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Investigation on conditions of hydraulic fracturing for asphalt concrete used as impervious core in dams

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HIGHLIGHTS

- Model tests carried out to simulate the conditions for very high asphalt core dams.
- The fractures of asphalt in the model tests due to the induced large tension strains.
- Hydraulic fracturing can be excluded for asphalt core in dams in common conditions.
- Hydraulic fracturing is discussed for asphalt core in dams in very extreme conditions.

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ABSTRACT

Asphalt concrete is used as impervious core in embankment dams. This paper investigates the conditions under which hydraulic fracturing could be possible to occur for an asphalt core in dams. Asphalt concrete test model was developed and tests were carried out on the models under tension, restraint and compression conditions corresponding to nearly-impossibly extreme conditions of an asphalt core in dams and finite element analysis was performed on the model test results. Test and analyzed results show that asphalt concrete models at fracturing are caused by large tensile strains in asphalt concrete under the imposed conditions rather than the so-call "hydraulic fracturing". The imposed conditions are extremely impossible for an asphalt core in dams in reality and therefore the so-call "hydraulic fracturing" may be excluded.

1. Introduction

The problem of hydraulic fracturing is one of major concerns in earth core embankment dam design. The void content of an earth core is commonly in a range of 10–20% and a continuous hydrostatic pressure develops in the earth core due to water flowing through the core when reservoir is impounded. When the hydrostatic pressure or pore water pressure is greater than the vertical total stress in the core a phenomenon of hydraulic fracturing may occur [1].

In contrast with the void content of an earth core in dams, the air void content of an asphalt core is less than 3% and mineral aggregates are bounded by bitumen with high viscosity. There is no system of voids in the asphalt core that would allow the entrance of water and thus the generation of a pore water pressure in the core. The main prerequisites for hydraulic fracturing are non-existent in the case of impervious asphalt concrete. The applications of more than 300 asphalt facings on banks and bottoms of reservoirs and on upstream slopes of embankment dams since the 1920s have been no indication of a hydraulic fracturing yet, although there are considerably low effective stresses (even some tensile strains) in the impervious asphalt layer of 5–10 cm thickness in comparison with the external reservoir water pressure. Therefore, as early as in 1992 the International Commission on Large Dams (ICOLD) excluded the effect of hydraulic fracturing for an asphalt core in dams [1]. Late in 1999 Schönian [2] also stated "the problem of hydraulic fracturing does not exist for core walls made of asphaltic concrete".

In last century the dam height of most embankment dams with an asphalt core or asphalt facing was less than 100 m and most dam embankments seated on rock foundations in valleys with gentle abutments. In this century with the experience obtained from researches and applications on asphalt concrete [3–6] the dam height of some asphalt core dams is more than 150 m and some dam embankments seat on deep compressive overburdens in valleys with steep abutments. For instance, the maximum dam height

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for the Cetin Dam in Turkey is 165 and 171 m for the Quxue Dam which seats in a narrow valley with a steep abutment of 1V:0.33H (72°) in China [7]. In the special cases asphalt core may be subjected to more embankment and foundation differential settlements which may result in suspension of the core on the more rigid zone of embankment and cause more reduction of the vertical stress in the core. 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. Such complexity of geological conditions for an asphalt core dam has caused the profession's uncertainty and concern about that how the effect of hydraulic fracturing for an asphalt core could be excluded in such special cases. This was the main incentive for the authors to undertake the following study: (1) determining the conditions of hydraulic fracturing on asphalt concrete with model tests; (2) calculating the tensile strains in the asphalt concrete for the model test results with finite element method; and (3) discussing the possibility of hydraulic fracturing in an asphalt core in embankment dams.

2. Test model and specimen preparation

Fig. 1 shows the schematic diagram of the developed equipment for asphalt concrete model tests for hydraulic fracturing.

The asphalt concrete specimen with dimensions of 150 mm in diameter and 250 mm in height was prepared in the cylindrical steel mold. Standard asphalt concrete core mix design criteria have been developed and, with relatively small variations, used for most of asphalt core dams for more than 50 years. The aggregate grain sizes usually lie between 0 and 16 or 18 mm. The mix design of the asphalt core for a high embankment dam in China was used in this study and shown in Table 1. The aggregates were crushed limestone. The added filler consisted of limestone powder and the total filler content (<0.075 mm) was 14% of the mineral weight. The bitumen was of grade B70 and the bitumen content was 7.0% of the mineral weight (6.5% of the total weight).

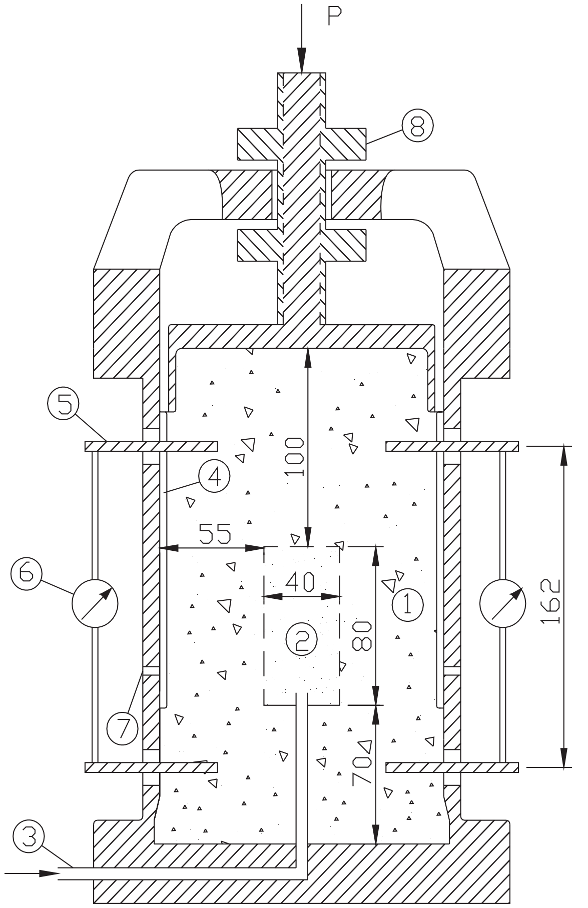

Fig. 1. Schematic diagram of the equipment developed to carry out asphalt concrete model tests for hydraulic fracturing. 1. Asphalt concrete; 2. natural sand (<2.36 mm); 3. pressure water; 4. lubricating paper; 5. displacement base bar of 8 mm in diameter; 6. displacement meter; 7. water outlet; 8. displacement adjustable screw.

Table 1
Asphalt concrete mix used in this study (% of mineral weight).

Sieve size (mm)						Bitumen content (B70)
13.2–19	9.5–13.2	4.75–9.5	2.36–4.75	0.075–2.36	0–0.075 (Filler)	
13	10	18	14	31	14	7.0

The dry aggregates, added filler and bitumen were heated and mixed and then the hot asphalt mix with a temperature of about 150 °C was placed in three consecutive layers in the cylindrical steel mold with a diameter of 150 mm. The top side of each layer was compacted with the standard Marshall hammer with a flat circular tamping surface of 98.4 mm diameter in a uniform distribution blows on the top area to simulate the field roller compaction of the core [8]. The compacted height of the asphalt base-layer was 70 mm and a copper tube of 6 mm in diameter was pre-set in the center of the base-layer. Before placing the middle-layer asphalt mix a thin cylindrical steel tube of 40 mm in diameter was temporarily fixed in the center and filled with natural sand in the tube and a lubricating paper was placed around the inner perimeter of the steel mold wall. After placing asphalt mix in the cavity between the tube and the steel mold wall the tube was pulled out and the asphalt mix together with the natural sand was compacted. The height of the asphalt middle-layer was 80 mm. The compacted height of the asphalt top-layer was 100 mm. The blows of Marshall hammer for the base-layer, middle-layer and top-layer asphalt were 150, 170 and 210, respectively, after having been trying to compact a few specimens to reach air void content of less than 2% and with air voids randomly scattered in the specimens. The differences among the three layers in blows were in correspondence with the different layer heights of 70, 80, and 100 mm from the base to top-layer with am approximately same compaction energy input. To measure the vertical displacement (vertical strain) of the asphalt specimen two displacement base bars were installed in the base- and top-layer asphalt, respectively. A steel cover was bound on the top of the specimen.

3. Model test results under tension, restraint and compression conditions

Asphalt concrete presents a viscoelastoplastic behavior and its stress–strain relation is time-dependent and temperature-dependent. Therefore, the model tests were carried out in a stepped-loading creep manner at different temperatures to reach relatively stable stress–strain states.

The selected test temperatures were 5, 10 and 20 °C, respectively, considering the temperature of an asphalt core being 5 °C for embankment dams located in sub-arctic climate, being 20 °C in sub-tropical climate and being 10 °C between the two extreme climates. Prepared test model was kept at specified temperature for at least one day before a designed test was carried out.

3.1. Model test results under tension

The test was designed with an attempt to investigate how large tensile strain the asphalt specimen could undertake with a

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