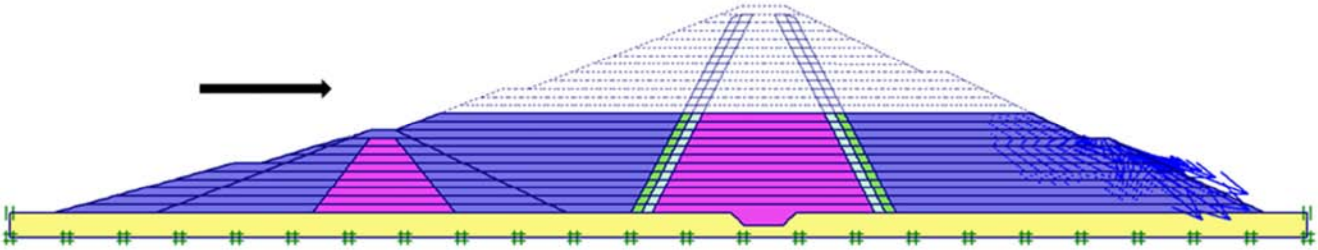

Figure 5. *Possible failure surface of the Clay core embankment dam during construction (Source: Plaxis output).*

The figures 4 and 5 shown above are used to represent a physical idealization of possible failure surface at the intermediate stage for ACCED and CCED respectively. The factor of safety computed for ACCED and CCED at the intermediate stage for which its physical idealization is shown above in figure 4 and 5 are plotted together against displacement as shown in figure 6. The graph plotted by blue color stands for FoS of ACCED and it reads as 1.638. Similarly, the one plotted by red color is stands for FoS of CCED which read as 1.618.

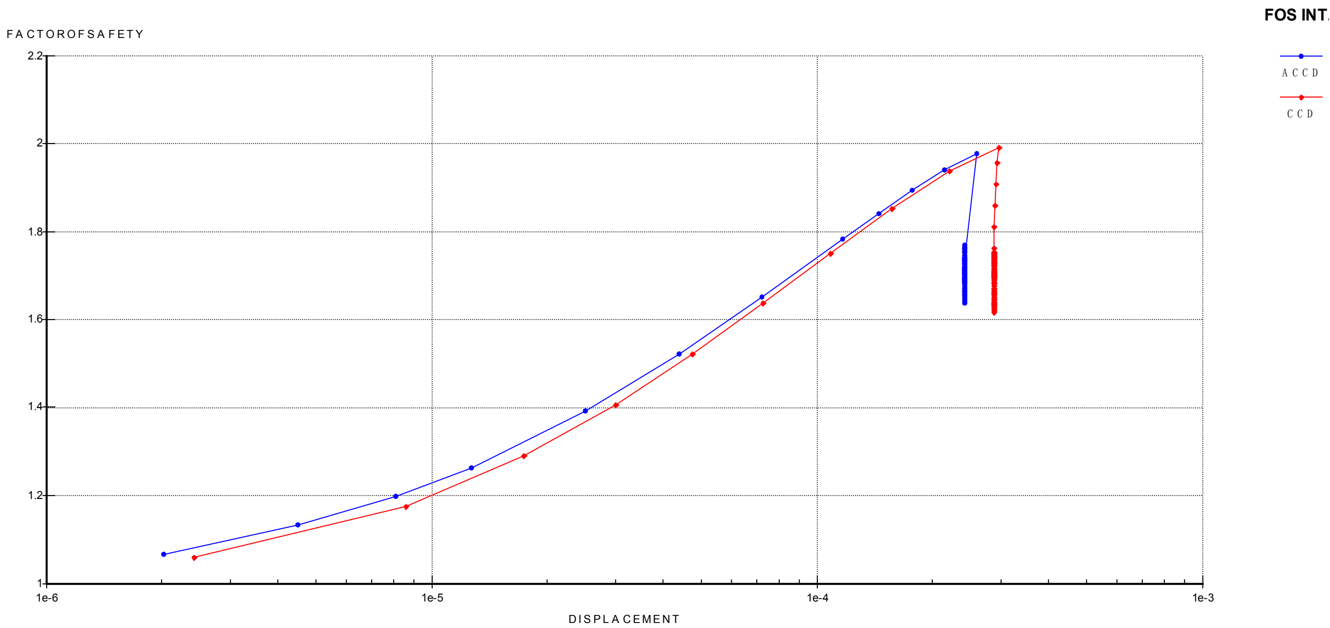

Figure 6. *Factor of safety of ACCED and CCED at intermediate stage (source: Plaxis Output).*

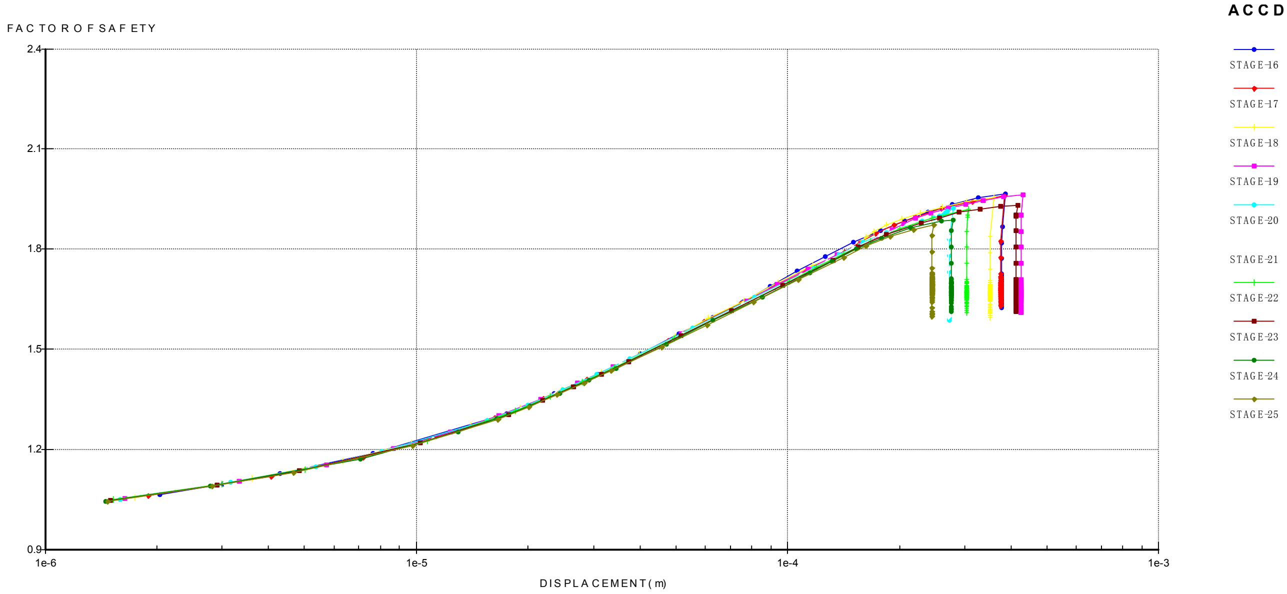

Figure 7. *Plotted safety factor for ACCD for the last 10 construction stage (source: Plaxis Output).*

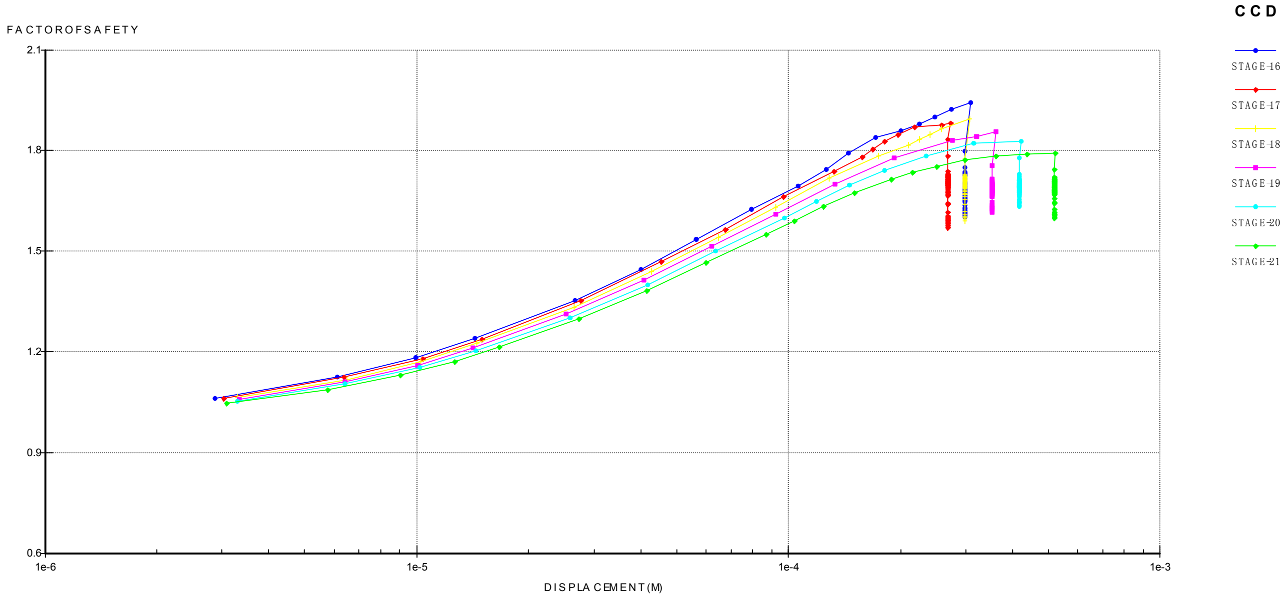

Figure 8. *Plotted safety factor for CCD for the last 5 construction stage (source: Plaxis Output).*

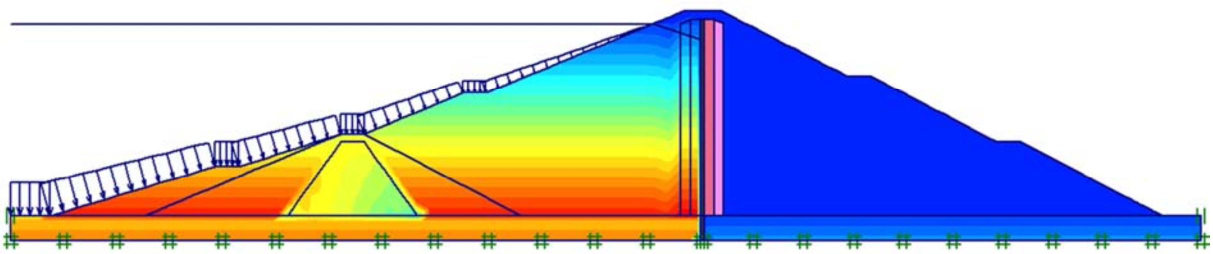

Figure 9. *Pore water pressure distribution in Asphalt concrete core embankment dam (source: Plaxis Output).*

The significant and most determinant that governs stability of embankment is not merely when the dam is under state of construction. Stability analysis during steady state, after impoundment of dam and end of construction due to pore water pressure development is yet another significant condition under which dam needs to be stable.

b. Result of Stability analysis of the dam during Steady state condition

After a prolonged storage of reservoir water, water percolating through an embankment dam will establish a steady-state condition of seepage and the dam is a need to be analyzed for this condition. The result of water pressure distribution due to prolonged storage of reservoir is indicated in figure 9 for asphalt concrete core dam shows that, due to the application of asphalt core in the dam, the downstream shoulder of the dam is dry. This shows imperviousness of asphalt concrete, that is why flux reading during seepage analysis is gives zero as shown under seepage analysis section in figure 22.

In dry soil, the pore pressure is zero (as shaded by dark blue) in figure 9. Above the water table, when the soil is saturated, pore pressure will be negative. Hence, the dam foundation is above the ground water table, there is no positive values of pore water pressure, and downstream is dry and the region labeled by values 0.000 at downstream is used represent dry soil due to block of seepage flow by asphalt core.

Upstream shoulder of the dam is labeled by negative values of pore water pressure, which is simply used to demonstrate the existence of the region under influence upstream water reservoir. The plotted result of stability analysis for asphalt concrete core dam shown below in figure 10 during steady state condition gives the good result of safety factor (1.661). But, CCED during this condition fails to attain the minimum factor of safety requirement recommended by USACE.

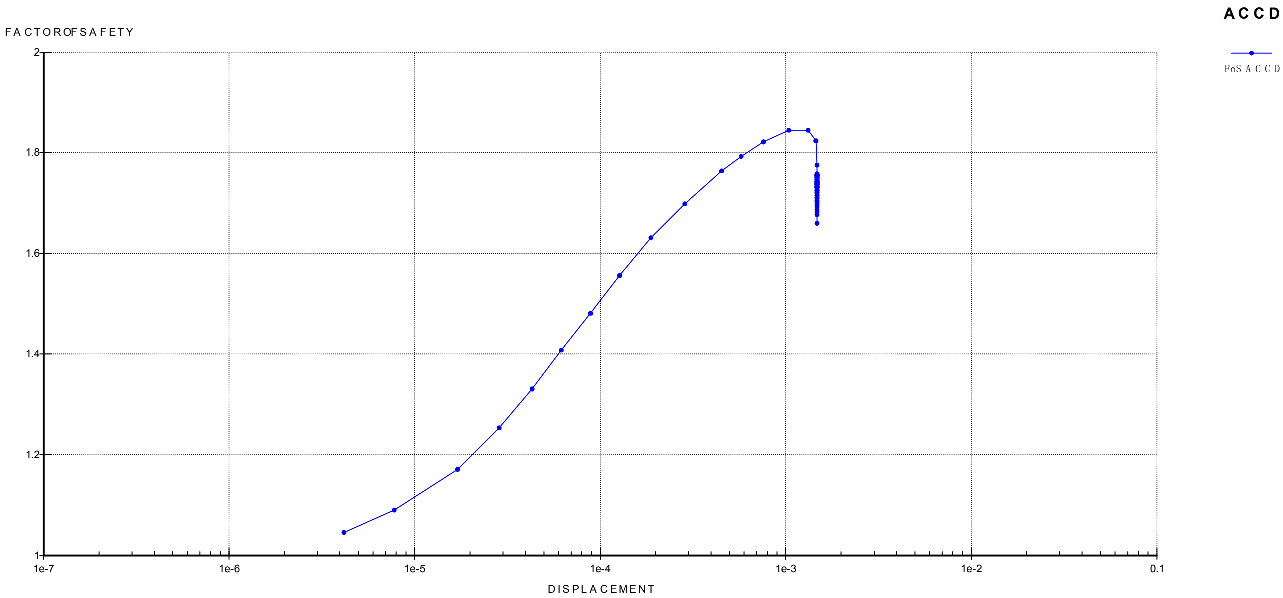

Figure 10. *Factor of Safety of Asphalt concrete core embankment dam (steady-state condition) (source: Plaxis Output).*

Likewise, under the same condition (steady state) the clay core embankment dam has also been analyzed for steady-state loading condition. Water pressure distribution in clay core embankment (shown in figure11) dam is different from that of the asphalt concrete core embankment dam shown above in figure 9. In CCED greater portion of the dam, the body is wet so that the downstream region of the dam is not totally dry as in the case of asphalt concrete core embankment dam. Due to this fact, relatively factor of safety of the clay core embankment dam is getting low below the minimum factor of safety requirement.

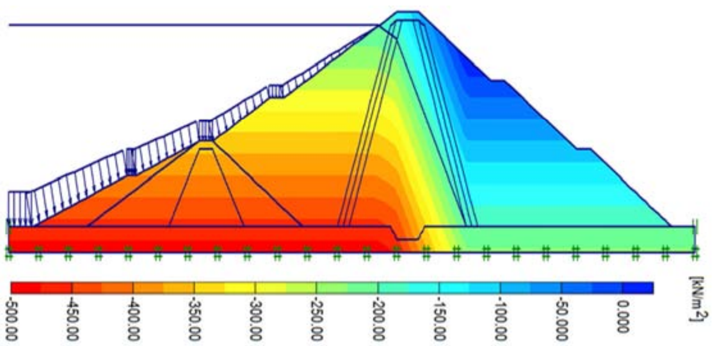

Figure 11. *Pore water pressure distribution in Clay Core embankment dam (source: Plaxis Output).*

Therefore, under steady state loading condition in which upstream water impounded within the dam highly influence the strength of dam materials, the use of the asphalt concrete core instead of clay core gives better FoS which is found within minimum safety factor requirement recommended by USACE. As shown in figure 12 the result of FoS of the clay core embankment dam is 1.466 which is below a minimum factor of safety requirement.

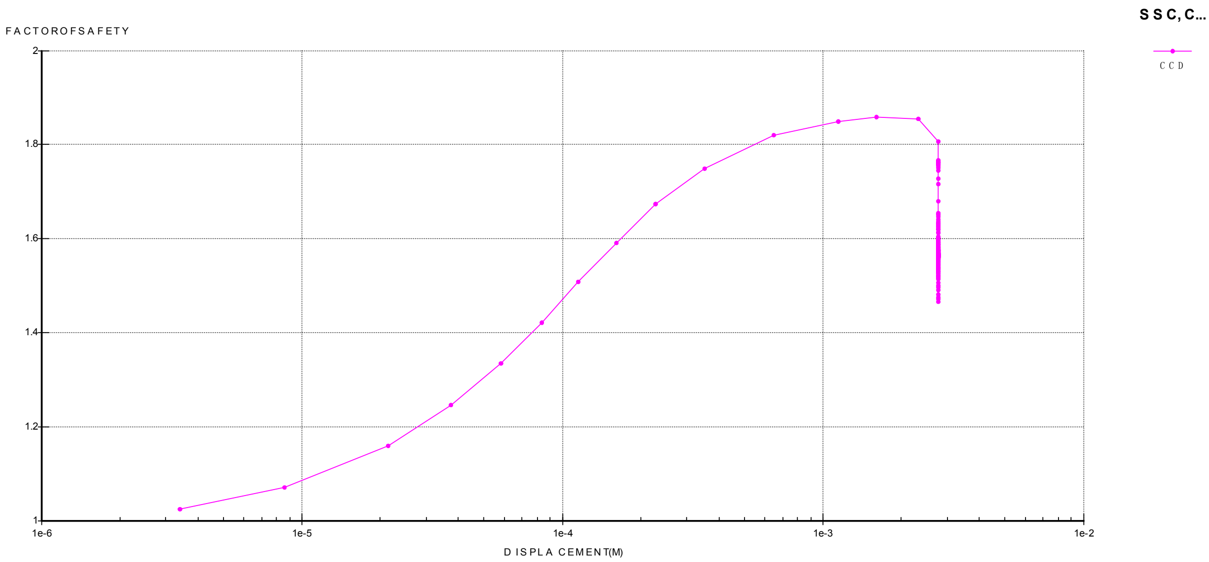

Figure 12. *Factor of Safety of Clay Core embankment dam (steady-state condition) (source: Plaxis Output).*

c. Result of Stability analysis of the dam at end of construction

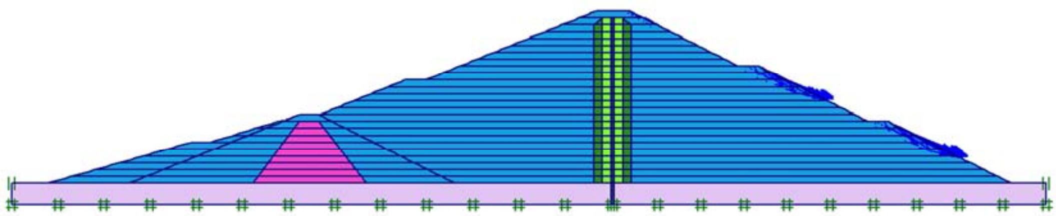

Figure 13. *Possible failure surface of asphalt concrete core embankment dam (by arrow approach) (source: Plaxis Output).*

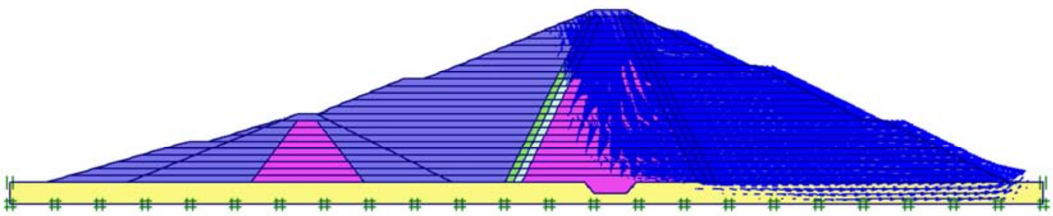

Figure 14. *Possible failure surface of clay core embankment dam (by arrow approach) (source: Plaxis Output).*

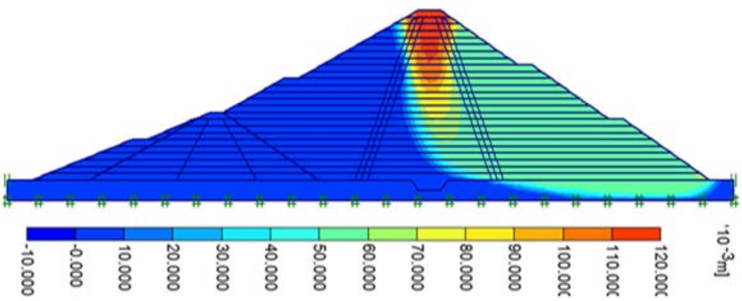

Figure 15. *Possible failure surface of clay core embankment dam (by shading approach) (source: Plaxis Output).*

During construction, embankment layers may become saturated as a result of consolidation of the layers or by rainfall. This can tends to the development of pore water pressure in clay core region of the dam. But, when asphalt concrete core is used instead of clay core there is no such development of pore water pressure in the dam (especially in core region of the dam). That is why FoS of asphalt concrete core embankment dam gives better result even when the two dam are analyzed under the same condition. As shown below in figure 16 the analyzed result ACCED during the construction gives safety factor of 1.600

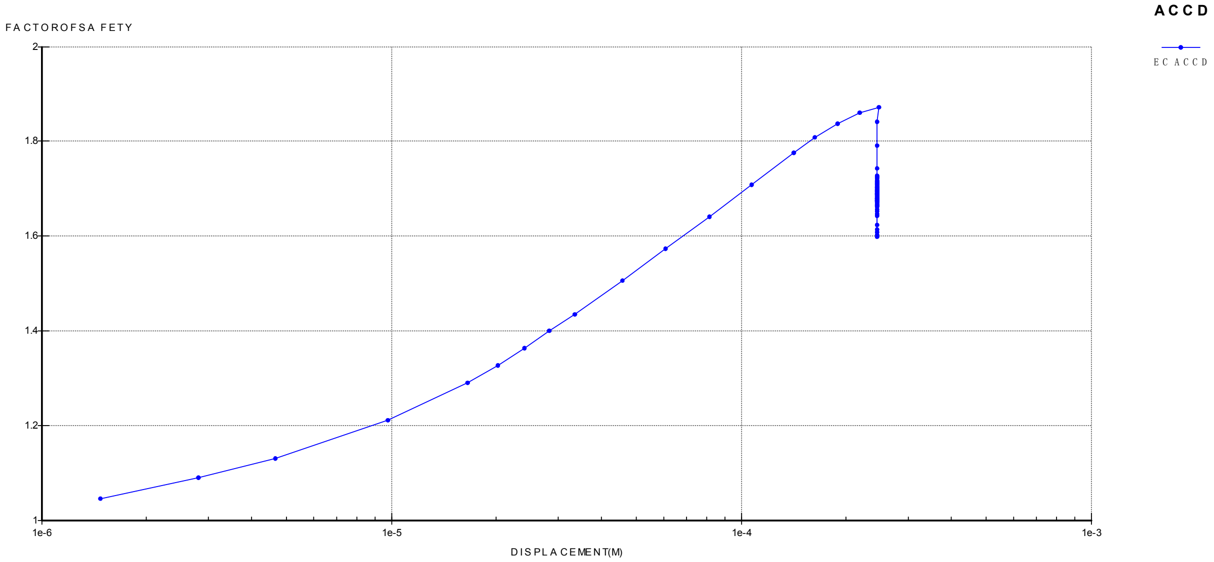

Figure 16. *Factor of Safety of Asphalt concrete core embankment dam (End of construction) (source: Plaxis Output).*

Due to the development of pore water pressure in clay core region of the dam as shown above in figure 14 and 15 the computed result of factor of safety for clay core embankment dam is lower than that of ACCED.

As shown above in figure 15 by shaded approach, due to fineness nature of clay core, the region is more susceptible to the pore water pressure development. This is because water which is showered clay core region during construction to maintain its optimum water content will not drain quickly as it to do in coarse region of the dam. As a result of this, the development of pore water pressure is highly expected to occur in clay core embankment dam, not in asphalt concrete core embankment dam so that clay core is represented by asphalt concrete.

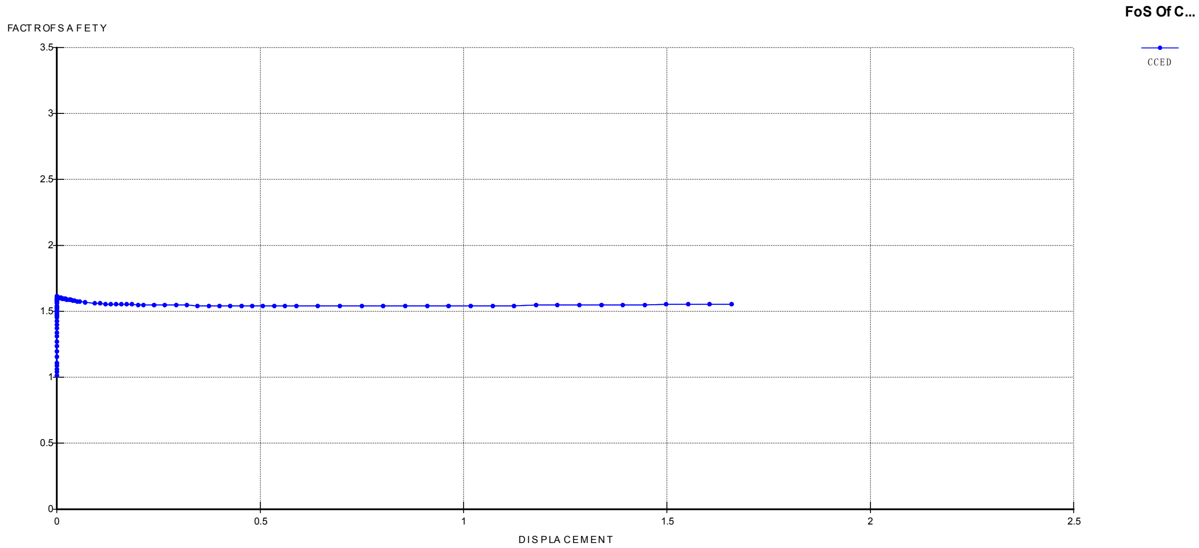

Figure 17. *Factor of Safety of Clay Core embankment dam (End of construction) (source: Plaxis Output).*

Therefore, the analysis result of the two dam shows that, use of asphalt concrete core instead of clay core can give better result of safety factor under the most significant loading condition (steady state and end of construction).

Table 2. *Summary of computed safety factor obtained for both dam and its comparison with standard.*

Loading condition	ACCED	CCED	Standard USACE,(2003)	Remark ACCD/ CCD
During construction(*)	-	-	1.3	Safe/Safe
End of construction	1.600	1.553	1.3	Safe/Safe
Steady state	1.661	1.466	1.5	Safe/not

*= during construction the values FoS is shown plotted in figure 7 and 8.

d. Vertical displacement

The position at which the maximum vertical displacement about to occur obtained in this study is confirmed to the result found by [2]. Fang and Liu has conducted their study on "Stress-strain analysis of Aikou rock fill dam with asphalt-concrete core" and the result of vertical displacement they found shows that, the maximum vertical displacement is appear near crest of the dam, which is similar to what is found here in this study.

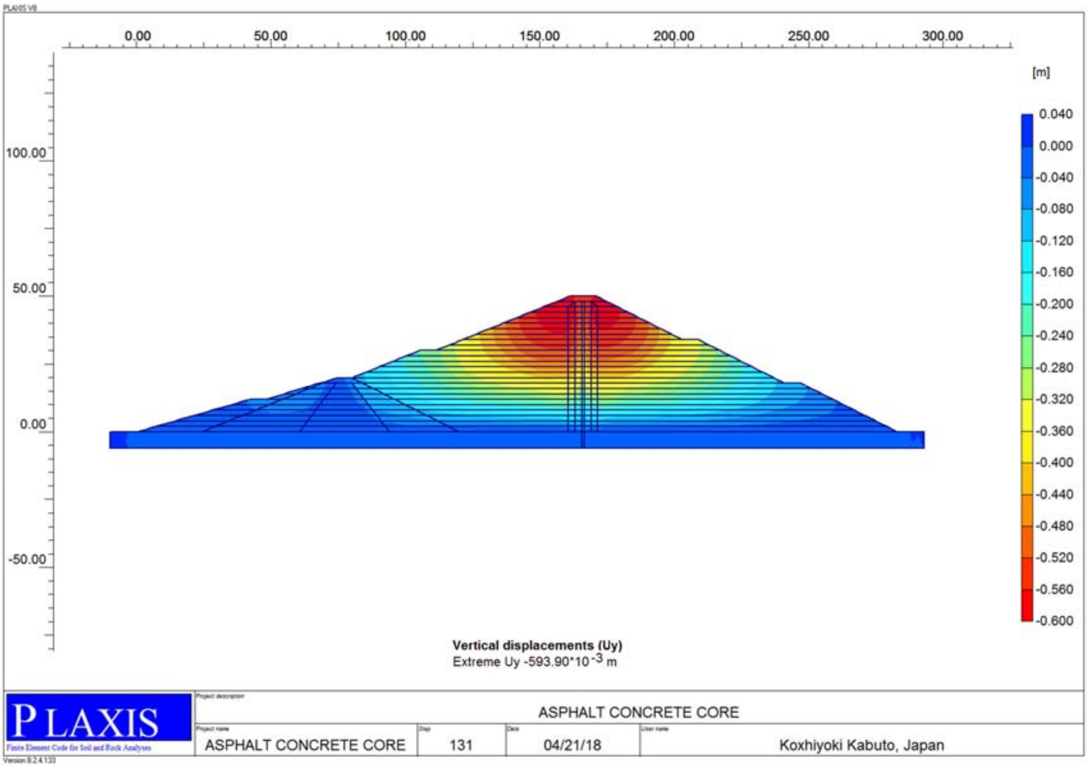

__Figure 18.__ Vertical displacement of asphalt concrete core embankment dam (source: Plaxis Output).

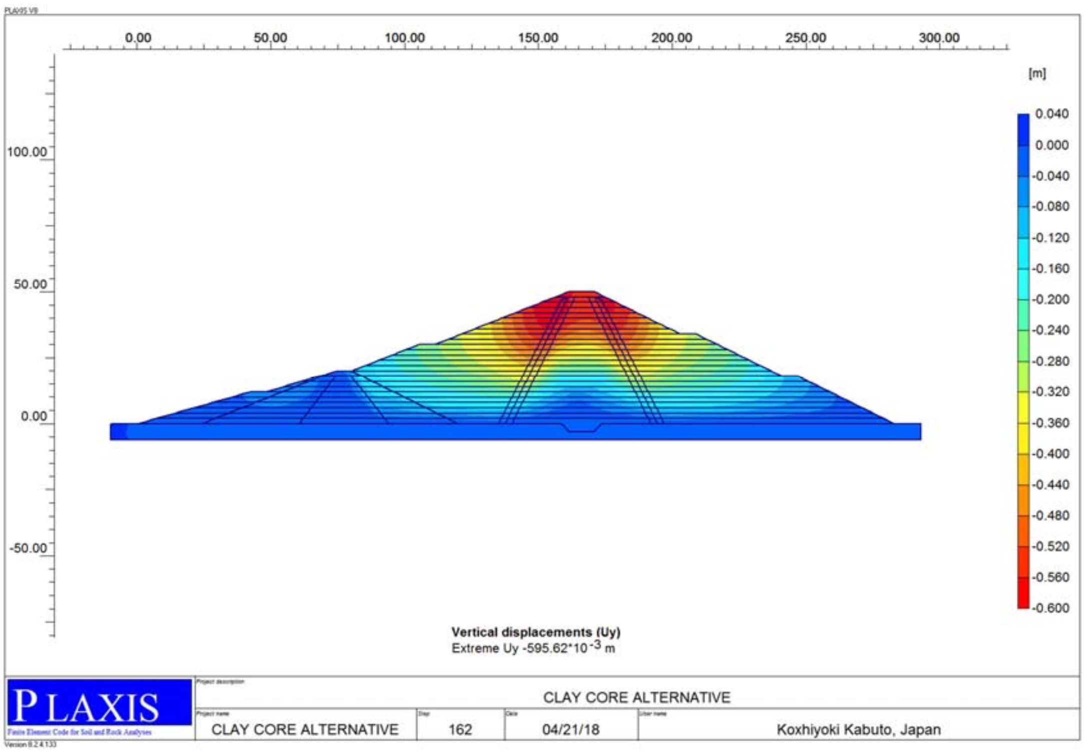

__Figure 19.__ Vertical displacement of clay core embankment dam (source: Plaxis Output).

The figure 19 shows that, the maximum vertical displacement of 0.59562 m is found near crest of dam. As this value is found within allowable recommended range, a vertical displacement of magnitude 0.59562 m in clay core dam will not have significant effect on the dam. Therefore, with regard to vertical displacement, the analyzed result show that both asphalt concrete core and clay core dam gives good result.

However, in case of excessive deformation, asphalt concrete core can be with stand the induced deformation without cracking. But, in case of clay core dam, it cannot withstand some excessive deformation without crack, and once if crack occur, without any doubt internal piping will affect the overall performance of the dam. So, with regard to this effect, the use of asphalt concrete core is desirable so that the dam can be stay safe throughout

e. Result of Horizontal displacement

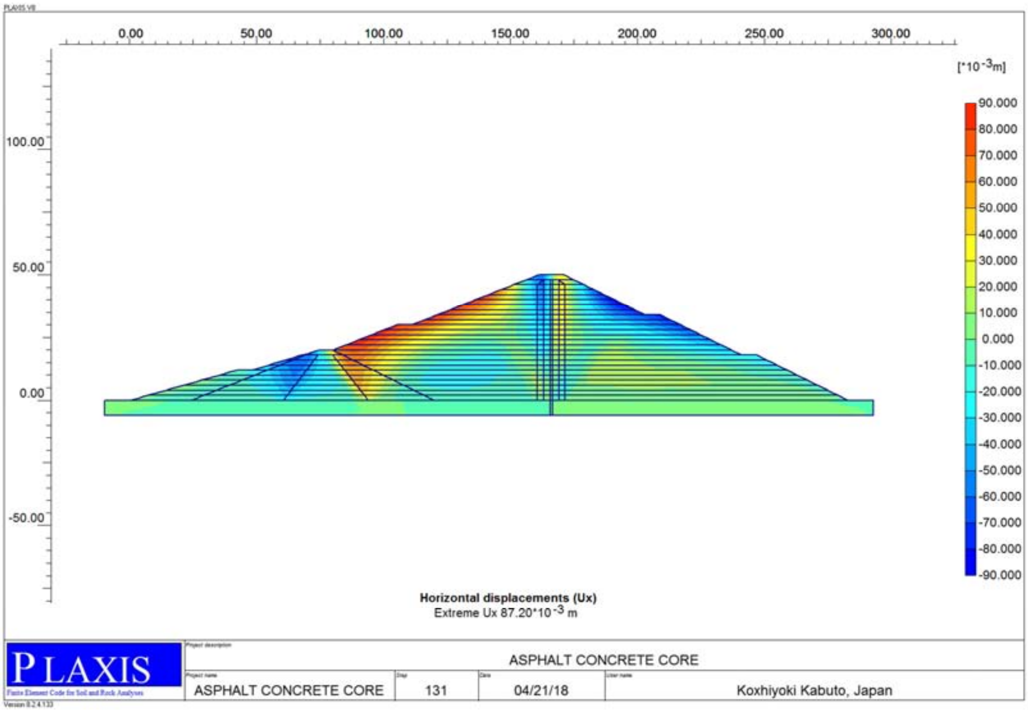

Figure 20. *Horizontal displacement of asphalt concrete core embankment dam (source: Plaxis Output).*

The result of horizontal displacement of clay core embankment dam shown below in figure 21 shows that, the maximum horizontal displacement of 385.98×10^{-3} m is nearly occurred in the clay core region of the dam, and the result of horizontal displacement for asphalt concrete core dam shown above in figure 20 shows that, the maximum horizontal displacement of 87.20×10^{-3} m is occurred in the rock fill shoulder of the dam.

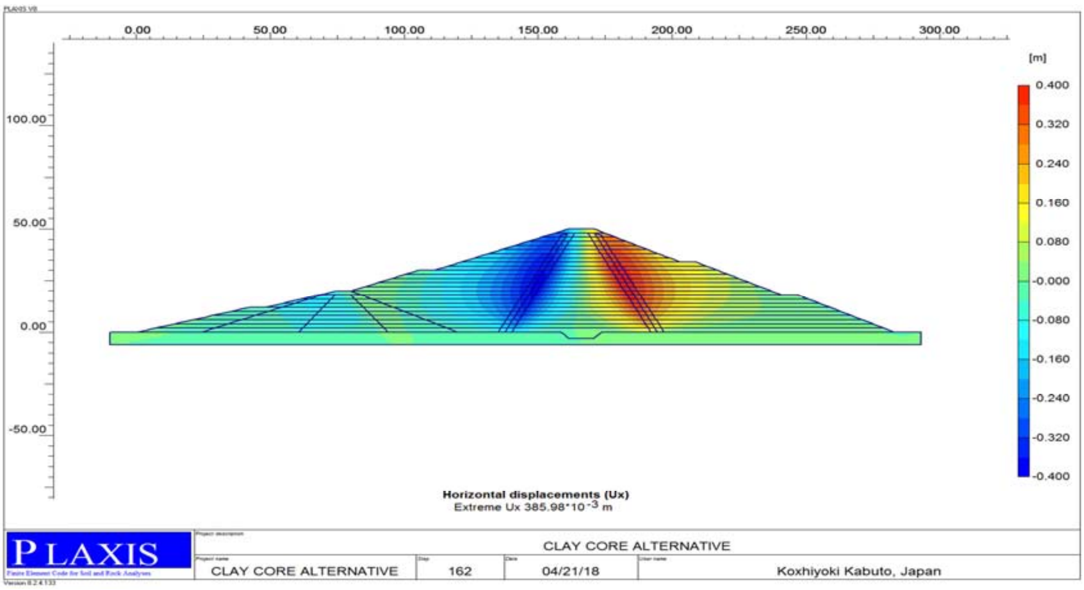

Figure 21. *Horizontal displacement of clay core embankment dam (source: Plaxis Output).*

So, when a horizontal displacement of magnitude 0.38598 m, which is above the allowable maximum values (0.5%H) is occurred in clay core region of the dam, it can be cause crack of the clay which facilitate piping problem in the body of dam. But, in the case of asphalt concrete core dam a very small magnitude of 0.08720 m, which is below the recommended values is about to occur in rock fill shoulder of the dam, which in turn will not bring any series problem on dam stability as the thin asphaltic concrete core has to follow and adjust itself to the movements and deformations appears in the dam

Table 3. *Maximum and minimum horizontal displacement of clay core dam.*

Horiz. Displ	Magnitude	standard	Remark
Maximum	0.386	0.05-0.25	Not safe!
Minimum	0.08	-0.1-0.5% H	

Therefore, from displacement point of view the result of analysis obtained from the two dam shows that, due to flexiable and visco elastic nature of the asphalt core, use of asphalt concrete core is better alternative

f. Result of Seepage Analysis

Seepage analysis of the dam is conducted by using SEEP/W. The result of seepage analysis obtained for asphalt concrete core dam in this study confirms to what is found and stated so far by many researchers Alicescu, Wang and Hoeg, Veidekke, and Hoeg [1, 2, 5, 14]. They conclude that, all existing asphalt concrete core dam have excellent performance record with a negligible seepage. The following result of flux reading shown in the figure 22 (0 m3 /sec) is obtained in the core section of the dam and this is justify the fact that asphalt concrete core is impervious.

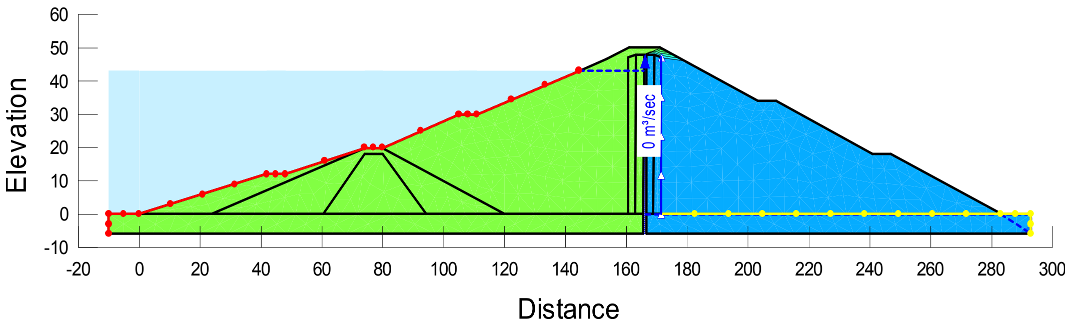

Figure 22. *Flux reading through asphalt core (source: Geostudio 2012).*

4. Conclusions

World experience of using asphalt concrete core in rock fill embankment dam and the result of analysis obtained here in this study indicate that, use of asphalt concrete core in rock fill embankment dam gives good result from the prospective of safety, seepage control and monitoring induced deformation. From the analysis results of this study the following conclusion can be deduced:

i. The problem of seepage that would covers higher percentage of embankment dam failure is reduced into insignificant values so that asphalt concrete core is impervious and resist to internal erosion.
ii. Under significant loading condition of steady state, in which upstream water pressure and its distribution in embankment material is highly reduce safety factor of clay core dam. By introducing asphalt concrete core in the dam, a reasonable minimum safety factor requirement has been attained, which satisfy the USACE recommendation. It also gives good result of safety factor for other loading condition.
iii. Induced deformation and settlement that would probably cause crack of clay core and facilitate internal piping in clay core dam could be overcome by the application of asphalt concrete core dam due to its self-healing and flexible nature.
iv. The maximum of vertical settlement and horizontal displacement of asphalt concrete core dam computed by finite element based software is appears near crest of the dam and in the shoulder respectively

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