The Alternative Design of Gidabo Embankment Dam by Introducing Asphalt Concrete Core: Southern Ethiopia

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ABSTRACT

The alternative selection of asphalt concrete core have much advantage over the clay core like the effective safety of the dam, economical prospective and the seepage reduction capacity; particularly in the area of Gidabo rock fill dam. This study is aimed to replace the clay core by asphalt concrete core in case of Gidabo rock fill dam located in the southern part of the Ethiopia. This is done by Geo Studio International Ltd., 2012 software which is the powerful software in design of geotechnical structures. By applying this software all loading condition are conducted and the safe result is obtained. The factor of safety at steady state of downstream side slope without earthquake consideration is 2.294 and 1.487 with earthquake consideration. The seepage quantity that can pass through asphalt concrete core is $4.08*10^{-9} m^3/s$*, and the vertical and horizontal deformation at the end of construction is 0.141 and 0.0148 respectively. The primary construction cost of the dam of asphalt core is larger than the clay core; but, due to the quick rate of construction the asphalt concrete core is more advantage than the clay core. Generally, the asphalt concrete core design fulfills the entire design requirement and can be applied for next design of rock fill dam of the country.*

Key Words: *Asphalt concrete core, Clay core, Geo Studio software, Gidabo dam*

1. INTRODUCTION

Embankment dams are mostly built with different types of natural soil that has a huge advantage than concrete dam. However, there were some advantage for designer to use embankment dams with asphalt concrete core, more than 50 years, by replacing the clay core material; asphalt concrete is used as a flexible and impermeable layer in dams. Germany is a pioneer in this industry (Shafei and Saied, 2016). This type of core is more attractive in the recent times for dam designers (Hassan et al., 2006). Sharifi (2015) state that the scarcity of clay borrows sources led to replace the clay core by asphaltic concrete core.

The impression of asphalt as a waterproofing means inside the embankment dams was first developed in Germany in the 1960. While the first asphalt concrete core Rock fill Dam (ACRD) was built, above 100 dams have been completed and some of it are under construction. The true output what we get from all these dams have an excellent record with rectifying seepage problems or required maintenance (Alicescu et al., 2010). The asphalt concrete was known with its workability during placement, ductility (to avoid cracking), impermeability and compaction behaviors (Feizi-Khankandi et al., 2008).

In recent years the use of asphaltic concrete core dams are greater than before especially in some areas with scarcity of clayey materials, these dams also contain less earth work in comparison with clay core dams. Application of dams with asphalt concrete core is a relatively very nice method among regions with high seismicity risk (Ghanbari et al., 2010). According to the Akhtarpour, and Khodaii (2013), the asphaltic concrete core behaves as an elastic behavior under seismic loading.

The idea of asphalt concrete core as a waterproofing material inside of the embankment dam was developed in Germany in the 1960 at the first time. From that the first Asphalt Core Rock fill dam was built, more than 100 dams have been under construction; all of these dams have an excellent example by blocking the massive seepage problem with no or minimum maintenance requirement. Asphalt concrete core embankment dams have been demonstrated to be safe and economical alternative to other traditional designs of embankment dam. These types of dams have been constructed under various climatic and foundation conditions; such that the flexible properties of the asphalt make suitable in earthquake areas. (Vlad et al., 2010).

The Gidabo site bedrocks near dam axis and reservoir area consists a sequence of inter-bedded pyroclastic fall deposits and rare tertiary basic lava and the right abutment is characterized by thick soil, weathered rock, and weak ignimbritic rock. The central parts of the left abutment consists slightly weathered ignimbrite, ignimbritic tuff, and have moderate quality (WWDSE, 2009). This indicates that there is weak foundation under the dam; therefore, the dam foundation is susceptible to the seepage. The seepage adversely affects both the embankments body and foundation of the dam's stability (Abdul et al., 2017).

The Eberlaste Dam located in Austria constructed by an asphalt core that was located on compressible and heterogeneous alluvium deposit. The foundation of the dam was settled about 2.20 m, but the dam was not show significant leakage after the construction of 40 years ago (Wang and Hoeg, 2009). This show that the asphalt concrete core does not susceptible to settlement on the compressible foundation. The strength of asphalt concrete core is not changed after application of cyclic and monotonic loading (Jafarzadeh and Yousefpour, 2009).

The soil used for clay core is available in two site within the neighborhood of the project area (between Dilla University and dam site) about 15 Km east of dam site with a potential of about 0.5 Mm^3 that is far from the dam site and poor in quality as stated in the design document (WWDSE, 2009).

The primary objective of this study is to give the solution of the seepage for the embankment dam and bring alternative dam design that reduce the seepage for Gidabo rock fill dam.

2. MATERIALS AND METHODS

2.1 Location

Gidabo dam irrigation project is located in Ethiopia, within the boundary of Oromia Regional state and SNNPR state, specifically Abaya district of West Guji zone in Oromia region and Dale district of Sidama zone in SNNPR state near Dilla town to east of Lake Abaya, which is 375 Km from Addis Ababa the capital city of Ethiopia. The geographical location of the area is between 6°20' and 6° 25' N Latitude and 38° 05' and 38°10'E Longitude, at an average elevation of 1190 m a.s.l (WWDSE, 2009).

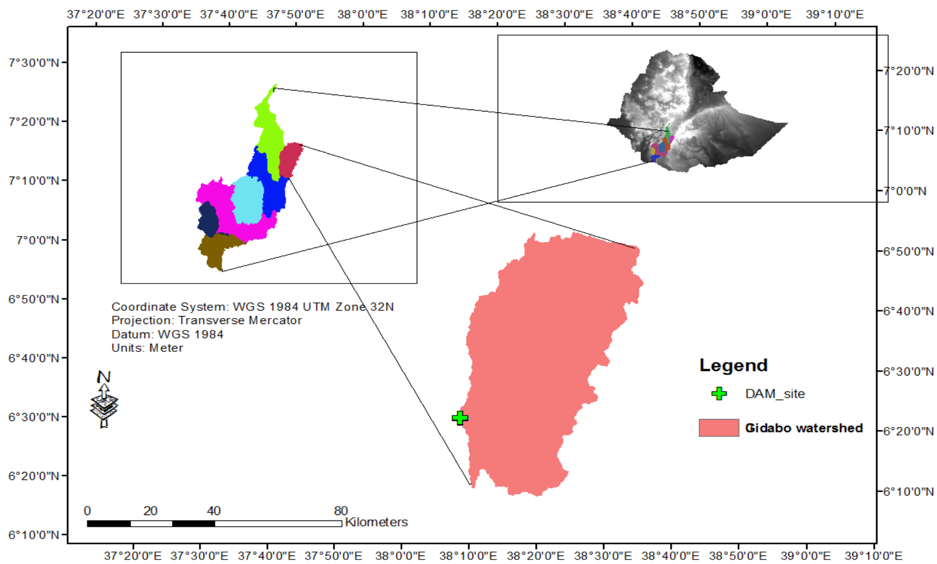

Figure 1 Location map of the Gidabo dam site

2.2 Seismicity of the area

The Ethiopian seismicity is generally confined within the Afar and MER, the MER pass from northeast to south west of the country. Hence, the Gidabo irrigation project is located in southern parts of the country in the MER, which is seismically active area. As seismic zone of Ethiopia, the study area (Gidabo irrigation project) falls in active region (WWDSE, 2008).

The Gidabo dam site, which is located between 0.15 and 0.2 of horizontal seismic coefficient (Fig. 2)

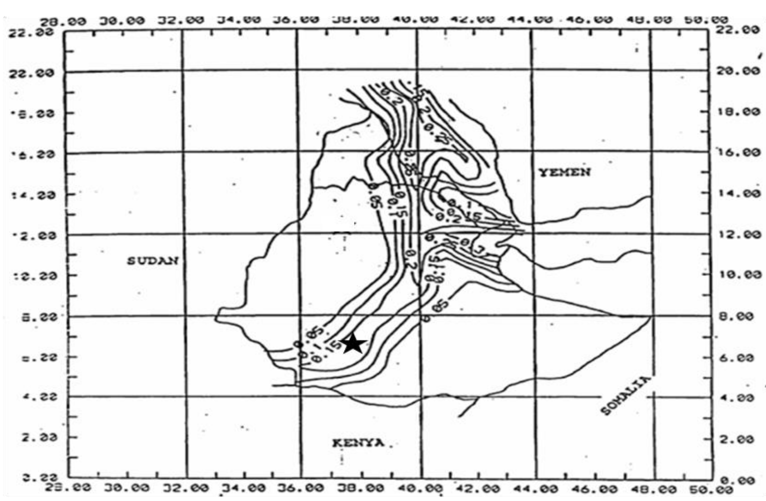

Figure 2 Seismic hazard map of Ethiopia and its neighboring countries (WWDSE, 2009)

★: *Gidabo dam site*

2.3 Parameters determined

- Permeability coefficient and shear strength parameter of the shell, core and foundation materials has been adopted from final design report of Gidabo dam as shown in table 1 and 2 (WWDSE, 2009).

Table 1 Permeability coefficients used in the analysis

Description	Permeability (m/s)	Horizontal Permeability (Kx) in (m/s)	Vertical Permeability (K_y) in (m/s)	References
Asphalt concrete core	-	-	$1*10^{-11}$	Akhtarpour et al., 2011
Impervious core	$4.80\ x10^{-8}$	$4.88*10^{-9}$	$4.88*10^{-9}$	WWDSE, 2008
Fine filter	$7.5\ x10^{-5}$	$1*10^{-6}$	$1*10^{-6}$	WWDSE, 2008
Coarse filter	0.05	$1*10^{-4}$	$1*10^{-4}$	WWDSE, 2008
Rock fill	0.05	0.001	0.001	WWDSE, 2008
Foundation	$1.0\ x10^{-8}$	$4.49*10^{-8}$	$4.49*10^{-8}$	WWDSE, 2008

Table 2 Material parameters for different zones of dam

Material Zones	Unit weight (γ) (KN/m^3)	Angle of internal friction (Φ') (°)	Cohesive (C) (KPa)	Poisson ratio (ν)	Elastic modulus (E) (MPa)	References
Asphalt concrete core	24.2	17	360	0.49	150	Akhtarpour et al., 2011
Impervious core	16	20	10	0.35	17,000 kPa	WWDSE, 2008
Rock-fill	22	40	0	0.27	24,000 kPa	WWDSE, 2008
Fine Filter	18	34	0	0.27	26,500 kPa	WWDSE, 2008
Coarse Filter	18	35	0	0.3	35,500 kPa	WWDSE, 2008
Foundation	17	28	5	0.3	90,000 kPa	WWDSE, 2008

As shown on design report of WWDSE, (2009) the soil characterized by reddish brown clayey silt is used for clay core of Gidabo embankment dam. This type of soil is available in two site within the neighborhood of the project area (between Dilla University and dam site) about 15 Km east of dam site with a potential of about 0.5 Mm^3 that is far from the dam site and poor in quality.

2.4 Method Used for Analysis

For this study, the Geo-Studio Software is used to analysis the dam under different loading conditions. Currently, stability and seepage can be analyzed using geotechnical software called

Geo-studio. Geo-Studio is one of the numerical modeling software's developed by Geo-Studio international based on limit equilibrium and finite element principles, developed specially for the analysis of seepage, stability, deformation of geotechnical structures etc. Its package includes tools like SEEP/W (for seepage modeling), SLOPE/W (for stability modeling), SIGMA/W (for stress and deformation modeling), QUAKE/W (for dynamic modeling), TEMP/W (for thermal modeling), CTRAN/W (for contaminate modeling) and VEDOSE/W (for vadose zone modeling) (Geo- Slope International Ltd., 2012). Specifically the Morgenstern method is used to determine the stability analysis by SLOPE/W and SEEP/W (Naga and Anbalagan, 2017).

The SEEP/W and SLOPE/W software are also used to solve the water problems underneath the surface for stable, uneven, wet and dry condition (Gopal and Kiran, 2014). The slope stability calculation is the calculation of the resistance of inclined surface that resists the failure by collapsing and sliding (Rafiqul and Omar, 2013).

3. RESULTS AND DISCUSSION

3.1 Dam Zoning and Geometry

Both static and dynamic stability analysis of the newly introduced dam is evaluated and shown in table 3 below. The dam cross section has been in line with the guideline by Khanna et al. (2014), Khanna et al. (2015), Khanna et al. (2017) and USSD, (2011). Hence, the newly introduced dam has 2H: 1V upstream and 1.75H: 1V to 2H: 1V downstream side slope, with asphalt concrete core of 0.5m thickness, and the same berm length, position of berm, dam crest, and top core thickness of original size was adopted as in figure 3. According to Li and Chen (2015), the straight core has a good safety margin than the slanting core; therefore, in this study the straight core is selected.

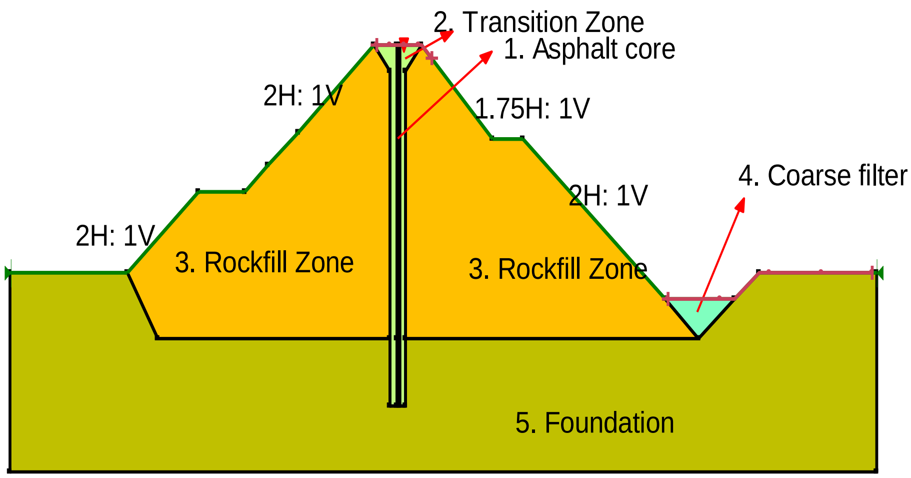

Figure 3 The newly introduced asphalt concrete core of Gidabo dam

3.2 Comparison of clay core and asphalt core

3.2.1 Comparison based on stability and seepage

During the comparison of clay core and asphalt concrete core, the static slope stability under different loading condition is conducted and compared based on their safety factor values. The respective values for different loading condition are showed in table 3. In addition to the excellent seepage protection, the asphalt concrete cores main advantage is its weather independent and short-term period of construction (Tschernutter and Kainrath, 2016).

Table 3 The comparisons of stability of dams of two cores (their factor of safety (FOS))

Different loading condition		Asphaltic concrete core	Clay core	Design standard*
End of construction without earthquake	U/S	2.39	2.27	1.3
	D/S	2.29	1.982	1.3
Stability during steady state seepage at normal pool level (NPL) (downstream (D/S))	Without earthquake	2.294	2.131	1.5
	With earthquake	1.487	1.388	1.5
Sudden drawdown (upstream (U/S))		2.29	2.12	1.3
Seepage at normal pool level (NPL) (m^3/s)		$3.73*10^{-7}$	$5.91*10^{-5}$	0.03

Design standard:* According to USACE (2003)

From table 3, it was shown that the asphalt concrete core has the highest factor of safety than the clay core; which all of it fulfill the design criteria. As well as the asphalt concrete core embankment dam has high tendency to protect the seepage problems; which is the same in line with Alicescu et al., (2010).

3.2.2 Comparison based on deformation

The horizontal and vertical displacements are compared at different loading condition and the vertical and horizontal displacement for both asphaltic concrete and clay core is shown in table 4 below. Thus, vertical and horizontal displacement of clay core is higher than the asphaltic concrete core which show that the asphaltic core is preferable than the clay core. This is due that, the clay core has a clay soil, which is susceptible to expansion and settlement; so the clay core increment induce high pore water pressure that increase the dam deformation.

The Gidabo dam is categorized under the central clay core earth and rock fill dam, the maximum limit of the vertical deformations (settlement) and horizontal deformation (displacement) should less than 1.25% and 0.5% of dam height respectively (Yaşar Zahit, 2010). Taking the maximum limit, the Gidabo dam has 22 m height from bed level, the maximum settlement allowed for this dam is 0.275m and maximum horizontal deformation should be less than 0.11m. According to USSD (2014), the Los Angeles dam that have 130ft was faced to the cracking along asphalt lining and settles 5.4" around its maximum section, therefore the computation of future settlement is mandatory.

Table 4 Comparison of deformation of two core types

Core types	Maximum horizontal displacement		Maximum vertical settlement	
	at NPL (m)	At end of construction	at NPL (m)	At end of construction
Asphalt concrete core	0.0155	0.0148	0.140	0.141
Clay core	0.020	0.023	0.18	0.192
Design standard**	0.11 (0.5% of dam height)		0.275 (1.25% dam height)	

Design standard **: is taken from Yaşar Zahit, (2010)

This result is also better when it is compared to Ghafari et al. 2016, which show the analysis done on Chenareh rock fill clay core dam of 120 m high; they obtained that the maximum settlement of 2.86m occur around middle height of the dam and is to some extent more than 2% of the dam height.

3.2.3 Comparisons in dynamic analysis and seepage quantity

QUAKE/W is formulated for direct integration in the time domain, which means that the analyses are performed at many different moments in time and at certain time intervals. In this model, the integration follows a specified time stepping sequence. The horizontal and vertical ATH data has been produced for Gidabo embankment dam (for K_h= 0.20 and K_v=0.10) from El Centro ATH of USA record. Because, there is no acceleration time history data produced in Ethiopia and this USA ATH data is mostly used throughout the world (Dagne, 2017).

The computed minimum factor of safety of asphaltic and clay core after earthquake are 1.49 and 1.3 for downstream respectively as shown on table 5. This value is greater than the minimum requirement suggested by Melo and Sharma (2004) for unusual loading condition (i.e. FOS > 1) which insures that the embankment is stable after earthquake in all two different cores. The stability of embankment dam during and after earthquake has been analyzed to assess the effect of the earthquake on stability.

As stated by Ghanbari et al., 2010 the asphalt concrete core is the most suitable in the area of active earthquake region, therefore the Gidabo dam is also located on active earthquake region; so the asphaltic concrete core is the best suitable option.

Regarding to the seepage quantity pass through the dam body; it is clear that the seepage quantity pass through asphaltic core is less than the clay core. The Gidabo dam is located on weak foundation that is susceptible to seepage; so the asphaltic concrete core is best option as seen on figure 4 and table 5.

Table 5 Comparison of two cores after earthquake happened

Core types	Factor of safety at steady state condition		Seepage at steady state	
	Upstream	Downstream	Through core	Through foundation
Asphalt concrete core	1.52	1.49	$4.08*10^{-9}$	$3.68*10^{-7}$
Clay core	1.39	1.30	$5.92*10^{-5}$	$4.43*10^{-8}$

Therefore, in particular for Gidabo embankment dam regarding to stability the asphalt concrete core is best selection.

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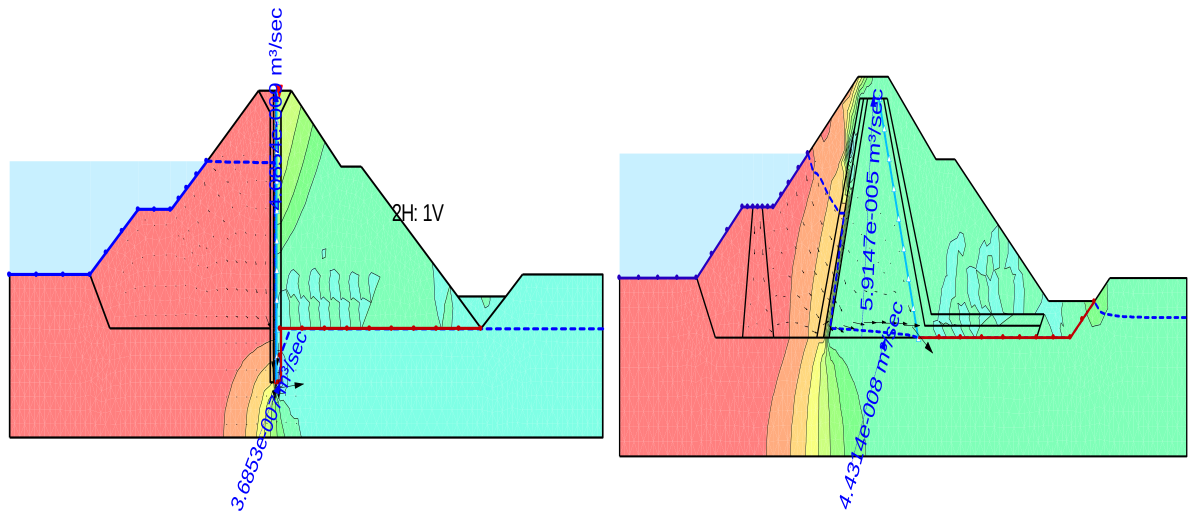

Figure 4 The seepage pass through asphalt concrete core and clay core respectively

3.3 Economical view of two cores

According to ICOLD, (2015) approved that the asphalt concrete core is economical in view of fast rate of progress when compared with clay core. The WWDSE, (2008) indicate that the Gidabo dam is constructing in 8 month per year; during the summer season the construction of clay core is impossible, because the rain make the clay expansive and difficult to compact.

The construction of this dam (on this study) is started in 2010 and still it is under construction that reaches around 90%; when we assume it may be completed in 2019 year, it takes 9 year. From this 9 year, the (12-8) months*9 year = 36 months or 3 years are the delayed time. If this dam is constructed in asphalt concrete core, there is no such like delay times; why because the asphalt concrete core is not weather dependent and can be constructed 12 months per year.

The income generation from this clay core dam in these three years is not obtained due to construction delay of clay core. See the table 7 shown below.

When we compare the construction cost of two core, the clay core is cheapest than the asphalt concrete core as shown in table 6; but when the overall benefit cost ratio is done, the asphalt concrete core is more advantages.

Table 6 Comparison cost of construction of two clay core (WWDSE, 2008)

Core type	Cost of unit rate (m^3)	Total Volume (m^3)	Total cost (Ethiopian birr (ETB))
Cost for clay core	213.4	78,327.52	16,715,092.8
Cost of rock fill placed in place of clay core subtracted	466.77	74,331.52	34,695,723.6
Cost for asphalt concrete core	1296.21	3,996	5,179,655.16
Variation of costs between two cores	5,179,655.16- (34,695,723.6-16,715,092.8)		-12,800,975.7

Hence, 12,800,975.7 much construction cost of Asphalt core is greater than the clay core cost. When we come up with total benefit gained from the two cores, the asphalt concrete core is much advantage than the clay core as shown in the table 7 below.

Table 7 Economic comparison based on irrigation production (WWDSE, 2008)

Irrigation	Income rate from irrigation (ETB/ha/year)	Total area (ha)	Year of production after completion (2010-2019 Year)	Total income per year from Irrigation
Cost for clay core	24,200	9876	0	0
Cost for asphalt concrete core	24,200	9876	3	716,997,600

4. CONCLUSION

This study is carried out on the Gidabo rock fill dam, by introducing the asphalt concrete core in place of clay core taking Gidabo rock fill dam as case study. Hence, the asphalt concrete core has high initial construction cost but the income gain due to fast construction rate is very high. The selection of asphalt concrete core is very effective in the reduction of seepage and over all benefit gain from the dam. Some of the advantages of asphalt concrete core are: the best factor of safety than clay core, in the active seismic area the asphalt concrete core is the best selection.

The vertical and horizontal deformation at end of construction for asphalt concrete core are 0.0141 m and 0.0148 m respectively and the vertical and horizontal deformation at end of construction for clay core are 0.192 m and 0.023 m respectively, which are safe. The upstream and the downstream slope stability of the embankment have been found stable after the earthquake shaking. The computed minimum factor of safety for asphalt concrete core after earthquake is 1.52 for upstream and 1.49 for downstream and for clay core after earthquake is 1.39 for upstream and 1.30 for downstream, which is safe as it is greater than recommended value (>1)

Both core types are analyzed for all loading condition, the finding under these conditions showed that all obtained values are within minimum safety factor requirement recommended by USACE, (2003), Yaşar, (2010) and Melo and Sharma (2004)

Conflict of Interest

Authors report none of conflict of interest.

Financial Disclosure

None

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