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The Special Character of Angkor Sand and the Preservation of the Central Tower of Bayon Temple

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Abstract: *The Bayon temple stands upon a thick sand mound of 15m in height from the ground. In1933, EFEO excavated at the center of the foundation mound down to the base and found the Buddha statue. The sectional drawing of the Bayon temple by EFEO shows a vertical shaft at the center with dimensions of about 2.5m x2.5m with a depth of about 14m. To study the safety of the foundation mound, JSA (Japanese Government Team for Safeguarding Angkor) made a boring at the center of the shaft in 2009. The boring shows that the shaft is filled back with very loose sand of N<5 down to the base of the foundation. Another boring was carried out from the surface of the third terrace at the outside of the central Tower. The results show a laterite block layer of 6m in thickness beneath sand stones at the surface followed by sandy mound with very large SPT N-values larger than N>100. The relationship between SPT-N values and water contents of the sample shows the larger SPT-N values with the smaller water contents. A Sampled soil was submerged into waer and gradually weakened and completely collapsed within 10 min. The Bayon tower stands upon the foundation sand mound with a thickness of about 15m. The climate season from May to October of Cambodia provides rainwater to weakening the sandy mound. However, the amazing fact is the sandy mound foundation has been stable since construction for more than 700 years. The paper provides the amazing mechanism of the Angkor Sand.*

Keywords: Bayon, Central Tower, Sandy Mound, Angkor sand

1. INTRODUCTION

Japanese government has been active to support the protection of conservation of the world heritage in Asian region. In 1975, I was a member of Kyoto University to study stability of slope of the Borobudur temple in Indonesia. After discussion meeting, I was told by Dr.Daigoro Chihara, the special adviser for safeguarding cultural heritage for Ministory of Foreign Affairs for Japanese Government, “Next target for you is Angkor in Cambodia”. It was 1994 after 19 years when I received the request to join the Japanese Government Team for Safeguading Angkor (JSA). Since then the geotechnical unit of JSA has intensively carried out geotechnical aspects in Angkor. We started our study to investigate ground condition by boring at Angkor Wat and Bayon Temple at Angkor Thom in 1994.

2. GEOTECHNICAL ENGINERING OF BAYON TEMPLE

2.1 Characteristics of Ground and Foundation Structure

Geological boring and long trench from the inner gallery to outside of the outer gallery at the northern area in the Bayon are shown in Figure-1. Vertical section is shown in Figure-2 with the results of boring, which revealed the ground consists of silty to clayey sand down to GL-35m followed by weathered tuff.

Underground water consists of the surface and the deeper waters with different levels; however, both show the water levels reach at the ground surface at the end of the rainy season. In the dry season, both water levels decrease by evaporation from the surface and by pumping the deeper water respectively.

SPT, N-values increases with depth in rainy season. The N-values at the top surface increase from N=0(rainy season)

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to N=20(dry season). This is caused by the increase of the strength by decreasing water contents by drying.

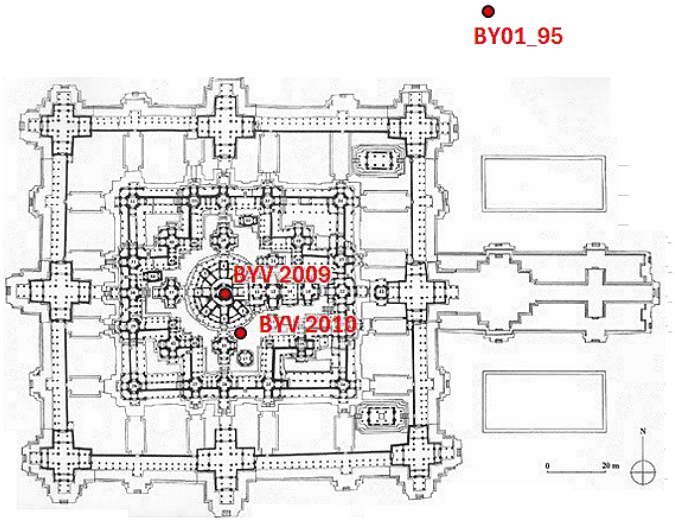


Fig.1 Plan of Bayon with boring points

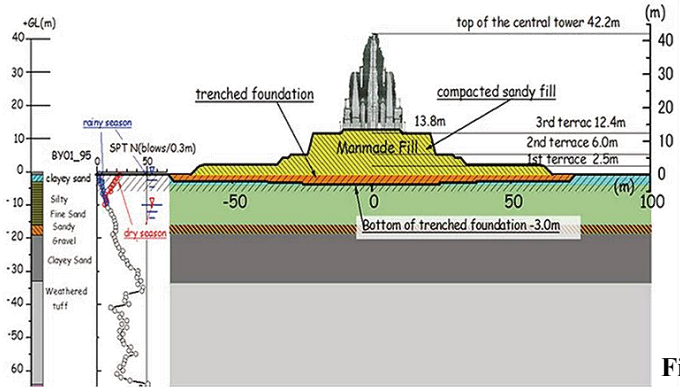


Fig.2 Section of Bayon temple with Boring BY01_95

2.2 Foundation Structure of the Main Tower

The Main Tower is supported by the base stone as shown in Figure-3. Archaeological survey was performed in 2008. Hand auger was inserted below the base stone at 5 points as shown in Figure-4. No stone was found beneath the base stone. It was only densely compacted sandy soil. This implies the Main Tower has been supported by shallow and direct foundation for more than 700 years without any special problems. It may the miracle as the direct foundation on sandy ground without any damage for the long period.

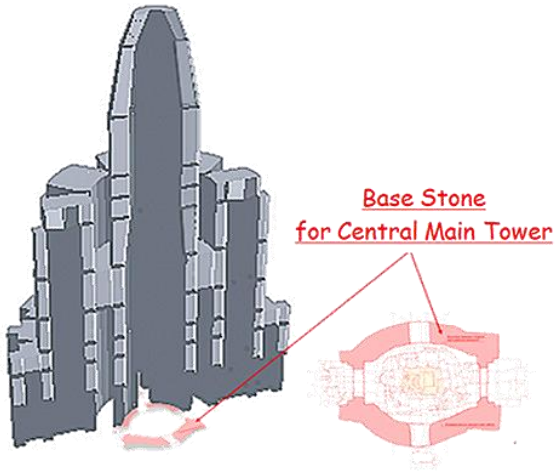


Fig.3 Base Stone for Central Main Tower

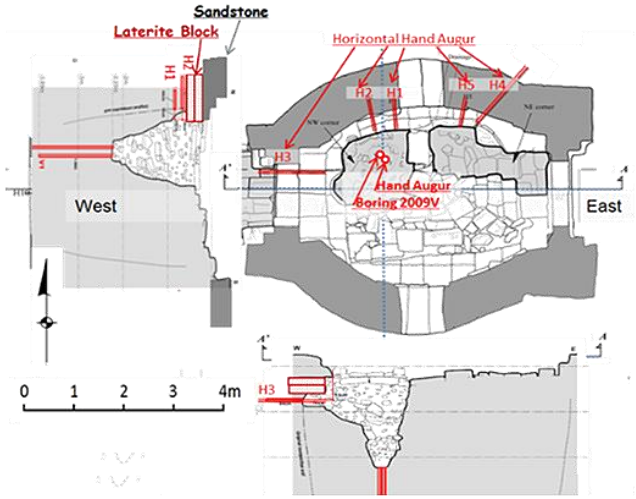


Fig. 4 Hand augur survey under base stone of Central Tower

2.3 Foundation Structure of the Central Tower

French EFEO excavated a vertical shaft with diameter of about 2.5m in 1933 and found a Buddha statue. Backfilled soil was studied by geotechnical boring in 2009[1]. Another boring was performed at the top terrace in 2010. Among the results of the boring, Standard Penetration Test and water contents of the samples are shown in Figure.5[2].

Very small SPT, N values of N<=4 at the central shaft BYV2009 shows the backfilled soil is very loose state without any compaction. The boring at the top terrace BYV2010 shows a layer of laterite block of about 6m in thickness beneath the paved sandstone and the laterite block is followed by compacted sandy soil layer with extra ordinary large SPT, N-values larger than N>100, compared to the common values of N= 20~40 for compacted sand.

Additional borings were carried out to study the laterite blocks in red colour as shown in Fig.6[3].

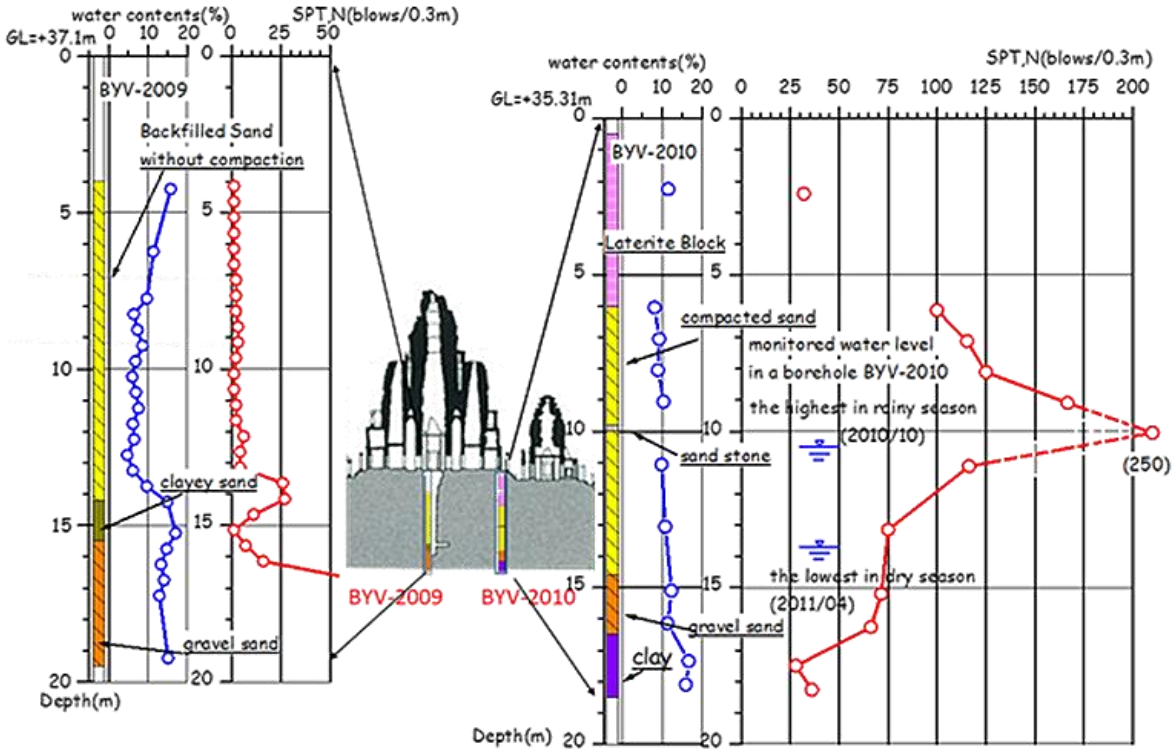


Fig. 5 Borings at the vertical shaft and at the top terrace for foundation of Main Tower

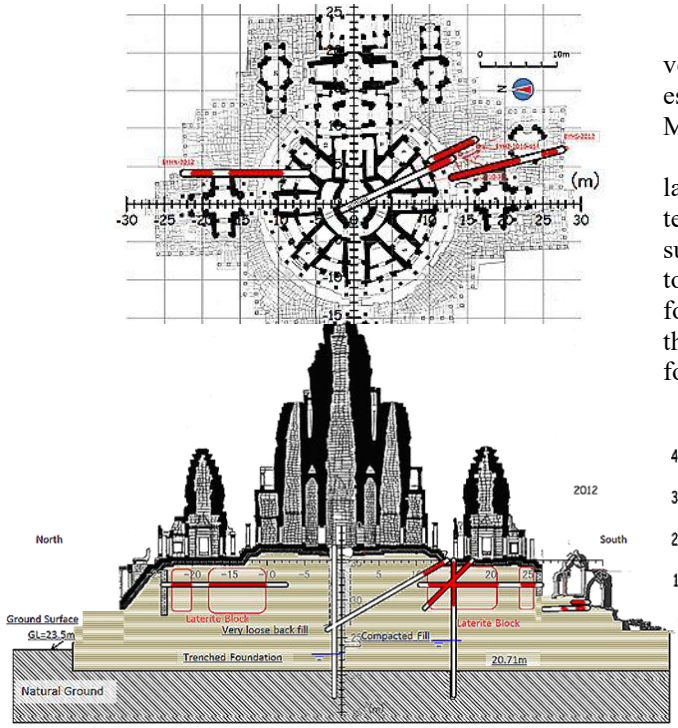


Fig.6 Boring results to show laterite blocks in red

Based upon the distribution of the laterite blocks of the vertical and horizontal borings, the laterite blocks are estimated to be constructed as a part of the foundation of the Main Tower surrouding the base as shown in Fig.7.

After the construction of the second terrace mound, the laterite block was installed for the construction of the top terrace, which was designed for the stability of the Main and sub-Towers. The block does not support the load of the towers but to prevent the horizontal displacement of the foundation soil beneath the direct base stone. This in one of the character defining elements of the authenticity of the foundation in Angkor.

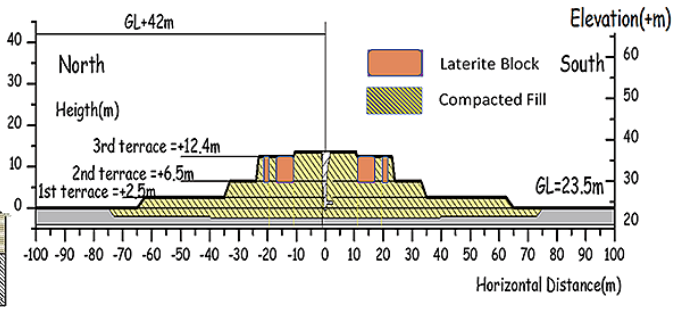


Fig.7 Foundation system of the Bayon Tower

3. CHARACTERISTICS OF FOUNDATION MOUND

3.1 Water sensitive Compression Strength of Sand

The relationship between SPT, N-values and water contents of BYV2009 and BYV2010 in Fig.5 is shown in Fig.8. The relationship between SPT-N and water contents of BYV2010 for the original compacted soil at the top terrace shows strong relationship. But it is not for the boring 2009 for the soil without compaction at the vertical shaft.

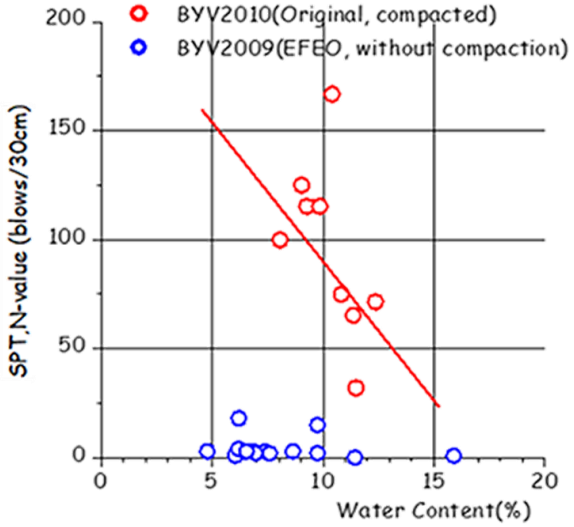


Fig.8 SPT and Water contents for borings in Fig.5



Fig.10 Yamanaka Cone



Fig.11 Cone Test

When the sand sample of the boring BYV2010 was submerged in water, the stiff sand sample collapsed within 10 minutes as shown in Fig.9.

3.2 Laboratory Test on the Compression Strength of Sand

The characteristic of strength and water contents was confirmed by laboratory test. Yamanaka Cone as shown in Fig.10 was used. The original sand was arranged as saturated state of about the water content =15% and compacted in more than 20 plastic containers as shown in Fig.11.

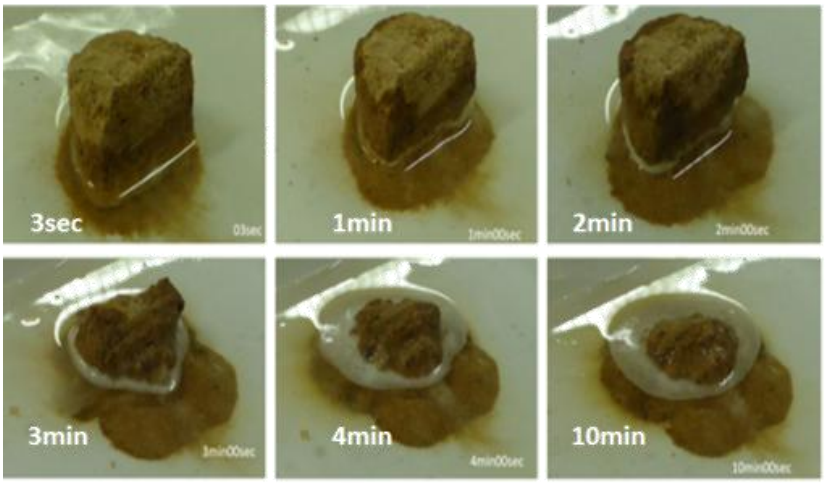


Fig.9 Collapse of stiff sand sampled by BYV2010

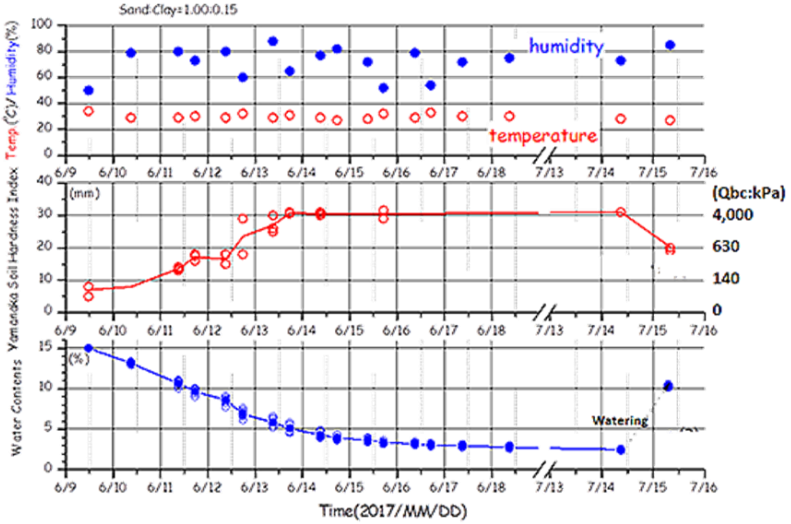


Fig.12 Change of Strength with drying

These containers were put outside, and the bearing strength of the soil was tested by Yamanaka Cone Stiffness tester after every few days and the results are shown in Figure-12. As shown in Figure-12, the cone bearing capacity is increased with the decrease of the water contents. Qbc=50-100(kN/m2) at w/c=15% had increased to 60-100 times at w/c=4~5%.

3.3 Special Character of Angkor Sand

The grainsize distributions of the sampled soils for the original soils at various sites of libraries and foundation mound of the Main Tower of Bayon, and the mound of Prasat Sour Prat are shown in Figure 13. Sandy soil shows about 10-20(%) of fine soil (less than d<0.06mm) and clayey soil shows about 30-40(%) of higher contents. The uniform shapes of the distribution curve of the sandy fill and clayey fill are specially recognized.

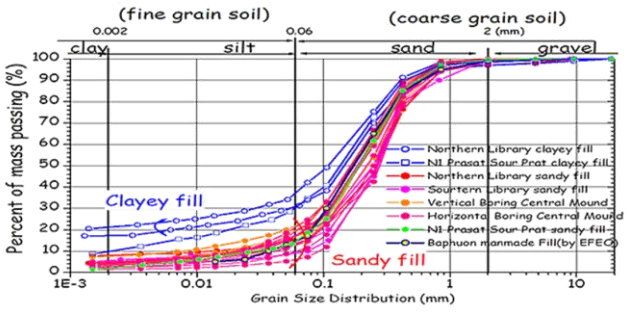


Fig.13 Grainsize distributions of Sandy and Clayey Fill

The X-ray diffraction analysis and the micro-photo are shown in Figures-14 and 15. X-ray diffraction analysis shows the Quartz and Halloysite which belongs to clayey mineral of Kaolinite. The photo shows clear particle of rounded ball shape of Quartz with clayey material surrounding the ball.

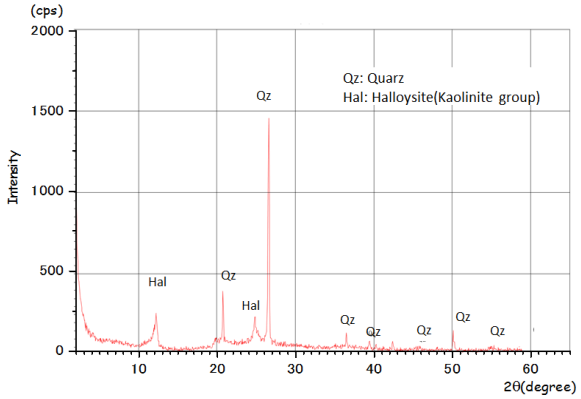


Fig.14 X-ray diffraction analysis

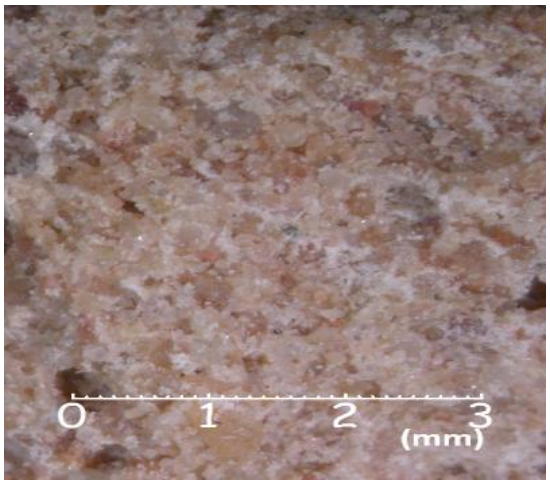


Fig.15 Micro-photo of Sandy fill

The mechanism of the increase of the strength with the decrease of the water content is considered as the stronger negative pressure of inside of the water membranes. When the soil becomes dry, the radius of water membrane becomes smaller which induces stronger tension as well as stronger negative suction pressure as shown in Figure-16. Compared to the chemical reaction, the water membrane is much easier and faster to be dissolved.



Fig.16 Vacuum suction of water within meniscus

4. WATER CONTENTS IN MONSOON CLIMATE

Angkor belongs to tropical monsoon climate zone. One of the question is the reason why the sandy mound in Angkor has been standing without failure in the last several hundreds years. Moisture sensors were installed at several depths beneath the paved stone in the top terrace as shown in Figure-17[4]. Two cases of rainfalls are shown in Figure-18. The first case is small rain fall of 5-7mm in two hours. The sensors responded to increase at upper depths at GL-0.5m and -1.0m but did not respond at GL-1.5m. The seepage did not reach to the depth of GL-1.5m. The second case is about 20mm in total rainfall. The rainwater infiltrated into GL-1.5m with seepage rate of around 1.0-1.5(m/hour).

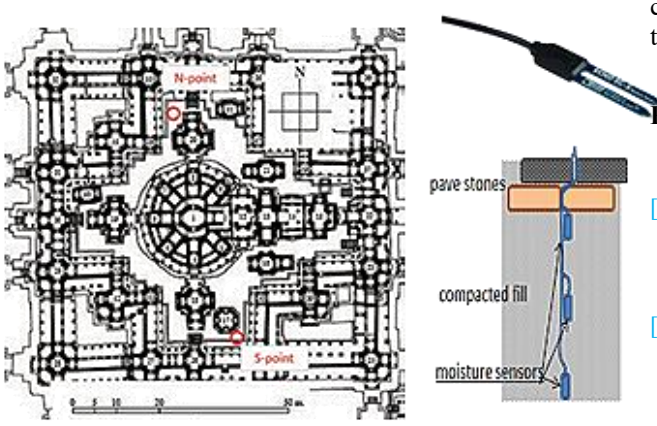


Fig.17 Volumetric Water Contents monitoring Sensor

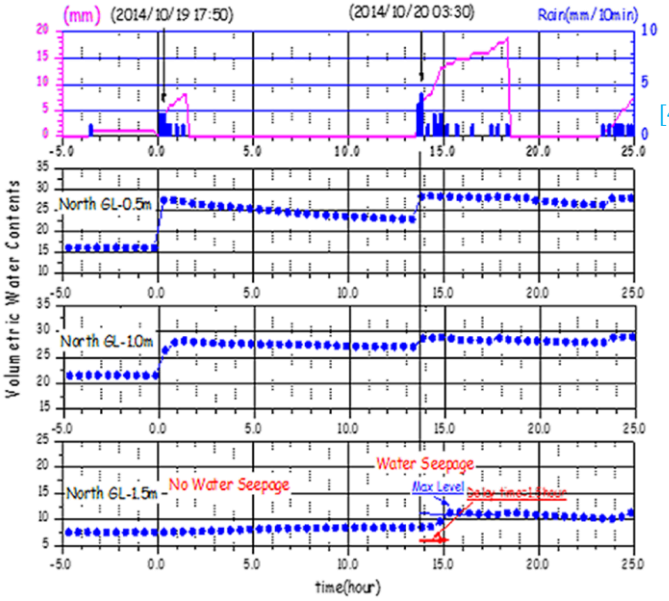


Fig.18 Monitored results of Volumetric Water Contents

After the rainfall, the water contents return to decreasing the moisture in the ground.

4. CONCLUDING REMARKS

Rainfall in the tropical monsoon zone is known as "Squall," which causes a sudden rainfall of rather strong intensity for a few hours and returns to normal good weather. Under the rain fall of the Squall type rain, the infiltrated rainwater in the ground shall turn to dry after the end of the rain and the water contents in the foundation mound shall keep the dry condition with strong strength. However, in the anticipated warm climate condition, the rainfall changes from the strong but short duration to long duration. To prevent the weakening of the strength of the foundation mound for the Main Tower, some countermeasures are necessary to safeguard the Bayon temple.

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