Construction and Building Materials 88 (2015) 225–231

Contents lists available at ScienceDirect

Construction and Building Materials

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

# Influence of nano materials in the distressed retaining structure for crack filling

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## HIGHLIGHTS

- Seepage problem was formulated for the water retaining structure.
- Critical location of the crack was identified by the software 3D SOLID WORKS.
- Crack oriented parallel to the flow permits more water than the one normal to the flow.
- Vertical cracks arrested more seepage.
- During the treatment, it was found that carbon nano tube can arrest more seepage.

ARTICLE INFO

*Article history:*
Received 23 January 2015
Received in revised form 19 March 2015
Accepted 18 April 2015
Available online 4 May 2015

*Keywords:*
Crack
Solid works
MATLAB
FEM
Nano materials
Repair
% Increase in arrested seepage

## ABSTRACT

In the water retaining structure, seepage through the body wall and foundation plays a major role in the failure of structures. To design any kind of structure for proper retaining, the effect due to seepage should be considered widely. In this paper, % of increase in arrested seepage is arrived from various analyses. Compressive strength of nano silica, nano alumina and carbon nano tube is found out by the experiment and Elastic modulus is calculated. Stress analysis is carried out with analysis software 3D SOLID WORKS. The critical location of the crack is noticed for various service conditions like water filled for full height ($h_d$), more than half height ($0.75h_d$) and half height ($0.5h_d$). The seepage analysis is carried out on the basis of two-dimensional Laplace equations. The partial differential equation (PDE) Toolbox in MATLAB, by the method of finite element method (FEM), provides a powerful and flexible environment for the seepage study. Values of the velocity contours are recorded for various sizes of the crack at the critical location before treatment. Later, these cracks are filled with the mortar of nano-silica, nano alumina and carbon nano tube. The values of the velocity contours are recorded again after the treatment. Finally, the percentage increase in arrested seepage is calculated and it is found that carbon nano tube has behaved better.



## 1. Introduction

Hydraulic structures, ranging from simple weirs to heavy dams for irrigation, surface reservoirs and overhead tanks for storage or off-shore platforms need to perform in both strength and seepage aspects. These structures are normally constructed to serve for a longer period may be more than 100 years. In the context of India, the famous Grand Anicut or Kallanai, as it is locally known, in the state of Tamilnadu, serves for more than 500 years. Hence, any hydraulic structure, which is in service, needs to be checked for its strength and performance both immediately after a disaster and at frequent intervals.

All the dams and weirs have seepage resulting from water penetration slowly through the dams and its foundation if any cracks are present. The existence of cracks is also due to shrinkage drying or swelling due to saturation. Raul et al. found that favorable internal erosion conditions also exist in contacts between soils and rigid walls, concrete structures and interface with bedrock foundation [1]. Seepage must be controlled in both velocity and quantity. If uncontrolled, it would progressively erode the material of the dam, thereby resulting in rapid failure. A suitable method should be followed for the evaluation of the performance of the structure.

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http://dx.doi.org/10.1016/j.conbuildmat.2015.04.022
0950-0618/

Bear et al. explained that the numerical methods used to solve the unconfined seepage problems are the finite difference method, the finite element method, and the boundary element method [2]. Segerlind recommended that the finite element method is preferable because the major advantage of this method is the ease with which we can solve two-dimensional problems composed of several different materials and having irregular boundary [3]. So, the current study is initiated to investigate the effect of cracks in terms of seepage through a parametric study for hydrological considerations using FEM. Hence, different size of cracks at different orientation is taken into consideration and the effects were studied for the various storage conditions of the structure. Velocity contour values were recorded. Later, these cracks are filled with nano alumina (NA), nano silica (NS) and carbon nano tube (CNT) admixed concrete. Then the velocity contour values were recorded and finally percentage of increase in arrested seepage is calculated.

## 2. Materials and methods

### *2.1. Materials and mixture proportion*

An ordinary Portland cement with the specific gravity of 2.82 was used. Its chemical composition is shown in Table 1. Fine aggregate was natural river sand with its fineness modulus as 2.60. Coarse aggregate was crushed stone with its fineness modulus as 3.8. The properties of nano particles are tabulated in the Table 2. Water cement ratio is taken as 0.50. The specimens are kept damp by water ponding for 28 days.

#### *2.1.1. Nano alumina*

There are a few reports on using nano alumina as an admixture in concrete. It has been stated by Jo et al. that the use of nano alumina as a partial replacement by cement leads to the C–A–S gel formation in concrete [4]. Nano alumina reacts with calcium hydroxide produced from the hydration of calcium aluminates. The rate of this reaction is, proportional to the amount of surface area available for the reaction. Therefore, it is possible to add nano alumina of a high purity and high blend fineness value in order to improve the characteristics of concrete [4,7]. Nazari et al. found that the cement would be advantageously replaced with nano alumina particles up to a maximum limit of 2% with average particle size of 15 nm [5,7]. Shaekari et al. suggested that Nano alumina improves mechanical properties of the concrete such as compressive and tensile strength. It also decreases the water absorption and chloride penetration improving the durability of the concrete [6,7]. So, cube Sample is casted with the concrete admixed with 2% nano alumina and also as a partial replacement of cement.

#### *2.1.2. Nano silica*

Many experimental results and literature reviews have proved the enhancements of the property of nano-silica in construction industry. Li proved that Nano-$SiO_2$ could significantly increase the compressive strength of the concrete, containing large volume of fly ash and at early age, improves pore size distribution by filling the pores between large fly ash and cement particles at nano scale [8]. Bigley et al. says that the Slurry of nano-silica improves the property of resistance to segregation in Self Compaction Concrete [9]. Henry explained that the dispersion/slurry of amorphous nano-silica is used to improve segregation resistance of Self-Compacting Concrete [10]. Above literature reviews show the various form of nano silica and its uses. Hence, nano silica in powder form is chosen and the cube Sample is made with the concrete admixed with 3% nano silica as a partial replacement of cement.

**Table 1**
Chemical composition of ordinary Portland cement.

| $iO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $Na_2 + K_2O$ | Loss on ignition |
|---|---|---|---|---|---|---|---|
| 21% | 6.45% | 0.50% | 63% | 4% | 2.80% | 0.90% | 1.35% |

#### *2.1.3. Carbon nano tube*

Mann proved that the Compressive and Flexural strength values of the concrete are increased if 1% of carbon nano tube by its weight is mixed [11]. So, cube Sample is made with the concrete admixed with 1% carbon nano tube.

### *2.2. Identification of distress by the stress analysis*

#### *2.2.1. Model of the domain chosen*

A typical cross-section of a retaining structure ABCDEFGH is the domain chosen for the study as shown in the Fig. 1. AH and GH are subjected to water pressure and boundaries GFED are considered impervious for flow consideration. Punmia derived the formula for the height of the structure which is denoted as $h_{d,}$ base width 'b' which is obtained from the stress criterion as given in Eq. (1), where $\rho$ is the density of the material of the dam [12].

Top width is considered as 'a' according to the road width which is to be provided at the top of the body wall. Minimum top width can be calculated as given in Eq. (2).

$$b = h_d/\rho^{1/2} \tag{1}$$

$$a = 0.14h_d \tag{2}$$

### *2.3. Seepage analysis*

The domain is again simulated with the crack at the critical location noticed in the structural analysis. Orientation of the crack is also given due importance. Crack is assumed parallel to the base and also perpendicular to the base and FEM is carried out.

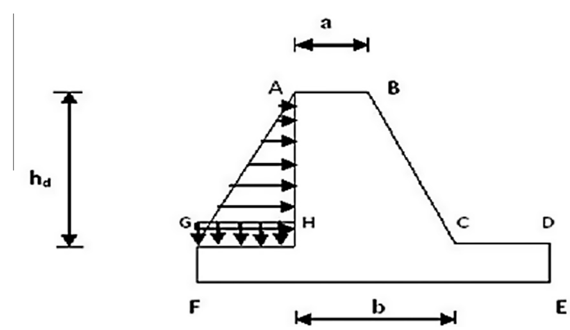


**Fig. 1.** Cross section of the domain.

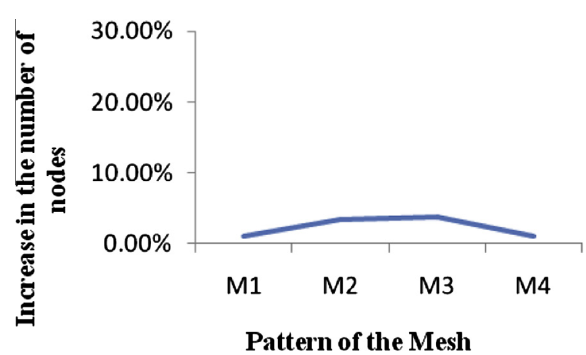


**Fig. 2.** Convergence study of the mesh pattern.

**Table 2**
Properties of nano particles.

| Property → Material↓ | Appearance | Average Particle size (nm) | Specific surface area ($m^2/g$) | Purity (%) |
|---|---|---|---|---|
| Nano alumina | White loose powder | 15–20 | 15–30 | 99.5 |
| Nano silica | White powder | 30 ± 10 | 150–300 | 99.9 |
| Carbon nano tube | Black | 20–40 | 500 | >90 |