LONG LASTING GEOTECHNICAL PROBLEMS TRIGGERED BY THE 2015 GORKHA EARTHQUAKE

Hikaru TOMITA[1], Kazuo KONAGAI[2], Rama Mohan POKHAREL[3] Takaaki IKEDA[4], Alessandra Mayumi NAKATA[5] and Masataka SHIGA [6]

[1]Graduate student, Graduate school of Urban Innovation, Yokohama National University
(Tokiwadai 79-5, Hodogaya-ku, Yokohama 240-8501, Japan)
E-mail: tomita-hikaru-vg@ynu.jp
[2] Fellow of JSCE, Professor, Institute of Urban Innovation, Yokohama National University
(Tokiwadai 79-1, Hodogaya-ku, Yokohama 240-8501, Japan)
E-mail: konagai-kazuo-gh@ynu.ac.jp
[3]Member of JSCE, Assistant Lecturer, Central Department of Geology,Tribhuvan University
(Kirtipur, Kathmandu 44618, Nepal)
E-mail: r-pokhrel@ynu.ac.jp
[4]Member of JSCE, Professor, Dept., Civil and environmental Engineering, Nagaoka University of Technology
(1603-1 Kamitomioka, Nagaoka 940-2188, Japan)
E-mail: ikeda@vos.nagaokaut.ac.jp
[5]Researcher, Institute of Urban Innovation, Yokohama National University
(Tokiwadai 79-5, Hodogaya-ku, Yokohama 240-8501, Japan)
E-mail:amnakata@gmail.com
[6] Graduate student, Graduate school of Urban Innovation, Yokohama National University
(Tokiwadai 79-5, Hodogaya-ku, Yokohama 240-8501, Japan)
E-mail: shiga-masataka-ft@ynu.jp

The Gorkha earthquake has caused many damages, including the detachment of soil mass in Dhunche and Ramche area. This damage could have a big impact on the Pasang Lhamu highway crossing this area, and also the hydro power plants nearby. The auther conducted an GPS measurement and UAV flights over some period of time to measure the creeping deformation. This paper describes the findings from measurement by GPS and UAV.

Key Words : *Nepal, GPS monitoring, UAV*

1. INTRODUCTION

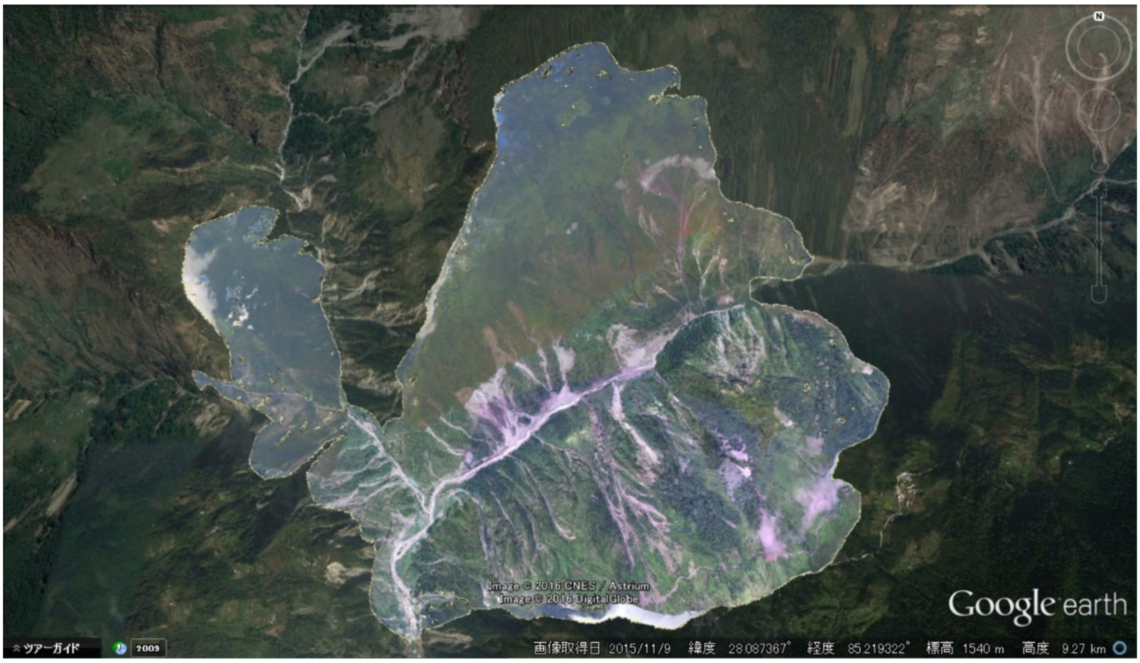
The April 2015 Nepal earthquake of Mw=7.8 (USGS), also known as the Gorkha earthquake, was the worst natural disaster to strike Nepal since the 1934 Nepal–Bihar earthquake. As of May 26th, the police report had confirmed 8,664 fatalities, with more than 21,954 injured (Source: Japan Embassy in Nepal). The quake was followed by many aftershocks including the one of M=7.3 that struck north-eastern Nepal on Tuesday, May 12th. Among the areas of most concern are those where soil/rock masses detached from steep mountain slopes have fallen into rivers[1)], posing an increasing menace to hydropower stations etc.

With no known major oil, gas, or coal reserves, and its position in the Himalayas, Nepal depends largely on its huge hydropower potential. And most of hydropower stations keep drawing waters directly from mountain streams, which stream beds can be easily subject to debris accretion.

Not only debris masses detached in the intense earthquake but also those remaining on mountain slopes can fall down at any time due to intense rainfalls and/or intense ground shakes. Therefore, signs of creeping ground are to be monitored and their volumes are to be estimated.

Monitoring of creeping movements has a significant importance particularly when a creeping mass is crossed by a highway.

(a)Satelite image of landslide one on December 12^{th}, 2016



(b)Orthophoto of landslide one on August 10th, 2016

Fig. 1 Landslide zone (Photos from Google Earth)

This paper focus on the Dhunche area, which lies along the Pasang Lhamu highway and beared many collapsed surface after the earthquake, and describes the findings from measurement by GPS and UAV.

2. DAMAGES IN DHUNCHE AREA

Pasang Lhamu Highway, a twisty mountain road, is one of the important highways of Nepal that connects Kathmandu to China via Dhunche. This highway is increasing its importance particularly after the earthquake and its largest aftershock hit very hard Araniko Highway, which had been of crucial importance to Nepal as it had been carrying a very large amount of goods from China. Actually China did supply its petro assistance of 1300 KL of oil through this Pasang Lhamu highway to Nepal, which country had been facing an economic and humanitarian crisis caused by a blockade in the country's south, leading to acute shortages of fuel and medicine.

When the main shock jolted moutains along the highway, a large number of unstable rock/ soil masses were detached all at once and ran about

1000m down the valley walls of Trishuri River in a thick cloud of dust. Many of them were found near Dhunche.

Fig. 1 compares the top view image of Dhunche area obtained before and after the earthquake. The upper one shows the satellite image taken on December 12th, 2014(photo from Google Earth). The image below shows an orthophoto extracted from UAV photos. This UAV flight was done on August 10th, 2016.

These two images show that many collapses occurred by the earthquake. The soil mass that fell into the Trishuli river will surely have a long term influence on the hydropower stations.

3. GPS MEASUREMENT AND UAV-BASED 3D DSM OF RAMCHE

As mentioned in the previous chapter, many landslides have been observed along Pasang Lhamu Highway, one of the important highways of Nepal. Among them, a landslide at Ramche is found crucial for maintaining this road. This massive landslide mass was detached from the hill slope of about 2100m above sea level in a rainy season of 2003. A temporary road was quickly constructed across this zone for the important traffic of this highway not to be suspended long. However, the detached mass has been moving inch by inch towards the Trishuli River around 1300m below this road.

Geologically, the landslide is at the southern limb of the Kuncha-Gorkha anticlinorium formed by alternating bands of metasandstones and chlorite-phyllite[2)]. Thick loosely packed colluvium with huge boulders are situated on the rocky slope.

To measure the movement rate of this landslide mass, GPS measurement for precise dynamic dual-frequency positioning was conducted four times over a one-year period (July 14th, November 1st, 2015 and June 10th, August 11th, 2016. See **Fig. 2** and **Table 1**) along the creeping section of this highway. A reference station was taken at a N28.01564º, E85.21363 º on an outcrop of sandstone on a stable mountain ridge. Then survey nails were driven at 13 locations for the first survey along the highway, and then four more points (points 16-19) were added at the third follow-up in a transverse line with respect to the highway. Some other new points were added along the highway in the 2nd and 3rd survey (point 14, point 15), to see the displacement along the highway in more detail. The movements of

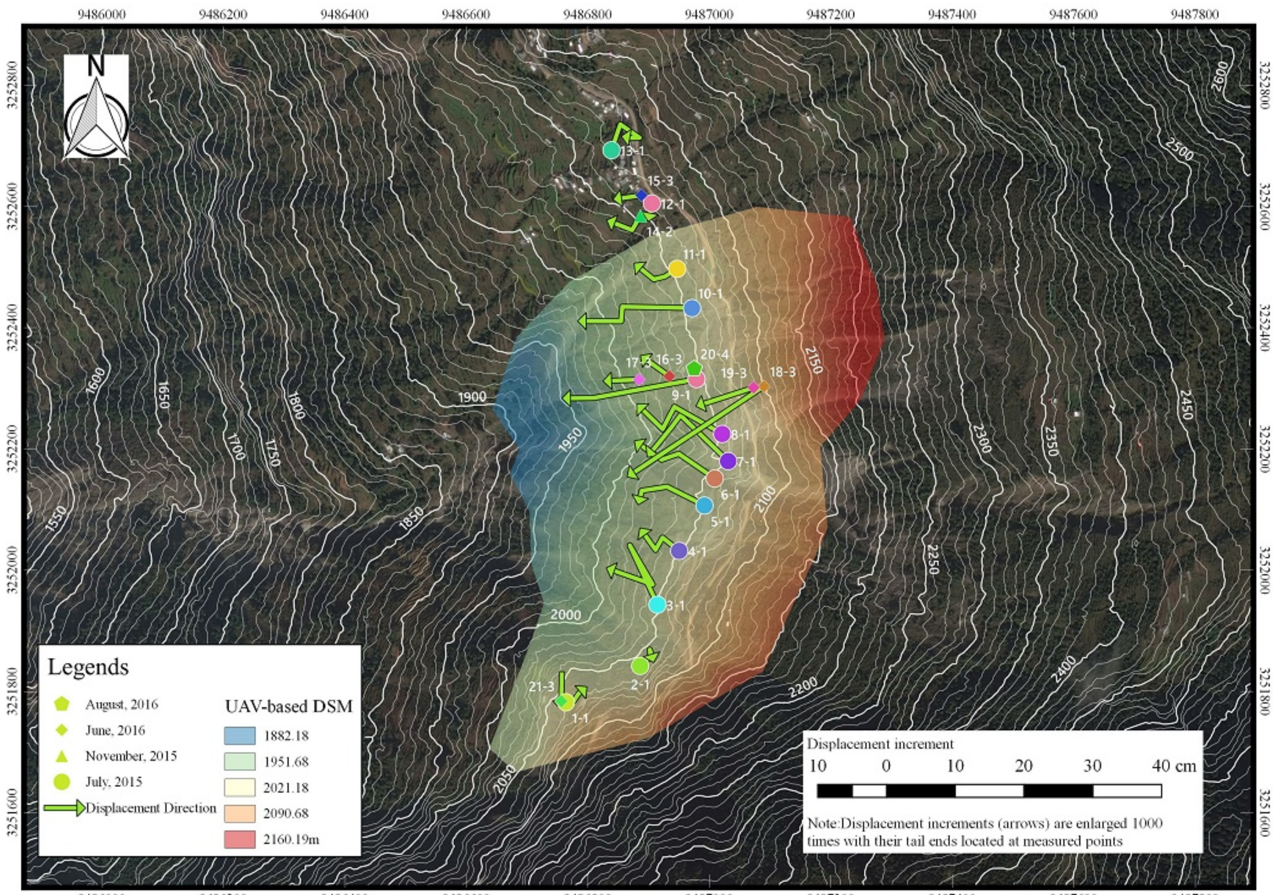


Fig. 2 Vectors of creeping displacements over one-year period from July 2015 to August 2016 (Photo from Google Earth)

Table 1 GPS mesurement data at Ramche landslide on July 14th, November 1st,2015 and June 10th, August 11th,2016

	Measurement on June 14th 2015			Measurement on November 1st 2015			Measurement on June 10th 2016			Measurement on Aug 11th 2016		
Point ID	Ellipsoidal Height(Z)	Longitude (Y)	Latitude (X)	Ellipsoidal Height(Z)	Longitude (Y)	Latitude (X)	Ellipsoid Height(Z)	Longitude (Y)	Latitude (X)	Ellipsoid Height(Z)	Longitude (Y)	Latitude (X)
REF	2001.718	324369.507	3100221.539									
1	2015.981	325109.149	3100945.428	2015.9855	325109.1604	3100945.429	2015.9326	325109.1676	3100945.434	2015.9635	325109.1706	3100945.4371
2	2013.151	325217.960	3100996.518	2013.1171	325217.9752	3100996.531	2013.1197	325217.9742	3100996.541	2013.1458	325217.9761	3100996.5347
3	2012.599	325244.320	3101084.913	2012.5663	325244.2812	3101085	2012.5456	325244.3136	3101084.943	2012.6113	325244.2582	3101084.9637
4	2011.994	325277.074	3101162.532	2011.9643	325277.0505	3101162.552	2011.9614	325277.0402	3101162.534	2011.9757	325277.0247	3101162.5561
5	2011.417	325314.846	3101227.664	2011.3625	325314.7921	3101227.692	2011.4051	325314.7551	3101227.686	2011.3866	325314.7529	3101227.6979
6	2014.762	325330.336	3101266.620	2014.7299	325330.2841	3101266.656	2014.7613	325330.2591	3101266.648	2014.7396	325330.2298	3101266.6688
7	2016.083	325350.264	3101291.537	2016.0262	325350.1954	3101291.605	2016.0443	325350.1816	3101291.587	2016.0268	325350.1542	3101291.6087
8	2014.210	325342.124	3101331.004	2014.1426	325342.0548	3101331.044	2014.1495	325342.0372	3101331.012	2014.1366	325342.0092	3101331.0404
9	2009.540	325305.984	3101411.039	2009.4288	325305.8337	3101411.014	2009.4646	325305.7998	3101410.982			
10	2016.858	325300.933	3101514.004	2016.7779	325300.8321	3101514.008	2016.7622	325300.8299	3101513.987	2016.8086	325300.7793	3101513.9881
11	2016.868	325280.150	3101571.300	2016.8521	325280.1322	3101571.289	2016.8295	325280.1162	3101571.285	2016.8237	325280.0973	3101571.3011
12	2022.466	325244.875	3101666.762	2022.4373	325244.8723	3101666.748						
13	2028.085	325187.198	3101744.659	2028.0751	325187.2117	3101744.696	2028.0721	325187.2393	3101744.676	2028.0907	325187.2252	3101744.6768
14				2013.1431	325227.9487	3101649.111	2013.0991	325227.9362	3101649.09	2013.1308	325227.9111	3101649.1010
15							2022.672	325229.7111	3101678.702	2022.6239	325229.6822	3101678.6982
16							1989.9374	325266.5006	3101415.852	1989.8932	325266.4692	3101415.8758
17							1967.5172	325222.3625	3101411.614	1967.4927	325222.3224	3101411.6132
18							2058.3517	325403.7855	3101399.069	2058.3011	325403.5951	3101398.9475
19							2047.2378	325388.707	3101397.521	2047.1653	325388.6348	3101397.4986

three orthogonal displacement components (X, Y and Z) for each points were measured in the survey.

As for the 1st and 2nd measurements, GDOP values range from 2.3 to 4.7, which means the expected errors are at most 0.009 m and 0.007 m at Points 3 and 13, respectively. The largest lateral displacement of 0.15 m was reached at Point 9 with an expected maximum error of 0.003 m. Therefore, at least the observed displacement for Point 9 is considered to have statistical significance indicating clear creeping nature of this landslide mass.

At the third follow-up on June 10th, the mark nail at the reference station was found buried beneath a pile of sand for some construction work, and we had experience of having to make a new reference point at N 28.0158°, E 85.213°. With this shift of the reference station, the increments of displacement at the pre-existing 14 nail-marked points are largely affected by the anomaly between the lost and new reference stations to be sure, but the measured increments over the dry season of about 7 months are in general relatively small. The increments of displacements of the points16-19 over the 2 months' period from third (Jun. 10) to fourth (Aug. 11) follow-ups are shown in **Fig. 3**. Point 9 lies on the Pasang Lhamu highway.

As shown in figure 2, displacement vector of point 16-19 are all facing toward the Trishuli river. The points in higher location shows larger displacement than those in lower location. Also, the depression angle of point 19, 16 and 17 are a little larger than the average slope inclination here. It is empirically known that vectors of creeping displacement observed on the surface of a coherent landslide mass can be about parallel to the slip surface lying below. This empirical knowledge suggests the possibility

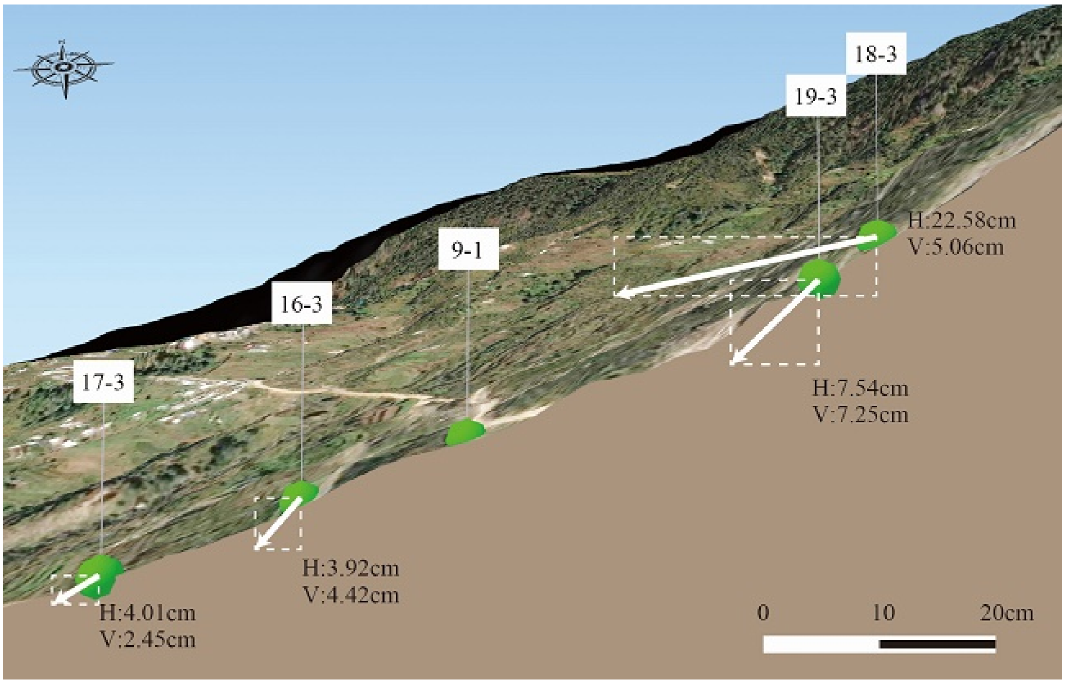


Fig. 3 Creeping displacements measured on transverse line to the highway over two months period from June 2016 to Aug 2016

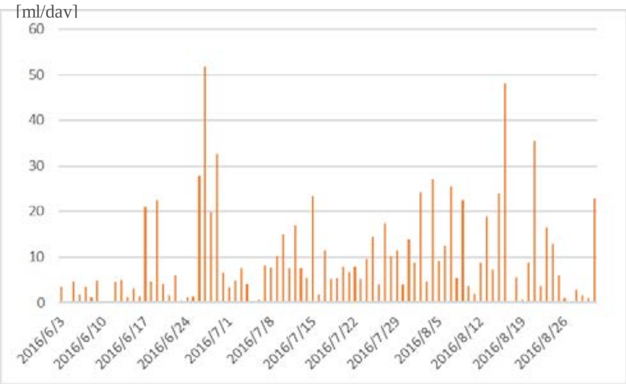


Fig. 4 Hourly and cumulative precipitations measured at the weather station (N 28.016°, E85.203°)

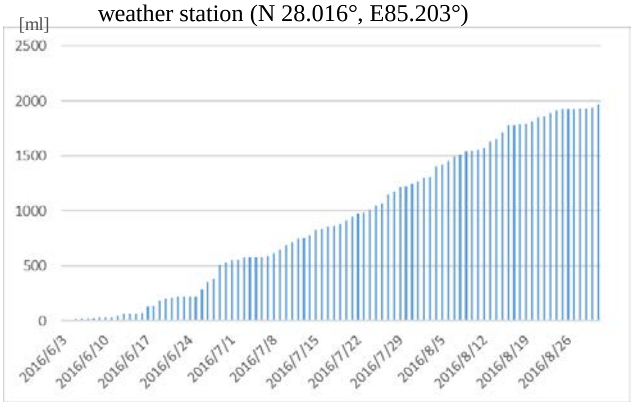


Fig. 5 Cumulative precipitations measured at the weather station (N 28.016°, E85.203°)

(a)Top view of survey area in dry season (photo taken on June 10th, 2016)

(b) Top view of survey area in monsoonal season (photo taken on August 11th, 2016)

Fig. 6 Top view of survey areas in a dry season and monsoonal season

that the highway crosses a little higher part of one of coherent landslide masses making up the entire slope.

The displacement increments shown in **Fig. 3** are reached in the short time period of only two months. This rapid movement can probably be attributed to the monsoonal rains, which precipitation has been being measured since the third follow-up of June 10, 2016 till now.

Fig. 4 and **Fig. 5** shows the hourly and cumulative precipitations measured at the weather station (N 28.016°, E85.203°). The rainfall increased from the end of June, and shows constant rainfall of about 10ml per day in July.

On the fourth follow-up survey in the middle of this monsoonal season, it was seen that waters from small gullies were splashing down onto the road, turning this creeping section of the highway into rivers. (**Fig. 6**)

A UAV-based 3D digital surface model (DSM) was prepared as shown in **Fig. 1**. To fully define the coordinate system for the extracted DSM, geo-referencing was made with total 5 nail-marked points for the GPS measurement.

The obtained DSM was compared with the digital 3D topographic data, AW3DTM, Class II of 5m ×5m spatial resolution, acquired from Advanced Land Observing Satellite "Daichi" (ALOS) of the Japan Aerospace Exploration Agency (JAXA) and high resolution satellite images(**Fig. 7**) A remarkably large anomaly in elevation reaching 30 to 40 m. Considering that the UAV-based 3D DSM was georeferenced using the exact locations of nail marks that were measured using the precise dynamic dual-frequency positioning system, the UAV-based 3D DSM is much more precise to describe micro terrain features of the creeping slope.

Fig. 8 shows the UAV-based 3D DSM and the contour line extracted from the model. The extracted 3D image shows small scarps in the middle of these creeping masses suggesting that they are not completely a single coherent mass but multiple, and some small slides have been continually occurring.

This precise measurement of micro-terrain of the creeping slope will be made at every follow-up survey, and the obtained DSMs at different times will be compared to extract Lagrangian displacement increments over the entire surface of the creeping soil mass. Given the Lagrangian displacements, the geometry of the hidden slip surface can be extracted minimizing the least squares estimator LSE. Details will be shown after the next follow-up survey.

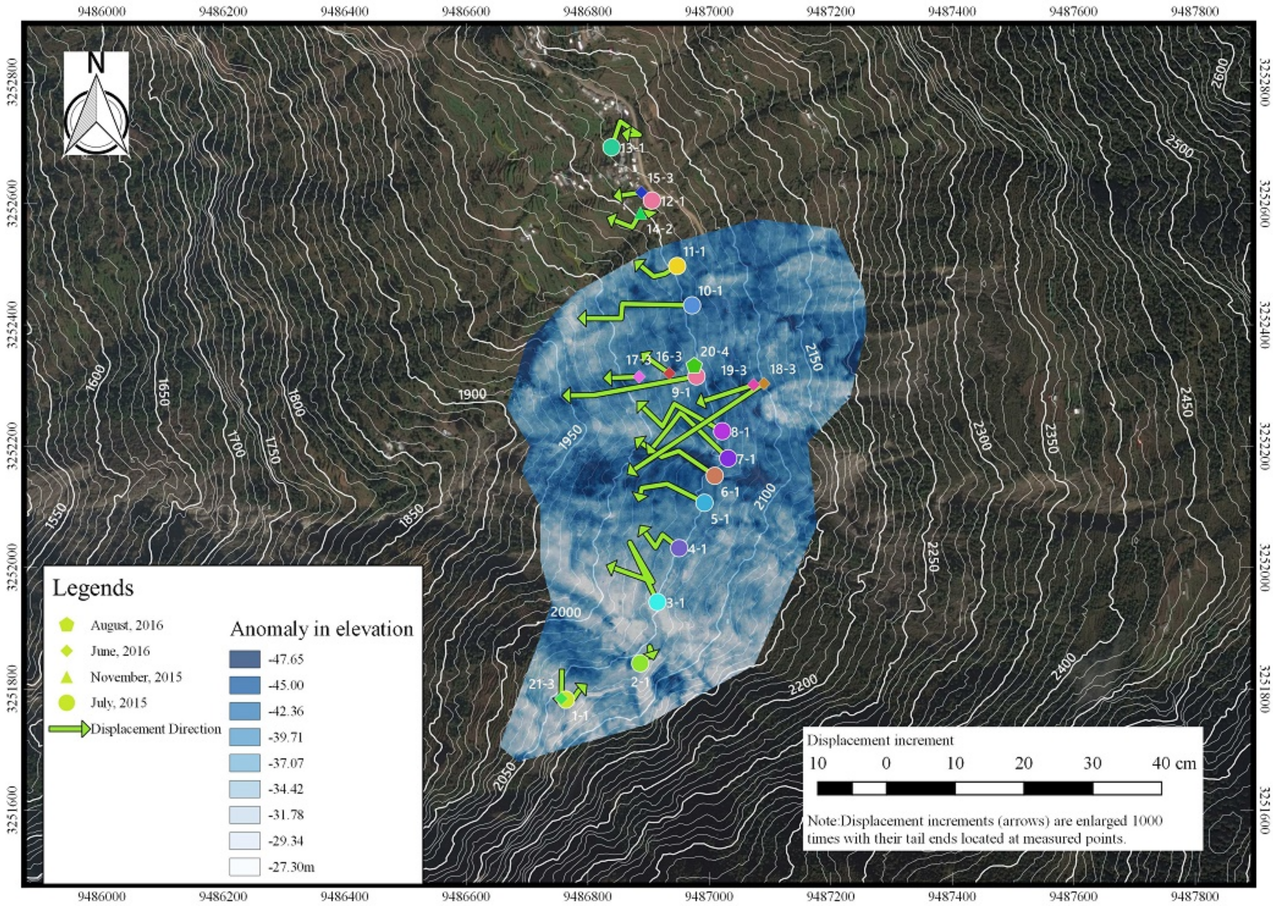


Fig. 7 Comparison of UAV-based 3D DSM and digital 3D topographic data from ALOS (Photos from Google Earth

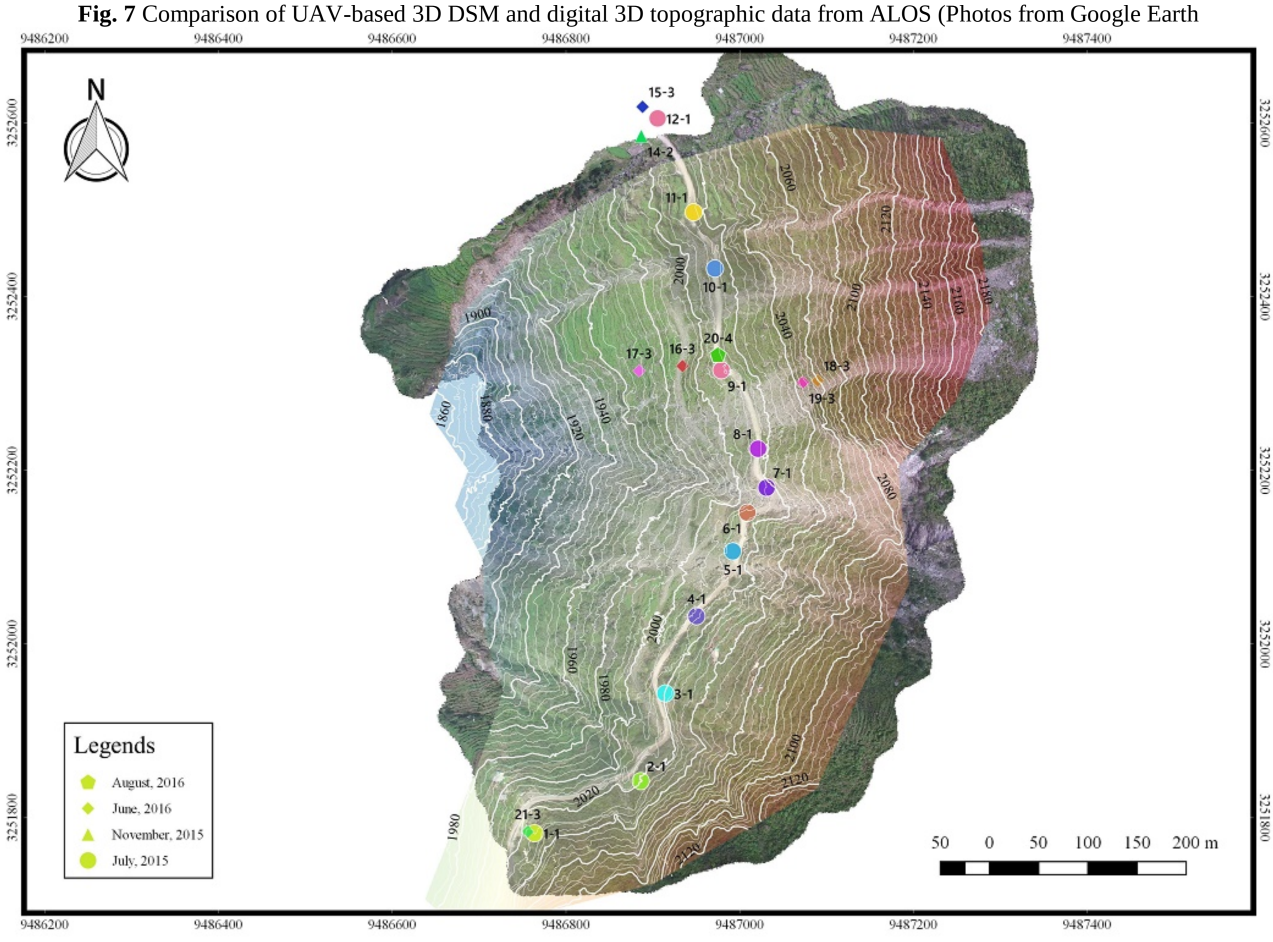


Fig. 8 UAV-based 3D DSM placed over UAV-based orthophoto

4. SUMMARY

Pasang Lhamu highway is an important highway for Nepal, connecting the central area of Nepal and China. However, the satellite images and UAV surveys show that many landslides have happened by the earthquake. The soil mass that poured into the Trishuli river will surely have an effect on the hydropower stations in the downstream of this area. By creating UAV-based 3D DSM on different occasions, the soil mass that may slip in the future can be estimated. As the highway and the hydraulic power plants play an important role in people's life, it is important to do the monitering to take the needed safety measures.

REFERENCES

1) Konagai, K., Pokhrel, R. M., Takaaki, I., Shiga, M., Rahman, M, A., Okuda, H..: Follow-up report of damage caused by the Gorkha Earthquake, Nepal, of April 25th, 2015. JSCE Journal of Diasster FactSheets, FS2016-E-0002, 2016.
2) Ghimire, T., Paudel, L. P., and Pant, B.: The Devas-tating Ramche Landslide (Rasuwa) and the Future of Pol-chet Residents, Journal of Nepal Geological Society, Vol 36, Special Issue, p. 27, 2007

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