NEWS

Primes in arithmetic progression

Prime numbers have fascinated people since ancient times. Since the last century, their study has acquired importance also on account of the crucial role played by them in cryptography and other related areas. One of the problems about primes which has intrigued mathematicians is whether it is possible to have long strings of primes with the successive primes differing by a fixed number, namely arithmetic progressions of primes. This longstanding question has been settled recently, by Ben Green and Terence Tao, showing that in fact there are arithmetic progressions of any desired length, consisting only of prime numbers; thus for any k, there exist primes $p_1, p_2, \ldots, p_k$, such that the successive differences $p_2 - p_1, \ldots, p_k - p_{k-1}$ are all equal. Once the existence is known for every k, it is automatic that there are infinitely many such strings for each k.

Green is a postdoctoral fellow at the University of British Columbia, Vancouver, and Tao is a Clay Prize Fellow affiliated with the University of California at Los Angeles.

Prior to the work of Green and Tao it was only known, thanks to the work of van der Corput in the late 1930s, that there are infinitely many strings of three primes each, in which the two successive differences coincide. Even for $k = 4$, such a statement remained open. The longest known arithmetic progressions of primes, known by computational methods, consist of 22 primes; two such strings are known, featuring primes with 14 and 15 digits (in decimal expansion), the successive differences being certain integers with 13 and 14 digits respectively.

A 49-page manuscript of Green and Tao, currently under circulation, has been the subject of much interest in the mathematical community. It draws upon earlier deep work on arithmetic progressions in sets of integers with positive 'density', due to Szemeredi, Furstenberg, Gowers and others, on the one hand, and some recent results of Goldston and Yildirim on prime members, on the other hand.

S. G. Dani, School of Mathematics, Tata Institute of Fundamental Research, Homi Bhabha Road, Mumbai 400 005, India.
e-mail: dani@math.tifr.res.in

NEWS FOCUS

Landslide disaster of 24 September 2003 in Uttarkashi

S. Sarkar, D. P. Kanungo and P. K. S. Chauhan

A landslide disaster occurred in Uttarkashi on 24 September 2003 which has affected a part of the town. The paper highlights the probable causes of the slide, degree of instability in the Varunavat hill and risk assessment. According to an earlier assessment some instability was persisting in the Varunavat Parvat which triggered the slide after a heavy rainfall. The earlier landslide scars and cracks present prior to the slide contributed to the instability in the hill. The potential zone of risk in the foothill had been assessed and suggestions were made to administrative authorities to minimize loss of life and property.

The state of Uttaranchal has been witnessing a number of natural disasters which include earthquakes, landslides and flash floods. Some of these disasters affected Uttarkashi and surrounding regions in the recent past. These are the flash floods of Bhagirathi in the late seventies, Gyansu landslide in 1980, earthquake in 1991 and the recent landslide in 2003. Figure 1 shows the satellite image taken on 5 October 2003, after the recent landslide in the Varunavat Parvat, Uttarkashi triggered on 24 September 2003. We surveyed the landslide area and field investigations were carried out to assess the severity of the problem. Here we present the observations made during the survey and the extent of damage. The probable causes and the associated risks are also discussed.

Geology

Uttarkashi town is in Garhwal Lesser Himalaya and is situated south of the Main Central Thrust (MCT) which passes near Sainj. The area lies in the high seismotectonically active zone (seismic zone V). The MCT zone has witnessed two major earthquakes since 1991. The epicentre of the 1991 Uttarkashi earthquake was in the vicinity of Uttarkashi town. The area was subjected to tectonic movements due to which several faults and weak planes have developed in the region[1]. The Uttarkashi Formation includes Netala quartzite, Lower Uttarkashi limestone, Pokhri slate, Upper Uttarkashi Limestone and Bareti Quartzite[2]. The rocks found in the landslide-affected area of Varunavat Parvat comprise thinly bedded quartzites and phyllites which are highly weathered, jointed and fractured. The beds are dipping at 15–30° towards N350° inside the hill slope. There are three sets of major joints.

Instability in the Varunavat Parvat

Prior to the recent landslide, the Varunavat Parvat was affected by two landslides, mainly the Gyansu landslide and the Tambakhani landslide. The Gyansu slide occurred in June 1980. Since then, the debris comprising of boulders and gravel frequently flows down along the Gyansu nala. The slide is only confined to the nala, which flows into the Bhagirathi river after crossing the Rishikesh–Gangotri road. The Tambakhani slide developed in an old slide zone in the Varunavat Parvat. It had a 60 m wide scarp at the top of the hill. However, the sliding zone at the road level is only 5 m in width. This slide is active over the last few years. On the eastern side of the Tambakhani slide and about 50 m upslope, there was another scarp which was also part of the old slide. There were a few cracks in the East–West direction in the vicinity of these landslide scarps. All these features had indicated that the hill was unstable prior to the landslide occurrence on 24 September 2003. The landslide scenario of the Varunavat Parvat is shown in Figure 2.

The recent landslide has produced a huge quantity of rock boulders and debris. Once the slide was triggered, it affected the dense forest cover resulting in uprooting of numerous trees. The uprooting of trees has further worsened the situation. Presently, the slide is active with progressive failure involving massive flow of debris and rockfall on the steep slope.

Causes

It is well known that the 1991 Uttarkashi earthquake has induced instability in many parts of Uttarkashi district, including Varunavat Parvat. The south-facing slope of Varunavat Parvat was an old slide zone. The area was already in an unstable condition due to the Tambakhani slide and the landslide scarp at the hilltop on the right side of the Tambakhani slide. The cracks present in the uphill slope further aggravated the instability of the hill slope. It was reported that the scarp of Tambakhani slide was enlarging easterly and was finally merging with the existing scarp on the eastern side. Anthropogenic activities at the toe of the hill slope have resulted in loosening of the rock mass and increase in slope gradient, which have also disturbed the stability of the slopes by increasing the shear stress. All these factors might have shifted the stability of the hill from a marginally stable to an unstable condition.

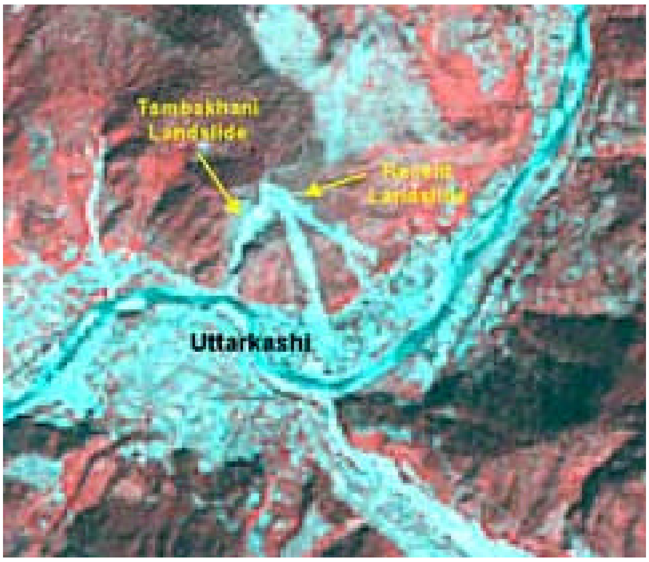

Figure 1. Varunavat landslide as seen on IRS 1D LISS III image (5 Oct. 2003).

Figure 2. Landside scenario of Uttarkashi.

However, the triggering factor for initiation of the landslide was the heavy rainfall which occurred during 20–23 September 2003. Rainwater percolated through the highly weathered, jointed and fractured rock mass and existing cracks, developing high pore pressure leading to detachment of the hill mass along the already developed scarp. This has formed a large landslide scarp extending up to the previously existing Tambakhani slide. The landslide thus produced a huge quantity of debris comprising rock boulders and soil. These rock boulders were continuously rolling down on the steep slope and finally got deposited at the road level. In this process, the movement of boulders was causing dislodgement of more rock blocks and uprooting of trees.

Landslide description

It was an old slide which got reactivated due to heavy rainfall. The landslide is of complex nature. After observing the slip surface and other features on the slope, it may be stated that initially the slide was of rotational nature followed by debris slide on steep slope. The crown of the slide is about 700 m high from the road level. The width of the slip surface near the crown was measured to be 60–70 m. The length of the slide surface on the upslope was more than 100 m. The exposed slip surface was dipping southwardly with 40° dip. The scarp was covered with pulverized clay along with scanty rock outcrops (Figure 3). The area is extremely unstable due to the presence of several cracks, some of which are more than a metre deep. Most of the cracks are transverse, while there are some longitudinal cracks also. Beyond the present limit of the sliding mass, it was found that there are a few cracks on the right flank, indicating possibility of widening of the landslide.

After surveying the slide area on 30 September, it was found that about 40,000–50,000 m^3 of slide debris was lying on the upslope. There was continuous movement of the debris along the downhill slope, which got finally deposited on the accumulation zone at the road level. On the uphill slope a few large boulders and uprooted trees had made a temporary barrier (Figure 4) across the main channel of debris flow, due to which a new channel had opened up on the right flank. In the downhill slope of this new channel, the debris was accumulated on a gentle slope which was temporarily supported by the uprooted trees and dense vegetation. It was assessed at that time that the debris along this channel could further destroy some part of the town. In view of this, evacuation of a few localities had been advised by the district administration.

The slide area was revisited on 23 October and it was found that the slide was still continuing. A new landslide scar had developed on the right flank due to debris flow along the new channel, as expected. It was observed that all the existing cracks on the moving mass got widened up to 30–60 cm. The dip of the slip surface became steeper (60°) compared to that earlier. The slip surface extended further towards the left flank. Development of new cracks was also observed on the uphill slope of the right flank. The sliding activity is still extending on both the sides.

Figure 3. Pulverized material and water seepage at slip surface.

Figure 4. Main channel of debris flow.

Damages

The landslide has deposited at the foothill, a huge quantity of debris which caused a huge loss of property. A large number of buildings were severely damaged. Recently constructed hotels and tourist lodges, which existed even after the landslide was triggered, were completely buried later under the debris (Figure 5). The debris has also buried the Uttarkashi–Gangotri National Highway-108, affecting about a kilometre stretch. It was reported by the district administration that about 362 dwelling houses were completely ruined by this landslide. However, it was fortunate that there were no casualties, as the district administration took prompt action to evacuate families as soon as the landslide was triggered, preventing a major catastrophe.

Risk assessment

On our first visit (30 September), it was assessed that the accumulated debris resting on the uphill slope might come down through the new channel and hence the habitants at the foot of the slope were in danger. This accumulation zone was not visible from the foot of the hill. Con-

Figure 5. Buildings standing after two days of sliding (***a***) and buried under debris later (***b***). (Figure 5 *a* courtesy Roopsagar Studio, Uttarkashi.)

sidering the risk, evacuation of buildings and habitation which may be affected by the sliding debris, was advised. On our next visit to the site (23 October), it was observed that the sliding activity had started in the anticipated zone of risk. Hence, the suggested evacuation plan had helped in minimizing property damage without any loss of life. After assessing the instability in the area, it was inferred that the foothill slope of the Varunavat Parvat between the Tambakhani slide and the newly developed landslide scarp, is a potential zone of risks. Hence, it is not advisable to rehabilitate this landslide-affected zone till the slope is stabilized.

Conclusion

The landslide activity can be minimized by implementing adequate remedial measures. These include sealing of cracks, slope-grading, construction of retaining walls, proper drainage measures, soil reinforcement using geo-grid and biotechnical measures. However, appropriate selection of these measures along with their design is only possible after an in-depth geological and geotechnical study of the slide area.

The experience with Uttarkashi landslide has provided a few lessons to the society and the researchers. One should try to avoid any disaster, if signs of instability are already known. As the area has a past history of instability, new constructions should have been avoided. However, the time gap between the initiation of the slide and the delayed debris accumulation caused by the nature of topography and dense vegetation, has helped the local authority to save human lives. Landslide susceptibility mapping should be carried out to delineate potential zones of instability, particularly in areas where human lives and properties are involved. If any indication of slope instability is noticed in an area which has major risk elements, the fact should be shared with society in a proper way.

One should investigate further if the cracks present in the hill had developed during the Uttarkashi earthquake. If so, the Varunavat landslide is earthquake-induced. But a big question remains as to why the slide was triggered after 12 years?

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S. Sarkar, D. P. Kanungo and P. K. S. Chauhan,*
Central Building Research Institute, Roorkee 247 667, India
**For correspondence.*
e-mail: shantanu_cbri@yahoo.co.in