Chapter 29
Review of Use of Asphaltic Concrete Core in Earthen/Rock Fill Embankment Dam

Satyajit Roy, V. K. Jain, Manish Gupta, and R. Chitra

Introduction

Introduction

The first embankment dam with a compacted asphalt concrete core was built in Germany in 1961–1962. Since then, asphaltic concrete core earthen dam have been constructed worldwide. More than 130 asphalt core embankment dams have been built so far [1]. Most asphalt-core dams have been built in Europe, but China has also built and is currently building several dams of this type, among them the 170 m high Quxue Dam that will be the highest so far. The Yele Dam is also an example of asphalt core rock fill dam constructed on the Nanya River along the border of Mianning County and Shimian County, Sichuan Province, China. It is 124.5 m high and 411 m long [2].

Advantage of Asphaltic Concrete Core

The main advantage for application of asphaltic cores in dams is an elasto-plastic behavior of the asphaltic concrete as building material. This elasto-plastic behavior helps to prevent cracks in the core subsequent to deformations of the embankment, thus ensuring the imperviousness of the core. The main specification to be complied with in the placing of a bituminous core is the maintenance of water impermeability under all conceivable deformation conditions. The prerequisite for achieving this aim is the workability, i.e., the placibility and compactibilty of the asphaltic mix [3]. The

S. Roy (✉) · V. K. Jain · M. Gupta · R. Chitra
Central Soil and Materials Research Station, New Delhi 110016, India
e-mail: satyajitcsmrs@gmail.com

K. Muthukumara et al. (eds.), *Earth Retaining Structures and Stability Analysis*,
Lecture Notes in Civil Engineering 303,
https://doi.org/10.1007/978-981-19-7245-4_29

Fig. 29.1 Asphaltic core in dam (Styggevatn Dam, Norway, [4])

asphaltic concrete core helps in providing the highest protection against mechanical defects caused by acts of violence or earthquake which it is possible to attain for a dam structure. Asphaltic concrete cores are non-erosive, crack free and thus water impermeability is ensured by the plastic deformability which conforms to all deformations of the dam body which cannot be accurately determined in advance during the design and calculation stages [3]. Impouding during construction is possible in asphaltic concrete core, as a result potential seasonal rainwater can be collected prior to full completion of the works. In case of occurrence of minor seepage in the core wall, the asphaltic concrete has a good possibility for self-healing due to subsequent creep and migration of fine particles form the upstream face transition zone into fissures or other small deficiencies of the core. The choice of an asphaltic concrete core allows continuous earth and rock fill operations for the dams' shells during and after a rainy period. These works are not sensitive to water but they are dependent on the progress of the core placing operation, which in the case of clay core is highly sensitive to rain and has not only to be interrupted during rainfall but can only be continued after a certain drying period. Figure 29.1 depicts the asphaltic core in Dam.

The asphaltic construction materials are insoluble in water, environmentally compatible and have been proven to be non-harmful to drinking water sources. The dams have been found suitable for construction under various climatic and foundation conditions.

Characteristics of Asphaltic Concrete Core

An asphalt concrete core, or each layer of an asphalt concrete facing, has a unique mixture of asphalt, aggregate and filler, designed to provide the intended function(s) of that element [5].

(a) The core, or the impervious layers of a facing system, the asphalt content varies from 6 to 8% in asphalt mix, compacted to about a 3% air voids content [3].
(b) For prime coat on the embankment, the tack coat between layers, the seal coat (SL) on the impervious layer, and the protective coating or layer (PT) special grades of asphalt or asphaltic emulsion, varying in penetration from 100 to 40 are used [5].

Table 29.1 Critical temperature related to asphaltic concrete [6]

Field Activity	Asphalt viscosity (Poises)	Temperature Low Viscosity Asphalt °C	Temperature High Viscosity Asphalt °C (°F)
Mixing	1	165	178
Start rolling	10	155 110	170 125
Stop rolling	100	80	95

(c) The density of aggregate in the impervious layer, should ranges from 2.1 to 2.5 tones/m^3 [1].
(d) Permeability's of the various layers vary from impervious (10^{-7}–10^{-9} cm/sec, and lower) for the core [1].
(e) The compaction of the mix generally should take place when the viscosity of asphalt in the mix ranges between 1 and 10 poise [1].
(f) The critical temperatures depend on the viscosity of the asphalt. The Table 29.1 given below shows critical temperature related to asphaltic concrete [6]:

The temperature of the binder at the time of mixing should be in the range of 150–165 °C and of aggregates in the range of 150–170 °C, provided that at no time the difference in temperature between aggregate and binder should exceed14 °C.

Design Principle

The thin asphaltic concrete core has to adjust to the deformations in the embankment and to differential displacements in the dam foundation [4]. Displacements accumulate during embankment construction, filling of reservoir, time-dependent consolidation and creep, fluctuations in reservoir level and any earthquake shaking or fault movements. The essential function of the core is to remain impervious without any significant increase in permeability due to shear dilatancy or cracking. ICOLD has given following guidelines in the field of design principles:

(a) The asphaltic concrete core is constructed at simultaneous levels with the dam fill [1].
(b) Dams' height over 30 m in height, the core thickness should be between 60 and 100 cm, depending on dam height [3].
(c) Grain sizes from filler, sand and chipping/gravel should lie between 0 and 16 mm [5].
(d) The bitumen (asphalt) content of mix should be 6% approx. (by weight), the mix is easy to place and compact to a void's percentage of below 3% (by volume) [3]. With this void content, the asphaltic concrete is impervious even under high water pressure. However, from other studies in design of asphalt concrete of embankment dams using the highest amount of bitumen for reaching the

flexibility against seismic load, allowed that amount of bitumen should be 5.5–7% in water barrier asphaltic concrete. Also, the amount of bitumen to reach flexibility during the earthquake and after that suggested 6.5–7% [4, 7].

(e) The transition zones installed on the upstream and downstream sides of the asphaltic concrete core should be 1–2 m and comprise graded hard rock material with a maximum grain size of 100 mm, although dams with well graded transition material have been built with a max aggregate size of 200 mm [3]. For implementing the self-healing of possible leakage points in the core, the upstream transition zones can receive an appropriate fine grain admix, which also helps in considerable reduction in the volume of water inflow at a defect. The upstream transition zone should also be designed in such a way that it is possible to introduce pipes into it to allow supplementary sealing at a later date by injecting bentonite or clay if any leakage occurs [1].

(f) The compaction of the transition zone and hot plastic asphaltic concrete core should be intensive for close interlocking of both construction material. As a result of which asphaltic concrete core will not deform differentially from the transition zone [1].

(g) For a dam with a height of up to 60 m, the core is usually carried out as vertical throughout. For higher dam and in order to increase the statically effective cross-section of the dam, core can be arranged nearer to upstream side or can be slightly inclined toward the downstream side in the upper side. This reduces the danger of the upstream embankment becoming detached from the core in the detached area [3].

(h) For hydraulic structures, asphaltic concrete is taken as water tight as long as its void content **does not exceed 3% (by volume)** [3]. However, this threshold value must be maintained not only after installation but also under all possible stress/strain and deformation states during operation of the dam.

Typical cross-section of Storglomvatn, Norway dam are shown in Fig. 29.2.

Construction Methods

Production

In design of asphaltic cores, it must be remembered that pure bitumen behaves like a liquid in the long-term, and will flow out of the core unless prevented by certain measures. For this reason, bitumen is mixed with various sized aggregate in different proportions to give a combined skeleton with sufficient capacity to avoid being over-filled with bitumen. Adhesion forces between the bitumen and the aggregate prevent the binder flowing out, and it can be proved by calculations that for a well-graded bituminous concrete the possible rate at which the binder can extrude is 1 cm per million years [1].

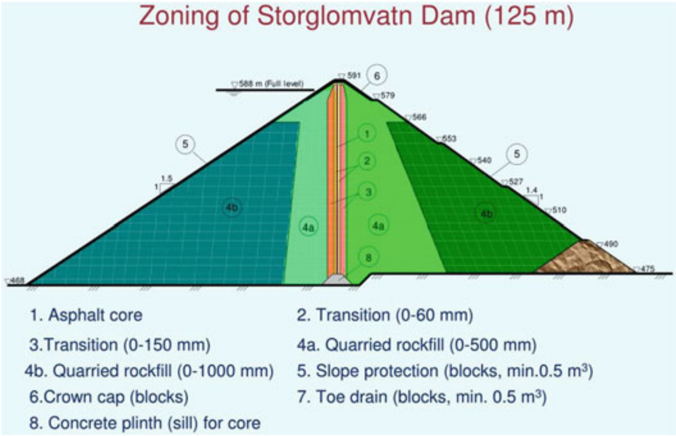

Fig. 29.2 Typical cross-section of Storglomvatn Dam (125 m), Norway [4]

Fig. 29.3 Modern asphalt concrete plant [8]

Asphaltic Concrete Plant

A reliable batch plant with a capacity of 50–60 tons an hour is normally sufficient having a minimum of 4 hot aggregate storage bins, and a data printout of all weights per batch [8]. An arrangement for adding filler in the mix is also attached in the plant. Figure 29.3 depicts the images of different asphalt concrete plant;

Spreading

The paving equipment shown in Fig. 29.4 places asphaltic concrete and filter simultaneously in 20 cm horizontal layers. The machine is a hydraulically driven crawler paver, and the widths of the core and filter screeds are adjusted according to the design specifications. The speed of the paver should be 1 m/min [4].

Fig. 29.4 Asphalt core placing machine (paver) [4]

Fig. 29.5 Simultaneous compaction of core and filter [4]

Compaction

Asphaltic concrete and filter are compacted by three vibrating rollers of 1.5–2.5 tons working in parallel as depicts in Fig. 29.5.

Joint Treatment

Treatment of joint is one of the vital activities for water tightness of the facing. The main challenge which comes during execution is to cut the uncompacted a layer on edges or before laying adjacent layer as it is mandatory for water tight joints.

Test Methods

Tests on Mixes

Marshall test for the mix is one of the main tests for finding suitability of mix. Marshall test includes (i) stability, (ii) flow, (iii) percent air voids, (iv) percent void in mineral aggregate, and (v) percent voids filled with bitumen. The other tests are density, permeability, unconfined compressive test at various temperature, triaxial test, flow test on slope, frost and temperature change resistance, aging, flexibility, creep etc.

Triaxial Test

For higher dams it is recommended that in every case the core and supporting shells material should also be given triaxial tests [1]. Stress–strain–strength tests were performed on 100 mm diameter samples drilled out of the asphalt core during construction. The results from strain-controlled compression triaxial tests, keeping the lateral confining stress constant during each test, as shown in Fig. 29.6. The stress–strain curves show a very ductile asphalt concrete behavior with insignificant strain-softening even for tests with very low confining stress [2].

Apart from the stability and deformability of the bituminous concrete core, placing of core material in clean surface, sufficient and uniform compaction must be ensured.

Figure 29.7 depicts typical image of asphaltic core concrete.

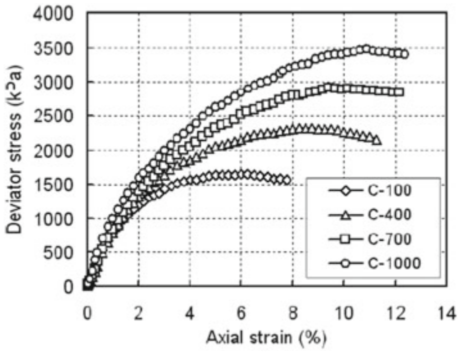

Fig. 29.6 Triaxial compression test, 100 mm diameter Yele Dam core [2]

Fig. 29.7 Typical image of asphaltic core concrete [8]

Asphalt Concrete Core Versus Clay Core

Relative Performance Evaluation

Nuresa Merga Bayisa, [9] tells that use of asphaltic concrete core in rock fill embankment dam gives satisfactory results from safety, seepage control and monitoring induced deformation point of view and used Plaxis 8.5, finite element-based software was employed for analysis of the dam as well as Geostudio 2012 for seepage analysis. The following comparison have been made in above study:

Seepage Analysis: Seepage records higher percentage of dam failure in embankment dam [9]. Figure 29.8 depicts flux reading through asphalt core:

The result of flux reading shown in the above figure (0 m^3/sec) is obtained in the core section of the dam and this is justifying the fact that asphalt concrete core is impervious. Many researchers Alicescu, Wang and Hoeg, Veidekke, and Hoeg [7, 8, 10] also confirmed zero seepage in asphaltic concrete core. Further, stability analysis of dam during different loading conditions analyzed by Nuresa Merga Bayisa [9] are presented in Table 29.2:

Again, Zomorodian et al. [11] has given following comparisons and are shown in Table 29.3:

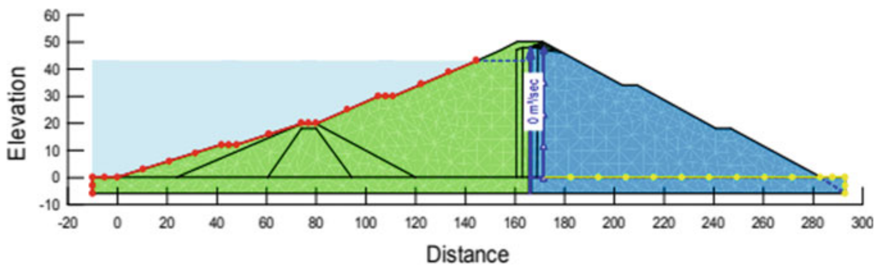

Fig. 29.8 Flux reading through asphalt core. *Source* Geostudio 2012 [9]

Table 29.2 Stability analysis during different loading conditions [9]

SL	Loading conditions/displacement	Asphaltic concrete core dam	Clay core dam
1	During construction factor of safety	1.638	1.618
2	Steady state factor of safety	1.661	1.446
3	End of construction	No Pore water pressure development in core	Pore water pressure developed in core
4	Vertical displacement	0.59562 m	0.59562 m
5	Horizontal displacement	87.20×10^{-3} m	385.98×10^{-3} m

Table 29.3 Stability analysis during different loading conditions [11]:

SL	Loading conditions/displacement	Asphaltic concrete core dam	Clay core dam
1	Seepage qty	26 L/sec	42 L/sec
2	During construction factor of safety	1.41	1.16
3	Steady state during full reservoir factor of safety	1.5	1.26
4	Rapid drawdown/earthquake factor of safety	1.5	1.26

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

Field Values of Seepage as Well as Displacement Values of Dams

The Result of seepage analysis of some of the earthen/rock fill embankment dam are given in Table 29.4 [3]:

Again, Table 29.5 reflects the performance in terms of vertical and horizontal displacement for some of the earthen/rock fill asphaltic core dam [1]

Table 29.4 Seepage analysis of some of the asphaltic concrete core dam [3]

SL	Description of dam	Seepage	Remarks
1	Yele Dam, China Max. height = 124.5 m Crest length = 411.0 m Total vol. = 6,200,000 m^3	277 L/sec, at full supply level	Anticipated design seepage at full supply level = 500 L/sec
2	**Storvatn Dam, Norway** Max. height = 90.0 m, Crest length = 1472 m Total vol. = 9.5 mill. m^3	At maximum reservoir level = 10 l/s	However, part of this comes from under seepage and from the abutments, so the leakage through the core is even smaller
3	**Megget Dam, Scotland** Max. height = 56.0 m, Crest length = 568.0 m Core wall = 20,000 m^2	1.61 l/s	Largest earthen dam in Scotland

Table 29.5 Performance in terms of vertical and horizontal displacement for some of the earthen/rock fill asphaltic core dam are given [1]

SL No	Description of Dam	Displacement	Remarks
1	Storvatn Dam, Norway Max. Height = 90.0 m, Crest Length = 1472 m	Maximum settlement of core = 165 mm at center of core or 0.18% of dam height Maximum embankment displacement (inside downstream shell at mid height) = 580 mm (520 mm vertically and 206 mm horizontally)	5 years after end of construction
2	Berdalsvatn Dam, Norway Max. Height = 65.0 m, Crest Length = 465 m Total Vol. = 1.0 mill. m^3	Maximum settlement of core = 70 mm at center of core or 0.1% of dam height	3 years after end of construction
3	Styggevatn Dam, Norway Max. Height = 52.0 m, Crest Length = 880.0 m Total Vol. = 2.5 mill. m^3 Core wall = 79,000 m^2	Maximum settlement of core = 35 mm at center of core The maximum displacements are 67 mm vertically and 68 mm horizontally at about Mid height of the downstream slope	1 year after end of construction

(continued)

Table 29.5 (continued)

SL No	Description of Dam	Displacement	Remarks
4	Riskallvatn Dam, Norway Max. Height = 45.0 m, Crest Length = 600.0 m Total Vol. = 1.1 mill. m^3	The maximum vertical settlement recorded at the top of the core = 45 mm or 0.1% of the dam height	6 years after end of construction

Conclusion

(a) In terms of safety, seepage control and monitoring induced deformation, it has been seen worldwide that using asphaltic concrete core in rock fill embankment gives good result in comparison with clay core.
(b) From the above review, it is understood that the optimum binder content for reaching flexibility during the earthquake and after that is 6.5–7%.
(c) The air void content should not exceed 3% (by volume) for asphaltic concrete to be water tight.
(d) Use of asphaltic concrete core reduces piping and internal erosion in core significantly, as a result probability for earthen dam failure also reduces.
(e) Under significant loading condition of steady state, upstream water pressure and its distribution in embankment material highly reduces the 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 [6].
(f) Use of asphaltic concrete core improve factor of safety for all the condition of stability analysis of earthen/rock fill dam, i.e., end of construction, steady state seepage, and rapid draw down.
(g) Self-healing and flexible nature of asphaltic concrete core reduces piping phenomenon in core, as a result settlement and induced deformation of core also reduces.
(h) In the high temperature region, the asphalt concrete core as water barrier has more concern. However, polymer modified bitumen may be used in in-lieu of normal bitumen as it increases softening point of bitumen.
(i) From the above review it is found that Marshall Stability test is one of the most important tests for evaluating stability and deformation of asphaltic core of earthen/rock fill embankment dam. For **higher dams** it is recommended that in every case the core and supporting shells material should also be given **triaxial tests**.

Figure 29.9 depicts **Storglomvatn Dam (125 m), Norway**.

Fig. 29.9 Storglomvatn Dam (125 m), Norway [8]

References

1. ICOLD 42: Bituminous cores for Earth and Rockfill Dam
2. Wang W, Höeg K, Zhang Y (2010) Design and performance of the Yele asphalt-core rockfill dam. Can Geotech J 47:1365–1381
3. ICOLD 84: Bituminous cores for fill dams
4. Höeg K (1993) Asphaltic concrete cores for embankment dams. Experience and practice. Norwegian Geotechnical Institute
5. ICOLD 32 a: Bituminous concrete facings for earth and Rockfill dams
6. United States Society on Dams Materials for Embankment Dams January 2011, Prepared by the USSD Committee on Materials for Embankment Dams
7. Veidekke (n.d) Asphalt core dams. NGI, Oslo
8. Wang W, Höeg K (2009) The asphalt core embankment dam: a very competitive alternative. Norwegian Geotechnical Institute NGI. Norwegian Geotechnical Institute (NGI), Chengdu, China, p 1
9. NM Bayisa (2019) Relative performance evaluation of asphaltic concrete core embankment dam and clay core embankment dam: by plaxis software application, Am J Sci Eng Technol 4(1):18–29. Department of Hydraulic and Water Resources Engineering, College of Engineering and Technology, Bule Hora University, Bule Hora, Ethiopia
10. Alicescu V (2010) Design and construction of Nemiscau-1 Dam. Canadian Dam Association, Ottawa
11. Zomorodian SMA, Charrakh M, Heidarpour M (2005) A comparision of asphaltic concrete core dams and asphaltic lining dams with clay core dams. EJGE