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A Review of the Embankment Dam with Asphalt Concrete Core

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Abstract- Embankment dams have served man at least 5,000 years. The remains of ancient structures and civilizations provide clues to the efforts of mankind in the engineering and construction of dams. Jansen (1980) traces the history of dams from the period BC to the 20th century. Of the earth dams built BC, Jansen comments"(USSD Committee on Materials for Embankment Dams, 2011): "Turning to the most available materials, the ancient dam builders made liberal use of soils and gravels. Since they had only the slightest understanding of the mechanics of materials or of flood flow, their methods were haphazard, and their works often failed. Embankment dams were low on the scale of public confidence for many centuries." (Jansen, 1980)

Embankment dams almost built with all types of the soils, it has more advantage than concrete dame. But there was some benefits for designer to use embankment dams with asphalt concrete core, more than 50 years, asphalt concrete is used as a flexible and impermeable layer in dams. Germany is a pioneer in this industry.

Asphaltic concrete core is considered because of impermeability, ease of construction and performance and etc. than clay core. Even is used as cutoff. Filer, aggregate and bitumen are the main part of the asphalt concrete so these have an important effect on asphalt concrete. Asphaltic concrete is used in all kind of climate zone and temperature but there is some concern in high temperature duo to change the asphalt properties.

This paper is review on the findings, results of the tests and observations from around the world for better understanding the advantages and disadvantages of dams with asphaltic concrete core of the existing earthen dam. It is predicted that in the future most of embankment dams in areas with earthquake hazard, construct like this.

Keywords- *embankment dam, asphalt concrete core, cutoff, drain and filter*

I. INTRODUCTION

A large embankment dam in the world are made with different materials (U.S. Department of the Army, Corps of Engineers, 1994) and there are three suggestion to build them: 1.soil core 2.upstream facing of reinforced concrete or asphalt or synthetic geomembrane 3.asphalt concrete core (Hoeg, Yalstad, Kjaernsli, & Ruud 2007) Asphalt concrete 50 years ago in Germany was used as waterproof coating (Hoeg 1993) & (ICOLD Press 1992) these days the asphalt concrete in dams, channels, pavement of roads and cut-off as waterproof coating and flexible with fine-aggregate, filler and suitable bitumen. (Wang & Hoeg, 2011)&(Kasatkin & Kuznetsov 2004) The International Commission on Large Dams (ICOLD) have summarized the experience with the design, construction, and performance of this type of dam presented experimental and field results and discussed the ductility, cracking resistance, permeability, and viscoelastic-plastic properties (viscoelastic-plastic properties create self- healing ability)of asphalt concrete used in hydraulic structures. (Wang & Hoeg 2011) Impermeability, flexibility, resistance of erosion and self-healing should be noticed in design of asphalt concrete.(Saxegaard & Veidekke 2003) In last century the height of most embankment dams with an asphalt core or asphalt facing was less than 100 m and most of them seated on rock foundations in valleys with gentle abutments but in this century the dam height of some asphalt concrete core dams is more than 150 m and some of them seat on deep compressive overburdens in valleys with steep abutments (Zhang, Wang, & Zhu 2015).

II. GRADING AND MIX DESIGN

For the project is more economical, the embankment dam design with exist material in site. Although for building special part of dam e.g. filters, drain and riprap can use material from out of the site. (USSD Committee on Materials for Embankment Dams 2011)

The asphaltic concrete use in dams and channels, have more fine aggregate, filer and bitumen than asphaltic concrete use as a pavement. That's for being impermeability and flexibility. (USSD Committee on Materials for Embankment Dams 2011)The asphaltic concrete use in embanked dams as water barrier include 6.5 – 8.5 percent bitumen bye mineral weight, 10-15 percent filler material (<0.075 mm), 35-52 percent fine aggregates (0.075- 2.36 mm), and 33-55 percent coarse aggregates (2.36-19 mm) (Saxegaard 2002)

"Aggregates used in the mixes that make up the lifts of an asphalt concrete core are normally crushed stone, suitable for use in Portland cement concrete. Fillers used to promote the workability and compact ability of the mix. Workability is important, because harsh mixes, low in fines content, tend to "tear" when being placed. In addition to improving workability, proper quantities of filler also decrease the volume of voids, making for a more dense and impervious mix. On the other hand, excessive quantities of filler will significantly increase the asphalt demand, because of the increased surface area. Typically, the ratio of (filler)/(aggregate + filler), by weight, have fallen in the range of 11 percent to 13 percent. It should be recognized, however, that workability is the key issue". (USSD Committee on Materials for Embankment Dams 2011)

Grading Curve of asphalt concrete mix design should be consistent with Fullers curves. (Norwegian Geotechnical Institute 1992)

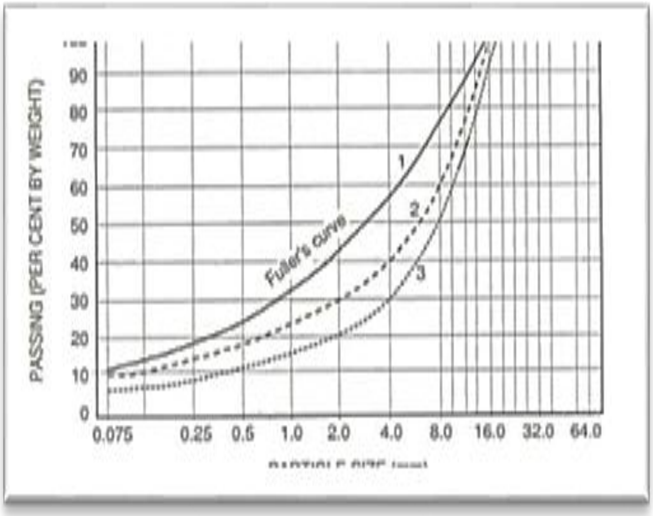

Figure 1. Fullers Curves

"The coarse aggregates used were crushed silicate sand and gravel satisfying Fuller distribution given by following equation":

$$p_i = 100\left(\frac{d_i}{d_{max}}\right)^{0.41}\ \% \qquad (1)$$

"where (p_i) is the percent by weight of material smaller than grain size (d_i) and (d_{max}) is the nominal size of the aggregates" (Akhtarpour & Khodaii 2013)

In figure 1, two grading curve is present. Air content in the asphaltic concrete that based on curve 3 does not be less than 3 percent due to it was permeable and brittle and least resistance between 3 samples. Although asphalt concrete make by same amount of bitumen identical with Fuller Curve was impermeability, formability behavior and most resistance against shear and tensional strain before fraction. (Norwegian Geotechnical Institute 1992) & (Norwegian Geotechnical Institute 1993)

In design of asphalt concrete of embankment dams using the highest amount of bitumen for reaching the flexibility against seismic load is suggested. Although there is no filed study for make sure about this (Feizi-Khankandi, Mirghasemi, Ghalandarzadeh & Hoeg 2008) The amount of bitumen is related to dynamic shear strain and level of environment temperature. (Akhtarpour & Khodaii 2013)

(Akhtarpour & Khodaii 2013) allowed that amount of bitumen should be 5.5-7 percent in water barrier asphaltic concrete. Also the amount of bitumen for reach flexibility during the earthquake and after that suggested 6.5-7 percent. (Hoeg 1993)

According to (Hoeg 1993) showed samples with more bitumen content has more yield strain, also in the top of the dams when the limited pressure is low, mixture of bitumen and asphalt increase dynamic shear modulus at low strain levels less than 0.4 percent. Maximum dynamic shear modulus is in the maximum limited pressure, this increase has the most value for 6 percent bitumen content and after that it decreases with an increase in bitumen content. The least and the most damping was observed at 6 percent and 7 percent bitumen content, respectively.by increasing the limited stress, the higher damping value can be obtained. With an increase in bitumen content, the shear modulus decreases. However, in low limited pressure (100 KPa), the behavior of the material is different and a reduction in shear modulus with increasing bitumen content is observed.(Akhtarpour & Khodaii 2013) Secant modulus increases with increasing amount of bitumen.

III. Temperature concern

The aggregate should be heated before mixing up the moisture content reaches 0.5% or lower asphalt cement must also be heated where will not drive off too many volatiles. The mixture critical temperature depends on viscosity. Table 1 shows this connection (USSD Committee on Materials for Embankment Dams 2011)

TABLE I. Critical Temperatures Related to Asphalt Concrete

Field Activity	Asphalt Viscosity (Poises)	Temperature Low Viscosity Asphalt ℃(°F)	Temperature High Viscosity Asphalt ℃(°F)
Mixing		165 (325)	178 (355)
Start Rolling	1 10	155 (310) 110 (225)	170 (340) 125 (255)
Stop Rolling	100	80 (175)	95 (200)

Many of embankment dams design and build in the word but there is not enough information about the dynamic properties of material in hot area.(Feizi-Khankandi et al. 2008) The recent studies show that the asphalt concrete core as water barrier has more concern in high temperature.

IV. IMPLEMENTATION

Test of material is one of the most important principles in the design and construction of asphalt concrete core. (USSD Committee on Materials for Embankment Dams 2011) The quality of asphalt concrete depends on construction process and the tests. (Wang & Hoeg 2011) The testing relates to the components of the mix (i.e asphalt, aggregate and filler), and to the mix itself. (USSD Committee on Materials for Embankment Dams 2011)

Vertical and inclined asphalt concrete core width is between 0.5 and 1 meter. This value depends on the height of the dam, seismic area, foundation conditions and quality performance. (Wang & Hoeg 2011)

In the implementation of asphaltic concrete core layers 0.2 to 0.3 meters compact by vibratory rollers 0.5 to 1 Ton to achieve 3 percent of the air content. According to laboratory results, in this porosity, is impermeable asphalt concrete under high water pressure if the porosity is more than 3 percent, permeability greatly increased. In porosity 6 percent, permeability will become $10^{-6}\ \frac{m}{s}$. (Norwegian Geotechnical Institute, 1992) In field measurements this value is often between 1 to 2.5 percent. (Wang & Hoeg 2011)

V. DRAIN & FILTER

"Indeed, many incidents of failure or near failure can be attributed to the absence of filters and/or drains or to filter protection that was not appropriate to the application. 30 to 50% of accidents on dams relate to inappropriate drainage or piping".

"The safety of earth and earth-rock dams depends to a large degree on the proper design, construction, and maintenance of filter and filter/drain systems" (USSD Committee on Materials for Embankment Dams 2011)

In the implementation of dams, filters and drains must be from materials with low cohesion, capable of collapse and self-healing.

$D_{15}/d_{15} > 5\ , or\ > 3\ to\ 5$ (U.S. Department of the Army, Corps of Engineers 1994)

Permeability varies approximately with the square of the D_{15}.

In addition at above criterion, the U.S. Soil Conservation Service (U.S. Department of Agriculture, Soil Conservation Service 1986) adds that D_{15} should not be finer than 0.1 mm. (USSD Committee on Materials for Embankment Dams 2011)

VI. ARCHING

For the first time in 1951 scientists found the significant decrease vertical and lateral pressures of the thin core in embankment dams with pressures measurement and reported an importance arching phenomenon. Decrease pressure relate to big settlement of core than crust due to transfer force from core to crust and in 1961 they found that arching could occur in valley profile between two abutment. Usually decrease vertical stress in centric level determine in compere of overhead pressure extent (γh). Extent of decrease stress because of arching depends on valley width and abutments slope. (Ohne & Narita 1977) Furthermore, if an asphalt core dam is located in a narrow valley with steep abutments arching effect may exist on the core in the longitudinal direction. (Zhang et al. 2015)

VII. EARTHQUAKE

Earthquake does not cause deformation of the slope and the permanent settlement in crest of embankment dam. (Swaisgood, 2003) So embankment dams in earthquake prone areas are appropriate. (Ghahreman Nejad, Soden, Taiebat, & Murphy 2010)

Earthquake affects the slope of earth dam but in the center core has little effect that this cause a lot of strain tensile deformation at upstream. The upstream facing become weathering and oxidation and radiation due to temperature changes, the results of these, are degradation, brittleness and cracks in the asphalt concrete as a consequence, asphalt concrete core design is preferred to asphalt upstream facing.(Ghahreman Nejad et al. 2010)

The slender core wall has to adjust to the deformations of the embankment fill during construction, impounding(Wang & Hoeg 2011)

VIII. CUT-OFF

Cutoff has used in all embankment dam all over the world and climate zone because of deformability, resistance to erosion, slow aging and high reliability.

Cutoff must design according to two characteristics impermeability and duration of service. For transfer stress to the downstream toe, the diaphragm should be inclined. Also to raise the upstream slope stability under earthquake load use inclined diaphragm or zigzag.

Based on the experiences of constructed diaphragm deformation of inclined sloop diaphragm in foundation, depend on significant settlement in toe. Amount of settlement in dams can exceed 1 m and its rate can reach $10^{-5}\ \frac{m}{s}$. While most of dam settlement in the first 10 years of operation. (Kasatkin & Kuznetsov 2004)

Thick of the asphalt concrete diaphragm is determined by calculations based on the results of physical tests.

The initial thickness of diaphragm is proportional to dam height.

The following table shows this proportion (VNIIG & Vedeneeva 1986)

TABLE II. INITIAL THICKNESS OF DIAPHRAGM RELATED TO HIGH

Thickness of Diaphragm (cm)	High (m)
50 to 60	≤ 30
60 to 100	> 30

"In the general case it is 50 cm on the crest of the dam and varies over the height as 50 + 0.008H, where H is the distance from the top of the diaphragm to the considered section". (VNIIG & Vedeneeva 1986)

IX. COMPARISON ASPHALT CONCRETE CORE AND CLAY CORE

According to (Zomorodian, Charrakh, & Heidarpour 2005) total seepage and settlement of dams with asphaltic concrete core were obtained 26 litter per second that amount in clay core obtain 42 litter per second and also hydraulic gradient in asphalt concrete core obtain 0.26 and in clay core 0.68. During the construction reservoir stability of asphalt concrete core was 1.41 that parameter in dams with clay core obtain 1.16 so this amount is less than Safety Factor (S.F=1.25) and stability analyze during full reservoir shows the S.F 1.5 for asphalt concrete core and 1.26 for clay core although minimum S.F is 1.5. The rapid discharge and earthquake S.F of both asphalt concrete core (1.5) and clay core (1.26) was acceptable.

X. CONCLUSIONS

- The amount of bitumen for reach flexibility during the earthquake and after that suggested 6.5-7 percent.
- Maximum dynamic shear modulus is in the maximum limited pressure, this increase has the most value for 6 percent bitumen content and after that it decreases with an increase in bitumen content.
- The asphalt concrete core as water barrier has more concern in high temperature.
- 30 to 50% of accidents on dams relate to inappropriate drainage or piping.
- Earthquake affects the slope of earth dam but in the center core has little effect.
- Amount of settlement in dams can exceed 1 m and its rate can reach 10^{-5} $\frac{m}{s}$. While most of dam settlement in the first 10 years of operation.

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