Construction and Building Materials 41 (2013) 319–334

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Experimental study of asphaltic concrete dynamic properties as an impervious core in embankment dams

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HIGHLIGHTS

- ▶ Asphaltic concrete core retains its stability even after a moderate earthquake.
- ▶ The higher Bitumen content, the more is the amount of failure axial stress.
- ▶ The more the Bitumen content and confining stress, the less is the Secant modulus.
- ▶ Increasing the values of K_c, will increase modules both in tension and compression.
- ▶ The least and the most damping is observed at 6% and 7% Bitumen respectively.

ARTICLE INFO

Article history:
Received 21 June 2012
Received in revised form 13 October 2012
Accepted 22 November 2012
Available online 11 January 2013

Keywords:
Asphaltic concrete core dam
Monotonic tests
Cyclic tests
Bitumen content
Seismic behaviour
Shear modulus
Damping

ABSTRACT

The seismic behaviour of asphaltic concrete used as an impervious core in embankment dams was investigated.

To evaluate the specimen's dynamic behaviour, an extensive series of monotonic and cyclic triaxial tests were carried out. Bitumen content between 5.5% and 7.0% with 0.5% increments were selected for the tests. Isotropic and anisotropic initial stress conditions with different principal stress ratio were also considered in this study. Thousands of cycles were imposed on some of the specimens, to study their fatigue behaviour due to seismic loading. A small degradation could be seen but no cracking was observed on the cutting surfaces. All tests were carried out at a constant temperature of 22 °C simulating a constant temperature inside a dam in tropical climate regions. Shear modulus in the compression region (G_c) and tension region (G_e) are presented for different Bitumen content, confining stress, stress ratio (K_c) and loading type. The damping ratio was also presented for different loading states. A regression equation was also derived for determining cyclic and maximum shear modulus (G_{max}) of the asphaltic concrete for different Bitumen content as a function of confining stress which can be used in numerical studies.

1. Introduction

Using asphaltic concrete as a water barrier in embankment dams began in Germany 50 years ago. Progresses in the design and construction of these types of dams have been achieved in recent years [1,2]. Significantly important engineering properties of asphaltic concrete including impermeability, flexibility, resistance against erosion, self healing [3] and independence of its placement from weather conditions, make it more a suitable and economically viable material in comparison with clay core in many locations [1,2]. Saxegaard provided an overview of asphaltic core dams constructed or currently under construction in the world [4]. The Yele dam is the highest asphalt concrete core dam built in China with a height of 125 m. Wang et al. provided some information on the design and performance of the Yele dam [5]. Although monitoring of these dams showed good performance during construction and operation, the behaviour of the slender asphaltic concrete core subjected to a severe earthquake needs more attention and exploration [6]. A large number of researches (examples from authors [7,8]) have been done on asphalt concrete used for road and airfield pavements. The effects of dynamic traffic loading on material behaviour and durability have been studied but there are only a few studies that provide information on the behaviour of asphaltic concrete used as a water barrier in hydraulic structures when subjected to simulated earthquake loading. The barrier must be designed to sustain cyclic compression as well as shear and tension stresses. Laboratory tests have been performed to study the material behaviour under such conditions [6].

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0950-0618/$ - see front matter
http://dx.doi.org/10.1016/j.conbuildmat.2012.11.044

This research was part of a comprehensive study on an asphaltic concrete core dam that is under construction in the south of Kerman province, Iran and is the highest asphaltic concrete core rockfill dam in the country [9]. The dam is located in a region with high average temperature around the year. Reviewing the temperature recorded data in the region showed that 22 °C is a good estimation of temperature inside the dam most of the year, so all tests were carried out at this temperature [10].

1.1. Previous experimental studies

The first experimental research in the field of seismic behaviour of asphaltic concrete used in hydraulic structures was performed by Breth and Schwab [11]. They concluded that asphaltic concrete behaves as an elastic body under seismic loading [11].

Ohne et al. performed uniaxial cyclic tests on specimens drilled out from Higashifuji dam [12]. They defined and measured the dynamic yield strain for the asphaltic material and concluded that applied compressive stresses can lead to cracking in specimens.

Wang reported a series of triaxial cyclic tests on specimens and showed that there was no sign of cracking or degradation on the specimens under the testing conditions used [13].

Nakamura et al. performed some tests to study tensile strength and tensile cracking strain of the asphaltic concrete [14]. The main goal of their study was to investigate the difference between engineering properties of conventional asphaltic concrete with a special admixture (called Superflex-asphalt). They showed that the new type of mix has a higher tensile cracking strain than commonly used asphaltic concrete.

It is important to determine the level of tensile strain that can cause cracking in the asphaltic concrete. This strain level is clearly a function of temperature and rate of loading. In earthquake prone regions, the asphalt mix is usually made with soft grade Bitumen and an added Bitumen content (0.5–1)% to increase flexibility and tensile cracking strain [15].

Baziar et al. performed a 3D finite difference analysis on the asphalt of Meijaran dam with a height of 60 m in Iran. Some cyclic tests were also carried out to estimate the shear modulus of the asphaltic concrete. Their numerical study showed that the upper part of the core will experience some plastic shear strains in a maximum earthquake level (MDL). They also concluded that the numerical response of the dam is not significantly dependant on the amount of shear modulus of the asphaltic core in a range of 800–1800 Mpa [16]. A small scale centrifuge modelling of the dam was also performed under impact load. They indicated that the numerical results agreed well with the data recorded during centrifuge tests and the asphaltic core showed similar behaviour in the numerical and centrifuge models. The results of the numerical study for the case study showed that in a severe earthquake, the asphaltic core behaves in a safe manner [17].

Feizi et al. performed an extensive series of monotonic and cyclic tests on triaxial specimens with constant Bitumen content at the Norwegian Geotechnical Institute [18]. Temperature and frequency effects on specimen behaviour and specimen degradation were studied under the cyclic loads in both isotropic and anisotropic conditions. Their findings showed that the dynamic shear modulus (G) derived from hysteresis loops were between 1.6 and 4.0 GPa at 5 °C and 0.75–1.75 GPa at 18 °C. They also reported extension behaviour during cyclic loading for some of the specimens at a higher temperature (18 °C).

Recently, Wang and Hoeg studied the effects of cyclic loading on the stress–strain behaviour and permeability of asphaltic concrete at different temperatures under static and cyclic stress conditions [19]. Their study indicates that at a mean sustained stress of 1.0 MPa, the cyclic modulus (E_d not G) is about 900 MPa at 20 °C, 1900 MPa at 9 °C, and about 2500 MPa at 3.5 °C [19]. They also concluded that the number of load cycles has no significant effect on the post-cyclic monotonic stress–strain–strength behaviour and permeability (water tightness) of the asphalt concrete.

Previous studies indicate that the main parameters affecting dynamic properties of the asphaltic concrete are temperature, confining stress, initial stress ratio, loading type, loading speed, frequency and Bitumen content. Only a few publications provide information on some of these parameters [18,19], however there is a lack in these studies especially in the field of Bitumen content effect and for seismic behaviour of asphalt concrete used in warm climate regions because most asphaltic concrete core dams have been constructed in cold regions. Also, previous studies did not clearly address the dynamic shear modulus of the material which can be used in nonlinear dynamic numerical analysis.

So this study tries to cover the main topics as mentioned below:

- Determination of monotonic and cyclic response of the asphalt concrete.
- Effects of different parameters on the behaviour of specimens.
- Fatigue behaviour and cracking possibility of the samples.
- Post-cyclic behaviour and degradation of the specimens due to cyclic loading.
- Suggestion of geotechnical parameters to be used for numerical analyses.

2. Mix design and specimen preparation

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. Marshal tests according to ASTM-D1559 were carried out with a Bitumen content of 5.5, 6.0, 6.5, 6.75 and 7.0 percentages by weight. B60 type Bitumen was used for all tests.

Bitumen content between 5.5% and 7.0% are permissible in asphaltic concrete used as a water barrier, but researchers commonly advise the use of between 6.5% and 7.0% by weight of aggregates [1]. This range of the Bitumen content is selected for most of the asphaltic concrete core dams in the world to achieve flexibility during and after an earthquake loading [1]. However, there is not much information on the effect of Bitumen content on the dynamic properties of asphaltic concrete used in dams. Hence, different percentages of Bitumen content from 5.5 to 7.0 by weight of aggregates were selected for this study.

The laboratory triaxial specimens were prepared in a 100 mm diameter and 200 mm height mould. Portland cement was used as filler in the mix. The specimens were built in four equal thickness layers using the compaction method which is in good accordance with field roller compaction in the field [20]. All samples were trimmed with a diamond cutter and the surfaces of specimens were polished to decrease the bedding error effect during the tests.

3. Static triaxial tests

Twelve triaxial compression tests were carried out to investigate the static behaviour of the asphaltic concrete. Membrane was used for all the test specimens. All specimens were placed into a constant temperature bath to reach 22 °C prior to monotonic testing. The triaxial cell was also filled with de-aerated 22 °C water. All monotonic tests were carried out using a strain-controlled compression loading system. After applying the predefined confining