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Numerical Analysis on Seepage through Earthen Embankment Protected by Cement Concrete Block (CC Block) in Bangladesh

M. A. Alim, M. L. Rahman*

Department of Civil Engineering, Rajshahi University of Engineering & Technology, Rajshahi, Bangladesh
*Corresponding author: lutforrony@yahoo.com

Abstract Flood submerges vast areas of Bangladesh every year. To protect agricultural lands and city areas from submergence due to flood, earthen embankments are provided. However, earthen embankments in Bangladesh are subjected to seepage and erosion. To protect embankments from seepage and erosion-Cement Concrete Blocks (CC Blocks) are usually provided. Provision of CC Blocks reduce erosion but cannot prevent seepage completely, which is one of the main causes of failure of earthen embankments in Bangladesh. In this study, five sections of Rajshahi City Protection Embankment (RCPE) are selected which are subjected to seepage and erosion during rainy seasons because they are not properly protected. Seepage analysis using Geo-Studio Software indicates that seepage through RCPE can be prevented completely, if the upstream surface of the embankment is protected by CC Blocks with joints between CC Blocks that are sealed properly.

Keywords: *earthen embankment, seepage, Cement Concrete Block (CC Block), Rajshahi City Protection Embankment (RCPE)*

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1. Introduction

Bangladesh is a flood prone area due to being situated on the Ganges Delta and the many distributaries flowing into the Bay of Bengal. Around 75% land area of Bangladesh is less than 10 m above mean sea level and 80% of it is floodplain, therefore rendering the nation very much at risk of periodic widespread damage [3]. Flooding normally occurs during the monsoon season from June to September. The conventional rainfall of the monsoon is added by relief rainfall caused by the Himalayas. Melt water from the Himalayas is also a significant input. Country has experienced highly damages floods in the 20th century. Since independence in 1971, Bangladesh has experienced floods of a vast magnitude in 1974, 1984, 1987, 1988, 1998, 2000 & 2004. The largest recorded flood in depth and duration of flooding in its history was occurred in 1998 when about 70% land area of the country was under water for several months [4]. As a measure of flood control, embankments along river banks have been accepted all over the world. Its wide use is manifested in the economics of embankment construction; it can be built cheaply with local material and manpower, the level of construction technology required is not high and operation and maintenance is also cheap and easy. The embankment projects are designed to provide protection from flood to the area behind it which then can be suitably developed for enhanced economic and agricultural production. Before implementation of the embankment project, the area used to be subjected to frequent flooding during the monsoon seasons when adjacent rivers attain high flood stage [1]. Since 1960, 13,000 km of embankments have been constructed to safeguard against inundation, intrusion of saline water and devastation. Nearly 7,555 km coastal embankments, 4,600 km of embankments along the bank of big rivers and nearly 4,500 km of low-lying embankments along the small rivers, and canals have been constructed. 1,488 regulators/sluices, 108 bridges and 923 other structures have been constructed in 135 polders over 472 km of embankment to protect 1.09 million ha of land [6]. The stability of embankments is influenced by seepage occurred during the increase and decrease of the adjacent water level in the river or reservoir [5]. Generally, problems associated with seepage are the flow into pits or out of reservoirs, seepage pressures and related effects that may have effect on the stability of slopes and drainage from fine-grain soils subjected to load increase [7]. The traditional practice for protection of embankments in Bangladesh is the use of Cement Concrete Blocks (CC Blocks), sand bags, stone or wood revetments, geotextile, geo bags, and tree plantation. Usually, CC Blocks are used where storm surge is high; sand bags or wood revetments are used where flow of water is moderately high [6]. But they cannot control seepage completely and hence cannot prevent failure of embankments as shown in Figure 1. On October 20, 2013 over 100 shrimp and fish enclosures in Shyamnagar upazila, Shatkhira, Bangladesh washed away as an embankment collapsed though it was protected by

CC Block. On August 16, 2013 the Teesta devoured a high school, 60 homesteads and large areas of cultivable lands and orchards as 100 m of protection embankment collapsed. On September 15, 2009 breaching of the Sirajganj town flood barrier occurred though it was well protected by CC Block having a "hundred year guarantee" given by the Korean construction giant to the BWDB on the construction of the 2.5 km embankment, was built between 1995 to 1999 at a cost of TK 332 core. To prevent seepage through the CC Blocks joints between the blocks can be sealed by Cement Mortar, Tar and other joint sealer used in sealing joints of Cement Concrete Road. Figure 1(b) shows an embankment protected by CC Block with joints sealed by Cement Mortar. Rajshahi City is one of the largest cities in Bangladesh with about eight million populations. It is situated near the mighty Padma. The average water level in dry season is about 8 m from mean sea level and in rainy season it is about 17 m-18 m from mean sea level. Therefore, very frequently the Ganges water level at RCPE rises above the danger level for Rajshahi city (18.5 m) [7]. To protect the city from flood Rajshahi City Protection Embankment was constructed in 1857 and to protect the embankment from seepage and erosion various protective works have been carried out i.e. construction of groins, provision of CC Blocks for protection against seepage and erosion etc. Provisions of these blocks have reduced erosion to a great extent but seepage still occurs through the joints between the CC Blocks. Like other parts of the country Rajshahi city had also suffered during the floods of 1988 and 1998. Flood level has also risen to significant level during the recent years. In this study Geo-Studio software has been used to determine the seepage through the five selected sections of Rajshahi City Protection Embankment considering without CC Block, with CC Block and joints between CC Blocks sealed for the flood of the years of 1988, 1998, 2011 to 2014 & for Highest Flood Level (HFL).

Figure 1. (a) Failure of earthen embankment in Bangladesh protected by CC Blocks. (b) Earthen embankment protected by CC Blocks with joints sealed by Cement Mortar

2. Materials and Methods

2.1. Geometry

For performing seepage analysis geometries of the embankment at five studied sections are collected. The height of the embankment is 10m. Top width of the embankment varies from 3.26 to 5 m and base width varies from 49.26 to 61 m. The embankment at Police Line and Ponchoboti section is fully protected by CC Blocks.

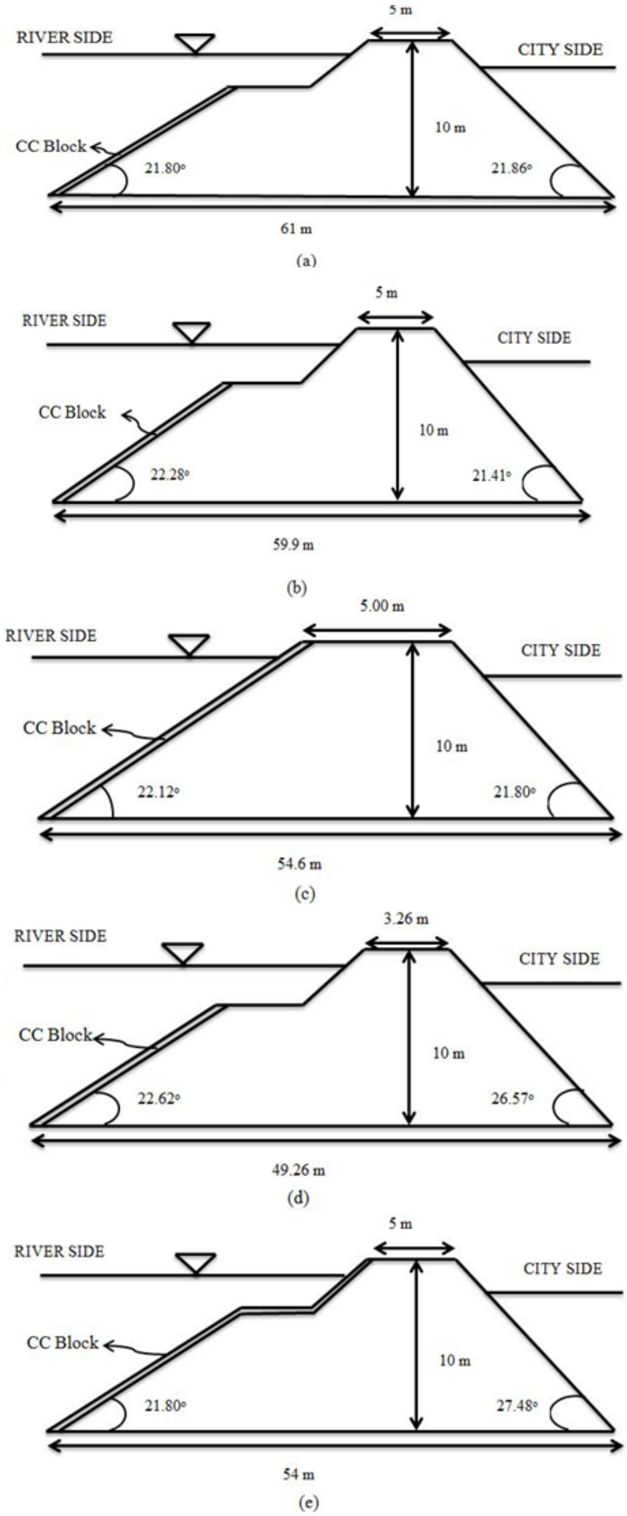

Figure 2. Geometry of (a) Khojapur (b) Talaimari (c) Ponchoboti (d) Dorgapara (e) Police Line section (Not to scale)

The average size of the CC Block is 0.45m×0.45m×0.45m and the average width between the joints of CC Blocks is 0.02 m. The CC Blocks are simply placed on the embankment fill material and no interface material is used between CC Blocks and the embankment fill material. The embankment at Khojapur, Talaimari and Dorgapara sections are partially protected by CC Block as shown Figure 2.

2.2. Index Property of Soil

To understand the engineering and physical properties of the embankment materials, soil samples were collected from the study areas and tested in the soil mechanics laboratory at Rajshahi University of Engineering & Technology (RUET). From the Particle Size Distribution curve as shown in Figure 3 soil classification was done using USDA Textural soil classification chart because the soil sample contains large amount of fine particles (silt & clay).

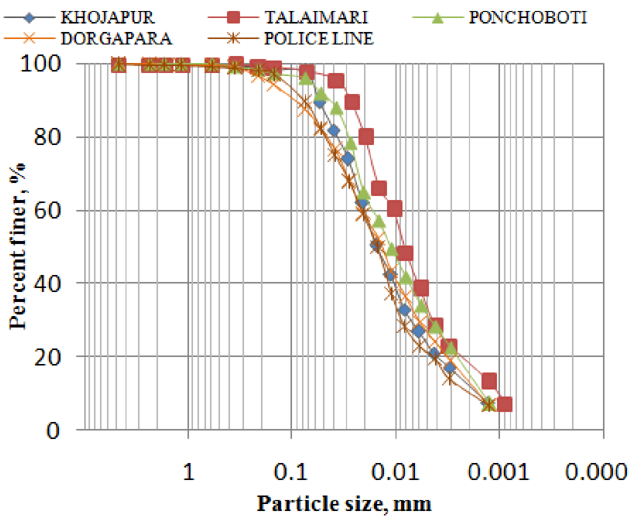

Figure 3. Particle size distribution curve for different sections

Table 1. Index Property of Soil

Index Property	Khojapur	Talaimari	Ponchoboti	Dorgapara	Police Line
γ (KN/m^3)	15.09	13.33	14.41	13.13	15.48
w (%)	10.09	4.05	11.45	8.97	3.51
OMC (%)	13.40	15.00	18.60	16.20	15.50
γ_d (KN/m^3)	17.25	16.56	16.07	16.86	16.66
Specific Gravity	2.66	2.68	2.69	2.64	2.65
D_{60} (mm)	0.02	0.01	0.018	0.0213	0.0213
D_{30} (mm)	0.0075	0.0045	0.005	0.00585	0.009
D_{10} (mm)	0.0018	0.001	0.0016	0.00175	0.002
Sand (%)	13.00	4.00	8.25	20.00	20.00
Silt (%)	75.00	78.00	78.75	67.00	70.00
Clay (%)	12.00	18.00	13.00	13.00	10.00
Soil type	Silt loam	Silt loam	Silt loam	Silt loam	Silt loam
k (m/s) ×10^{-05}	1.117	1.275	1.104	1.198	1.070

Percentage of sand, silt & clay indicates Silt Loam types of soil for all the five samples. Field density (γ) was determined using Core Cutter Method and field moisture content (w) was determined using Oven Drying Method. Field density of the soil samples varies from 13.13 KN/m^3 to 15.48 KN/m^3 and field moisture content varies from 3.51% to 11.45%. Standard Proctor Test was done to know the Maximum Dry Density (γ_d) & Optimum Moisture Content (OMC) of the soil samples. Maximum dry density of the soil samples varies from 16.07 KN/m^3 to 17.25 KN/m^3 and OMC varies from 13.40% to 18.60%. Falling Head Permeability Test was conducted to know the Coefficient of Permeability (k). Coefficient of Permeability of the soil samples varies from 1.07×10^{-5} m/sec to 1.275×10^{-5} m/sec. Index properties of the soil samples are depicted in Table 1.

2.3. Annual Highest Flood Level Data

Seepage analyses were done using the annual highest flood level data for the years of 1988, 1998, 2011-2014 & for HFL. The HFL of the Padma River at Rajshahi point is 20 m above the mean sea level and 9 m from the embankment base. In 1998 flood level was 19.68 m from mean sea level. Flood level has also risen to a significant level during recent years. In 2013, flood level rose to 18.70 m from mean sea level which exceeds the danger level 18.5 m (FFWC, 2013). The annual highest flood level data of the Padma River at Rajshahi point are tabulated in Table 2.

Table 2. Annual highest flood level of the Padma at Rajshahi point (Flood Forecasting and Warning Centre, BWDB)

Flood	Flood level above mean sea level, m	Height of water above embankment base, m	Days above danger level
1998	19.68	8.68	28
1988	19.00	8.00	24
2013	18.70	7.70	7
2011	18.17	7.17	-
2012	17.87	6.87	-
2014	17.45	6.45	-
HFL	20.00	9.00	*NA

*NA = Not Available.

2.4. Seepage Analysis

2.4.1. Flow Net

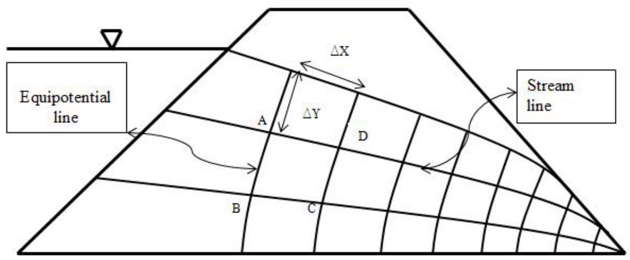

Figure 4. Flow Net

The amount of seepage can be easily calculated from the flow net. Let us assume that, the soil is isotropic, i.e. its permeability is constant in all directions, or $K_H = K_V$ (i.e. horizontal permeability is equal to the vertical permeability). The seepage rat can be computed from the flow net, using Darcy's Law, Applying the principle of continuity between each pair of flow lines, it is evident that the velocity must vary inversely with the spacing. Assuming the embankment cross-section of Figure 4 to have a unit width, the flow through the square ABCD (called field) or through the flow channel containing this square $= \Delta q = k.iA = k(\frac{\Delta H}{\Delta x})(\Delta y \times 1)$, where ΔH is the energy drop between the two equipotential lines bounding the square ABCD

$$\therefore \Delta q = k(\frac{\Delta H}{\Delta x})\Delta y$$

But

$$\Delta H = \frac{\text{Total drop, i.e. total head causing flow}}{\left(\begin{array}{l}\text{Number of increments into which}\\ \text{the total drop is equally divided}\end{array}\right)}.$$

Or

$$\Delta H = \frac{H}{N_d}$$

where, N_d = Total number of drops in the complete flow-net.

$$\Delta q = k\frac{H}{N_d}(\frac{\Delta y}{\Delta x}) = \frac{kH}{N_d}(\text{since}, \Delta y = \Delta x).$$

The total flow through all the channels, i.e. the total flow through the unit width of the embankment = $q = \sum \Delta q = \frac{kH}{N_d} \times$ number of flow channels.

Or

$$q = \frac{kH}{N_d} N_f. \qquad (1)$$

This is the required expression, representing discharge passing through a flow net and is applicable only to isotropic soils.

2.4.2. Schafeernak's Solution

Figure 5 shows an embankment having a top width of B. Height of water above the embankment bed level is H. Upstream slope angle of embankment is **b** and downstream slope angle is **a.** Coefficient of permeability of the embankment fill material is k.

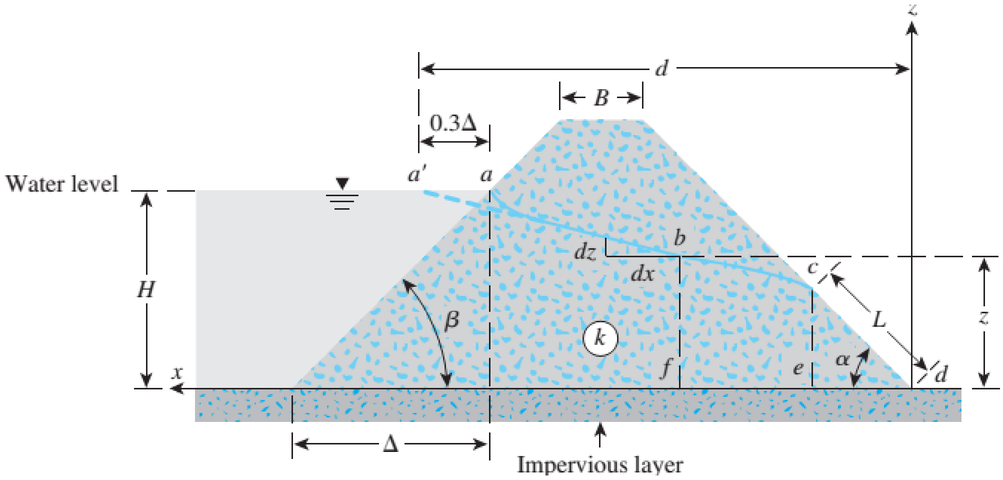

Figure 5. Flow through an embankment constructed over an impervious base (Principles of Geotechnical Engineering, BM Das)

Following is a step-by-step procedure to obtain the seepage rate q (per unit length of the embankment):

$$L = \frac{d}{\cos\alpha} - \sqrt{\frac{d^2}{\cos^2\alpha} + \frac{H^2}{\sin^2\alpha}} \qquad (2)$$

$$q = k(\tan\alpha)(L\sin\alpha) = kL\tan\alpha\sin\alpha \qquad (3)$$

1. Obtain α.
2. Calculate Δ (see Figure 5) and then $0.3\,\Delta$.
3. Calculate d.
4. With known values of α and d, calculate L from Eq. (2).
5. With known values of L, calculate q from Eq. (3).

2.4.3. Geo-Studio Software

Geo-Studio is Finite Element Method (FEM) based software and was developed by Calgary, Alberta, Canada. In Geo-Studio the model is designed in a generic way which provides opportunity of changing various parameters. Geo-Studio basically provides two-dimensional model. Geo-Studio software includes SLOPE/W, SEEP/W, SIGMA/W, QUAKE/W, TEMP/W, CTRAN/W and VADOSE/W programs. For seepage analysis we have used the SEEP/W program.

2.4.3.1. Without CC Block

At first a region was created similar to the embankment geometry. Then property of the embankment material was defined. Boundary conditions were applied on the created region. A flux section was drawn to know the flow rate. A mesh size equal to one was applied and the analysis was done. Figure 6 shows an embankment model in SEEP/W software considering without CC Block. Boundary conditions like potential seepage face, water level, zero pressure were applied during analysis.

2.4.3.2. With CC Block

At first a model was created without CC Block. Then a region was drawn to create a single region representing the blocks and the joints. After drawing region a material was created to represent the blocks having a permeability of 5.67×10^{-13} m/sec [8]. Then this material was applied to the CC Blocks. After assigning CC Blocks, lines were created where the joints exist and underneath the fill. After clicking on all lines and generating interface elements having a width of 0.02 m (width of joints between CC

Blocks), material was applied to the lines representing the joints. Here it was assumed that joints between CC Blocks have the same permeability as the fill material. No interface element was used between the CC Blocks and the embankment fill material. Figure 7 represents embankment model in SEEP/W software considering with CC Block.

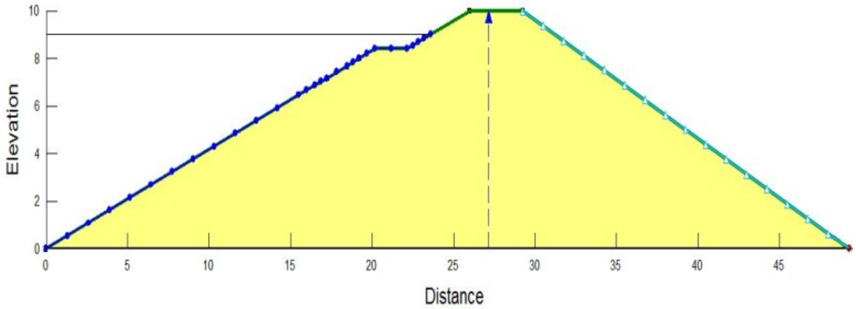

Figure 6. Embankment model in SEEP/W software (without CC Block)

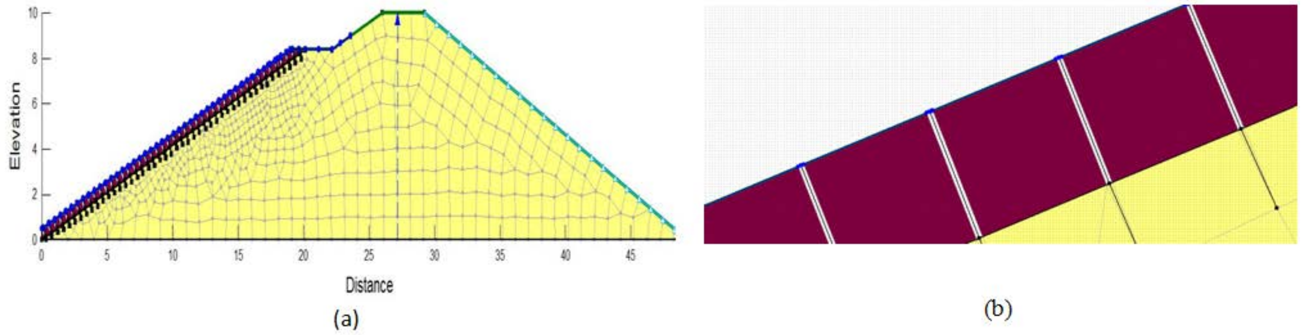

Figure 7. (a) Embankment model in SEEP/W software (with CC Block) (b) Enlarged view of CC Blocks

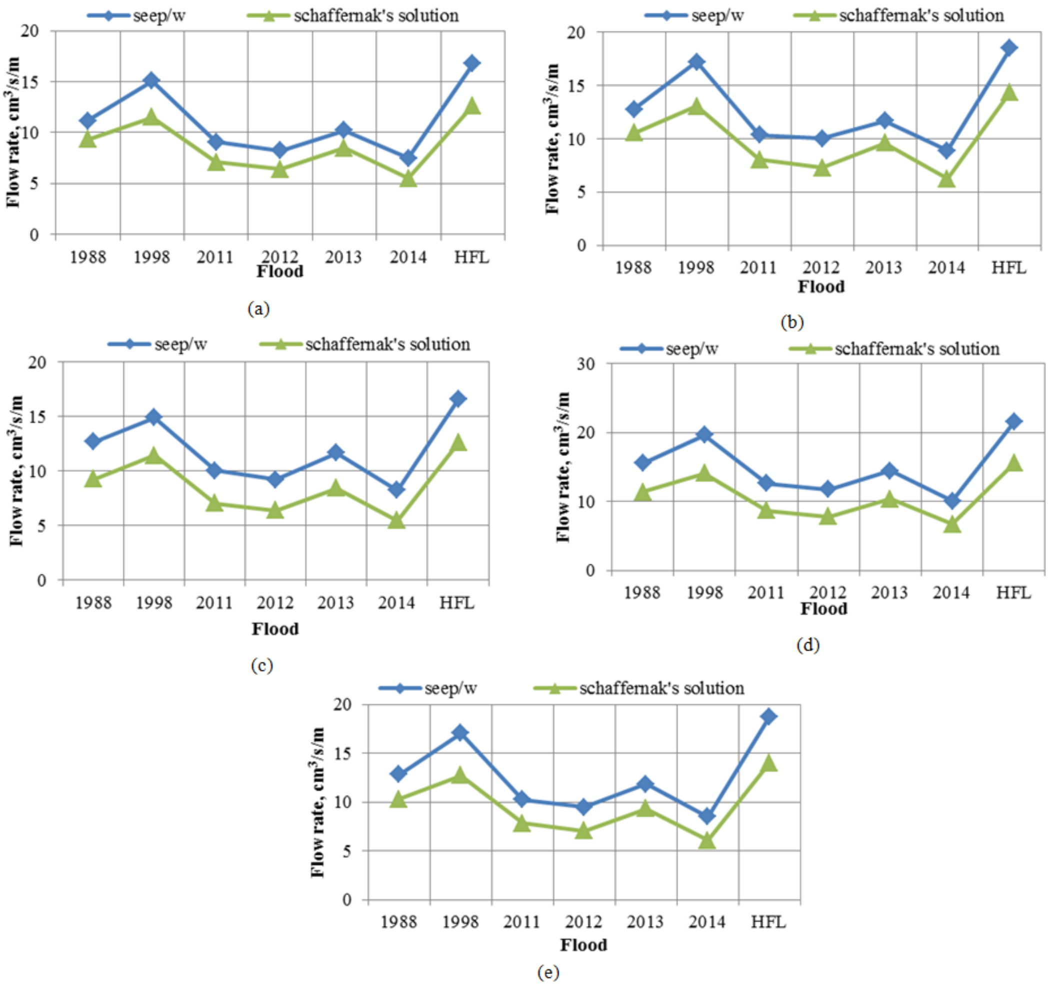

Figure 8. Variations between results of SEEP/W & Schaffernak's Solution for (a) Khojapur (b) Talaimari (c) Ponchoboti (d) Dorgapara (e) Police Line section

2.4.3.3. With CC Block (Joint sealed)

After creating the model as mentioned in 2.4.3.2 a material was applied in the joints having the same permeability as the CC Block.

3. Result and Discussion

In Bangladesh there are many embankments which have not yet been protected by CC Block. So seepage analyses using SEEP/W were performed considering without CC Block, as shown in Figure 9(a), to know the seepage rate through RCPE if it had not been protected by CC Block. Seepage analyses were also done by using Flow Net and Schaffernak's Solution to know the variations between results obtained from SEEP/W, Flow Net & Schaffernak's Solution. The results obtained from flow net and SEEP/W is quite similar because SEEP/W software is based on Flow Net theory. For the flood of the year of 2013 seepage rate obtained from SEEP/W, Flow Net & Schaffernak's Solution through RCPE at Khojapur section are 10.05 cm^3/sec/m, 10.21 cm^3/sec/m & 8.46 cm^3/sec/m respectively.

Variations between results of SEEP/W & Schaffernak's Solution are shown in Figure 8. SEEP/W & Schaffernak's Solution show variations varying from 15% to 20%.

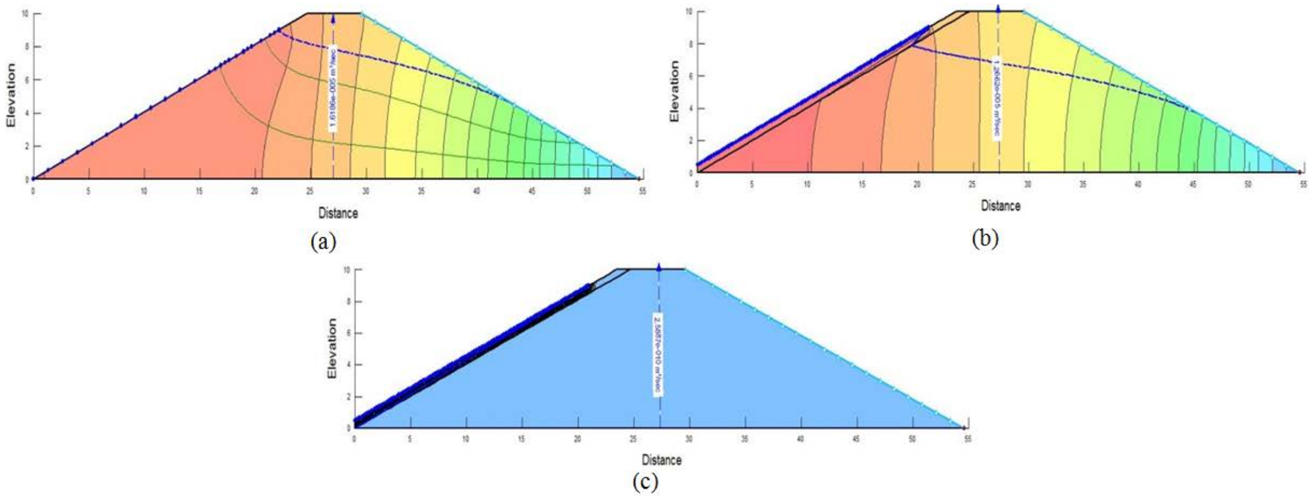

Figure 9. Seepage analysis considering (a) without CC Block (b) with CC Block (c) joint sealed

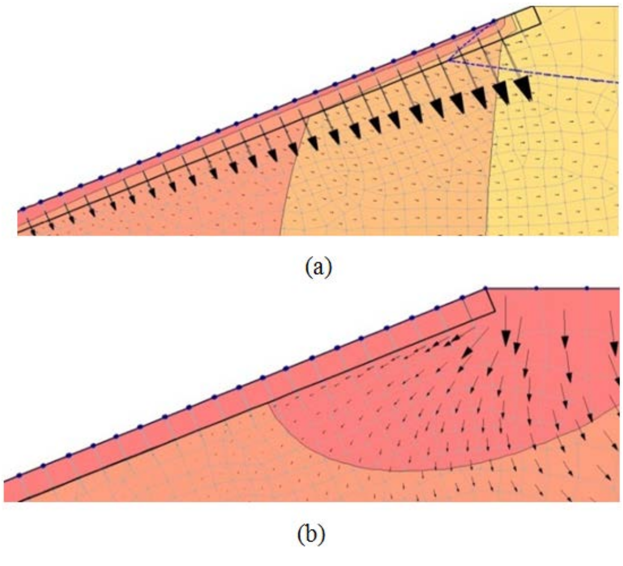

Figure 10. (a) Flow of water through the joints between the CC Blocks (b) No flow of water through the joints between CC Blocks

Seepage analysis for RCPE considering with CC Block & joint sealed was performed using SEEP/W as shown in Figure 9(b) & 9(c). Here Schaffernak's Solution and Flow Net could not be used because of complexity in the geometry when CC Block & joints between the CC Blocks were considered. Figure 10(a) indicates that, provision of CC Blocks cannot prevent the seepage because flow paths are generated between the joints of CC Blocks. Figure 10(b) shows that if the joints are sealed then there will be a little seepage through the embankment. There is seepage flow existence in the steady state of embankment through CC Block in theory. Figure 9(c) shows that seepage rate through embankment for joint sealed condition is very little e.g. 2.59×10^{-8} cm^3/sec/m and hence seepage through the embankment fort this condition were assumed to be zero.

For Ponchoboti section seepage analysis using SEEP/W shows that seepage rate for the flood of the year of 2013 is 11.24cm^3/sec/m when CC Blocks are not considered. When CC Blocks are considered seepage rate is 9.26cm^3/sec/m. If the joints between the CC Blocks are sealed, then there will be no seepage through RCPE at Ponchoboti section for the flood of the year of 2013. Seepage analyses were also performed for other sections for the flood of the year of 1988, 1998, 2011-2014 & for HFL. For Ponchoboti and Police Line section there is no seepage through RCPE at these two sections even for a flood equal to the HFL as shown in Figure 11. For Khojapur, Talaimari & Dorgapara section there is no seepage for the flood of the year of 1988, 2011, 2012, 2013 & 2014 when the joints between the CC Blocks are sealed.

The distances of each section from Police Line section were measured. The distances of Dorgapara, Ponchoboti, Talaimari & Khojapur section from Police Line section are 2.68, 5.89, 6.89 & 8 Km. Multiplying flow rate (cm^3/sec/m width) with the distances between each sections the flow rate (cm^3/sec) through RCPE over the studied area was obtained. It is clear from Table 3 that, if the joints between CC Blocks were sealed there would be no seepage through Rajshahi City Protection Embankment

(RCPE) for the flood of the year of 1988, 2011, 2012, 2013 & 2014. For the flood of the year of 1998, the seepage rate through RCPE is 87.49×10^3 cm^3/s (Joint sealed condition). This is because of the fact that the full surface of the upstream face of RCPE is not protected by CC Block at some sections.

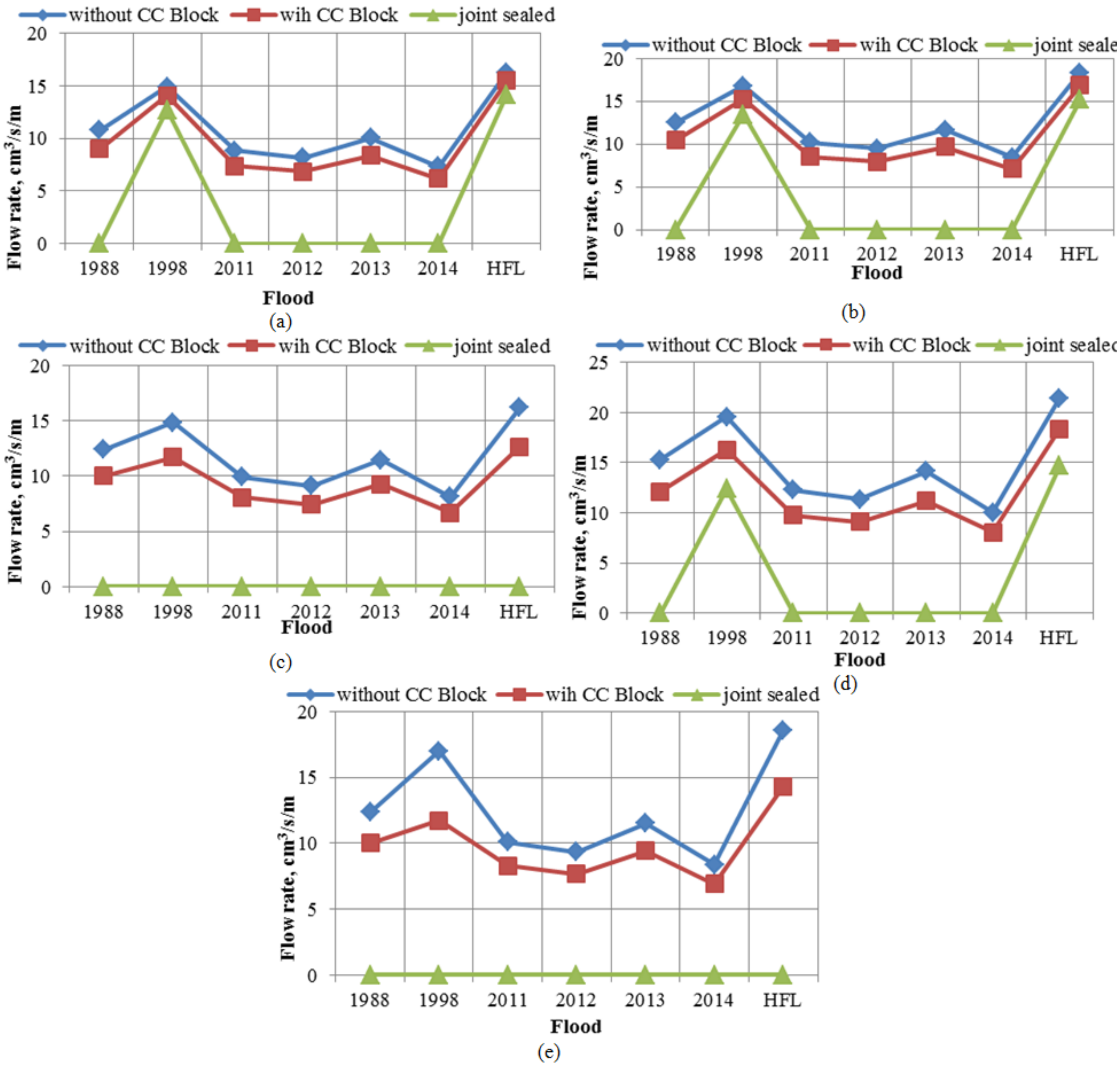

Figure 11. Flow rate through embankment at (a) Khojapur (b) Talaimari (c) Ponchoboti (d) Dorgapara (e) Police Line section

Table 3. Flow rate through RCPE

Flood	**Flow rate, cm^3/s ($\times 10^3$)**		
	Without block	With block	Joint sealed
1988	122.58	100.53	-
1998	161.37	138.49	87.49
2011	99.54	81.89	-
2012	91.90	75.96	-
2013	113.76	93.38	-
2014	82.09	67.99	-
HFL	176.13	154.19	99.10

4. Conclusion

Seepage analyses through Rajshahi City Protection Embankment indicate that seepage rate for without CC Blocks, with CC Blocks and joints between CC Blocks sealed conditions are 16.28 to 21.44 $cm^3/s/m$ width, 12.66 to 18.36 $cm^3/s/m$ width and 0 to 15.22 $cm^3/s/m$ width respectively for a flood equal to the HFL. Provision of CC Blocks have reduced seepage rate by 12.46 to 18.00%. It is found that using CC blocks is not effective unless the joints are sealed properly. The flood event in 1998 and HFL caused flow through the embankment for the case of CC Blocks with sealed simply because the water level was higher than the height of the CC Blocks.

References

[1] Amanullah, (1989). “A study on Flood Control Embankment in Bangladesh”. Department of Water Resources Engineering, Bangladesh University of Engineering & Technology, Dhaka, Bangladesh.

[2] Das, M. B. (1998), “Principles of Geotechnical Engineering”. PWS Publishing crop, USA, 7th edition, p215.

[3] Flood Forecasting and Warning Centre (FFWC). (2005, 3011, 2012, 2013, and 2014) Annual Flood Report, BWDB.

[4] Hossain, A. N. H. A., (2004) “Flood Management: Issues and Options”. Presented in the International Conference Organized by Institute of Engineers, Bangladesh.

[5] Hossain, M. B., Saki, T., and Hossain, M. Z. (2011) “River Embankments and Bank Failure: A Study on Geotechnical Characteristics and Stability Analysis”. American Journal of Environmental Sciences, Vol. 7 (2), pp102-107.

[6] Islam, M. S., Nasrin, S., Islam, M. S., and Moury, F. R. (2013) "Use of Vegetation and Geo-Jute in Erosion Control of Slopes in a Sub-Tropical climate". Proceedings of International Journal of Civil, Environment, Structural, Construction and Architectural Engineering, Vol:7, No:1, pp54-62.

[7] Monir, M. M. U., and Khan, Y. A. (2004) "Seasonal Potential Seepage Analysis of Rajshahi City Protection Embankment, Rajshahi, Bangladesh". Proceedings of Ninth international symposium on river sedimentation, October 18-21,2004, China, pp1659-1665.

[8] Schneider, S., Mallants, D., and Jacques, D. (2012) "Determining hydraulic properties of concrete and mortar by inverse modelling". Material Resources Society, Vol. 1475, pp367-372.