Flow through Granular Dam Filters and Modeling of Particle Migration

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Abstract

Most of current granular filter design guidelines in practice are based on the experimental investigations and empirical reasoning. These guidelines do not explain the fundamental filtration mechanisms, particularly, the phenomenon of base soil particle migration into the filter under the boundary conditions of various influencing filtration parameters such as hydrodynamic forces, particle size distribution of base soil, particle and constriction size distribution of filter etc. Consequently, these guidelines do not give enough confidence to industry professionals while they employ such guidelines in real life situations. According to comparison of the fundamental equations and boundary conditions, the ANSYS function of temperature field analysis is applied to that of seepage flow field, the element birth or death technique with overlap method is adopted to calculate the saturation line site, in order to solve the problem of Huangbizhuang reservoir (in HeBei Province of China) earth dam seepage flow stability. Based on the result of the calculation, many reasonable suggestions are posed to help the management and reinforcement of Huangbizhuang reservoir earth dam.

Introduction

All dams have some seepage as the impounded water seeks paths of least resistance through the dam and its foundation. Most of current granular dam filters design guidelines in practice are based on the experimental investigations and empirical reasoning. These guidelines do not explain the fundamental filtration mechanisms, particularly, the phenomenon of base soil particle migration into the filter under the boundary conditions of various influencing filtration parameters. Particle migration analytical models can have an important application in the design and construction of granular filters for dam safety.

In the recent years, some rigorous analytical studies have been carried out to describe the time-dependent particle transport phenomenon using the principles of conservation of mass and momentum and finite difference technique to solve the governing equations. Although these studies have been successful to distinguish between effective and ineffective filters based on the time-dependent changes in the filtration parameters such as amount of base soil mass migration, permeability, porosity etc, there is further scope to extend these models to describe clogging of granular filters based on base soil particle migration. My research will focus on extending these models to describe particle migration in clogging filters. The governing equations will be developed based on these fundamental fluid mechanical principles of mass, momentum and energy. ANSYS simulation tools will be used to solve these equations to simulate the particle transport. According to comparison of the fundamental equations and boundary conditions, the ANSYS function of temperature field analysis is applied to that of 2-D or 3-D seepage flow field, the element birth or death technique with overlap method in APDL is adopted to calculate the free water surface site (saturation line), in order to solve the problem of Earth dam seepage flow stability. Large-scale filtration tests will be carried out and the use of recent development in porosity measurement techniques such as Mercury Intrusion Porosimeter will be made to validate the models.

Theoretical Concepts

The Finite Element Method is developed to fluid dynamics in 1960s. The seepage field stability is studied at first. The basic differential equation for 2D(X-Z) seepage is:
The optimal control equation of temperature field applied in ANSYS:

\[
\frac{\partial}{\partial x} \left( K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial z} \left( K_z \frac{\partial h}{\partial z} \right) = 0 \quad (1)
\]

Boundary conditions:

\[
\begin{cases}
T = T_0, & T \in T_r \\
\{q\}^T \{\eta\} = -q_0, & T \in T_q
\end{cases} \quad (3)
\]

T-temperature; \( \rho \)-the media density; \( q \)-unit heat build-up; \( c \)-specific heats; \( K_x, K_y, K_z \)-the media 3D heat conductivity, \( \{V\} \)-heat mass transport velocity vector.

If the seepage total head function(h) replace T and the media 3D heat conductivity \( K_x, K_y, K_z \) replace thermal conductivity, let \( \{V\} \), \( q \) and \( c \) become zero. The formula simplified as:

\[
\frac{\partial}{\partial x} \left[ K_x \frac{\partial T}{\partial x} \right] + \frac{\partial}{\partial y} \left[ K_y \frac{\partial T}{\partial y} \right] + \frac{\partial}{\partial z} \left[ K_z \frac{\partial T}{\partial z} \right] = 0 \quad (4)
\]

If considered as 2D heat conduction, the fundamental differential equation becomes:

\[
\frac{\partial}{\partial x} \left( K_x \frac{\partial h}{\partial x} \right) + \frac{\partial}{\partial z} \left( K_z \frac{\partial h}{\partial z} \right) = 0
\]

Compared with the basic differential equation for 2D(X-Z) seepage, two equations are uniform.

As analyzed above, the soil seepage is the special form of the temperature field.

**Practical Applications**

According to comparison of the fundamental equations and boundary conditions, the ANSYS function of temperature field analysis is applied to that of seepage flow field, the element birth or death technique with overlap method is adopted to calculate the saturation line site, in order to solve the problem of Huangbizhuang reservoir (in HeBei Province of China) earth dam seepage flow stability. Based on the result of the calculation, many reasonable suggestions are posed to help the management and reinforcement of Huangbizhuang reservoir earth dam.
Figure 1. The elements mesh generation

Figure 2. The seepage hydraulic head distribution

Figure 3. The flow velocities distribution
Conclusion

The model described in this paper predicts the time-dependent transport and capture of noncohesive base soils, within granular filters. Analytical models can have an important application in the design and construction of granular filters for large projects such as embankment dams. To describe and test the validity of the model predictions, a comparison with a series of laboratory tests is described. In addition, the time-dependent predictions of the model are outlined, determining the time-dependent change in base and filter flow rate, mass transfer, permeability, and porosity. A method to apply the filtration model to a 2D flow net is described.

It is an effective method to apply the ANSYS function of temperature field analysis to that of seepage flow field. The element birth or death technique with overlap method in APDL is adopted to calculate the saturation line site. Based on the result of the calculation, many reasonable suggestions are posed to help the management and reinforcement of large projects.

References
