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Assessment of Some Old Earth Dams in Malaysia Through Observation and Computer Simulation

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ASSESSMENT OF SOME OLD EARTH DAMS IN MALAYSIA THROUGH OBSERVATION AND COMPUTER SIMULATION

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ABSTRACT

In this study, two earth dams located in Malaysia were studied. The Labong Dam is a non-homogenous earth dam, whilst the Bukit Merah Dam is a homogenous earth dam. The performances of both dams against seepage were studied through the analyses of both observed and simulated phreatic surfaces. Simulations of seepage rate and phreatic surfaces through the dam were conducted by using SEEP/W model. The study showed that the SEEP/W model was able to predict (simulate) both the seepage rates and phreatic surfaces of the homogeneous and non-homogeneous earth dams with a reasonable accuracy. The Absolute Error (AE) between the predicted and observed seepage rates of both dams were found to be 0.03 m^3/min to 0.18 m^3/min. The average AE in the predicted phreatic surfaces for the maximum and minimum water levels in the reservoir were 0.6 m and 0.38 m for the non-homogeneous dam (Labong Dam), and 0.595 m and 0.75 m for the homogeneous dam (Bukit Merah Dam).

INTRODUCTION

Earth dam is a well-compacted designed earth embankment for water storage. The storage is normally used for water supply, flood control, flood mitigation. The recent advances achieved in the design and construction sector make the construction of earth dams safer and more economical than those constructed in the past. Earth dams are generally economical structures compared with gravity dams, which usually are constructed using huge masses of concrete.

The failure of earth dams can be caused by seepage, piping, foundation instability, deformation, deterioration, and from earthquakes. To avoid failure of earth dams due to seepage, settlement, and piping, observations before and after construction are essential. During construction of earth dams, continuous field observations of deformation and pore water pressures have to be made while field observations after construction normally include seepage and the piezometric head. Without the observations, the dam may suddenly fail, and the loses of life and property damage will be great because of sudden release of a large volume of water, often with little or no advance warning. There are many causes of failure of an earth dam. Seepage is one of the most dangerous defects in earth dams. 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. Recently, great efforts have been paid to develop effective techniques for detecting, positioning, and mapping of seepage under and through earth dams. These efforts will help to find ways and means to minimize and control seepage and increase safety of earth dams.

Although there are many advances occurring in the field of geotechnical engineering, the design of earth dams is still considered not an easy job. This is because of uncertainty of the behavior of the soil used in dams, the complicated flow pattern through earth dams, difficulties in determining the required safety factor, and serious consequences of failure. The character of the materials comprising the foundation and the embankment of earth dam has a very important influence on seepage and its effect.

Li and Ming [2004] studied the driving seepage force and its effect on earth dams through a set of fully coupled finite element analysis. Xu et al. [2003] formulated an optimum hydraulic design regarding an earth dam cross section and the design depends mainly on reducing the saturated zone and minimizing material cost. 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. Panthulu et al. [2001] utilized an electronic method for delineation of seepage zones. Leontiev and Huacasi [2001] used mathematical programming technique to conduct numerical simulation for unconfined flow through porous media. They perform boundary element discretization and applied interior point algorithm to solve it. They propose to use the method of solution for 2D real size problems and extended to 3D problems. Zhang et al. [2001] proposed a simplified approach based on finite element technique to predict the seepage line (phreatic line) through non-homogenous rock fill dam with toe drain or core wall. Kalkani [1997] presented the case of Bakoyianni earth dam in Greece in which the dam abutment experienced seepage problem and he evaluated the dam safety and remedial measure to control seepage. Huang [1996] described and applied a numerical method using finite element technique to check the stability of earth dams after filling of their reservoirs.

In this study, two old earth dams located in Malaysia were examined. The Labong Dam was a non-homogenous earth dam, whilst the Bukit Merah Dam was a homogenous earth dam. The performances of both dams against seepage were studied through the analyses of both observed and simulated phreatic surfaces. Simulations of seepage rate and phreatic surfaces through the dam were conducted using a numerical model, SEEP/W.

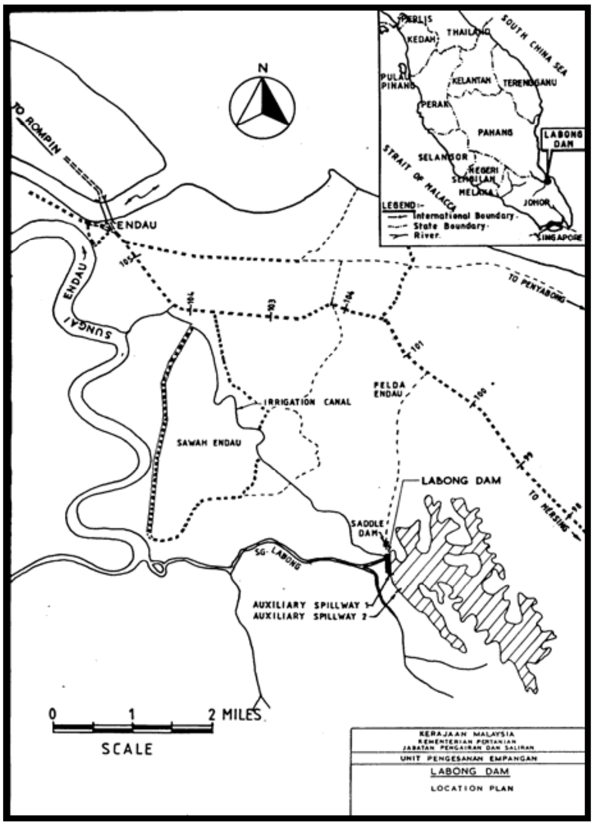
CASE STUDIES

The case studies will include two dams located in Malaysia and one dam is located south Malaysia while the other one is located North Malaysia. The first is called Labong Dam while the second one called Bukit Merah Dam.

Labong Dam (Non-homogenous Earth Dam)

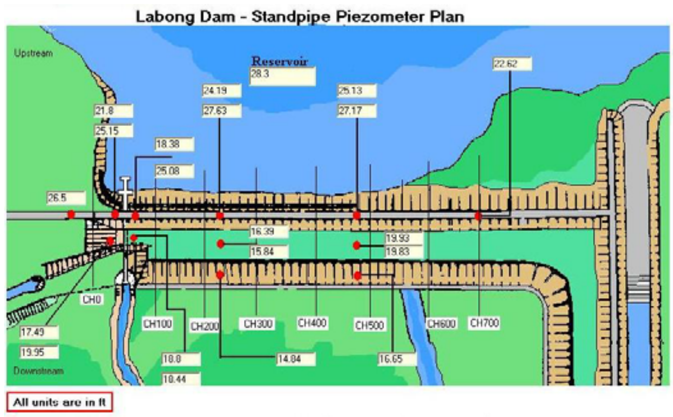
Labong Dam is a non-homogenous earth fill embankment located at the northeastern tip of the state of Johore, Malaysia as shown in Fig. 1. It is sited across the Labong River valley, about 5.5 km upstream of the confluence of this river with another river called Endau River. The feeding catchments of the dam are about 16 km^2 and have a storage capacity of 11.59 million cubic meters. The reservoir, at its maximum active storage elevation of RL 8.03 m, covers an area of about 6 km^2.

The dam was constructed in 1949 to supply water for irrigation. Labong Dam consists of a main earth fill embankment, irrigation intake structure, and two auxiliary spillways. The main earth fill embankment was designed with a thin puddle-clay core extending 1.5 m into the foundation to reduce seepage whist the material of the dam embankment consisted of lateritic soil with varying amount of sand and clay content. The length of the embankment is 259 m and the maximum height of fill is about 10.67 m while the top width is 3 m. The upstream slope was designed at 2.5:1, and the downstream slope 2:1, followed by a 15m wide berms and 3:1 slope to the toe of the dam. Based on a recent survey, the upstream slope above RL 7.3 m was about 2:1 which is steeper than the designed gradient. A reversed filter toe drain was added in 1964 to intercept seepage exiting from the downstream face of the dam. A 100 mm diameter clay perforated pipe was incorporated in the toe drain to collect seepage flow to a sump, which directs the flow into the siphon spillway outlet channel. In year 1989 a system of piezometer comprising of 12 standpipe piezometer was added as shown in Fig. 2. Historically the dam experienced settlement and seepage problems. For example, the recorded maximum crest settlement in 1962 at CH 90 m was found to be 0.8 m. The main data acquired from the Department of Irrigation and Drainage (DID) included piezometric levels at various points along the dam, seepage rate, and water levels in the reservoir. Figure 3 shows a sample of an annual variation of the piezometric levels for the Labong Dam at CH 60 m.



Source: Department of Irrigation and Drainage, Malaysia

Fig. 1. Location of Labong Dam



Source:Department of Irrigation and Drainage, Malaysia

Fig.2. Locations of the piezometer for Labong Dam

Bukit Merah Dam (Homogeneous Earth Dam)

Bukit Merah Dam is one of the oldest dams in Malaysia and located in the state of Perak. It was constructed in 1906 on Kurau River (Fig. 4). The dam is designed to provide water from its reservoir for irrigation and water supply. The dam is designed to provide water from its reservoir for irrigation and water supply. Since its construction, the dam had undergone some modifications to overcome problems that had risen and also to upgrade the dam to accommodate the increasing water demand. The dam is classified as homogenous earth embankment type. The material forming the embankment is clayey sandy silt and clayey silty sand. The upstream slope is 1:3 above elevation 7.92 m, and 1:5 below elevation 7.92 m, while the downstream slope 1: 3 above elevation 5.79 m and mildly slope below elevation 5.79 m. The main dam is 579 m long with a maximum height of 11.28 m. There are 20 piezometers distribution along the dam as shown in Fig. 5. The material forming the embankment is clayey sandy silt and clayey silty sand. The upstream slope is 1:3 above elevation 7.92 m, and 1:5 below elevation 7.92 m, while the downstream slope 1: 3 above elevation 5.79 m and mildly slope below elevation 5.79 m. The main dam is 579 m long with a maximum height of 11.28 m. There are 20 piezometers distribution along the dam as shown in Figure 5. The dam has a reservoir capacity of 117 million cubic meters at maximum operation level of EL 9.1m. The catchment's area of the dam is about 480 km^2. At the downstream of the dam there are several populated areas such as Bagan Serai town and about 20 villages that would be susceptible in case of dam break. The dam experienced slope failure and seepage problems. A maximum seepage rate of 1.7 m^3/min was observed in 1966. Seepage rate was measured using 100 mm PVC pipe and V-notch weir. Precautions were taken in order to reduce and control the seepage from the dam. The main data acquired regarding the dams are the piezometric level at various points along the dams and the seepage rate at different water levels in the reservoirs. Figure 6 shows annual variation of the piezometic level of the dam at CH 180 m.

MATHEMATICAL CONCEPTUALIZATION AND APPLICATION OF SEEP/W MODEL

The available analytical tool used to simulate seepage rate and phreatic surface through the dam was the SEEP/W model. The numerical model is internationally well known and produced by GEO-Slope International Ltd. SEEP/W could be used to analyze both simple and highly complex seepage problems with many capabilities.

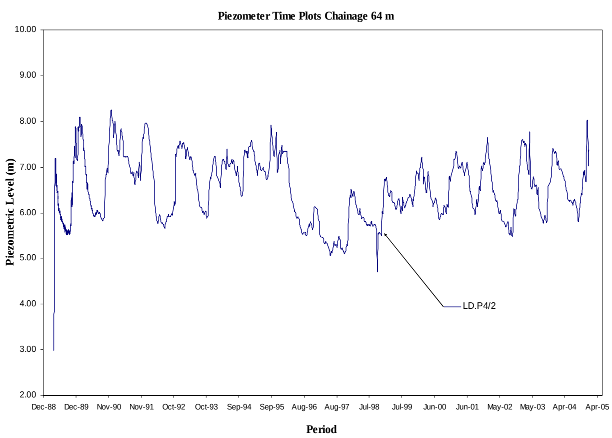
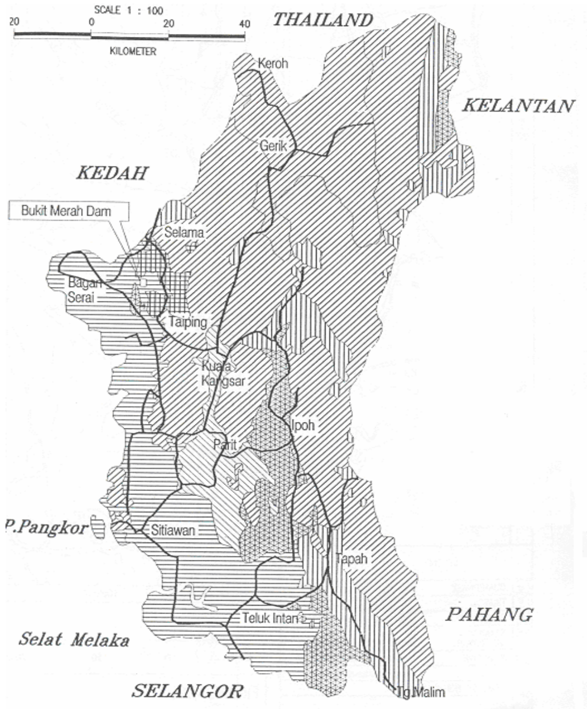
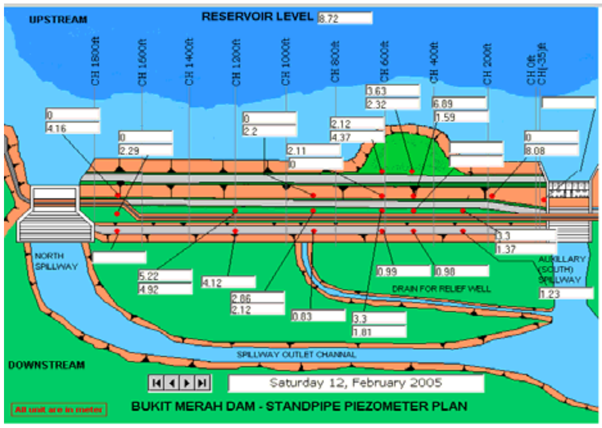


Fig. 3. Annual variation of piezometric level for Labong Dam at CH 60 m



Source: Department of Irrigation and Drainage, Malaysia

Fig. 4. Location of Bukit Merah Dam



Source: Department of Irrigation and Drainage, Malaysia

Fig. 5. Location of the piezometers for Bukit Merah Dam

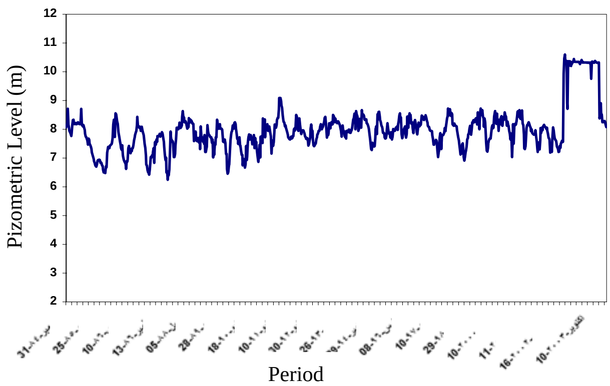


Fig. 6. Annual variation of piezometric level for Bukit Merah Dam at CH 180 m

SEEP/W model was based on numerical solutions using finite element technique for the two dimensional Darcy's equation. The application of the model was commenced by sketching the studied problem and the problem domain must be discretized into a finite element meshes. To facilitate this, quadrilateral and/or triangular regions were drawn in the problem domain. Inside each region, any number of finite elements could automatically be generated. Individual or groups of nodes and elements might be moved or deleted. Figures 7 and 8 show how a quadrilateral region was interactively meshed with quadrilateral elements for both Labong Dam (non-homogenous) and Bukit Merah Dam (homogenous). Each element in the mesh must be associated with a soil type. Boundary conditions such as total head, maximum negative pressure and tail water table must be assigned to nodes and edges. Simulation of seepage rate and the phreatic surface for an earth dam using SEEP/W model required boundary conditions. The boundary conditions were hydraulic conductivity, pore water pressure, and reservoir levels. For the case of the non-homogeneous Labong Dam, the hydraulic conductivities of the dam ranged 0.95 to 0.14 m/day at various locations. The required function between the hydraulic conductivity and pore-water pressure was determined from the filed data of studied problems. The pore water pressure at various points of the problem domain was determined by multiplying the pizometeric reading with unit weight of water which is usually taken as 9.81 kN/m^3. SEEP/W could readily handle unconfined flow problems because it was formulated to compute both saturated and unsaturated flow. SEEP/W discretized the entire flow domain into a finite element mesh. After achieving a converged solution, the zero-water pressure contour within the mesh was the phreatic surface that is not a flow boundary, but simply a line of zero pore-water pressure. The model also included the flow in capillary zone above the phreatic surface, which was a real and significant component of the total flow and this increased model accuracy. It was also important to predict the seepage fluxes across some section of the problem domain. The model allowed getting the flux at various sections through the problem domain. The location of sections could be selected and the model could predict flux quantities at each selected section. The critical section for which the seepage rate was required to be predicted was usually located at filter outlet of the dam. One of the model capabilities was displaying the flux quantities on that selected section of problem domain. The predicted rate of the flux through the selected section of the problem domain was given using unit of l/min.

OBSERVED AND SIMULATED RATE OF SEEPAGE AND PHREATIC SURFACES

The Labong Dam represented a case study for a non-homogenous earth dam, whilst the Bukit Merah dam represented a case study for a homogeneous earth dam. Two cross sections (CH 60 and CH 120m) were selected for the Labong Dam, whilst only one cross section (CH 180 m) was selected for the Bukit Merah Dam. The Labong Dam was classified as non-homogeneous earth since it had a thin core from hard clay. The dam was constructed in 1949, and was considered as an old dam. Field inspection showed that the dam experienced seepage. Maximum seepage rate recorded was 0.4 m^3/min. The dam had witnessed some modification whereby the dam height was increased to cope with the increasing inflow coming to dam reservoir from the feeding catchments. The Bukit Merah Dam was a homogenous earth dam. Maximum recorded seepage rate at this dam was 0.68 m^3/min. Table 1 shows the recorded and estimated (simulated) seepage rates for both the Labong and Bukit Merah Dam. The model accuracy was checked using Absolute Error (AE) defined as follow:

$$AE = X_m - X_p \quad (1)$$

where, X_m is recorded values and X_p is predicted values

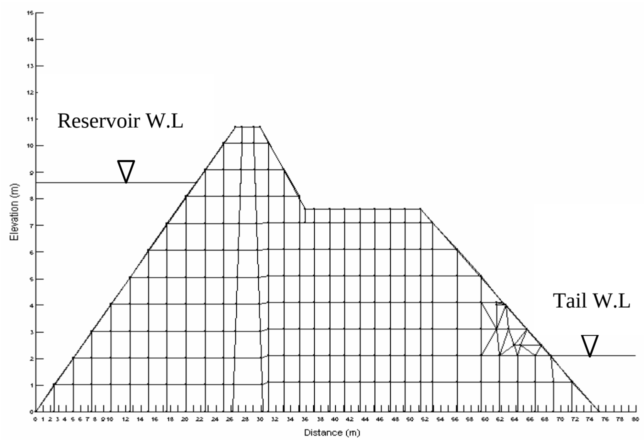


Fig. 7. Discretization of the domain of Labong Dam cross-section into finite elements meshes

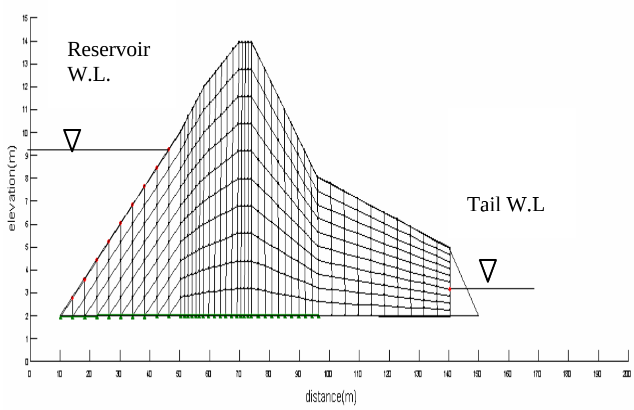


Fig. 8. Discretization of the domain of Bukit Merah Dam cross-section into finite elements meshes

The Absolute Error (AE) between the predicted and observed seepage rates of both dams were found to be 0.03 m^3/min to 0.18 m^3/min. The differences between the predicted and the observed seepage rates could be attributed to the assumptions used in the formulation of SEEP/W model, and to the differences in the hydraulic conductivities along the dam. In any case, the results obtained were reasonably close. Figures 9 and 10 show the comparisons between simulated and observed phreatic surfaces through the non-homogeneous Labong Dam at CH 60 m with maximum and minimum water levels in the reservoir. Figures 11 and 12 show the comparison between the observed and simulated phreatic surfaces at CH 120 m.

Table 1. Simulated and observed seepage rate for Labong and Bukit Merah Dam

Dam	dam section	Observed seepage rate (m^3/min)	Simulated Seepage Rate (m^3/min)	Absolute Error (m^3/s)
Labong (non-homogeneous earth dam)	CH 60 m	0.4	0.52	0.12
	CH 120 m	0.4	0.58	0.18
Bukit Merah (homogeneous earth dam)	CH 180 m	0.68	0.65	0.03

Figures 13 and 14 show the comparison between observed and simulated phreatic surfaces for Bukit Merah Dam at CH 180 m for maximum and minimum water level in the reservoir. Table 2 shows the maximum Absolute Error (AE) for the predicted phreatic surfaces for both the Labong Dam and Bukit Merah Dam. For the Labong Dam, the average Absolute Errors (AE) for the predicted phreatic surface at CH 60 m and at CH 120 m for maximum water level in the reservoir were 0.6 m and 0.5 m respectively. Whilst the average Absolute Errors (AE) for the predicted phreatic surface at CH 60 m and at CH 120 m for minimum water level in the reservoir were 0.38 m and 0.35 m respectively. For Bukit Merah Dam, the average Absolute Errors (AE) for the predicted phreatic surface at CH 180 m for maximum and minimum water level in the reservoir was 0.595 m and 0.75 m respectively. The average computed AE for the For Bukit Merah Dam, the average Absolute Errors (AE) for the predicted phreatic surface at CH 180 m for maximum and minimum water level in the reservoir was 0.595 m and 0.75 m respectively.

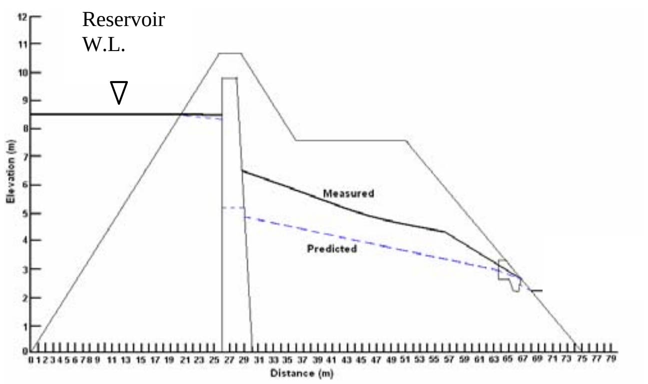


Fig. 9. Observed and predicted phreatic surfaces for Labong Dam at CH 60 m (Maximum water level in the reservoir)

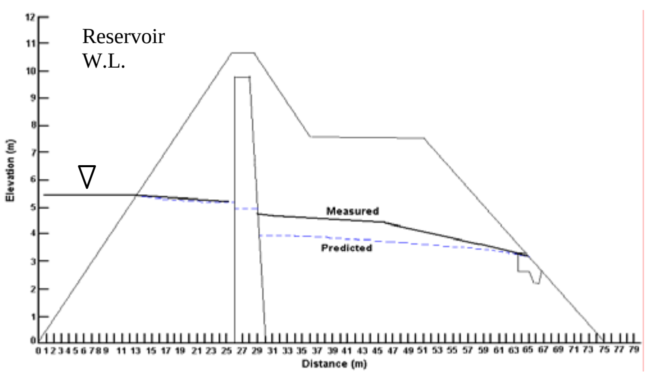


Fig.10. Observed and predicted phreatic surfaces for Labong Dam at CH 60m (Minimum water level in the reservoir)

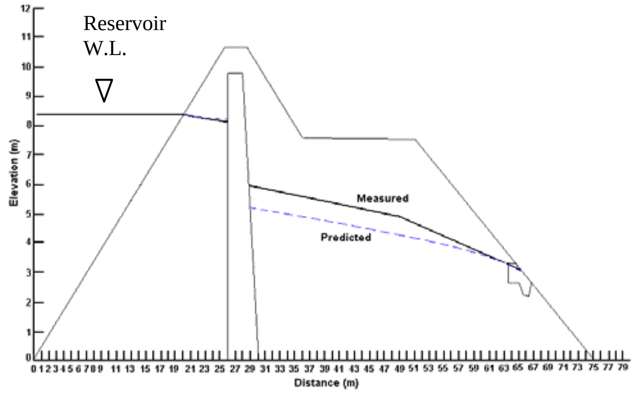


Fig. 11. Observed and predicted phreatic surfaces for Labong Dam at CH 120 m (Maximum water level in the reservoir)

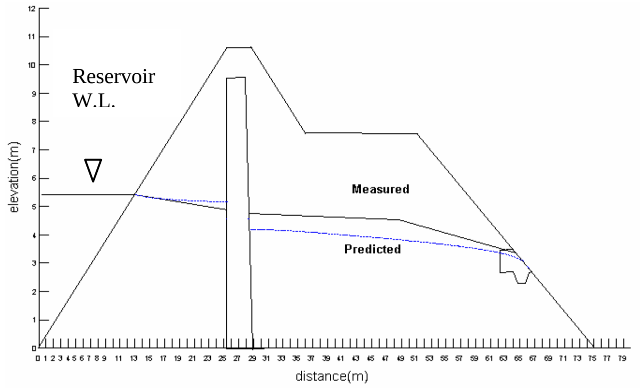


Fig. 12. Observed and predicted phreatic surface for Labong Dam at CH 120 m (Minimum water level in the reservoir)

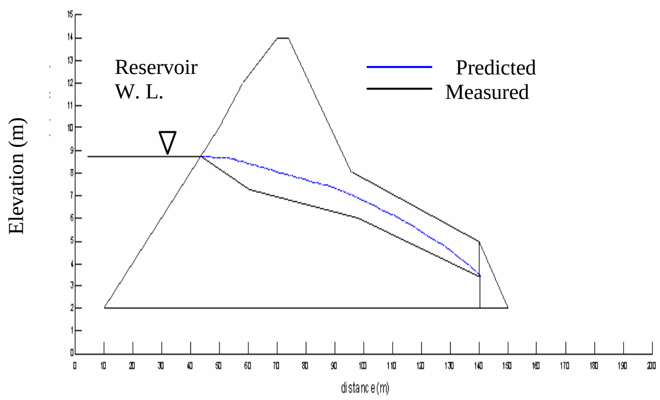


Fig. 13. Observed and predicted phreatic surfaces for Bukit Merah Dam at CH 180 m (Maximum water level in the reservoir)

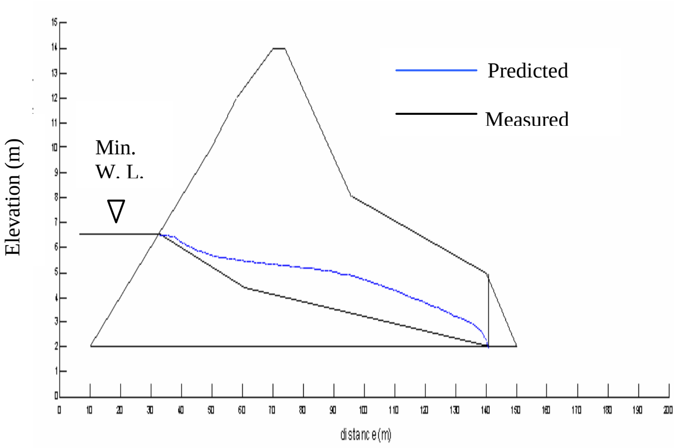


Figure 14. Observed and predicted phreatic surfaces for Bukit Merah Dam at CH 180 m (Minimum water level in the reservoir)

Table 2. Absolute Error for simulated phreatic surface for Labong and Bukit Merah Dams

Dam	Dam section	Type of dam	Water level in the reservoir (m)	Average Absolute Error (AE)
Labong	CH 60 m	Non-homogenous	Maximum	0.60 m
			Minimum	0.38 m
	CH 120 m		Maximum	0.50 m
			Minimum	0.35 m
Bukit Merah	CH 180 m	Homogenous	Maximum	0.595 m
			Minimum	0.75 m

The average computed AE for the cases of maximum and minimum water levels in the reservoir for Labong Dam were found to be consistent and reasonable. The slightly higher value of the average AE for the Bukit Merah Dam at minimum water level in the reservoir could perhaps be attributed to the difference between the actual hydraulic conductivities of the dam embankment and that used in running the SEEP/W model. This could be attributed to the fact that the degrees of compaction at various places along the dam during construction stage were not the same. It might also be related to the settlement that had occurred in the dam.

CONCLUSIONS

The study showed that the SEEP/W model was able to predict (simulate) both seepage rates and phreatic surfaces of a homogeneous and non-homogeneous earth dams. The Absolute Error (AE) between the predicted and observed seepage rates of both the homogeneous and non-homogeneous earth dams were found to be 0.03 m^3/min to 0.18 m^3/min. The average AE in the predicted phreatic surfaces for the maximum and minimum water level in the reservoir were 0.6 m and 0.38 m for the non-homogeneous dam (Labong Dam), and 0.595 m and 0.75 m for the homogeneous (Bukit Merah Dam).

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