DEVELOPMENT OF AN INNOVATIVE SUB-SURFACE STORMWATER CONTROL SYSTEM

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ABSTRACT

Flooding and pollution due to increase in the impervious areas as a result of urbanization are common problems. Several stormwater control systems were developed to reduce the effect of urbanization on the quantity and quality of stormwater runoff. Systems installed in sub-surface have the potential of being used in developed areas where land cost and/or availability are major concerns. A new competitive sub-surface stormwater retention system was developed and called the Storage-Infiltration Block (SIB) system. Modeling of the SIB system using finite element technique was performed to improve its configuration design and to evaluate its structural capability under the design load. The structural and hydraulic performance of the system was evaluated experimentally based on laboratory models. In this paper a description of the SIB system, its performance, advantages, and the applications will be briefly discussed. Furthermore, an overview of the SIB system designer which is a computer program developed to facilitate the design of the system will be presented in this paper.

Keywords: *SIB, System, Sub-surface, Stormwater, Detention, Retention*

1. INTRODUCTION

Systems installed above the ground surface such as retention basins need large tracts of land which may be expensive or unavailable in developed areas. Therefore, systems installed in sub-surface have the potential of being used in such areas. These systems are typically installed under parking lots or other paved surfaces to provide storage of stormwater and peak runoff flow control (EPA, 2001).

Systems such as concrete pipes and concrete tanks are relatively expensive compared to above surface storages due to its high construction cost. Systems such as steel pipes, plastic pipes and arched champers need spacing to provide room for proper backfill to enable for adequate side support and these spacing will increase the surface area required for the system and increase the stone aggregate required. Furthermore, these systems are manufactured in limited dimensions which make the achievement of its length, width or height difficult or impossible. These systems also have little storage capacity and little surface area available for infiltration. Therefore, developing a new system manufactured locally and based on readily available material (PVC-U) in the local market will encourage the local industry and contribute to achieve the needs of the country in reducing the flooding and pollution in urbanized areas. Furthermore, this new system will have competitive advantages among other typical systems such as arched chamber and pipe systems and this will be discussed later in this paper.

The system that has been developed is called the Storage-Infiltration Block system* (AL-Hamati, 2007). This paper will refer to the system as the SIB system (SIB means Storage- Infiltration Block). The system is intended to be installed in sub-surface, and as such, it has been designed to have sufficient structural strength and storage capacity, allows water to infiltrate at high rates, light in weight, requires low maintenance and can be installed easily.

To ensure that the system will perform as intended, it has been evaluated theoretically and physically using models. Theoretical evaluation of the structural capability of the system under the design load was done using the finite element modeling technique. Experimental testing was carried out in the laboratory to investigate the structural and hydraulic performance of the system under different operation conditions. Only a brief description of some of these tests will be included in this paper. This paper briefly describes the SIB system and its performance, advantages, and applications. Furthermore, an overview of the SIB system designer will be presented in this paper.

2. DESCRIPTION OF THE SIB SYSTEM

SIB system is a new sub-surface stormwater control system developed for the purposes of reduction of stormwater runoff and recharging of groundwater. The components of the SIB system as shown in Figure 1 are the Storage-Infiltration Block (SIB), geotextile, geogrid, porous soil, and porous pavement surfaces (e.g. porous concrete, porous asphalt, concrete paving blocks, etc).

The SIB is a new storage and infiltration module that has been developed using pipes that are commonly used for water supply and sewer systems (AL-Hamati et al., 2006a). The function of the SIB is to store the stormwater runoff temporarily and then release it by infiltration to the groundwater or by an outlet to the drainage system. The SIB consists of nine hollow plastic pipes held vertically together by two plastic holders to form a block as shown in Figure 2. Both pipes and holders are made from rigid polyvinyl chloride (PVC-U). Experimental tests revealed that the PVC-U pipes have a great

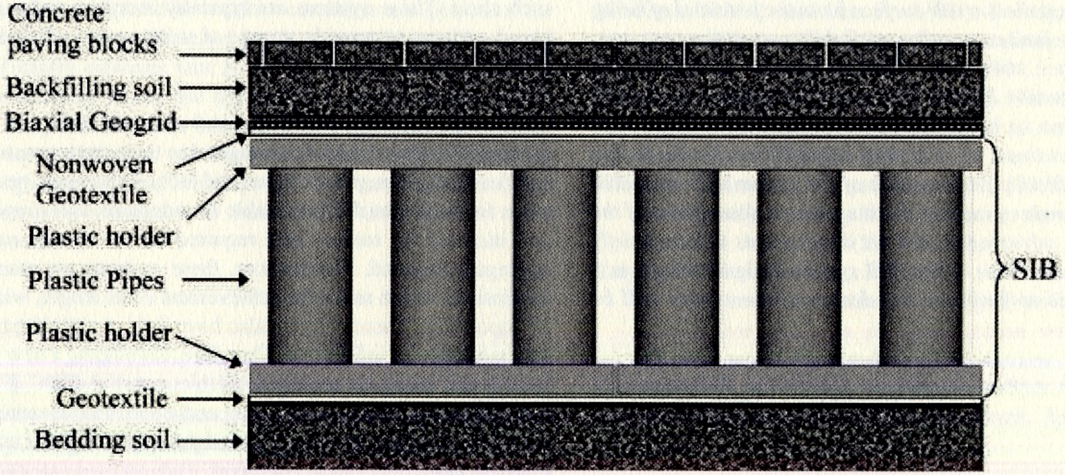


Figure 1: The system with two SIB columns (Source: Malaysian Utility Innovation Application No. UI20064728).

capability to support loads when axially loaded (AL-Hamati et al., 2006b). Orifices (holes) are made on the pipe wall to allow water to flow more easily out of the pipes (AL-Hamati et al., 2007).

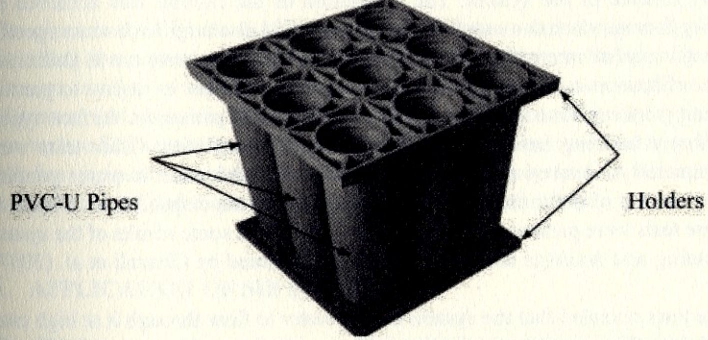


Figure 2: A SIB module
(Source: Malaysian Utility Innovation Application No. UI20064728).

The functions of the SIB holders are to hold the pipes in place, distribute and transfer the load applied on top of the SIB to the pipes and transfer the load from the pipes to the system foundation. The design of the holder takes into consideration several criteria such as it must be strong enough to sustain, transfer and distribute the loads applied on it to the pipes, it can allow the blocks to be stacked up to achieve a desired height for the system, it must hold the pipes tightly without using any fasteners, and it should have high percentage of open space to allow water to flow into the block easily. The holder has an open space of 76% of the total holder area that will allow water to flow through very easily.

Nonwoven geotextile has been selected for the SIB system due to its high permeability and its suitability for such applications. The system is encased by the geotextile to separate the surrounding soil particles and the SIB and at the same time it allows stormwater to flow to or from the system (Figure 1). Biaxial geogrids are used for applications in which the stresses are essentially random (Koerner, 1998). Due to the type of loadings that the system will be subjected to (e.g. vehicular loads), the stresses are expected to occur randomly on top of the system; therefore, biaxial geogrids have been selected to be used on the system (Figure 1). The main purposes of using the geogrids are to protect the geotextile from damage due to soil pressure and to enhance the stability of the backfilling soil on top of the system.

Natural soils below the SIB system should be leveled with minimum compaction to avoid any reduction in its infiltration capacity. To provide satisfactory bedding below the system, a compacted crushed stone should be placed over the entire bottom of the system. Adequate backfilling soil cover depth is required to prevent the system from receiving direct traffic load. Bedding, surrounding, and backfilling soils should be pervious enough to allow easy flow of stormwater from and into the system.

Different options of porous pavement surfaces that can be used above the SIB system are available. These surfaces are installed for similar purposes but they have different durability and infiltration capacity. Therefore, the selection of the surface type depends on different factors such as the traffic volume above these pavements, the infiltration rate required and the pollutions at the site.

3. PERFORMANCE OF THE SIB SYSTEM

Finite element analysis was used to ensure the suitability of the design configuration of the SIB and to evaluate its structural performance under the maximum expected load on the system as shown in Figure 3.

Results show an excellent ability of the SIB to sustain the design load (details of this analysis is not included). Then, several SIBs were fabricated and the structural and hydraulic performance of the system was investigated by conducting 40 experimental tests using laboratory models under different testing conditions (AL-Hamati, 2007). Details of these tests will not be included in this paper except for a brief description of some of these tests will be presented.

A total of 20 experimental tests were done to investigate the structural performance of the system. The main purpose of these tests is to evaluate the ability of the system to withstand the design axial compression load of 93 kN which is the maximum expected load to occurr when the system is installed in a parking area. Tests were also done to evaluate the ability of the system to support lateral loads equivalent to the lateral soil pressure of up to 3 m depth

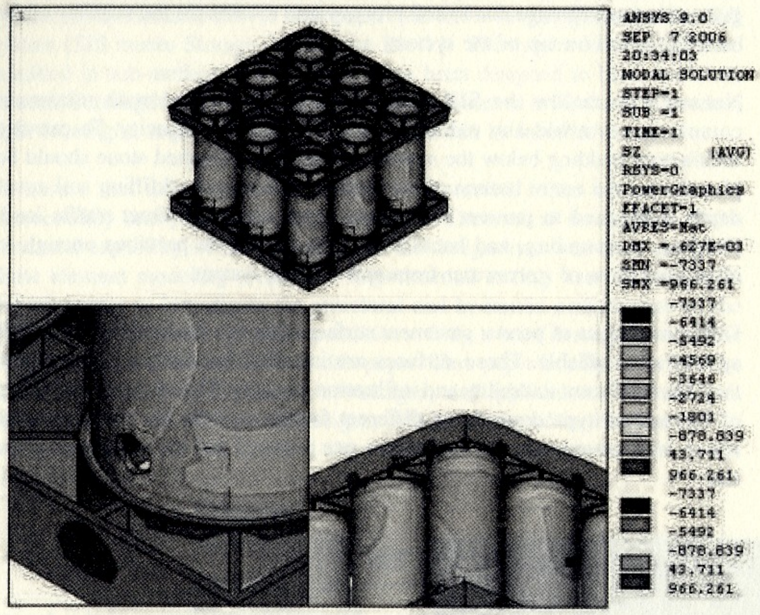


Figure 3: SIB stress distribution obtained from finite element simulation.

below the ground surface and to find the maximum load that the SIB can withstand before failure. Other tests were conducted to evaluate the behavior of the stacked SIB under axial compression loads and the improvement in the SIB bonding strength by using PVC-U solvent cement for bonding the SIB pipes and holders. Incremental axial compression loads were applied to the system, and strains and displacement were recorded during the tests.

Axial compression and lateral tests demonstrated that the system has high strength to sustain the applied loads. Ultimate strength tests revealed that the SIB has an ability to support axial compression loads of up to 490 kN (50 tonnes), which is five times larger than the design load. As expected, using the PVC-U solvent cement to fasten the SIB components (pipes and holders) will enhance attachment between the holders and the pipes significantly. In general, for all tests performed under the design loads, it was found no critical stress occurred that may lead to a system failure and no failure was observed in the geogrid or geotextile.

Another 20 experimental tests were carried out to evaluate the hydraulic performance of the system. The simulation of the rainfall was achieved by using four spry nozzles supplied with a controlled discharge to produce specific design rainfall intensities. The main purposes of these tests are to determine the infiltration rates through the system and to evaluate its ability to prevent water ponding on top of the system for different pavement surface types, different bedding layers, and different rainfall intensities. Other tests were conducted to determine the relation between the reduction in water ponding level on top of the surface area of the system with the elapsed time. Details of these tests were presented by AL-Hamati (2007) and some results of the system ponding and drainage time tests were also presented by Ghazali et al. (2007).

The tests revealed that the system allows water to flow through it at high rates and thus demonstrates an excellent efficiency in preventing ponding of water on the surface even under high rainfall intensities that vary from 300 mm/hr to 420 mm/hr for 5 minutes and 10 minutes rainfall durations. The type of porous pavement surface used on top of the system significantly affects inflow rate of stormwater into the system and ponding time. Evaluation on the system capacity to store water shows that the system has high storage capacity and reaches a value of 93% of the total volume of the SIB.

4. SIB SYSTEM ADVANTAGE

The SIB system has some advantages over other typical systems such as arched chambers and pipes systems. These advantages are: height flexibility (Figure 4), less surface area required, less stone aggregate required, high infiltration rate, high strength, and light in weight. The system can be installed to any desired height from the minimum of 8 cm to the maximum of 3 m. This flexibility in height is a major advantage especially at sites with extremely high water table. The SIB system is installed by stacking the blocks vertically and arranging the columns horizontally such that the SIB columns are in contact with adjacent columns as shown in Figure 1. After installation, a system with depth of 3 m installed beneath a one meter square of surface area can store 2.8 m^3 of water.

No stone is required in the excavated volume of the SIB system and this will reduce the cost of the system installation. SIB has large openings at the top, bottom, and sides with approximately 76% of the total area in the vertical direction and with full openings on the sides (100% opening area) as shown in Figure 5. Therefore, stormwater volume can infiltrate and exfiltrate faster from the system.

The pipes in the SIB are held vertically together to sustain the load applied. Installing the pipes in vertical direction makes them very strong with the ultimate strength of the SIB equals to 1944 kN/m^2 (one SIB can support up to 50 tonnes) (AL-Hamati, 2007). The weight of a SIB is considerably light and can be handled manually. As a result the system installation is much quicker than heavy pipes or concrete structures. Furthermore, the system can be installed in smaller areas and requires less heavy machinery and labour.

5. APPLICATION OF SIB SYSTEM

The SIB System can be applied in several ways. It allows high infiltration rate from the surface to reduce stormwater runoff and allows sub-surface infiltration (water percolation) to take place with improvement of water quality that can be allowed to recharge ground water. The system can also be used as rainwater harvesting storage due to the improvement of water quality during the infiltration process from the ground surface into the system through the porous media. Clean water can then be used to irrigate landscape areas and gardens.

When the system is installed below an open space such as parking areas, it can reduce the stormwater runoff. It can also be used as a drainage system of the roadway by installing the SIB at roadway sides. The system can also be used as a sub-surface channel or drain, therefore, replacing the open channels or drains which require vast areas of land and have safety and health problems.

6. SIB SYSTEM DESIGNER

A computer program called SIB System Designer (SIBD) was developed to facilitate the design of the system. The program is based on derived equations which depend on the system configuration and also the design and installation procedures of the system (AL-Hamati, 2007). The required input data of the SIBD and its output data are presented in Tables 1 and 2 respectively. The data presented before in Table 1 will be entered in the SIBD through the input data window as shown in Figure 6. The output results will be presented in the output data window of the program as shown in Figure 7.

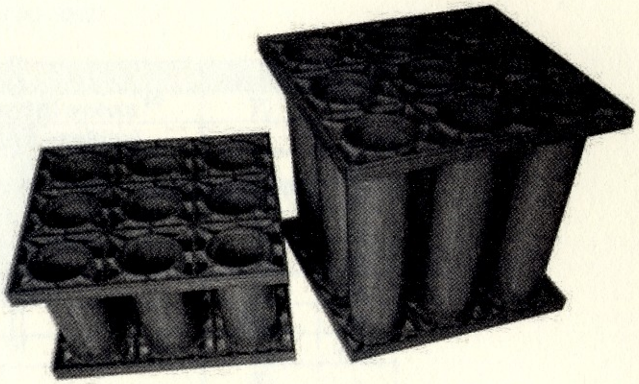


Figure 4: SIB with different heights
(Source: Malaysian Utility Innovation Application No. UI20064728).

7. CONCLUSION

This paper presents an alternative stormwater control system with some of its test results and potential applications. The system was developed for the purposes of reducting the volume and flow rate of stormwater runoff. The system is intended to be used below the ground surface such as roadway and parking area drainage, sub-surface channels or drains, sub-surface storage tank (rainwater harvesting tank) and groundwater recharge. The system is called the Storage-Infiltration Block (SIB) system. The main component of the SIB system is the SIB which is made from PVC-U material for stormwater runoff storage and infiltration. SIB consists of PVC-U pipes held together at the top and the bottom by two plastic holders.

Results from finite element analysis show the suitability of the designed configuration of the SIB to sustain the design load required. Results of structural tests revealed that the system has high structural strength to sustain the design loads applied in axial and lateral directions and under different operation conditions. Results of hydraulic tests proved that the system has high infiltration rates and demonstrates an excellent efficiency in preventing water ponding on the surface under high rainfall intensities. The system has high storage capacity that can reach up to 93% of the total volume of the system. A computer program called SIB system designer was developed to facilitate the design of the SIB system.

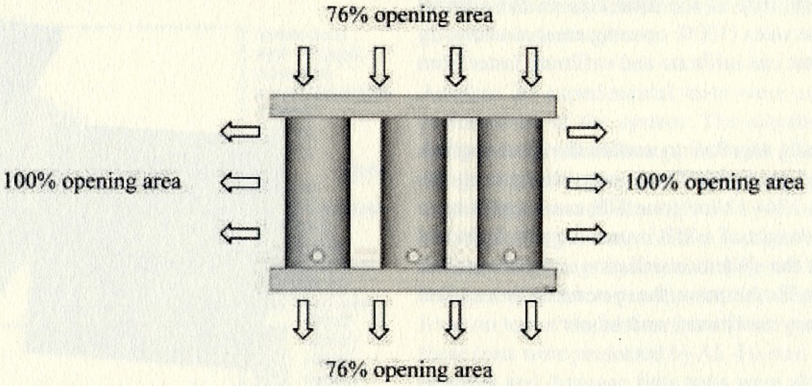
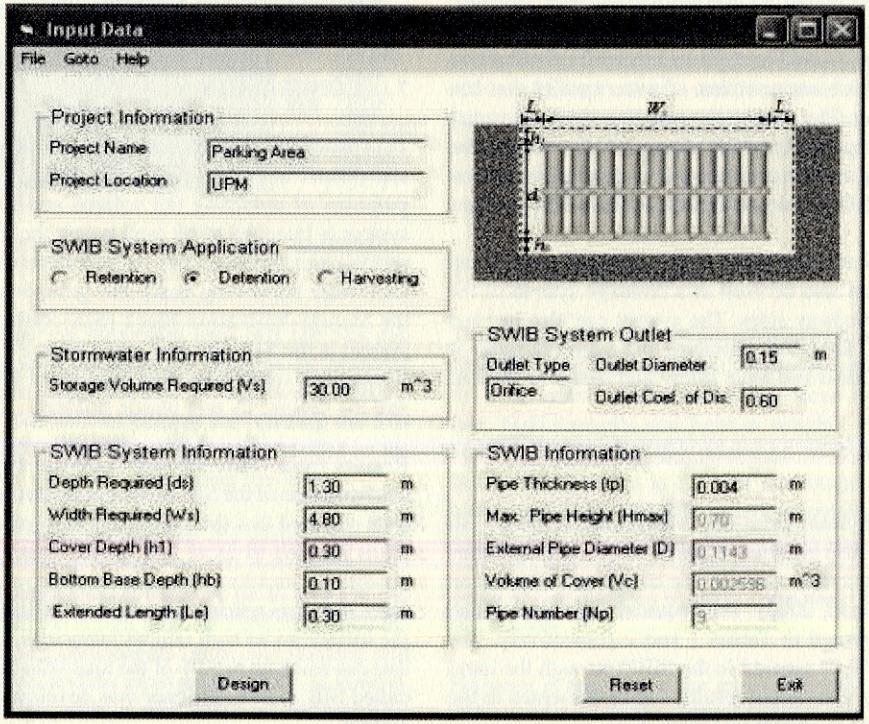


Figure 5: Opening areas of the SIB.



Project Information

Project Name	Parking Area
Project Location	UPM

SWIB System Application

○ Retention ● Detention ○ Harvesting

Stormwater Information

Storage Volume Required (Vs)	30.00	m^3

SWIB System Outlet

Outlet Type	Orifice	
Outlet Diameter	0.15	m
Outlet Coef. of Dis.	0.60	

SWIB System Information

Depth Required (ds)	1.30	m
Width Required (Ws)	4.80	m
Cover Depth (h1)	0.30	m
Bottom Base Depth (hb)	0.10	m
Extended Length (Le)	0.30	m

SWIB Information

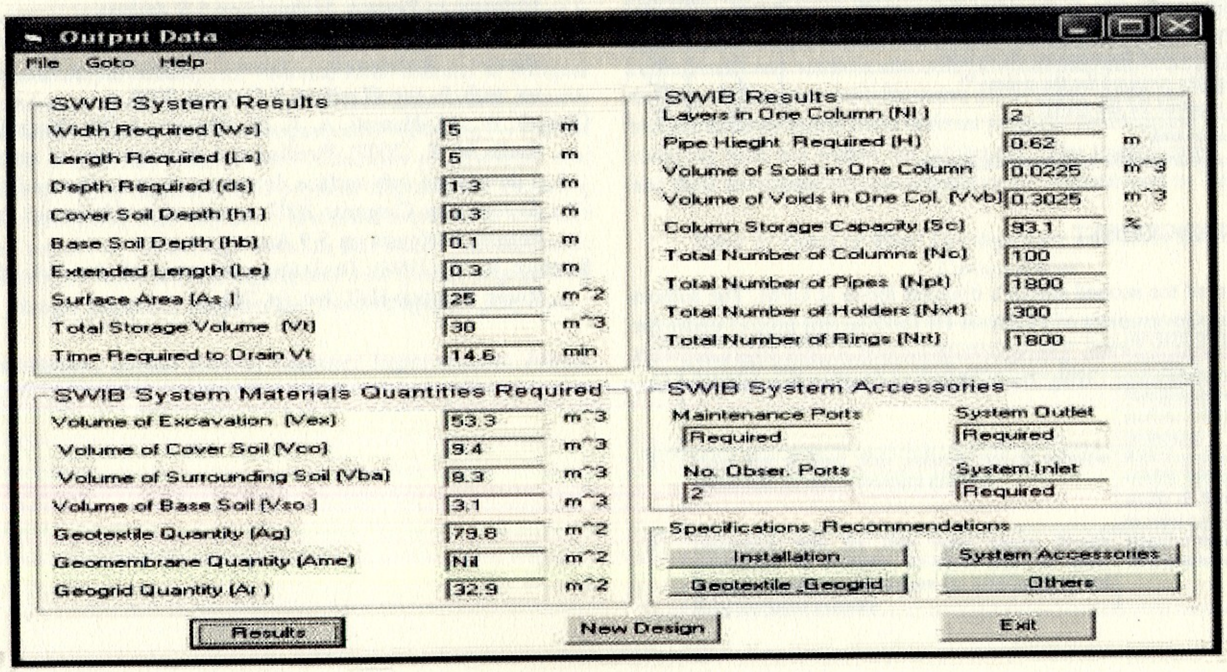
Pipe Thickness (tp)	0.004	m
Max. Pipe Height (Hmax)	0.70	m
External Pipe Diameter (D)	0.1143	m
Volume of Cover (Vc)	0.002536	m^3
Pipe Number (Np)	9	

Figure 6: Input Data Window of the SIB System Designer.

Table 1: Required Input Data of the SIBD

Description	Symbol	Unit
Volume of stormwater that must be stored in the in the SIB system [(a)]	V_s	m^3
System primary function (detention, retention, or water harvesting)		
Depth required [(b)]	d_s	m
Width required [(c)]	W_s	m
Depth of soil cover above the SIB system	h_1	m
Depth of base soil below the SIB system	h_b	m
Extended length beyond the SIB system length and width	L_e	m
Maximum allowable pipe height [(d)]	H_{max}	m
Pipe wall thickness	t_p	mm
Number of pipes in one SIB (fixed)	N_p	-
Volume of one SIB holder with 18 rings (fixed)	V_c	m^3

[(a)] This value represents the total volume of the stormwater entering the SIB system through the porous pavement surface and through the system inlet.



SWIB System Results
Width Required (Ws) 5 m
Length Required (Ls) 5 m
Depth Required (ds) 1.3 m
Cover Soil Depth (h1) 0.3 m
Base Soil Depth (hb) 0.1 m
Extended Length (Le) 0.3 m
Surface Area (As) 25 m^2
Total Storage Volume (Vt) 30 m^3
Time Required to Drain Vt 14.6 min

SWIB Results
Layers in One Column (Nl) 2
Pipe Hieght Required (H) 0.62 m
Volume of Solid in One Column 0.0225 m^3
Volume of Voids in One Col. (Vvb) 0.3025 m^3
Column Storage Capacity (Sc) 93.1 %
Total Number of Columns (Nc) 100
Total Number of Pipes (Npt) 1800
Total Number of Holders (Nvt) 300
Total Number of Rings (Nrt) 1800

SWIB System Materials Quantities Required
Volume of Excavation (Vex) 53.3 m^3
Volume of Cover Soil (Vco) 9.4 m^3
Volume of Surrounding Soil (Vba) 8.3 m^3
Volume of Base Soil (Vso) 3.1 m^3
Geotextile Quantity (Ag) 79.8 m^2
Geomembrane Quantity (Ame) Nil m^2
Geogrid Quantity (Ar) 32.9 m^2

SWIB System Accessories
Maintenance Ports: Required
System Outlet: Required
No. Obser. Ports: 2
System Inlet: Required

Figure 7: Output Data Window of the SIB System Designer.

Table 2: Output Data of the SIBD

Description	Symbol	Unit
Number of layers required in one column	N_l	-
Adjusted pipe height	H	m
Volume of solid of the SIBs in one column	V_{sb}	m^3
Total volume of SIBs in one column	V_b	m^3
Volume voids of SIBs in one column	V_{vb}	m^3
Storage capacity of the system	S_c	%
Total storage volume of the system	V_t	m^3
Width required (or adjusted) of the system	W_s	m
Length required (or adjusted) of the system	L_s	m
Surface area of the system	A_s	m^2
Number of columns required in the system	N_c	-
Number of adjusted columns required in the system	N_{ca}	-
Total number of pipes required in the system	N_{pt}	-
Total number of SIB holders required in the system	N_{ht}	-
Total number of rings required at the top and bottom of the system	N_{rt}	-
Volume of excavation required for the system	V_{et}	m^3
Volume of backfilling soil required to cover the system	V_{co}	m^3
Volume of backfilling soil required surrounding the system [(a)]	V_{bu}	m^3
Volume of Base soil required below the system	V_{so}	m^3
Geotextile quantity required for encasing the system	A_g	m^2
Geomembrane quantity required for the system [(b)]	A_{mg}	m^2
Geogrid quantity required for the system	A_r	m^2

[(a)] Soils at the site may be used.

[(b)] Used when the system designed for water harvesting purposes.

8. ACKNOWLEDGEMENT

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