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Water table fluctuaction and impact on the remains of Maya Devi Temple, the Birthplace of the Lord Buddha, UNESCO World Heritage Site (Lumbini, Nepal)

Fluctuation de la nappe phréatique et impact sur les vestiges du temple Maya Devi, lieu de naissance du Seigneur Bouddha, site du patrimoine mondial de l'UNESCO (Lumbini, Népal)

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ABSTRACT: Maya Devi Temple is the major archaeological heritages in the Lumbini Sacred Garden (Nepal). The Temple is currently suffering for the rising dampness into the foundation and general weathering of the masonry bricks. Geotechnical and geophysical investigation were carried out on Spring 2016, defining the geological stratigraphy of the area and the possible aquifer. In the period June 2015 - November 2015 a manual monitoring of water table (WT) was conducted on a daily base on existing 5 shafts and 3 pipes. The data, integrated with direct survey in other periods, show the rapid onset of the water table, just after the rainfall, but also the declining and low disappearing of such WT in dry season. Based on 2017 field mission it was possible to establish (clearly and unequivocally) that there is a direct relationship between rainfall and water table in the surrounding of the Maya Devi Temple. The water table shows an ephemeral character, emerging only in monsoon period, with the aquifer possibly localized into *"cultural deposit"* (historical and modern fill containing large volumes of brick, boulders and a clay matrix). This is a material mobilized during the construction period to rise the topography in order to protect against riverine floods. Some alternative solutions to mitigate the impact of water table have been proposed in the present paper. Each of them has both positive and negative features, to discuss with local Institution, in order to find the most appropriate solution.

RÉSUMÉ: Le Temple de Maya Devi est le plus important patrimoine archéologique des jardins sacrés de Lumbini (Nepal). Le Temple souffre actuellement de problèmes d'humidité ascendante dans les fondations ainsi que détérioration générale de briques de maçonnerie. Une étude géophysique et géotechnique a été réalisée durant le printemps 2016, qui a établi la stratigraphie géologique du site ainsi que le probable aquifère. Dans la période Juin – Novembre 2015 une surveillance manuelle de la nappe phréatique a été menée quotidiennement sur les 5 puits et 3 tubes piézométriques existantes. Les donnés, integrés avec des sondages directes menés à d'autres moments, montrent la montée rapide de le niveau phréatique, juste après la pluie, mais également la baisse et la lente disparition de cette niveau piézométrique pendant la saison sèche. En se basant sur l'étude sur le terrain du 2017 il était possible de constater (de manière claire et sans équivoque) qu'il existe une rélation directe entre la pluie et le niveau phréatique dans les environs du Temple de Maya Devi. La nappe phréatique montre un caractère éphémère, qui émerge seulement pendant la période de mousson, et l'aquifère est probablement situé dans le "*comblement cultural*" (les comblements historiques et modernes contiennent de grandes quantités de briques, rochers et matrice d'argile). Ce sont des materiaux apportés pendant la construction afin de rehausser le nieau du sol pour le protéger des inondations fluviales. Dans le présent document sont proposées des solutions alternatives pour atténuer l'impact de le niveau phréatique. Chacune d'entre elles possède des caractéristiques tant positives que négatives, qui peuvent étre analisées avec les institutions locales afin de trouver la solution la plus appropriée.

Keywords: UNESCO, Cultural Heritage, Lumbini, Temple Foundation, Water table

1 INTRODUCTION

Lumbini, the Birthplace of the Lord Buddha, lies within the Nepal Terai, a subtropical chain of forests, marshes and grasslands, now intensively cultivated, between the Indian border and the Siawalik Range of the Himalayas (fig. 1). This gently sloping plateau is bisected by the Ganga's tributaries, creating alluvial fans and meanders.

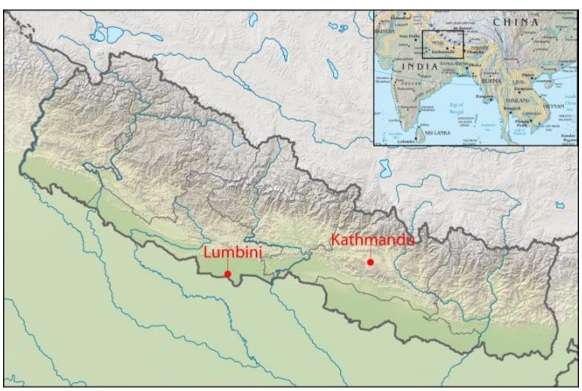

Figure 1. Location of the investigated site.

The site of Lumbini, includes numerous artefacts, archaeological structures and a series of gardens (Coningham et al., 2013). Most relevant is the Maya Devi Temple, constructed in 2002 to protect the archaeological structures by the action of weathering effetcs; it is a large, enclosed structure, constructed mainly of iron beams and concrete, and equipped with two entrance doors and some windows for ventilation (fig.2).

Figure 2. May Devi Temple, the sacred garden and a detail geological section marked A-B (in red).

Lumbini is inscribed in the UNESCO World Heritage List since 1997. The site was subject to periodical flooding, since hystorical time, due to the heavy rainfall which occur during the monsoon period. To solve the problem, before inhabiting the site, the place where to build the urban settlements has been filled with earth and debris, in order to rise the topographic level, above the potential flooding. In April 1967 the UN Secretary-General U Thant visited Lumbini, and proposed the development of Lumbini into a major centre of pilgrimage. In 1972, Kenzo Tange was in charge to prepare a development Master Plan for Lumbini; with this master plan a new circular embankment (levee) was constructed to protect Lumbini from flooding (Kenzo Tange e Urtek, 1968 and 1981). This solution certainly protected from external floods but also did not allow, to the rainy water which falling between the temple and the levee, to flow properly out of the site. Raising of water table was also evident in the Maya Devi temple, manly in rainy seasons, affecting the conservation of the bricks and then of the archaeological structures. Inside the temple are conserved the archeological walls, made of fired brick and mud mortar; these archaeological structures are directly affected by phenomena of fluctuation of the groundwater level and, therefore, are subject to continuous variations in the quantity of moisture, as well as the effect of condensation due to the microclimate inside the temple. Under these conditions of continuous hygrometric variability, significant deterioration phenomena are created, among which the most serious are:

1. formation of saline crystallization, this could cause the deterioration of the bricks (salts dissolved in the groundwater migrate, by capillarity, inside the walls and can crystallize on the surface by evaporation).
2. deformation of the wall structures made with mud mortars, due to the volumetric variation of the clay materials when in the presence of strong hygrometric variations;
3. growth of micro-organisms on the structures.

The management of water table below the Maya Devi Temple is the major topics of present paper. Geological, geotechnical and geophysical investigations were performed to identify spatial and temporal distribution of the aquifer containing the water table; investigation on seasonal fluctuation was implemented with a daily monitoring of piezometric level and rainfall in the period June-October 2015.

2 GEOLOGY OF THE AREA

Lumbini is located in the Terai region, which is a morphologically flat area, along the foothills of Himalayas. The Terai plan is composed by alluvial deposits of Holocene age, which also include channel sand and gravel deposits and outwash deposits. More in detail, the alluvial sediments in the plain are mainly clay and silts intercalated with layers and lenses of gravel and sand. Regionally, the sediments show variation in grain size from north to south becoming finer towards south. Very complex is also the distribution and bedding of different strata since distinctive layers are generated by local floods, with confined spatial distribution, sometimes excavated and then filled by palaeo-channels. Available data in Lumbini are not enough to allow the 3D reconstruction of different geological strata and then the respective hydrogeological properties. Some general data are from Kenzo Tange and Urtec (1968) and (1981). Later on, some more detailed information were obtained by the archaeological investigation developed by Coningham et al., (2011) and Coningham and Acharya (2011), (2012), (2013a) and (2013b). Nonetheless, even with the above information it is not clear which geological formation is comprising the aquifer (a geologic formation from which significant amounts of ground water can be extracted), the aquiclude (geological formation that acts as such a water barrier) as well as aquitard (a geological formation that acts as such a minor water barrier and still permits the flow of water). A preliminary hypothesis based on the auger drilling developed by Coningham and Acharya (2011), (2012), (2013a) and (2013b) is reported in the following figure 3.

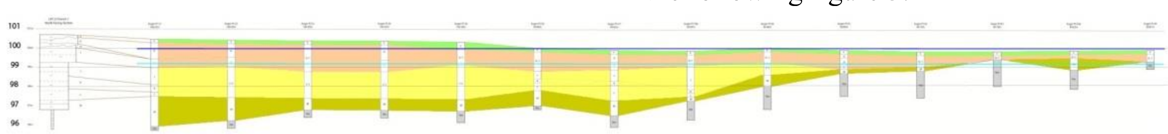

Figure 3. Geological section (A-B) of Maya Devi temple (Durham University Report, 2012). In blue and cyan is reported the water table at the maximum and minimum registered in the period June-October 2015 and extrapolated from the monitoring area in the period June-October 2015.

From the above figure it is possible to synthesize the five major geological formation, even if more they are differentiated from the archaeological point of view: Green is compact loamy clay topsoil; orange is modern fill containing large volumes of brick, boulders and a clay matrix (Cultural Deposit); yellow is alluvial deposits, consisting of dense clays; dark yellow dense clay with trace elements of kankar; grey is compact clay with kankar inclusions.

2.1 Geotechnical boreholes

In order to increase and to detail the available lithological and hydrogeological information, three boreholes have been planned, jointly with a geophysical prospection based on passive seismic analysis. The position of the boreholes and the geophysical prospection is reported in the following figure 4. The boreholes were executed far away from the Maya Devi Temple, according to the risk map for cultural heritages prepared by Coningham (2013). In this way we are probably missing the real stratigraphy of the Temple but we did not damage any valuable heritage. All the boreholes were executed with the support of archaeologists of the Lumbini Development Thrust.

Figure 4. Geotechnical and geophysical prospection implemented in Lumbini in April 2016.

In one case, the boreholes found some brick remains and it was agreed to abandon this position (n. 4 in the figure 3). The three boreholes resulted in similar alluvial materials with a limited vertical variability. The first boreholes is drilling an alternation of alluvial deposit, mainly silt, reflecting different flooding periods. Water is appearing at 4,4 m. below the surface. The second boreholes was initially drilling the modern fill, containing some ceramics, boulders and a clay matrix. After that, alternation of alluvial deposit is appearing.

Two piezometric surfaces were recovered, the first at 6,1 and the second at 8,2 from the surface. The third borehole, in the Northern part, is exhibiting the same alternation of alluvial deposit, but without water until the depth of 7,5 m from surface. The following figure 5 is an example of material recovered in borehole n. 1. It is possible to notice, in a predominant silty material the different color of layers and the presence of small gravel.

Similarly, looking at physical properties obtained from laboratory tests in all the three boreholes, there is no large variability among the different sample.

Figure 5. The stratigraphy in borehole n. 1 (box n.1).

In figure 6 we report the Plasticity chart for all the investigated 9 samples, from the three boreholes. Similarly is in the grain size distribution. There is no major differences from the investigated samples. Only in one case a layer of sand was clearly identified in Borehole n 3 (-4,3 m from surface). In conclusion, the area is interested by cross bedded layers, with palaeo-channels, but the geotechnical properties are almost constant among the different sample. Some small layer of sand may appear but with a very limited thickness. Such sand layers are responsible for the three limited water tables we found in borehole 1 and 2

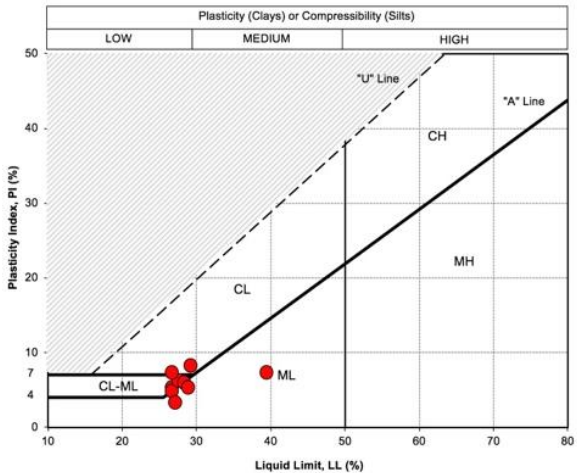

Figure 6. Plasticity chart for the investigated samples.

This is making the hydrogeological situation not uniform, and vary depending from local situation. Not a general water table can be assumed in the area, at least in the first 7-10 meters.

3 ACTIVE AND PASSIVE SEISMIC ANALYSIS

3.1 Active seimic analysis

In order to implement and integrate informations coming from boreholes boreholes, a geophysical (seismic) survey was implemented. An active seismic survey by means of Surface Waves method was perfomed using a single 3-component geophone (figure 7 left) along a profile with 8 shot points, simulating a multichannel dataset usign a single receiver. The relative phase velocity spectrum is reported in Figure 7. In figure 7 a the final Vs model is reported and compared with S2 borehole stratigraphy.

It's worth to note that the thickness of each geological stratum has been not used as constrain in the Vs modeling, it implies that the very good match in thickness (differences less than 10%) of seismic layers and geological ones could be representative of a different degree of stiffness of each geological unit.

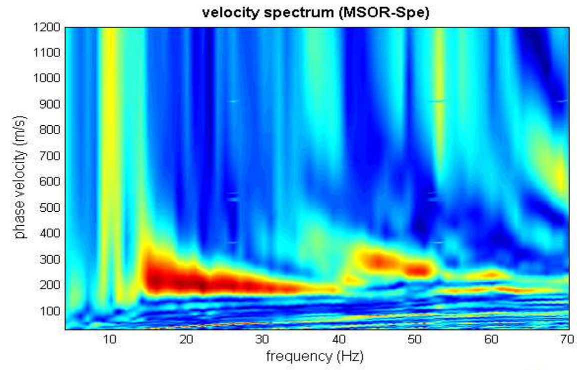

Figure 7. Phase velocity spectrum of the MSOR (Multichannel Simulation with One Receiver) considering the Rayleigh-waves vertical component.

The first 3 layers seems to not differ very much as the increase in Vs value is less than 50 m/s in about 4 m (from 175 to 220 m/s).
waves impedance contrast is absent.

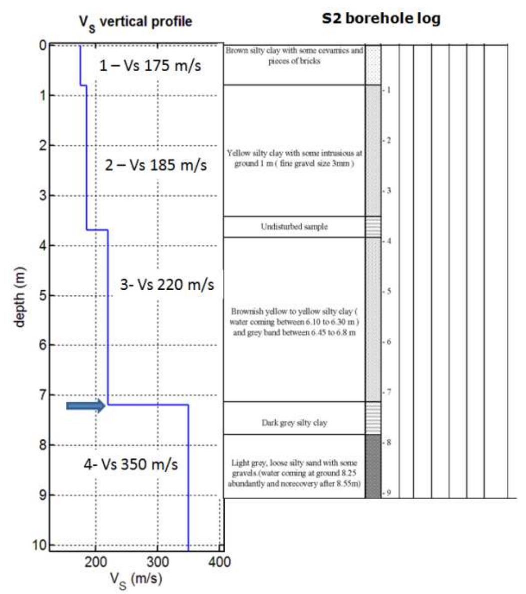

Figure 8. S2 borehole stratigraphy log compared to the Vs final model.

A little more significant increase of Vs value is located just below 7 m in depth where the shear wave velocity reaches 350 m/s (fig. 8 blue arrow). The deeper seismic layer is poorly constrained, nevertheless as described below, the HVSR curve supported the hypotesis that strong shear-

3.2 *Passive seimic analysis*

Exactly 32 noise ambient vibration recording has been acquired for a fast and preliminary inspection of seismic site response (April 2017 filed survey). The horizontal-to-vertical spectral ratio curves have been elaborated for all the recordings (fig. 9).

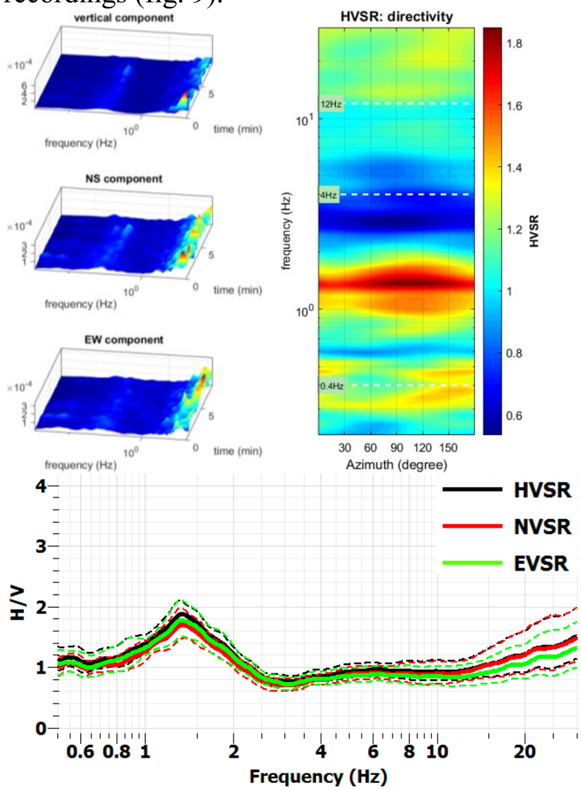

Figure 9. Example of HVSR processing: directivity analysis (up) and mean HVSR curves from the 32 ambient recordings while considering each horizontal component (NVSR, EVSR) also separately (down).

On the basis of this survey, the seismic site response of the whole area could be sketched considering a simply 1D geotechnical model (a single layer over bedrock) supporting the main outcomes derived from the 3 boreholes and laboratory tests and geotechnical characterisation. The main peak frequency is located at about 1.3 Hz suggesting the presence of a seismic impedance contrast located very deep, nevertheless the mean amplitude of the peak not exceed the value of 2 (i.e. it does not meet the SESAME 2004 criteria). Since based on ambient vibration recordings, the outcomes of the survey should be confirmed by means of further investigations (e.g. HVSR using earthquakes recordings) before to 1) infer the fundamental frequency of the site and 2) to assess the possibility of stratigraphic amplification of ground motion. The spectral ratio curves are quite similar along the whole area, no significant variation in shape has been observed even when considering each single horizontal component with the respect to the vertical one (no directivity).

4 HYDROLOGICAL CONDITION OF THE MAYA DEVI TEMPLE.

The major conclusion of the previous geotechnical investigations was the identification of an area mainly covered by the s.c. “*cultural deposit*“ previously described, which may act as an acquifer, overlapping an aquiclude composed by the alluvial deposits. The distribution of such “*cultural deposit*“ is reported in the following figure 10.

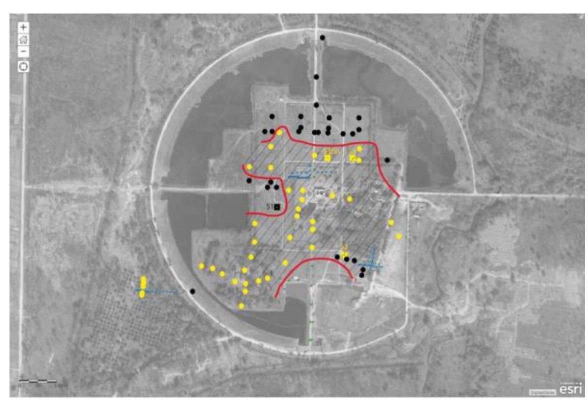

Figure 10 – Distribution of the modern fill (dashed area) containing large volumes of brick, boulders and a clay matrix (Cultural Deposit). Yellow dots are archaeological pits where the upper "cutural

deposit" is identified while the black dots do not reveal (data from Cunnhighan, 2011 and 2012).

The new Maya Devi Temple was built in 2002 to protect the archaeological structures by the action of weathering; it is a large, enclosed structure, constructed mainly of iron beams and concrete, and equipped with two entrance doors and some windows for ventilation. The state of conservation of the building is very poor, in particular, oxidation of some iron elements and traces of infiltration of rainwater from the roof is highly evident. In addition no one drainage system was properly designed and implemented for the rainy water collected from the top terrace and roof. This is one of the major critical issue, especially during the monsoon season where the intensity of rainfall is very high.

The consequence is that a large amount of water, collected on the roof, is now discharging close to the border of the Maya Devi construction, where it is very easy to infiltrate. This mechanism, likely also connected with the infiltration from the surrounding of the temple, is explaining the emerging of an ephemeral water table inside the cultural deposit, as well as the almost contemporary timing rainfall. During the year 2015 a proper monitoring of water table in 5 small shafts (out but close to temple) and three plastic pipes (inside the temple), (Fig. 10) have been successfully implemented by the Lumbini Development Thrust. Measurements were collected on a daily basis. Similarly, the rainfall gauge (pluviometer) located in the sacred garden has been reactivated by the Lumbini Development Thrust, with daily measurement.

This data base, together with the water level measurements, are a unique data set to understand the relationship between rainfall, water table rise and impact into the temple.

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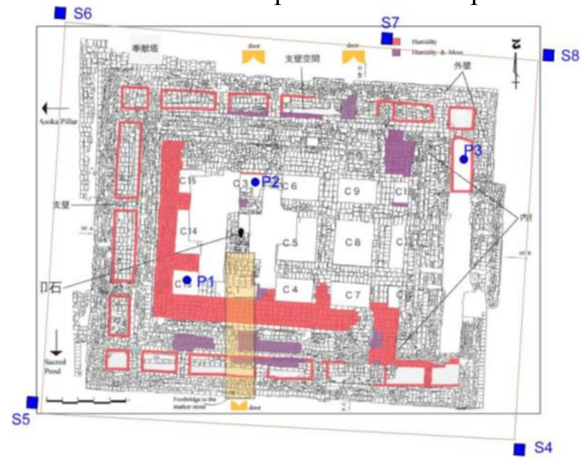

Figure 11. The monitoring network around the Maya Devi Temple location, composed by 5 shafts (blue squares) and the 3 small pipes (blue circle). (Foreground image from Atzori, 2006).

The major achievement of the monitoring system was the discovering that the water table was not existing all the year long but only during the rainy season, with a very short reaction time with respect to the rainfall (see figure 12).

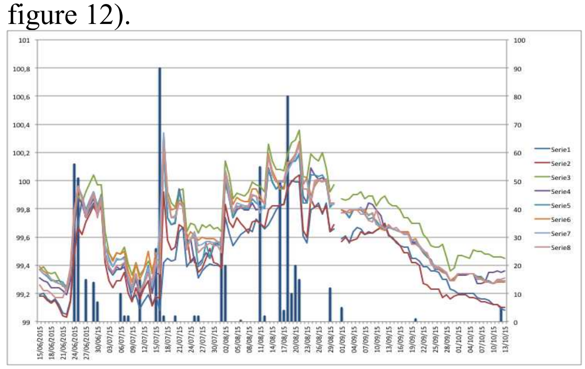

Figure 12. Daily water table oscillation and daily rainfall measurement from LDT during 2015.

5 CONCLUSION AND POSSIBLE MITIGATION ACTIONS

The present paper summarize the main output from geological and seismic field survey carried out during 2017 field survey. The interpretation of the analysis was highlighted in order to provide geological conditions that lead to the occurrence of a water table below the Maya Devi temple. Based on previous field mission it was possible to establish (clearly and unequivocally) that:

- there is a direct relationship between rainfall and water table rise in the surrounding of the Maya Devi Temple;
- one day is generally enough to transfer precipitation into a piezometric level (water table level rise);
- The rising of water table in mm is a bit higher than the precipitation in mm, even without considering evapotranspiration, suggesting the possibility that below the Temple, the water is concentrating from a wider area. This phenomena could be explained by the huge amount of water collected by the roof and directly discharged in the nearby the temple.
- the water level is always the same in all the 8 inspection points (5 shafts and 3 plastic pipes);
- the water table is ephemeral and strongly related to rain precipitation. During dry season, there is not piezometric level in the underground;

The water table shows an ephemeral character, emerging only in monsoon period, with the aquifer possibly localized into the s.c. *"cultural deposit"*. Possible mitigation measurement may include: a long term topographic monitoring to evaluate the effect of water in the potential surface deformation of archaeological remains; limiting the infiltration in the area of the *"cultural deposit"*;the realisation of a drainage system starting from a new rainfall evacuation system from the top of the roof; re-connecting all existing pipes avoiding dispersion into the soil; drainage out of the sacred Garden (*cultural deposit*) as much as possible. Clearly the proposed strategy must be discussed with local institution, in order to involve local community in the decisional process. Anyway, wathever solution must be verified with the continuation of the hydrogeological and meteorological monitoring.

6 ACKNOWLEDGEMENTS

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