Construction and Building Materials 140 (2017) 301–309

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Development of an asphalt concrete mixture for Asphalt Core Rockfill Dam

Jung-Woo Seo, Dae-Wook Park *, Tri Ho Minh Le

Dept. of Civil Engineering, Kunsan National University, 558 Daehak ro, Kunsan, Jeonbuk 54150, Republic of Korea

HIGHLIGHTS

- Asphalt concrete mixtures designed for rockfill dam require higher bitumen content than that for road pavement.
- The strength behavior and moisture resistant of test specimens were impacted considerably by filler content.
- Confining pressure has a remarkable effect on triaxial compressive strength of asphalt concrete specimens.
- A small change in air void content of asphalt concrete mix could results in significant increase in permeability property.

ARTICLE INFO

Article history:
Received 28 November 2016
Received in revised form 21 January 2017
Accepted 19 February 2017

Keywords:
Asphalt Core Rockfill Dam
Hot mix asphalt
Triaxial strength
Indirect tensile strength
Permeability

ABSTRACT

The main objective of this paper is to develop asphalt concrete mixture and conduct performance tests for Asphalt Core Rockfill Dam (ACRD). Three conditions of mineral filler content have been used: 10, 12 and 14%, namely: F10, F12 and F14 respectively. The amount of optimum bitumen for each filler condition were determined by Marshall mix design method. The stress strain properties of the asphalt concrete (AC) were studied through Unconfined Compression Strength (UCS) Test, Indirect Tensile Test (IDT) and Triaxial Tests. Moisture susceptibility and water penetration were evaluated using Indirect Tensile Test and Permeability Test respectively. The result exhibits that the increase of filler content from 10 to 14% has significant effect on optimum asphalt content and properties of asphalt concrete mixture. Among all mixtures, mix F10 yielded highest strength behavior and moisture resistance. Result also suggests that asphalt concrete specimen was impervious to water (k value $<10^{-8}$ mm/s) when the mixture was produced at air void content no larger than 4%, 3.4% and 3.6% in mix F10, F12 and F14 respectively.

1. Introduction

The embankment dam using asphalt core was first developed in Germany in the 1960s. Since then, more than 150 ACRD dams have been built in many regions around the world but mostly in northern Europe, including several in Norway. The first dam with an asphalt core was completed in Norway in 1978, and nearly all large Norwegian embankment dams have been built using this method. Nowadays, many countries around the world have recognized the huge advantages of asphalt core dam and several asphalt core dam projects have been constructed. The Chinese developed their knowledge of the structures and built their first asphalt core dams in the 1970s. To date 13 dams of this type have been completed in China. In North America, Canada is the first country completing construction a dam of this type. After that, the biggest energy company in Canada Hydro Quebec has decided to construct several more dams of this design.

Over the past few years detailed cost comparisons have been made between asphalt concrete core dams and their alternatives at the design stage of projects. For the Urar dam, completed in 1997 in Norway, tenders were submitted for a Roller-Compacted concrete (RCC) dam and a rockfill dam with asphalt core. When only considering contractor costs and additional spillway expenses, the asphalt core alternative turned out to be approximately 10% cheaper than the RCC option. For the Greater Ceres dam, completed in 1998 in South Africa, three alternatives were compared at the design stage: RCC, concrete faced and asphalt concrete core dams. The latter was chosen due to cost and because the dam was located in an earthquake region on a poor sandstone foundation. It seems quite probable that embankment dams with asphalt concrete cores are likely to find a more prominent place in future dam construction.

* Corresponding author.
E-mail addresses: sjwcpt@kunsan.ac.kr (J.-W. Seo), dpark@kunsan.ac.kr (D.-W. Park), lehominhtri92@gmail.com (T.H.M. Le).

http://dx.doi.org/10.1016/j.conbuildmat.2017.02.100
0950-0618/

In spite of the few economic data, this type of solution seems competitive, especially for locations where fine materials for the construction of a traditional core (clay) are scarce. Also, the increased use of asphalt concrete rather than earth core is partly due to the profession's increased concern about internal erosion of earth core. By adjusting the bitumen content or the viscosity penetration, the viscoelastic-plastic properties can be tailored to local conditions and climate which makes asphalt core dams especially suited to seismically active areas, and on compressible foundations where stiffer structures like Concrete Face Rockfills Dam (CFRD) and RCC dam may not be suitable. The reservoir can be filled during construction, which is not feasible for an upstream facing alternative. Furthermore, overtopping of an asphalt core during construction will not have the dramatic consequences as for a clay core or an upstream facing solution.

Vlad [12] presented that asphalt core embankment dams built on good foundation have outstanding record with no seepage problems or required maintenance. Wang and Höeg [13] suggested that asphalt concrete core not only offers virtually impervious and flexible characteristic but also resists to erosion and ageing. Especially, the self-healing ability can be provided by the viscoelastic-plastic and ductile properties of asphalt core. This unique ability could prevent cracks develop in the core wall due to differential displacements (shear distortions) caused by severe earthquake loading. Asphalt concrete is also a very "forgiving" material in its behavior relieving itself of stress concentrations. The use of softer bitumen than in previous construction increases the self-sealing quality and allows lower operating temperatures and energy input during material production, transportation and core placement. Besides, some researches present another ideal advantage of asphalt core dam named joint-less core construction which dramatically enhance the dam quality. Furthermore, the core may be constructed in cold and rainy weather without construction delays. Therefore, asphalt core is a competitive and economically viable alternative in comparison with other traditional ones [11].

The mix design of asphalt concrete used in impervious facings and cores in embankment dam originated from road asphalt concrete experience [13]. However, there are significant differences between a road pavement and an interior dam core with respect to loading and environment conditions. The asphalt which is used on roads and airfields, where deterioration becomes evident in potholes etc, has a different composition to the asphalt used in dams. Inside a dam the asphalt is kept under virtually ideal conditions. Fairly constant temperatures without exposure to the sun and the rich, dense asphalt mix means that oxidation or hardening does not occur over time. Typically, the road asphalt concrete mixes consist of 4–6% bitumen by mineral weight, 4–8% filler material (<0.075 mm), and 20–40% fine aggregates (0.075–2.36 mm). The air voids content for road asphalt concrete after compaction is in the range of 3–10%. In the other hand, the asphalt concrete used in dam is required to be impervious and flexible and it consists of more fine aggregates, filler and bitumen than the asphalt concrete used in pavements. In previous designs of asphalt core dam (e.g. Höeg [13], Vlad [12]), these authors suggested the optimum asphalt content about 6.5 to 7.3% by mineral weight, <15% filler mineral (<0.075 mm), 35–52% fine aggregates (0.075–2.36 mm), 33–55% coarse aggregates (2.36–19 mm) and laboratory air void content no larger than 2% which will provide a virtually impervious asphalt concrete (permeability <10–8 mm/s).

Particularly in recent years, construction of this type of dam in the seismic areas of the world such as Japan, China and Iran has caused researchers to focus on the dynamic behavior of asphalt cores. However, few researchers have investigated the stress-strain behavior of asphalt concrete used as watertight elements for dams by laboratory tests. Especially, very little has been reported on the research of filler content suitability for hydraulic dense grade asphalt concrete with air porosity less than 3%. With parameters derived from the carried-out tests, the acceptable level of the rheological behavior and stress train properties of bituminous concrete mixes can be revealed. This research data can be very useful for geotechnical engineers to conduct numerical analyses and predict field performance of asphalt core dams for different situations.

2. Research objectives and scope

The purpose of this paper is to systematically develop asphalt concrete mixture and conduct performance tests for ACRD. Preliminary studies have indicated the specific content of filler for ACRD, but lack of researches has clearly justified the effect of this mineral content to the properties of asphalt concrete mixture. Therefore, three filler content: 10, 12 and 14% were selected to evaluate in this study based on trial testing and previous experiences. The Marshall mix design method was conducted to determine the optimum asphalt binder content in each condition. The stress strain properties of the asphalt concrete were documented through Unconfined Compression Test, Indirect Tensile Test and Triaxial Tests. The ductility of the specimen after reaching peak strength and any strain weakening behavior of the mix was also evaluated to assure that the asphalt concrete exhibits flexible and ductile (not strain-softening) behavior required to adjust to dam deformations caused by static and dynamic loads and differential foundation settlements. Indirect Tensile Test and Permeability Test were carried out to determine the moisture susceptibility and water penetration respectively. Air void content also plays a very important role in the performance of asphalt concrete, especially the permeability. Air void content in asphalt concrete mixture was modified from approximately 2–8.5% to determine the influence of this content to the water penetration factor.

3. Material and methodology

3.1. Material

HMA is a mixture of mineral aggregate and bituminous binder. Asphalt binder PG58-22 was used in this study as it is the most widely used in Korea. The specific density of coarse and fine aggregate is 2.647 and 2.671 respectively following the AASHTO T 84-10 [1] and AASHTO T 85-10 [2] standard. The nominal maximum size of 13 mm gradation was selected to enhance the design of impervious asphalt concrete. As mentioned before, there are three conditions of filler in this study: 10, 12, 14%. It is a combination of 50% pan and 50% mineral limestone which passing sieve #200. Based on preliminary asphalt core dam studies and experiences, the particle size distribution of aggregate designed for impervious core is shown in Table 1.

Table 1
Particle size distribution of aggregate.

Sieve size	Percent passing (%)
19 mm	100
13 mm	99
10 mm	84
#4	57
#8	43
#30	29
#50	23
#100	18
#200	10/12/14*

* Three different ratios of filler content: 10, 12 and 14%.