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Unique characteristics of silty soils of loess soil in Kazakhstan, silty rock at Bamiyan in Afghanistan, and manmade platform mound in Angkor, Cambodia

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ABSTRACT: A special type of silty soil that is rather strong under dry condition, however, easily weakened when the soil is mixed with water. Bamiyan valley in Afghanistan is famous for great Buddhas on a high cliff that consists of conglomerate and siltstone. Siltstone is very weak against water, which might be the reason to have created the almost vertical cliff. In Angkor, Cambodia, the stone masonry tower of Bayon temple with 42m in height has been standing with a simple direct foundation on manmade sandy fill for 700 years. In Almaty, the old capital of Kazakhstan, several RC apartment housing with 9 stories at Algabas zone suffered foundation damage caused by a heavy and continuous ran in 2016. The foundations are monolithic thick slab of 1m in thickness. The heavy rain has caused differential settlement due to the weakened loess soil.

RÉSUMÉ : Un type particulier de sol limoneux qui est plutôt solide à l'état sec, cependant, facilement affaibli lorsque le sol est mélangé avec de l'eau. La vallée de Bamiyan en Afghanistan est célèbre pour ses grands bouddhas sur une haute falaise composée de conglomérat et de siltstone. La siltite est très faible face à l'eau, ce qui pourrait être la raison d'avoir créé la falaise presque verticale. À Angkor, au Cambodge, la tour en maçonnerie de pierre du temple du Bayon, d'une hauteur de 42 m, repose sur une simple fondation directe sur un remblai de sable artificiel depuis 700 ans. À Almaty, l'ancienne capitale du Kazakhstan, plusieurs appartements RC de 9 étages dans la zone d'Algabas ont subi des dommages aux fondations causés par une course lourde et continue en 2016. Les fondations sont des dalles monolithiques épaisses de 1 m d'épaisseur. Les fortes pluies ont provoqué un tassement différentiel en raison du sol de loess affaibli..

KEYWORDS: water sensitive soil, siltstone Bamiyan, compacted sand Angkor,loess soil in Almaty

1 INTRODUCTION.

Soils and rocks are usually grouped by geological age and the younger formation is weak compared to older one. Younger formation is considered to show rather lower strength. However, sometimes the strength of the young formation shows large strength due to some reasons.

2 BAMIYAN

The geology of cliff of Bamiyan consists of sedimentary layers of alternation of conglomerate and siltstone. The area is about 2500m in height surrounded by Hindu Kush mountains of 7500m

Collison of the India-Eurasia continent plates has created the Hindu Kush mountains around 50million years The movement is still active at present. The decomposed materials of the Hindu

Figure 1. Splitting process of vertical cliff at Bamiyan

Kush mountain have been carried out to the lower level of Bamiyan of 2500m in height and deposited.

As shown in Figure-2 the continuous vertical cliff continues and more than 1000 grottoes had been created. The site had been developed as the most western end of Buddhist activity.

The site was registered as a World Heritage Culture in 2003 after the great Buddhas had been exploded by Taliban.

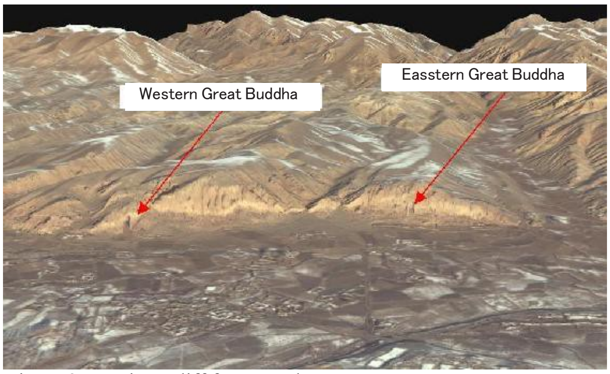

Figure 2. Bamiyan cliff from South

The horizontal formations of alternative layers are seen in Figure -1 and 2. The height of the cave is 53m and 35m at western and eastern side, respectively.

2.1 *Geomorphological feature*

Afghanistan is a dry and rather cool country in the high altitude. The average annual rain is about 160 mm with the average temperature of 7^{o} C.

As shown in Figure- 3, vertical cracks are recognized behind the front surface of the cliff, probably because of the extension stress caused in the surface zone at some depth from the vertical surface.


Figure 3. Cliff with crack behind the surface (Margottini, 2004).

2.2 *Geological features*

The geological formations are reported to consist of conglomerate and siltstone (Margotitini, 2004). The geotechnical characteristics show density of about 17kN/m3 and 22kN/m3 for the conglomerateand siltstone respectively. The uniaxial strength estimated from point load testing shows 4-8MPa and 6-15MPa for the conglomerate and siltstone respectively.

The density of the conglomerate is rather low but the strength is high because the material is strengthened by cemented carbonite. The special character of the siltstone is shown in Figure 3 under the condition with water.

The siltstone does not contain the carbonate material but keeping the big strength due to drying condition.

When the two materials are treated with water, the response is quite different. The conglomerate stone keeps it strength; however, the siltstone loses the solid structure and its strengthafter only a few minutes of immersion in water as shown the comparison of two materials in Figure-4.


Figure 4. Comparison of Conglomerate (left) and siltstone after immersion of water (Margottini, 2004)

The high density of the siltstone could not be realized under the common deposit mode of free surface. To obtain such high density should have been under some condition of being pressed by some such big stress. It is very likely to have had been caused by heavy load under thick ice river during the last ice period.

The cliff in Bamiyan is about 130m in height in Figure 5. How this vertical cliff developed? The process may be related with some geotechnical characteristics of the geological formation.

The process of creation of high and vertical cliff is considered as follows,

1. vertical crack formation behind the front face
2. siltstone near the bottom surface meets with surface water
3. siltstone degrades by water and results horizonal void
4. vertical front block falls off and new face will appear

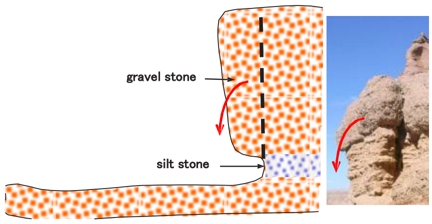

Figure 5. The cliff in Bamiyan.

3 BAYON, ANGKOR THOM

Angkor is an ancient great Khmer culture developed in Cambodia from A.D.9th to 15th century. Bayon, as shown in Figure 1, is the central temple of Angkor Thom constructed around in late 12th to early 13th century.

The temple was constructed in Buddhism style. Bayon means Ba Yon (beautiful tower) in Khmer and Thrones for Gods in Sanskrit. Many four face towers stand surrounding the main tower as shown in Figure 6.

Figure 6. Bayon Temple, Angkor Thom from South

3.1 *Japanese Government Team for Safeguarding Angkor*

The Angkor heritage has been studied and conservation works was carried out by French since 1907. Geotechnical aspects are not much investigated before 1994. Japanese Government Team for Safeguarding Angkor (JSA) was organized including various fields of archaeology, historical structure, conservation science, geotechnical engineering of interdisciplinary group.

The first author had joined JSA since 1994 and has been engaged in the study of the geology of Angkor area and the geotechnical aspects of foundation of the monuments.

3.2 *Trenched foundation*

Archaeological study of long trenchshown in Figure 2 trenching from inside to outside of the temple structure showed that the natural ground had been excavated two to three meter in depth and replaced by compacted sandy fill extending about 10m outwards from the boundary.

3.3 *Filled foundation*

The Bayon temple consists from 54 towers of four faces on each sides andthe main central tower of 42m in height from the ground. They are constructed as stone masonry with sandstone and laterite blocks upon filled mound. The filled mound consists from three stepped terraces of about 2m, 6m, and 12m in height from the surrounding ground as shown in Figure 2.

3.4 *Base structure of the central tower*

The central part of the base stone of the main tower consists of two separate stones in oval shape as shown in Figure 3 Archaeological study of trench and hand auger drilling beneath the stone revealed that no special structural element was found but only simple laterite block and base stone.

In addition to the direct foundation of the central tower of Bayon, the problem is a vertical shaft that had been excavated by French in 1933 and found a large Buddha statue as shown in Figure-4.

The diameter of the shaft is about 2.5m and the depth is around 14m. After the excavation, it was recorded as filled back with no information of compacted or just filled.

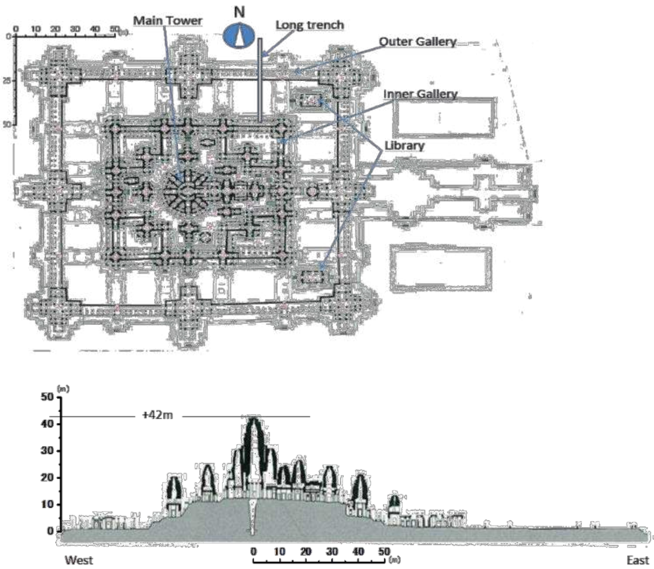

Figure 7. Plan and section of Bayon temple

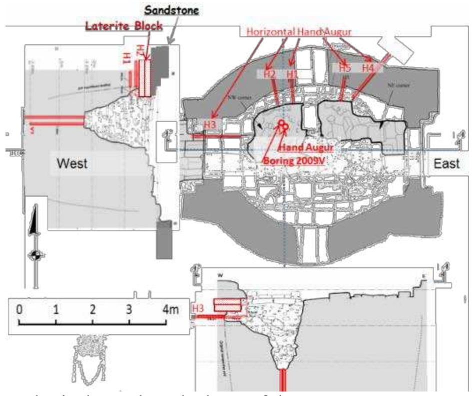

Figure 8. Archaeological trench at the base of the tower

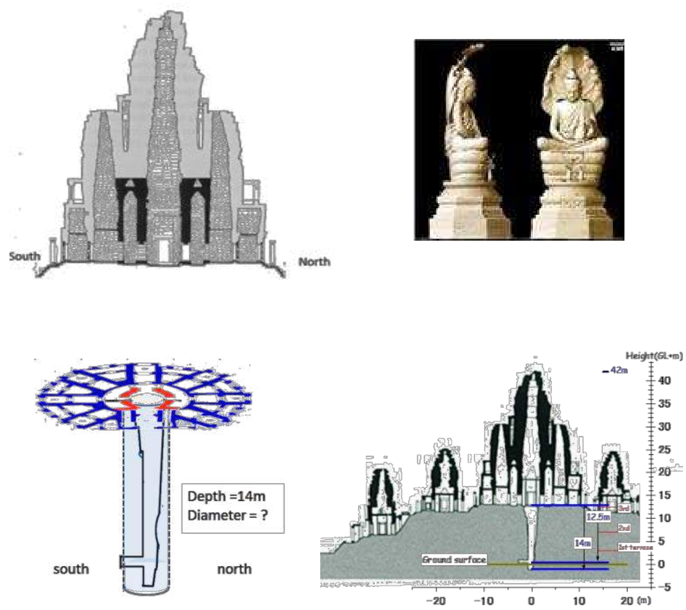

Figure 9. Vertical shaft at the center of the foundation of main tower

The vertical load on the base stone is more than the design load of 10 story Reinforced Concrete building. The present foundation practice never allows the direct foundation for any structures with more than three stories on the sandy filled ground

3.5 *Boring of the filled mound supporting the Main Tower*

The first boring was carried out at the vertical shaft in 2009. The result shown in Figure-5 and SPT N-value of the backfilled soil is about N=4, very loose sand was identified. The second boring hole was carried out at the top terrace in 2010.

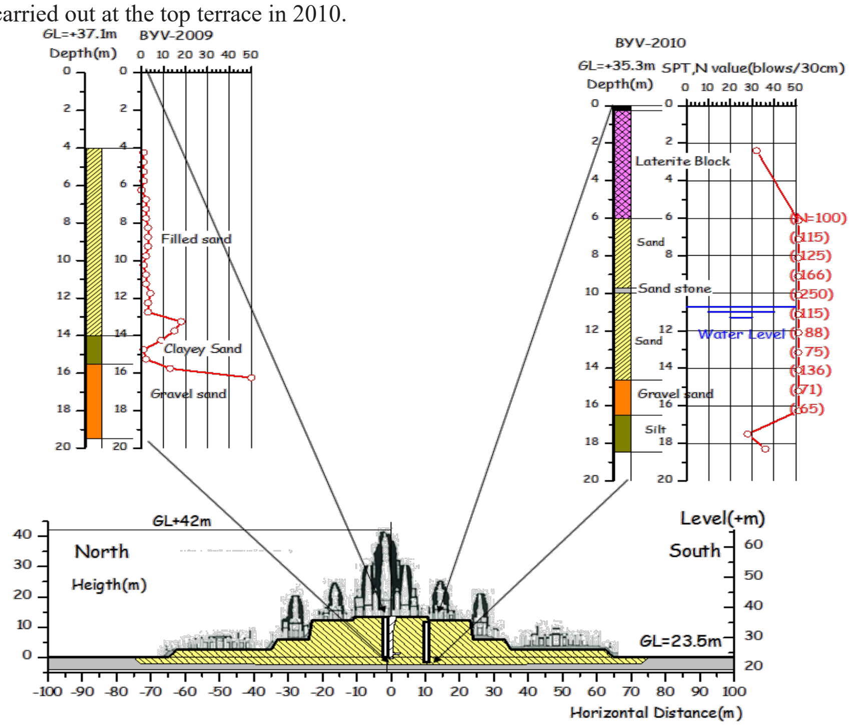

Figure 10. Boring at manmade mound Bayon (Iwasaki, 2018)

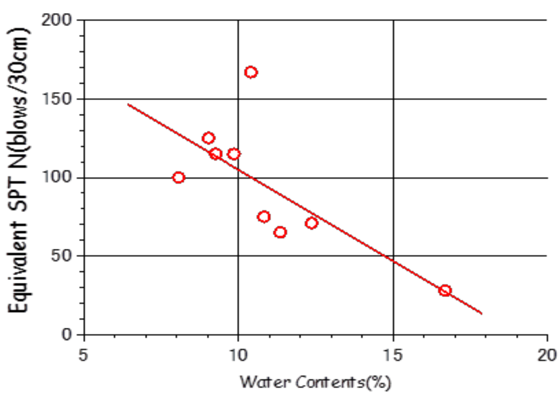

Figure-11 SPT-N-values and water contents

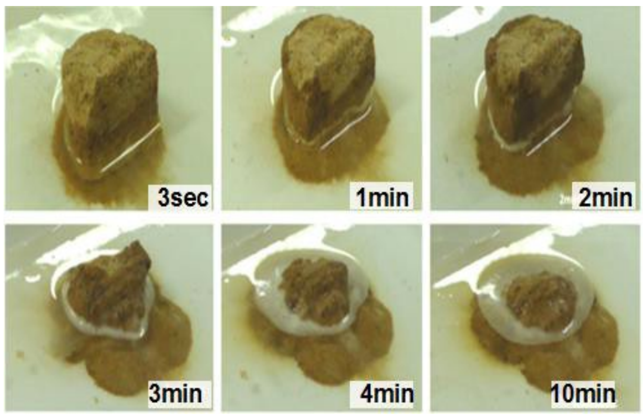

Figure 12. Collapse of stiff sand in water

The boring result shows the soil condition of the platform mound as follows,

Beneath the stone pavement followed by laterite block of 6m in thickness, very dense sand filled continued down to the natural layer.

The SPT, N-value for the filled sand is extremely large value around 200. The SPT, N-values are plotted against water contents as in Figure-11. The figure shows that the decrease of the water contents increases the SPT, N-values A small block of the sampled sand was put in water and it gradually soaked water and finally collapsed in 10 min. as shown in Figure 7.

The grain size distributions of the sampled soil of borings of the platform mound are shown in Figure 13. The filled soils show a uniform distribution of silty sand with silt contents of 10 to 30%. The fine part of the filled soil was analyzed by X-ray diffraction as shown in Figure-14. The soil was identified to composed of Quartz and Kaolinite. The photomicrograph of the fill is shown in Figure 15. The photo shows the rounded shape of the sand particles are covered by whitish Kaolinite, which sticks sand grains together. The strength of the silty sand in unsaturated state depends upon the negative water pressure in addition to the cohesion from the Kaolinite.

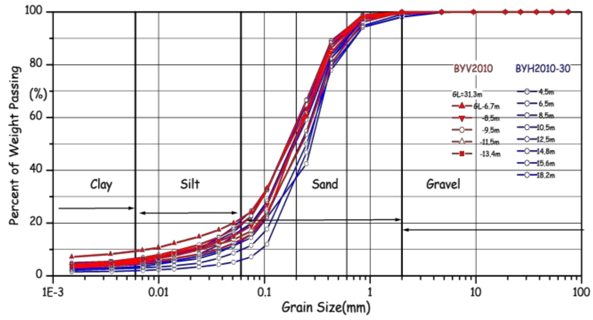

Figure 13. Grain size distribution of filled soil

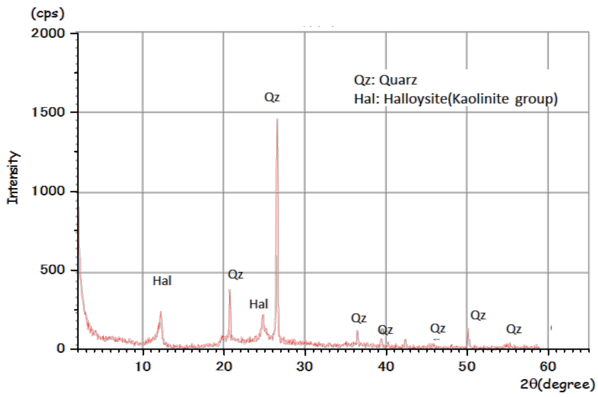

Figure 14. X-Ray Diffraction analysis

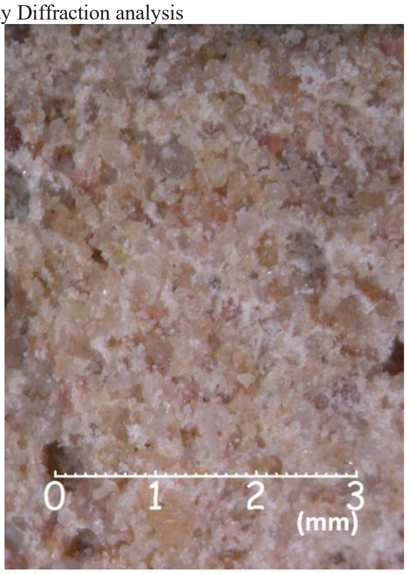

Figure 15. Photo micrograph of the filled sand

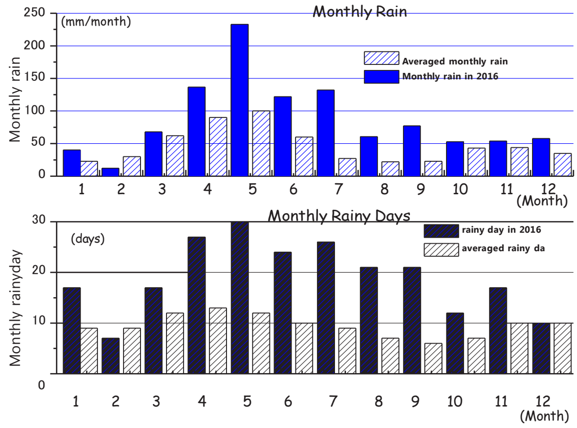

Figure 16. Monthly Rainfall in Almaty in 2016

Apartment houses were constructed in Algabas-micro district, Almaty as shown in Figure 17 and several of these houses were found damaged after the heavy rain with some differential settlement of 5 10cm.

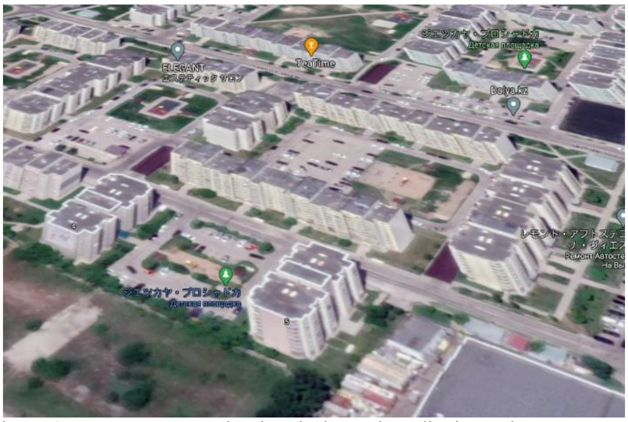

Figure 17. Apartment Housing in Algabas-Micro-district, Almaty

Figure 18. Tilted RC Apartment House with 9 stories (Bespaev,2019)

4 FOUNDATION FAILURE IN ALMATY, KAZAKHSTAN

4.1 *Heavy rainfall in 2016 caused foundation damage*

Almaty, the old capital of Kazakhstan experienced heavy rain in 2016. As shown in Figure 16, which shows monthly rainfall and rainy days for every month in 2016 compared to the averaged values, it rained as much as 210mm for May 2016 more than two times larger than the yearly averaged value of 100mm/month.

4.2 *Foundation and Geotechnical Condition*

The bases of the apartment houses were designed as direct RC foundation of with dimension of 11m by around 20-45m. The thickness is 1m with cushion layer of about 1m of gravel and sand.

Surface soil down to about 3m is fill and plant layers followed by yellow to brown loess soil. The loess soil continues to about 16.5m. The loess layer consists of upper layer of low density of 15.5kN/m3 and lower layer with much large density of 19.7kN/m3 as shown in Figure 19.

Ground water had been recognized at about GL-12m, but found at GL-7.5-7.9m when the soil survey was carried out after the accident.

When the water level increases as experienced in Almaty in 2016, the wetting process shall cause the settlement of the loess layers due to the collapse of the soil structure.

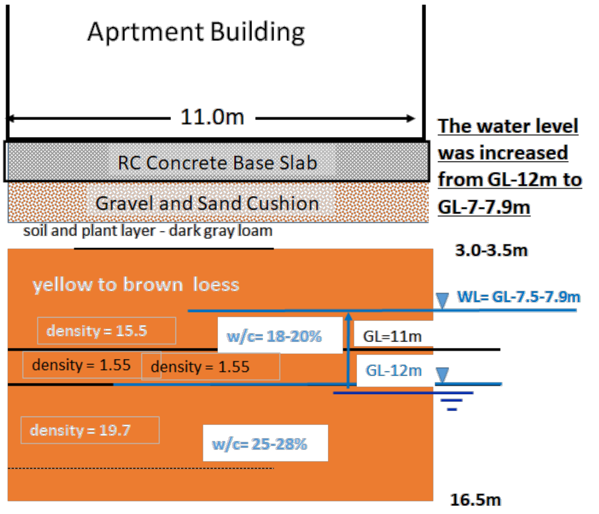

Figure 19. Soil condition

4.3 *Distribution of Loess soil near Almaty*

Loess soil is a special type of soil found as the top surface soil of the ground near desert. The soil has been carried by wind and deposited. The deposition was made in air and the density becomes less than in water deposition.

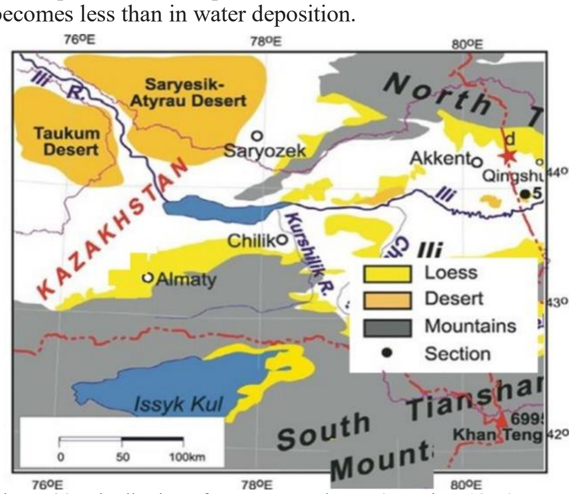

Figure 20. Distribution of Loess near Almaty (Ananjev, 1955)

The distribution of loess soil near Almaty is shown in Figure 20. Some 10-30km from the foot line of the mountain is shown and is considered has damage potential from ground settlement caused by wetting compaction of the loose loess.

5 CONCLUSIONS

Three different types of soils with silt and sand are introduced to compare the effects of the water upon the soil strength. The grainsize distributions are compared in Figure 21.

The densities of these soils are the characters to differentiate the soil behavior to water.

Siltstone, being over compressed by icesheet, becomes to expand and weaken by being dispersed when soaking water. Silty sand becomes weakened by disappearing the tension strength of water membrane by negative water pressure. Loess shall be lost it structure by soaking water.

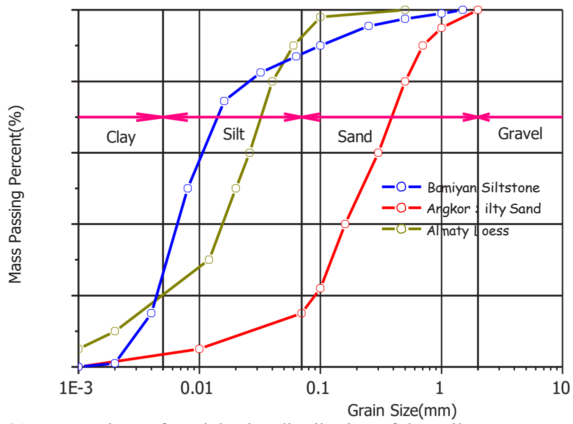

Figure 21. Comparison of particle size distribution of the soils

Table1. Comparison of three sites

Site	Soil type	dry density	
Bamiyan	siltstone	22kN/m3	
Angkor	silty sand	17kN/m3	
Almaty	loess	15.5-19.7kN/m3	

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