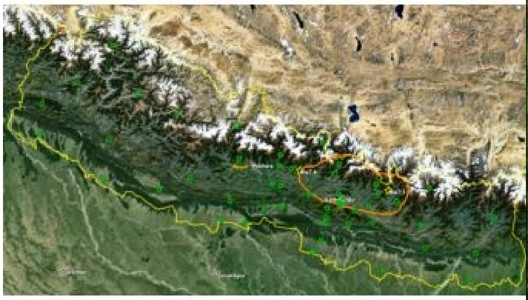
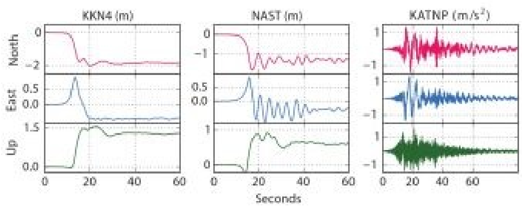
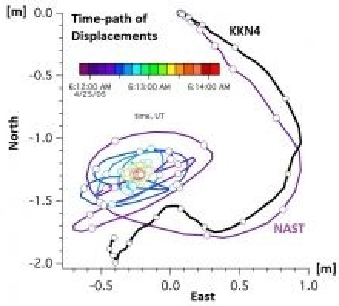
RUPTURE AREA COVERED BY A 5HZ GPS NETWORK FOR THE FIRST TIME

GPS and the 2015 Gorkha earthquake







Nepal is prone to earthquakes and throughout the centuries the country's capital city, Kathmandu, has been regularly struck by earthquakes which appear to have similar epicentres and behaviour. The portion of the Main Himalayan Thrust ruptured by the 2015 Gorkha earthquake lies directly beneath a network of GPS continuously operating reference stations (CORS) recording three-dimensional positions at a high rate of 5 samples per second (5Hz). This is the first time a large continental thrust earthquake has been measured by a 5Hz GPS network with receivers on both sides of the fault rupture.

The various earthquakes which have plagued Nepal over the centuries have caused major destruction, starting in the year 1255 (the earliest one recorded) and subsequently in 1344, 1408, 1681, 1833, 1934 and most recently in April 2015. The latter, the Gorkha quake, had a magnitude of 7.8 and was similar to the 1833 event. The quake in 1934 destroyed 20% of the buildings in Kathmandu and appears to be a repeat of the 1255 one. In comparison, the Gorkha quake destroyed less than 1% of the buildings. Considering the magnitude of the Gorkha quake and its proximity to Kathmandu one would have expected more damage to the vulnerable dwellings, although they are four storeys tall at most. Meanwhile, some high-rise buildings suffered severe damage, such as the 60m tall Dharahara tower which collapsed, despite having partially survived the 1934 earthquake.

CORS GPS network

Since the 1990s the California Institute of Technology (Caltech) has partnered with the Nepal Department of Mines and Geology (NDMG) to build a network of 28 GPS stations, consisting of Trimble NetRS, NetR8 and NetR9 reference station receivers. This largest and highest-quality CORS network in Nepal aims at monitoring tectonic strain. In total there are about 50 CORS GPS stations operational, established by several national organisations in close cooperation with various scientific institutions from France, Italy and UAS. Figure 1 shows a map of the GPS CORS network in Nepal based on data provided by UNAVCO, a non-profit university-governed consortium which facilitates geoscience research and education using geodesy. The Caltech GPS receivers capture data at 15-second and 0.2-second (5Hz) intervals. The 15-second intervals provide information on the normal, slow plate motion over several weeks, months and years. The 5Hz data provides details on the shaking during the quake itself. In 2013 the stations were equipped with cellular modems to transmit 15-second GPS data to FTP servers at UNAVCO for long-term monitoring of the plate motion and geophysical research. As the 5Hz data is only needed for examining behaviour and effects when a quake strikes and the volume of data is also too big for the limited bandwidth of cellular connections, the data is stored on the receivers for several weeks. Once a quake happens there should be sufficient time to collect the data by on-site visits. In order to deal with connection failures the receivers can also store 15-second data for up to one year or up to three years, depending on the type of receiver. As the 5Hz data accumulates very rapidly and recent data prevails, older data is overwritten by newer data within several weeks. Therefore, to prevent loss of important data, the data must be downloaded during on-site visits within just a few weeks of an earthquake striking.

Figure 1, GPS CORS network in Nepal; green circles indicate GPS stations; the orange line shows the Gorkha rupture zone (data courtesy UNAVCO, background image via Google Earth).

Data rescue

Notwithstanding all these precautions, data retrieval became precarious once the Gorkha quake struck. Two years after installation, the wireless connections of many GPS stations were disrupted. At the time of the quake, just nine stations could transmit data while the status of the others was unknown. Although many stations had lost connection, they continued to store GPS data. However, retrieval through on-site visits appeared to be very troublesome due to landslides and other hazards making the area difficult to access. Added to this, there was only limited availability of helicopters since they were, of course, more urgently needed for rescuing people in dire need. Through funding by Trimble, helicopters could be hired in for the few hours they were not occupied with rescue work. On site, data was downloaded and, wherever possible, receivers with a broken connection were fixed. Irreparable receivers, including those damaged by lightning strikes and vandalism or other causes, were replaced by new GNSS receivers and transported to Kathmandu for data recovery and repair and reuse if possible. The quake caused differing degrees of damage to the various sites and battered the receivers somewhat but it did not incapacitate any of them or damage any antennas, despite some of the stations being located directly over the fault rupture (Figure 2). The integrity of the GPS data appeared to be consistently good. Obviously, the short-braced monuments were solid enough to withstand the shock waves.

Figure 2, Damaged French GPS station GUMB; neither the GPS receiver nor the antenna was harmed (image courtesy: John Galetzka).

Results

Figure 3, showing the 5Hz GPS measurements at two individual CORS (KKN4 and NAST) during the quake, clearly demonstrates the occurrence of large initial displacements and accelerations associated with the shaking at the strong motion accelerometer KATNP, installed at the American Club operated by the U.S. embassy in Kathmandu. KKN4 is located on rock and NAST on sediment in a valley. The north and east displacements of the two stations clearly show different behaviours (Figure 4). NAST shows prolonged sediment resonance with a sweeping path of almost 2m. The small circles on the KKN4 displacement path indicate one-second intervals; the larger circles on the NAST displacement path indicate intervals of 0.2 seconds. Combining 5Hz GPS data and data captured by KATNP shows that the Kathmandu valley heaved upwards by 60cm and moved southwest by 1.5m at velocities of up to 50cm/s in less than 5 seconds. In the following 60 seconds valley sediments oscillated laterally at 4-second intervals with 20-50cm amplitude. Surfaces horizontal prior to the quake are now tilted down to the southwest by less than 1 degree. The runway at Kathmandu's airport lifted roughly 50cm and tilted by 12cm. The shaking in Kathmandu was not as violent and severe as one would expect based on the large amount of strain released. More work is needed to understand whether the Gorkha quake put additional stress on other faults in the area, which could influence occurrence of future earthquakes. Surface displacements were also measured with interferometric synthetic aperture radar (InSAR). The combination of all these measurements enables visualisation of the kinematics of the sources and the strong ground motion that led to the pattern of damage.

Figure 3, Records of ground displacements and accelerations (right) during the Gorkha earthquake (source: Avouac et al.).

GNSS receivers

Nepal's GPS network continues to monitor tectonic motion. Because the GPS equipment at the existing stations was largely undamaged, many of the receivers donated by Trimble for replacing incapacitated receivers were instead used to establish new stations. Since those receivers are GNSS-capable, they capture not only GPS signals but also signals from GLONASS, Galileo and BeiDou. This extension of the amount of signals allows placement of receivers in deep valleys where they are easily accessible. Seismic sensors are installed at many CORS sites.

Concluding remarks

The earthquakes occur at regular time intervals but that does not mean that the moment they will strike can be predicted exactly, even with the use of the most advanced instruments and technologies. However, modern measurement technology enables an understanding of the pattern of earthquakes and GPS data enables modelling of the tectonic strain accumulating along the plate boundaries and estimation of the strength of upcoming quakes. Added to this, the measurements taken during the Gorkha quake enable construction improvements to mitigate future damage and loss of life.

Figure 4, The north and east displacements of KKN4 and NAST in Figure 3 shown as two time paths (courtesy: Dave Mencin, UNAVCO).

Further reading

Avouac, J-P., Meng, L., Wei, S., Wang, T., Ampuero, J-P (2015) Lower edge of locked Main Himalayan Thrust unzipped by the 2015 Gorkha earthquake, *Nature Geoscience* 8, 708–711.

Avouac, J-P, Melgar, D., Bock, Y., et al. (2015) Slip pulse and resonance of Kathmandu basin during the 2015 Mw 7.8 Gorkha earthquake, Nepal imaged with geodesy, *ScienceXpress*, sciencemag.org/content/early/recent / 6 August 2015.

Acknowledgements

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