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Study on sliding stability of porous-concrete retaining wall model test subjected to rainfall infiltration

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Study on sliding stability of porous-concrete retaining wall model test subjected to rainfall infiltration

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Abstract. The common disadvantage of a conventional retaining wall is a heavy object as a block that is difficult to lift and handle conveniently. A drainage pipe is commonly used to displace water from the backfill. In areas with high annual rainfall, the soil could be saturated in a short time and added lateral load significantly. In this study, porous concrete was utilized as a retaining wall material with the advantages of the lighter weight of the block and additional drainage capability due to its high void ratio. A set of a laboratory-scale retaining walls using conventional and porous concrete walls was investigated through three different rainfall modes. To initiate the instability condition, a vertical load was applied then the lateral moving was recorded using LVDT sensors. Soil moisture content sensors recorded hydrologic responses of the saturation process. The loading test results showed that the porous concrete wall model was being displaced less than experienced by the conventional concrete wall. It shows that the porous concrete wall model can withstand the load as the additional lateral load from infiltrated rainwater dissipates rapidly. Therefore, the porous concrete wall has the advantage of being used as a Retaining Wall Material.

keywords**:** retaining wall, rainfall infiltration, porous concrete

1. Introduction

Retaining walls are an important aspect of urban development when it comes to creating additional spaces for development in areas where land is scarce. The primary goal of these constructions, which are frequently made of masonry, stone, brick, and concrete, is to prevent soil movement down slope or to withstand the lateral pressure exerted by soil [1-2]. On the other hand, conventional concrete retaining walls are sometimes associated with exorbitant costs, poor aesthetics, and lengthy building times. Overturning, sliding, and bearing capacity are the three main checks required for the Retaining Wall design [3]. The common disadvantage of conventional retaining walls is that, due to the dense properties of concrete forming the wall, a conventional retaining wall is a heavy object as a block that is difficult to handle conveniently and disadvantage in poor drainage as impermeable material. The water table, which has a considerable impact on lateral pressure, is crucial for the retaining wall. Rainfall infiltration has a major role in increasing the lateral force that affects the phreatic line [4] The water pressure created by the water table reduces the effective stresses that are detrimental to wall stabilization; it functions as extra pressures on the wall, forcing retaining wall to overturn and slide [5-6].

When the wall is exposed to rain, drainage provisions are essential to keep it stable. A drainage pipe is commonly used to displace water from the backfill. To provide appropriate drainage, granular, non-cohesive soil is used as reinforced backfill materials in constructing reinforced soil walls. After compiling a database of failed reinforced soil structures, Koerner and Koerner[7] conclude that most of the failures were caused by the use of low-quality fill material and a poor drainage system [7]. In some extreme situations, such as in areas with high annual rainfall, where sudden and intense rainfall can significantly increase water infiltration, the soil could be saturated in a short time and added lateral load significantly. Yoo and Jung [8], conducted a detailed investigation of the failure of a segmented reinforced wall and found that, while rainfall infiltration initiated the failure, improper design and low-quality backfill were the primary causes of the failure [8]. As a result, it's critical to keep the retaining wall stable against lateral pressure from rain infiltration. In this study, porous concrete was utilized as a retaining wall material with the advantages of the lighter weight of the block and additional drainage capability due to its high void ratio.

In the 1980s, Japan developed porous concrete as an environmentally friendly material. Since then, it has been widely used in a variety of applications in Japan, the United States, and Europe due to its numerous environmental benefits, including the control of storm water runoff, the restoration of groundwater supplies, and the reduction of water and soil pollution [9–11]. Because of the porous concrete's water-permeating, water-draining, and water-retaining properties have been used in road pavements, sidewalks, parks, building exteriors, and water treatment [12-14]. This concrete has also been used for plant bedding and permeable rainwater retention facilities like permeable trenches, gullies, and gutters [15–17]. In general, a gap graded conventional porous concrete (CPC) or ‘‘no fines" concrete is obtained by using a uniform size of coarse aggregate at a low water-cement ratio (W/C). On the other hand, this CPC had poor workability (30%) and required vibration equipment for proper compaction and curing for the production of precast products and drainage pavement application [18].

2. Materials and Methods

A set of laboratory-scale retaining walls using conventional and porous concrete walls was investigated through three different rainfall intensities to clarify the failure process. Porous concrete has a high porosity of 15 to 30% air voids, allowing water to move through easily. The coarse aggregate used affects the specific gravity of porous concrete. Porous concrete has a slump value near zero, according to ACI 522R-10, and is made of coarse aggregate, cement, little or no fine aggregate, additives, and water. Figure 1 shows a sketch of the retaining wall model installed in the test box.

Four experiments were conducted on those two test objects. The porous concrete model was subjected to three rain intensity variations: 846 mm/h, 960 mm/h, and 1105.02 mm/h. As a comparison, a standard concrete retaining wall is only applied to a single rainfall intensity of 960 mm/hour.

Poorly graded sand was used as backfill material in this study. Some basic soil tests to examine the soil characteristics of sand were performed as follow:

a. Grain Size Analysis (ASTM C-13-46)
b. Specific Gravity (ASTM D-854-58)
c. Standard Compaction (ASTM D-698-70)
d. Direct Shear (ASTM D-3080-72)
e. Constant Head Permeability (ASTM D 2434-1989)
f. Concrete Loading test (ASTM C-39)
g. Porous Concrete Permeability (ASTM C-39)

The intensity of the rain is controlled by a rainfall simulator, which is fed by a series of pipes that drain water using a mini pump. The poor-graded sand was compacted in a box 100x50x50cm with a final height of 45 cm to obtain a relative density (RC) of 80% and simulated as backfill soil.

Furthermore, a vertical load 52 kg was applied to initiate the instability condition. The lateral moving of the retaining wall was then recorded using LVDT sensors. Soil moisture content sensors recorded hydrologic responses of the saturation process. Figure 2 shows the appearance of the installation of testing tools mounted inside the test box.

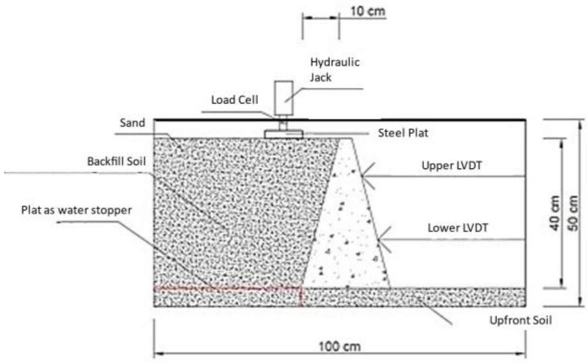

Figure 1. Sketch of the Retaining Wall Model.

Figure 2. The Installation of Testing Tools Mounted Inside the Test Box

3. Results and Discussion

3.1. Stability Test Results on Normal Concrete Retaining Walls (RW) with Rain Intensity 960 mm/hour
It rained for 4 minutes in the loading test, at a rain intensity of 960 mm/hour. The loading was then maintained until a load of 52 kg was obtained. As shown in Figure 3 below, the results of lateral deformation caused by rain and load are achieved in this test.

There was a displacement of 1.2 mm from the retaining wall during the 52 kg loading test. The water content of the backfill soil reaches 15%, whereas the soil in front of the wall is near to zero since groundwater does not pass through the wall, as presented in Figure 4.

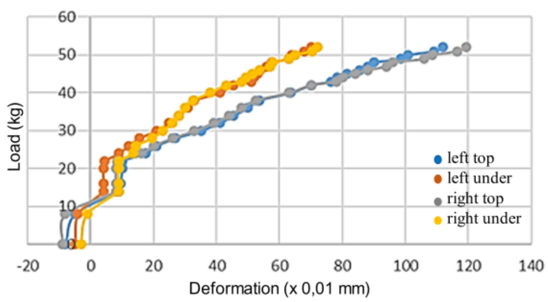

Figure 3. Deformation on Normal Concrete RW due to Rainfall Intensity of 960 mm/hour under Loading test (using LVDTs)

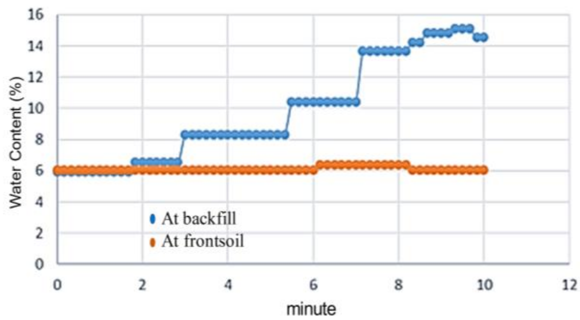

Figure 4. Soil Water Content surrounding Normal Concrete RW with Rainfall Intensity of 960 mm/hour

3.2. Stability Test Results on Porous Concrete Retaining Wall (RW) at Varied Rainfall Intensities.

3.2.1. Porous Stability Test on Porous Concrete RW under Rainfall Intensity of 846 mm/hour.
During the loading test, it rained for 4 minutes at a rate of 846 mm/hour. After that, the load was increased to 52 kg. The results of lateral deformation due by rain and load are observed in this test, as indicated in the Figure 5 below.

There was a 0.4 mm displacement in the retaining wall at the time of the 52 kg loading test. The backfill soil has a 12.5 percent water content. Meanwhile, because groundwater can flow out via the voids of the porous concrete, the soil in front of the wall has a water content of 12.7%, as presented in Figure 6.

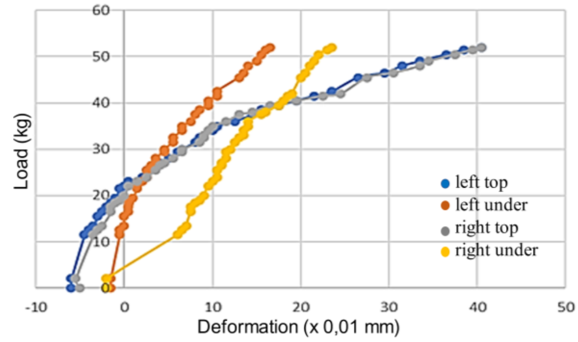

Figure 5. Deformation on Porous Concrete RW due to Rainfall Intensity of 846 mm/hour under Loading Test (using LVDTs)

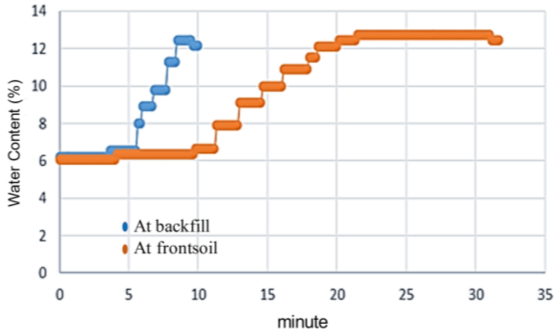

Figure 6. Soil Water Content surrounding Porous Concrete RW with Rainfall Intensity of 846 mm/hour

3.2.2. Porous Stability Test on Porous Concrete RW under Rainfall Intensity of 960 mm/hour.
During the loading test, it rained for 4 minutes at a rate of 960 mm/hour. After that, the load was increased to 52 kg. The results of lateral deformation due by rain and load are observed in this test, as indicated in the Figure 7.

There was a 0.65 mm displacement in the retaining wall at the time of the 52 kg loading test. The backfill soil has a 13 percent water content. Meanwhile, because groundwater can flow out via the voids of the porous concrete, the soil in front of the wall has a water content of 13,3%. The findings of testing the water content in the soil on both sides of the retaining wall are shown in the Figure 8.

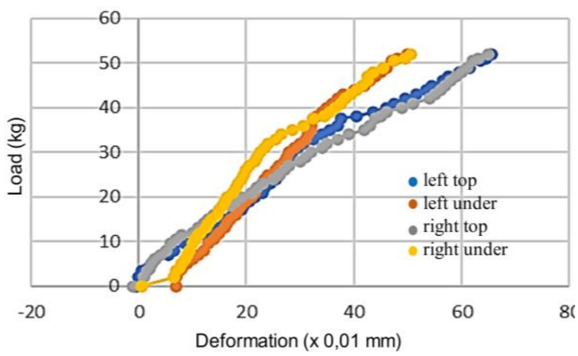

Figure 7. Deformation on Porous Concrete RW due to Rainfall Intensity of 960 mm/hour under Loading Test

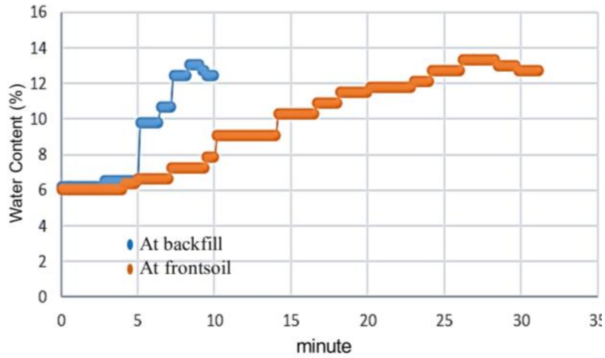

Figure 8. Soil Water Content surrounding Porous Concrete RW with Rainfall Intensity of 960 mm/hour

3.2.3. Porous Stability Test on Porous Concrete RW under Rainfall Intensity of 1105 mm/hour.
It rained for 4 minutes in the loading test, at a rain intensity of 1105 mm/hour. After that, the scale was loaded until it reached 52 kg. The results of lateral deformation due to rain and load are achieved in this test, as shown in Figure 9.

There was a 0.94 mm displacement in the retaining wall at the time of the 52 kg loading test. The backfill soil has a 14.2 percent water content. Meanwhile, because groundwater can flow out via the voids of the porous concrete, the soil in front of the wall has a water content of 14.5%. The findings of testing the water content in the soil on both sides of the retaining wall are shown in the Figure 10.

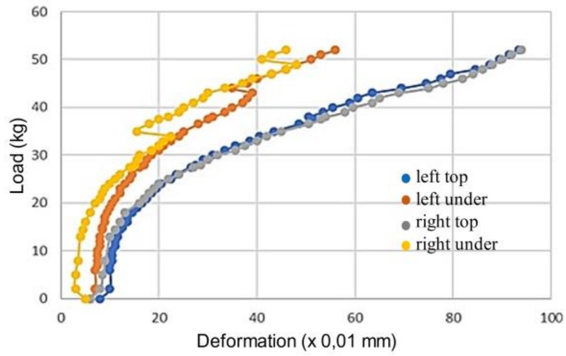

Figure 9. Deformation on Porous Concrete RW due to Rainfall Intensity of 1105 mm/hour under Loading Test (from LVDTs)

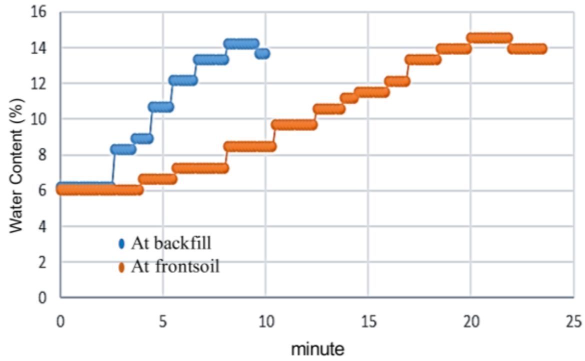

Figure 10. Soil Water Content surrounding Porous Concrete RW with Rainfall Intensity of 1105 mm/hour.

3.3. Comparison of Retaining Wall Deformation to Rainfall Intensity

The deformation values and moisture content that occurred in each experiment were determined in this investigation, as compiled in Table 1.

Table 1. Comparison of Deformation RW and Moisture Content.

Retaining Wall	Deformation	Water Content	
		backfill	front
Normal C – 960 mm/h	1.20 mm	15%	0%
Porous C – 846 mm/h	0.40 mm	12.5%	12.7%
Porous C – 960 mm/h	0.65 mm	13%	13.3%
Porous C – 1105 mm/h	0.94 mm	14.2%	14.5%

The loading test results showed that the porous concrete wall model was being displaced less than experienced by the conventional concrete wall model. It shows that the porous concrete wall model can withstand the load as the additional lateral load from infiltrated rainwater dissipates rapidly.

3.4. Sliding Stability Analysis with Finite Element Method

In addition, a finite element-based software approach was used to perform a sliding/shear stability analysis. The FEM based-seeping software analysis employs a transitory method, whereas the FEM based slope stability software analysis employs a morgenstern-price approach with an entry-exit approach. Specific gravity and permeability of the retaining wall, both normal and porous concrete, are among the characteristics entered into the software.

3.4.1. Seepage and Stability Analysis on Normal Concrete Retaining Wall

According to the software analysis results, the safety number for a Normal Concrete Retaining Wall with a rain intensity of 960 mm/hour was 0.997 using the entry-exit method (Figure 11 – 12).

3.4.2. Seepage and Stability Analysis on Porous Concrete RW under Rainfall Intensity of 846 mm/h

According to the software analysis results, the safety number for a Porous Concrete Retaining Wall with a rainfall intensity of 846 mm/hour was 1.079 using the entry-exit method (Figure 13 – 14).

3.4.3. Seepage and Stability Analysis on Porous Concrete RW under Rainfall Intensity of 960 mm/h

According to the software analysis results, the safety number for a Porous Concrete Retaining Wall with a rain intensity of 960 mm/hour was 1.017 using the entry-exit method (Figure 15 – 16).

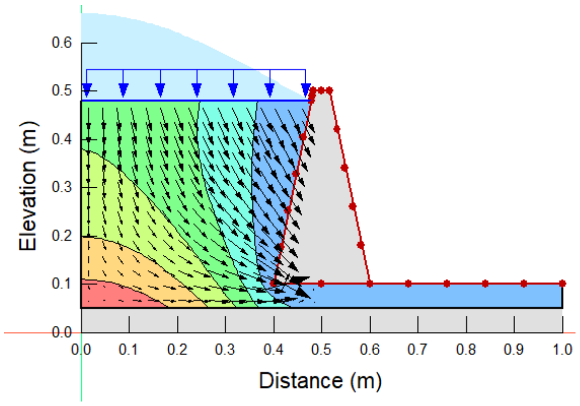

Figure 11. Seepage Simulation on Normal Concrete under Rainfall Intensity of 960 mm/hour

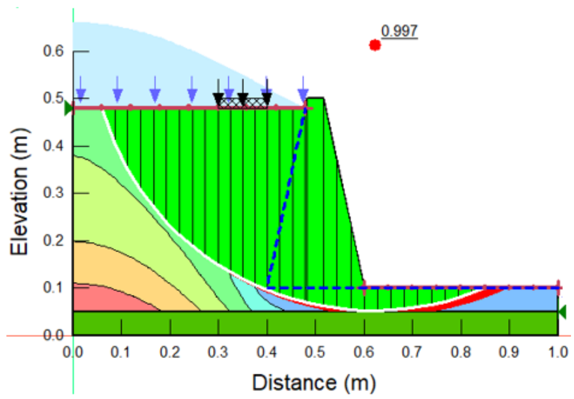

Figure 12. Factor of Safety using Entry and Exit Method on Normal Concrete under Rainfall Intensity of 960 mm/hour

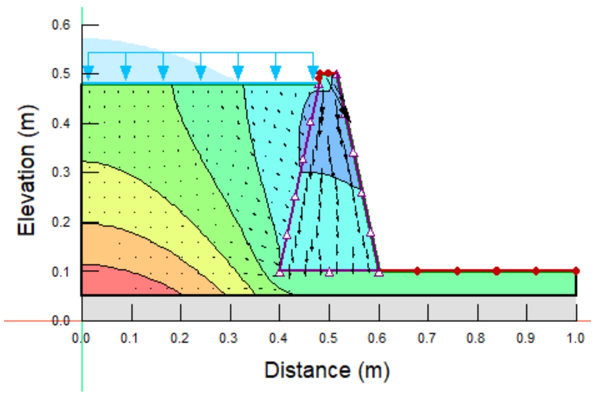

Figure 13. Seepage Simulation on Porous Concrete under Rainfall Intensity of 846 mm/hour

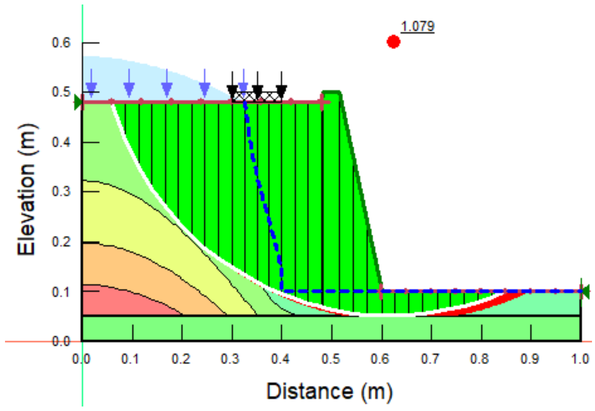

Figure 14. Factor of Safety using Entry and Exit Method on Porous Concrete under Rainfall Intensity of 846 mm/hour

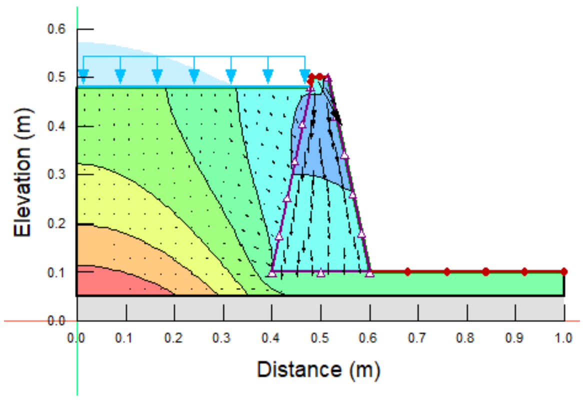

Figure 15. Seepage Simulation on Porous Concrete under Rainfall Intensity of 960 mm/hour

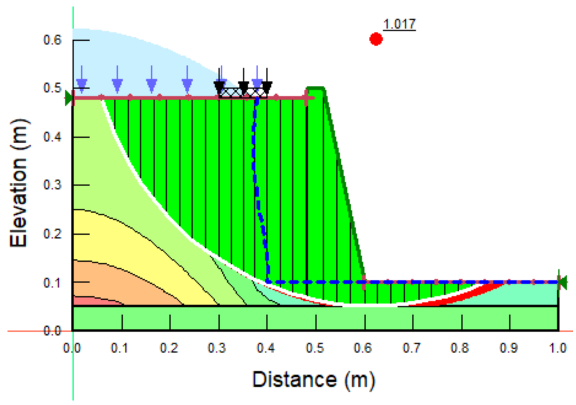

Figure 16. Factor of Safety using Entry and Exit Method on Porous Concrete under Rainfall Intensity of 960 mm/hour

3.4.4. Analysis on Porous Concrete Retaining Wall under Rainfall Intensity of 1105 mm/h

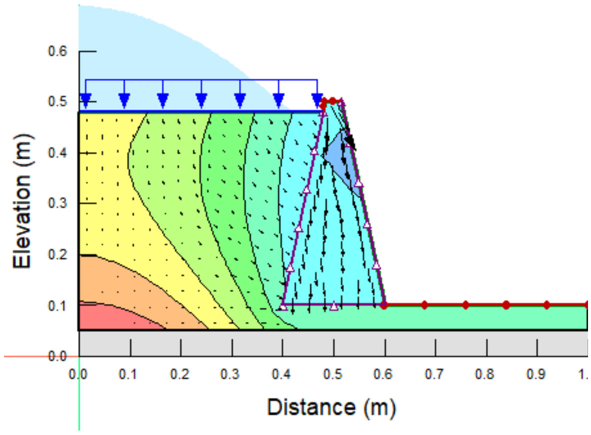

Figure 17. Seepage Simulation on Porous Concrete under Rainfall Intensity of 1105 mm/hour

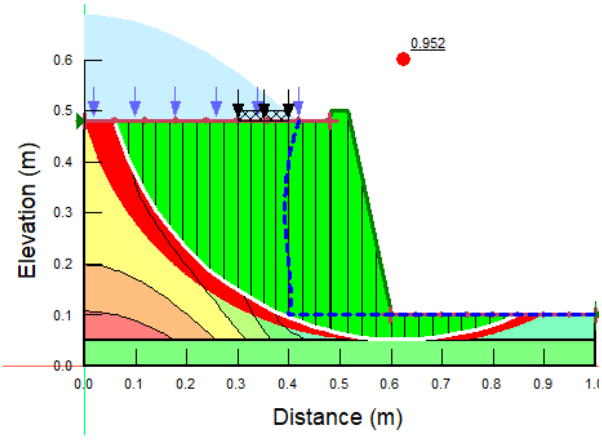

Figure 18. The factor of Safety using Entry and Exit Method on Porous Concrete under Rainfall Intensity of 1105 mm/hour

According to the software analysis results, the safety number for a Porous Concrete Retaining Wall with a rain intensity of 1105 mm/hour was 0.952 using the entry-exit method. The stability analysis results using FEM software showed that the porous concrete wall model was more stable than experienced by the conventional concrete wall model. This is because the additional lateral pressure caused by infiltrating water in the backfill is reduced in porous concrete after the infiltrated rainwater seeps out through the retaining wall voids (Figure 17 – 18).

4. Conclusion

This study shows that the lateral force behind the retaining wall is reduced due to the discharge of infiltrated water through the porous concrete retaining wall voids. Since the porous concrete retaining wall is more stable and less susceptible to displacement under applied loads, the advantages of using a porous concrete retaining wall are very considerable.

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