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Anomalous Seepage Flows and Piping in Oje-Owode earthdam: Granular filter-drain media as controlling measure

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Abstract

There was loss of water at Oje-Owode dam embankment through seepage. Evidence of some degrees of fracturing and seepage at the dam toe been reported. Previous results showed that the dam embankment was permeable and anomalous seepage occurred at the toe. This study, therefore attempted the application of locally sourced granular filters, precisely, stone dust from quarry, to model the control of seepage and piping at the toe of the dam embankment. Coarse soil samples were collected from quarry site as selected granular filters. Granite stones of sizes ½ - ¾ inch were selected as the drain samples. These were subjected to particle size analysis, compaction tests, specific gravity; and constant head permeability test. Numerical analyses were also carried out to generate flow lines, seepage rates and velocity vectors of the dam. The results of the simulated flow net showed a seepage value of 3.8066×10^{-8} m^3/s per width, while total seepage at maximum phreatic level and at full length (896m) of dam axis was 3.4107×10^{-5} m^3/s. This indicated loss of water from dam toe through seepage. The velocity vector contours showed flow directions and maximum velocity magnitude of 3.6×10^{-8}m/s in the direction of decreasing heads. The modelled filter-drain installed at dam toe controlled the anomalous seepage water and prevented piping as though it were a horizontal drain. The flow lines were controlled at coordinate points (36.25m, 0.56m) and remained horizontal through the filter media, until it exited the dam at the toe at coordinate points (41.88m, 0.59m), which is relatively a save point for collection. The modelled filter-drain media installed at dam toe controlled the anomalous seepage water and prevented piping.

Keywords: Oje- Owode dam, Piping, Granular Sand filter, Numerical analyses, Seepage

1. Introduction

Dams are major engineering structures that are designed and constructed with long life expectancy. An earth dam has its relevance in the supply of water for human and animal consumption and irrigation purposes. Water impoundment is accomplished by the construction of an earth embankment usually 3-8 m high and several hundred of meters long across a river channel. The integrity of a dam embankment can be undermined by the existence of geological features (e.g. faults, fissures, jointed or shear zones), precipitated seepage zones in the bedrock and /or discontinuities in the structure itself. Apart from loss of huge financial investment, other consequences of dam failure can be very devastating. Human, animal and material resources located on the immediate downstream side of such a failed dam are lost. Vast irrigable agricultural resources are wasted, so also are the aquatic lives in the previously impounded water. The cost of rehabilitation of failed dam can be enormous. In most cases, failed dams are completely redesigned and reconstructed at much higher cost. Dams are known to occasionally fail due to a combination of factors. These factors include age, decaying infrastructures, engineering design defects due to poor understanding of the subsurface geology, unstable construction materials, construction defects and lack of monitoring or maintenance of the dams (Olorunfemi, *et al.*, 2000). Adequate assessment of geotechnical properties is an important aspects of dam safety investigations (USDACE, 1986).

Filter with a simple but effective job is one of the principal parts in an embankment dam which is able to immune the dam against erosion, prevent water escape and seal unfavorable cracks that may occur through the impermeable core (Yasrobi and Azad, 2004).In addition to production, construction and economical aspects, choosing a proper, optimum and fit-to-need filter also should be taken into account. But the excess of the effective factors influencing the soil-filter system behavior and also the lack of efficient geotechnical parameters to introduce soil-filter relations, offers challenges to engineers for designing and to scholars for proposing a perfect criterion. Gradation curve and its properties, relative density of filter, soil compaction, grain shape, hydraulic gradient, physico-chemical properties, fine content, filter thickness, internal stability, problematic soils, etc. are the examples of the factors cause a complex set.

The common kind of impermeable cores in embankment dams are clayey soils that can effectively resist water pressure at upstream the dam. However the occurrence of unfavorable cracks is not avoidable. In this case, filter with a simple job can improve the core duty and immune the dam against erosion and even control and seal the cracks. Therefore, choosing a proper filter for a certain base soil (the soil which should be protected) is needed.

Sherard and Dunnigan (1989) after about 10 years study on the filters, erosion and embankment dams proposed a repeatable test to assess a soil-filter system (for the critical filters). However this test has not a standard procedure, it is frequently used and it is suggested to be used for filter designing (e.g. ICOLD, 1994).The proposed test was NEF (No Erosion Filter) test. The NEF test apparatus is made of a plastic cylinder with upper and lower caps each has holes for inlet and outlet water. In the cylinder Gravel Drain, Base Soil, Filter and Gravel Drain are located from top to bottom respectively. A 1.0 mm hole (for cohesive soils) should be created in the base soil that represents the simulated cracks in the core.

During some experimental studies on assessment of filters which are not satisfy the design criteria, Foster and Fell (1999) found that there is another boundary before which filters can finally stop the erosion while after this boundary filters are not able to control the erosion. This boundary called Continuing Erosion boundary can be found using a new test. They proposed CEF (Continuing Erosion Filter) test that is a modified version of NEF test. Similar to NEF that seeks the No Erosion boundary, CEF test could search for the continuing erosion boundary.

Agbede and Oladejo (2010) had attempted the application of locally sourced granular filters and drain to model the control of seepage and piping in the fractured foundation of Awba dam, University of Ibadan, Nigeria; while in 2011, Agbede and Oladejo investigated the dam embankment and its foundation for seepage problems, and to model the dam with the installation of granular filter-drain, as means to controlling anomalous seepage and piping.

2. Materials and Methods

Oje-Owode dam is an earth-fill dam, impounds river Oje in Oje-Owode town in Saki-east local government area, Oyo state. The dam construction started in the year 1985 and was commissioned by the then military administrator of Oyo state Col.Chinyere Ike Nwosu on Monday 31st July 1995. The dam is multipurpose; serving the following distinct purposes: flood control, irrigation purpose, community water supply, while the roadway serves as pedestrian or vehicular bridge across the river. The dam is being maintained by Oyo State Agricultural Development and Eradication Program (OYSADEP). The embankment dam is 7.5m high, 897m long, 43.2m wide, and 4.0m wide crest. The dam impounds 290,000m^3 capacity.

The dry season is characterized by the dry cold harmattan that comes from north-eastern wind from the Sahara desert while the wet season that runs from April to mid October and early November is characterized by the wet humid and moisture laden south western wind that comes from the Atlantic Ocean. The rainfall is about 1262mm per annum while the temperature ranges between 27 ^oC and 29 ^oC (Oladejo and Ajibade, 2013).

2.1. Application of filter and drain to control piping problems in dam foundation

Previous works have shown that there was loss of water at the toe of Oje-Owode dam embankment through seepage. Oladejo and Ajibade (2013) reported that evidence of fracturing and seepage has been noticed at the toe of the dam. Geotechnical investigations and Numerical simulations were carried out on the dam and results showed that the dam embankment was permeable and anomalous seepage occured at the toe. Granular sand filter and toe gravel drains as a controlled solution for piping was recommended (Oladejo and Ajibade, 2013). This study, therefore attempted the application of locally sourced granular filter and drain to model the control of seepage and piping at the toe of Oje-Owode dam embankment.

Granular soil samples (peat sand, run-off (gutter) sand, and quarry dust) were collected from peat borrow pit, line drain and quarry site respectively. Granite stones of sizes ½ - ¾ inch were selected as the drain samples. These were subjected to the following laboratory tests: particle size analysis, compaction test, specific gravity; and constant head permeability test as reported in Agbede and Oladejo (2011). The numerical analyses were carried out with installation of vertical filter-drain of 2.69m height and 36.30m from the dam toe. A Finite element seepage program SEEP 2D was used to simulate flow lines, seepage rates and flow velocity vectors of the dam embankment.

3. Results and Discussion

3.1. Flow lines and Seepage Rates

The output models were presented in Figures 1- 3 for case I (dam toe without filter-drain system, Oladejo and Ajibade, 2013); while Figures 4- 6 for case II (dam toe with installed filter-drain system). The generated finite element mesh has 190 triangular elements and 126 nodal points. The boundary conditions were selected to represent a piezometric level of 5.0 m equal to the water level of the Oje-Owode river dam.

The simulated flownet for case II was presented in Figure 4. These flow lines represented the path of fluid flow through the dam materials and the flows occurred in the direction of decreasing total head. For dam material with isotropic permeability, flow lines are perpendicular to contours of total head. The generated flow rates ranged between 1.58x10^{-8} m^3/s/width and -3.81x10^{-8} m^3/s/width with cross- sectional seepage value of 3.8066 x10^{-8}

m^3/s/width and the total seepage at maximum phreatic level and full length (896m) of dam axis was 3.4107 x 10^{-5} m^3/s (Figure 5). The results from the present research showed a relative increase in the seepage quantities estimated for the same problem domain in case I as reported by (Oladejo and Ajibade, 2013). The difference in seepage values may be due to the present hydraulic conductivity state of the soils constituent of the dam, as effected by the filter-drain system.

From many statistics, the failure of earth dams were mainly due to seepage or piping and it is widely recommended that the monitoring of seepage through an earth dam will control the safety of the dam. Seepage takes place through and under earth dams (Mohammed, *et. at*, 2006). Li *et.al* (2003) proposed element free method for seepage analysis with free surface and the method was applied to steady seepage and transient seepage in uniform earth dams and the application showed satisfactory results. Agbede and Oladejo (2009) had reported a cross- sectional seepage value of 1.02x10^{-6} m^3/s/width and a total seepage value of 6.52x10^{-5} m^3/s (approx. 5633.3 L/day) along the whole length of Awba dam axis.

Mohammed*et.al* (2006) recorded an estimated maximum seepage rates for both Labong and Bukit Merah Dam as 0.52 m^3/min and 0.65 m^3/min respectively. Ali Zomorodian *et al* (2005) reported that in a clay core dam, the total seepage registered at maximum reservoir level is 42 l/sec, while the total seepage registered at maximum reservoir level in asphaltic core dam and asphaltic lining dam are 26 and 0.55 l/s respectively. In this research, the results of the simulated flow net showed a seepage value of 1.075 x $10^{-6}$$m^3$/s per width while the total seepage at maximum phreatic level and at the full length of the dam axis as 6.88 x 10^{-5} m^3/s. This was an indication of loss of water predominantly through the dam foundation.

3.2. Flow Velocity Vectors

The velocity vectors model for case II (dam toe with installed filter-drain system) was presented in Figure 6. The velocities were between the range of 3.6x10^{-8} and 5.57x10^{-12}. This was relatively, a slow soil water movement within the embankment. The Figures showed the flow of the seepage water within the embankment, towards the dam toe, in the direction of decreasing total heads. The flow vectors displayed the groundwater flow velocity vectors at each node of the mesh.

It was noted that, comparatively, the flow velocity at case II was higher to than of cases I; this could be attributed to the fact that the position of the filter-drain at the dam toe, facilitated easy flow and control of seepage water by channeling the flow through the filter-drain as modeled in Figures 3and 6. The installation of the filter-drain as in case II has satisfied the conditions for effective filter for the control of piping in embankment dam. The higher velocity rate also indicated limited clogging of the flow path by clay particles and that the seepage water could be drained technically, at the toe end of the dam. Hence, case II could be adopted as a redesign for Oje-Owode dam to control the present piping problem.

The flow vectors indicated the direction of groundwater flow, and the relative size of the flow vector indicated the relative velocity of the groundwater flow. High velocity flows through the dam embankment can cause progressive erosion and piping of the embankment or foundation soils, (IDNR, 2003). If this condition continues unchecked, complete dam failure can result. Saturated soil areas on the embankment slopes, the abutment, or the area at the toe of the dam can slide or slough, resulting in embankment failure. Piping and badly saturated areas can result in settlement of the soils in the lower the height of the dam and create a potential for overtopping during storm events.

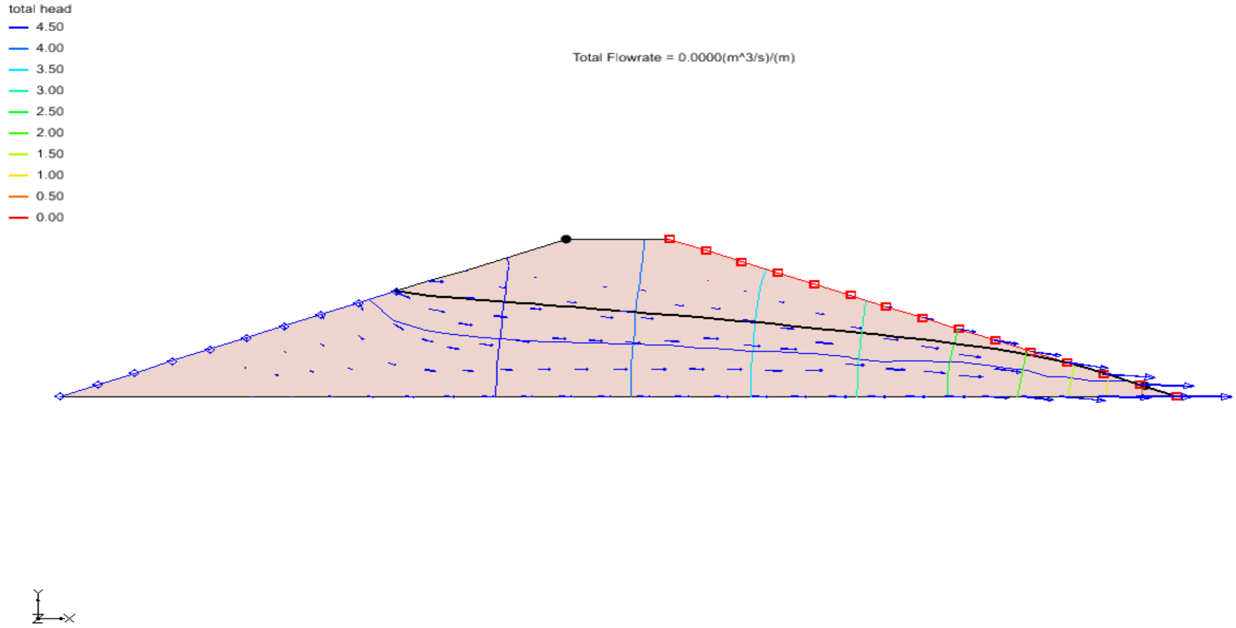

Figure 1: The generated Total Nodal Flow (Flownet) of problem domain (CASE I)

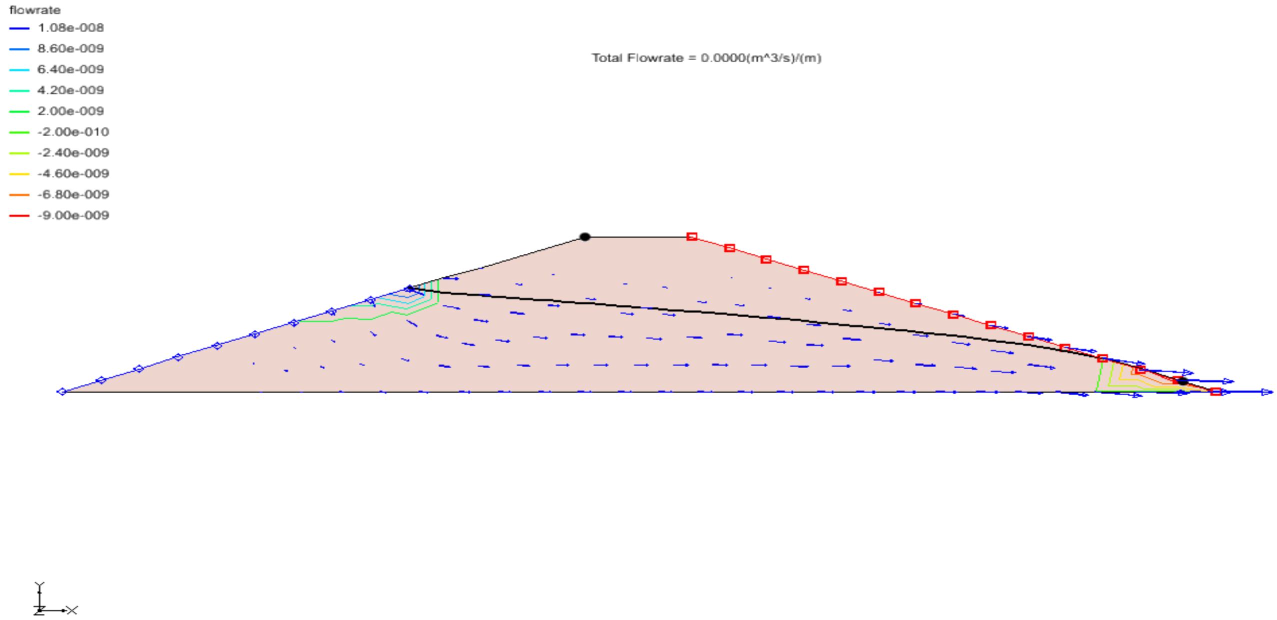

Figure 2: The generated Flow rate and direction of Flow of the problem domain (CASE I)

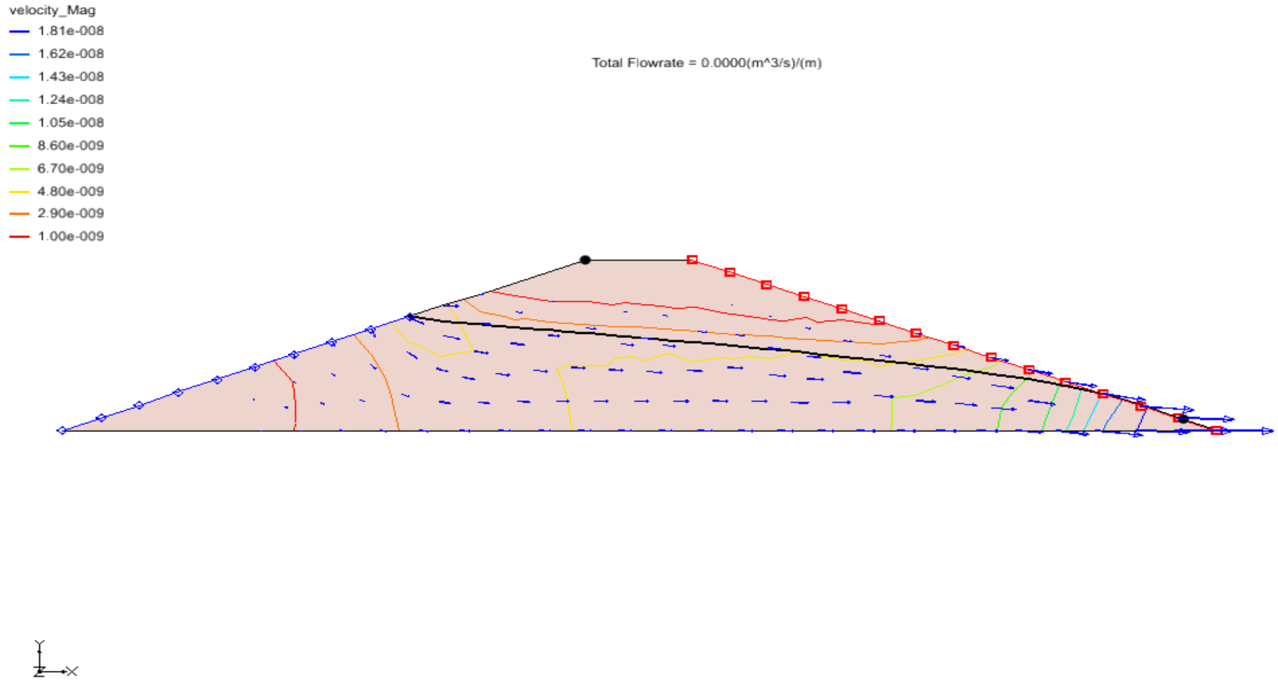

Figure 3: The generated Flow Velocity Vectors of problem domain (CASE I)

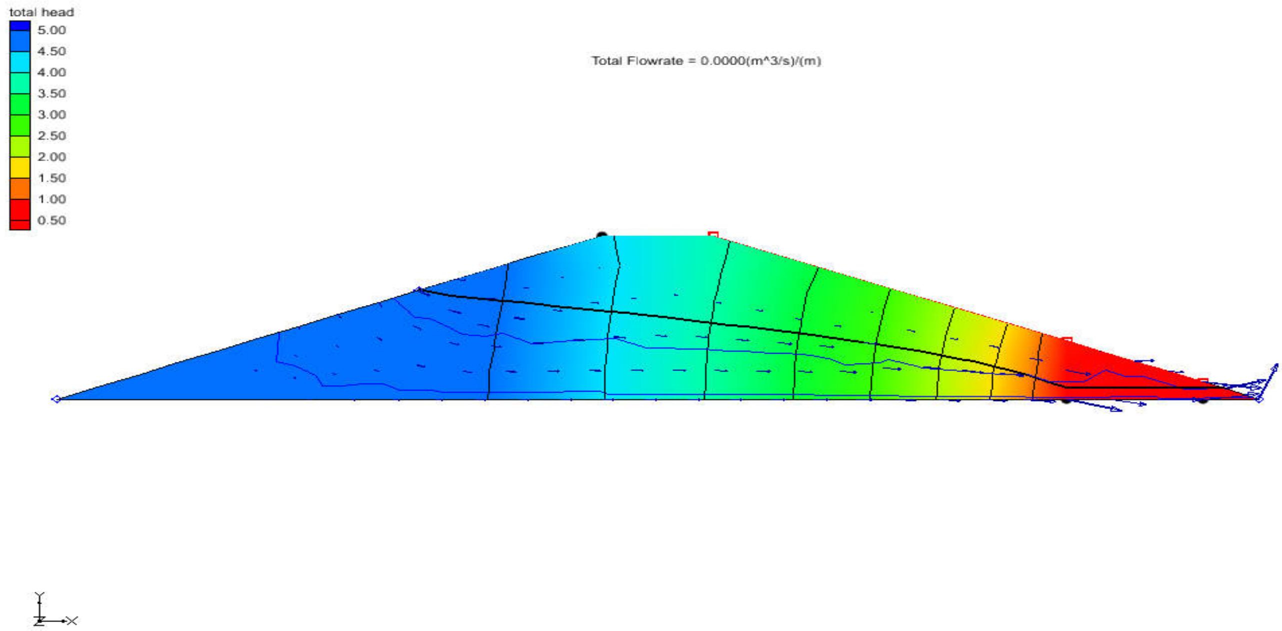

Figure 4: The generated Total Nodal Flow (Flownet) of problem domain (CASE II)

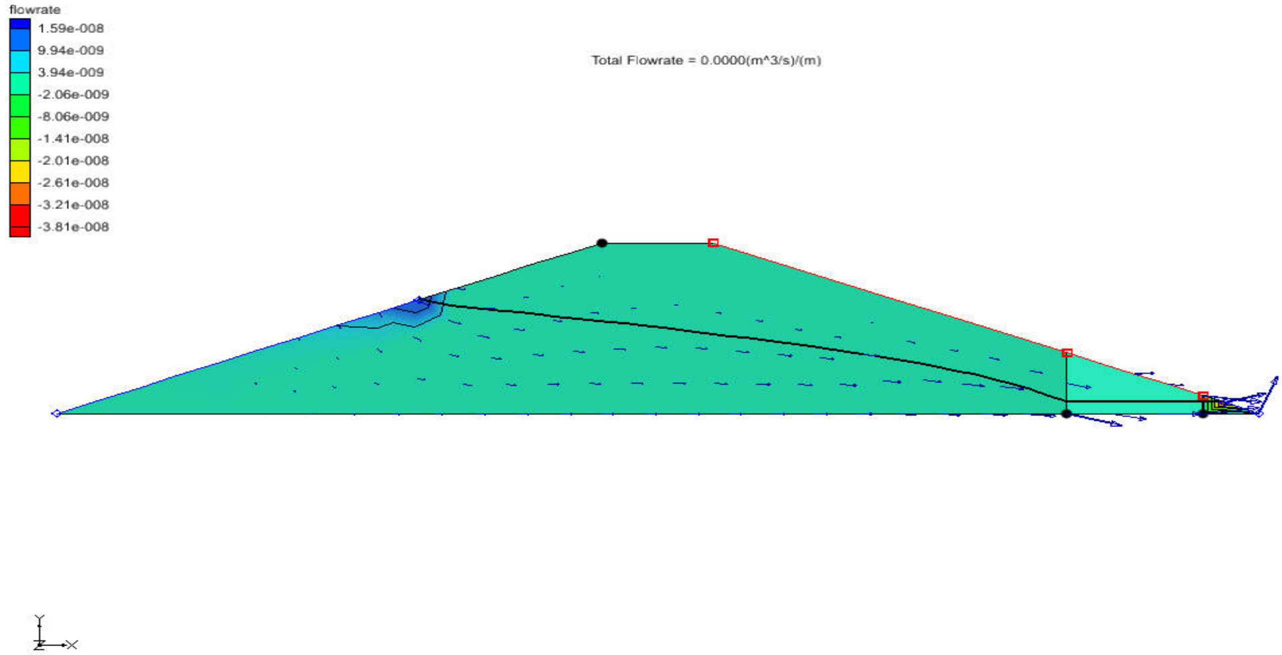

Figure 5: The generated Flow rate and direction of Flow of the problem domain (CASE II)

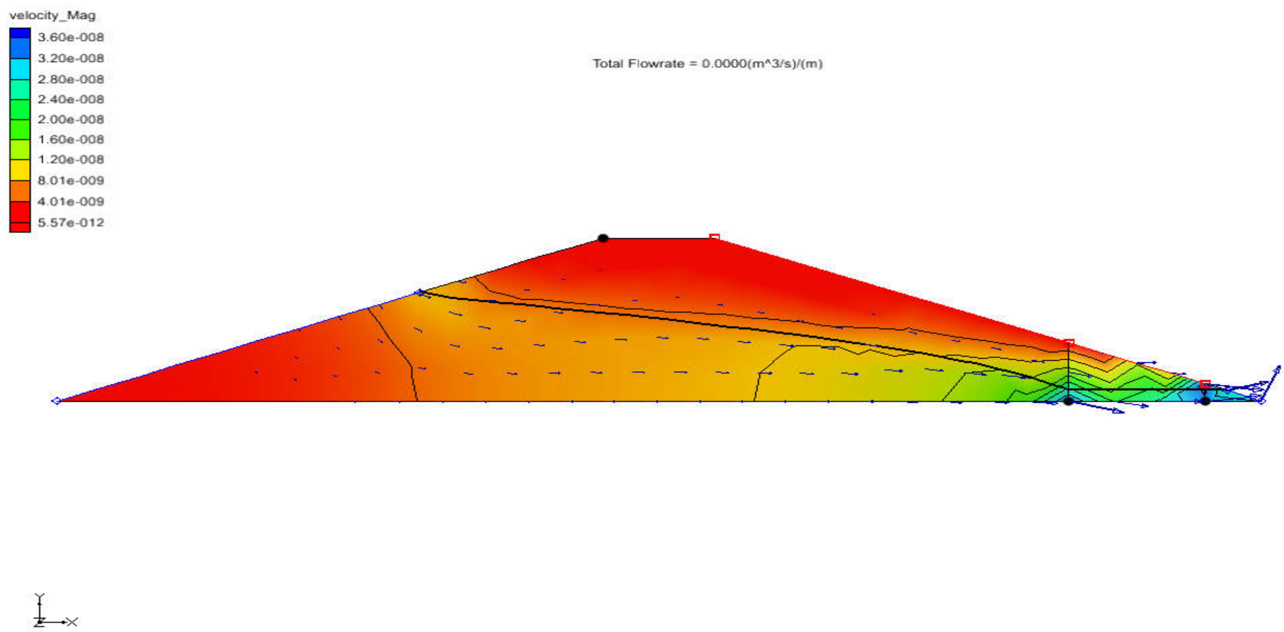

Figure 6: The generated Flow Velocity Vectors of problem domain (CASE II)

4. Conclusions and Recommendations

Oje-Owode dam embankment is loosed and permeable and the results from previous reports established the erosion of fine particles from the upstream and the deposit of the same at the downstream of the dam embankment. There was loss of water by seepage through dam toe. The modelled filter-drain installed at dam toe controlled the anomalous seepage water and prevented piping as though it were a horizontal drain. The flow lines were controlled at coordinate points (36.25m, 0.56m) and remained horizontal through the filter media, until it exited the dam at the toe at coordinate points (41.88m, 0.59m), which is relatively a save point for collection. The use of Geophysical Programs for further anomalous seepage assessment is also recommended.

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