Natural Hazards
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Lecture – 15
Case study on 2015 Gorkha Earthquake

Welcome back. So, in previous lecture we told that we will come back with some case study on earthquake and today, we are going to talk about the Gorkha earthquake, which occurred in 2015 and subsequently. They were like two earthquakes, which occurred in Nepal.

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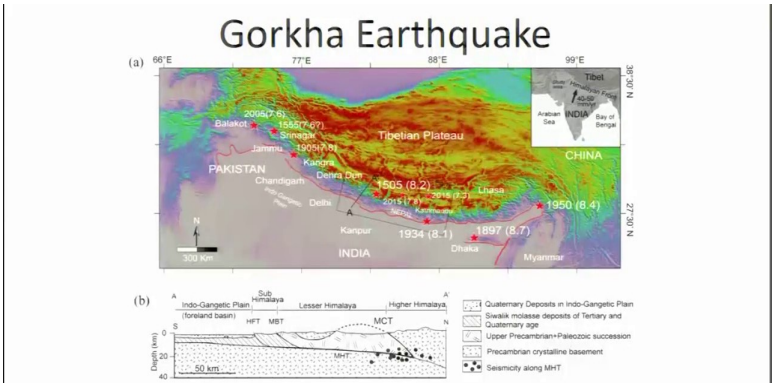

Figure 1: Map showing locations of four major large-magnitude earthquakes during 1905 Kangra (Mw 7.8), 1934 Bihar (Mw 8.1), 1950 Upper Assam (Mw 8.4) and 2005 Muzaffarabad (Mw 7.6) earthquakes. Also the two recent **25 April 2015 Gorkha (Mw 7.8) and 12 May 2015 Kodari (Mw 7.3)** earthquakes of Nepal are marked. **(b)** North–South generalized geologic section across the Central Himalaya, seismicity along the Main Himalayan Thrust is marked by black dots (Ni and Barazangi, 1984). Location of the section is marked by A–A' line in Figure 1a (after Seeber and Armbruster, 1981). Inset on right top is DEM of Indian sub-continent. (*Source: Malik et al., 2015, BSSA)*

Of course, we are fortunate enough that we did not experience much of damage ah from this earthquakes, although the magnitude was a 7.8 and 7.3 there were two consecutive earthquakes; one was in 25th April 2015, which was named as Gorkha earthquake which is shown here, this one and then another one was triggered on 12 May and that was, the 2015 7.3, which was towards the westerns, eastern side of the Gorkha earthquake.

Now, there are debates, but that this two events, may be separate events, but looks like that 2015 12th May event, but magnitude 7.3 was a sort of in triggered event, as a resulted by the 7.8 magnitude Gorkha earthquake.

Now, if you look at the Himalayas we have the high topography here, comprising of folded Himalayan chain and this is the boundary, which marks the, are the present day tectonic boundary between our plate boundary between the Tibetan plate and the Indian plate. And apart from the earthquakes, which I have been given here this was of 2015, both these earthquakes. There are few more which were been experienced by this region and one of the large magnitude earthquake or the great Himalayan earthquake was 8.1, 1934 Bihar, Nepal earthquake. There are few more, but I am not going to get into detail right now, of those, but you can look at that, we have 2005 here, then historical events are under steady your 1555 of Srinagar and then there was in 19 5 Kangra earthquakes 7.8 and this was been considered as and was one of the devastating earthquake at that point of time. Then we have 1934 and we have 1950 8.4 and there was another earthquake, which was on Shillong Plateau 1897 8.7 magnitude.

So, looking to so many earthquakes of a very large magnitude ranging from about 7.6, arranging up to 8.7 ah. The most important part, which the scientific community learned this time in 2015 7.8 earthquake of Nepal, was that why the damage a pattern was different ah, which was experienced if we compare 19 of 5, 7.8 magnitude, the magnitude were very much similar.

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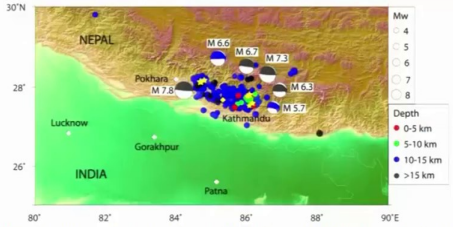

Figure 2. Map showing the earthquake distribution with focal mechanism of earthquake with 6.0>M≤7.8. Most of the earthquakes were pure thrust, a few with slight strike-slip component.

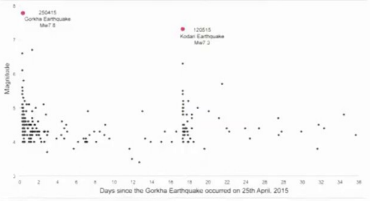

Figure 3: Time series plot of earthquakes occurred in Nepal from 25 April 2015 to 30 May 2015. The two major events of 25 April 2015, Gorkha earthquake (Mw 7.8) and 12 May 2015, Kodari earthquake (Mw 7.3) are marked by red dots.

Now, if you look at further what we see here is that, we have the distribution of the earthquakes foreshocks ah, aftershocks and the main shocks, which have been shown

here. So, this is an basically the rupture area which was been identified based on the distribution of the earthquake or the occurrence of the earthquakes. Now, one interesting thing, which was been noted here was again that, ah, this was the main shock 7.8 and then we had another earthquake of 7.3, but other than that we kept on having the earthquake like magnitude a 6.6, which is again a moderate earthquake, but yes of course, we sitting at IIT Kanpur in the Indo Gangetic plain felt all these events; 6.3, 6.7, 6.6 also and along with that of course, this where we are also been the experienced. Now, this shows, this map here, the time series, which was plotted which shows the plot of earthquakes occurred in Nepal from 25th April 2015 to 30th May 2015.

Now, two major events, which are been the state here, are been shown here in the red dots that was of 25th April 2015 and another was Kodari earthquake of 12th May 2015. And you can see the earthquake occurrence that is the number of earthquakes, which were occurred and then slowly the seismicity dies out and again it picks up and then we are having and in between, we are having this magnitude earthquake which I was showing of magnitude about 6. ah 6 like 6.6, 6.7, 6.3 and so on.

Now, this is all information is extremely important for the seismologist and the people who are dealing with seismic hazard assessment of any particular region. In particular we all, understand that this region that is been shown in green, that is if we are having the Indo Gangetic plain is thick alluvium a will be affected the most ok, if we are having the earthquake of similar magnitude in the foothill zones.

Now, what I believe is that, if this earthquake would have occurred like, few kilometers along this boundary then the damage scenario would have been different.

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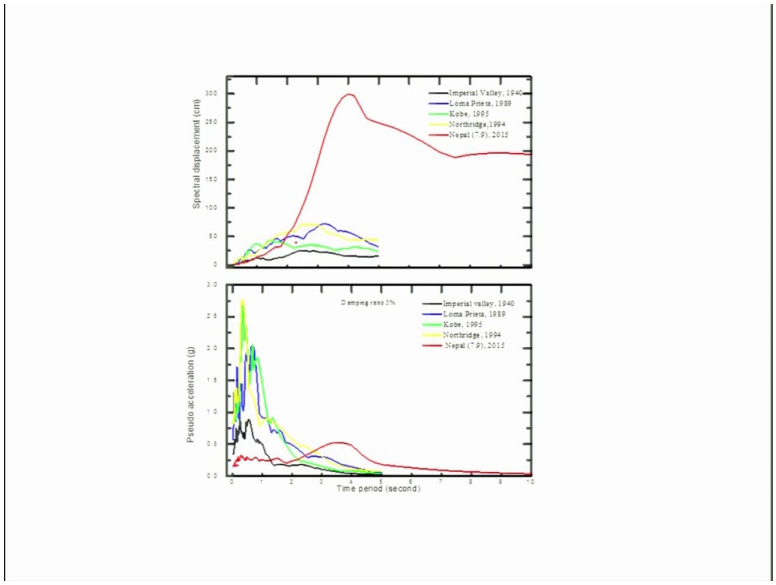

Another important thing which was been compared and observed was and usually the earthquakes with similar magnitude ah, will be triggered and then they release the energy very quickly, but here the oscillation was very subdue type.

So, here there are like earthquakes, which I have been given here in black, blue, green, yellow, red. Red is your Nepal 2015 ah 7.8 magnitude here it showed a different acceleration as compared to what was been observed in the Imperial Valley earthquake of 1940, Loma Petra in 1989, KOBE in 1995, Northridge 1994.

So, this was one of the reason that the damage was not much in the areas, in the epicen tral areas as well as away from the epicenter area otherwise, we would have faced ah very huge damage. Another reason could be, that this earthquake was triggered in the inner part of the Hinterland side not in the frontal part, because if you put this sketch here like this section which has been shown in the first figure here, the earthquake was somewhere in this region. It did not rupture this portion. Now, another the a lot of studies have been talking about that ah, this event occurred somewhere here and the next event will rupture this portion.

So, we can expect a similar earthquake, which was experienced in 1934 and that could be more devastating for the people who are living in the Indo Gangetic plain, because the ah the damage pattern will be much higher and the ground shaking will be much higher.

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So, we decided to take up a complete field survey and this was the you are travel plan we started from Kanpur moved to Gorakhpur and then we covered this part of the area, because we wanted to see that what is the damage pattern over here ah, resulted by the Gorkha earthquake and then we moved towards the eastern side covering this area and to look at the damage pattern, which was in two fold like we, I can say the initially by this and later on by this earthquake that was 7.3, 12th May 2015 event and then we moved out and came back, by the same or the other route from the other side and covering the areas in this Indo Gangetic plain.

I will, I will show couple of the damage ah pattern, which we observed. I am not going to get into the detail that what was the ah the problems with the construction and all that, but very briefly I can talk about, but we will mostly see that why this was ah, the damage was not much, even though we were having a magnitude of 7.8. The reason one, which is already been given comparing the other earthquakes from different part of the world and the Gorkha earthquake not the acceleration was quite different, which we observed it was just like and seesaw, which slowly moved and moved the earth, earth crust, but nothing much was happening, but then also we see a considerable damage.

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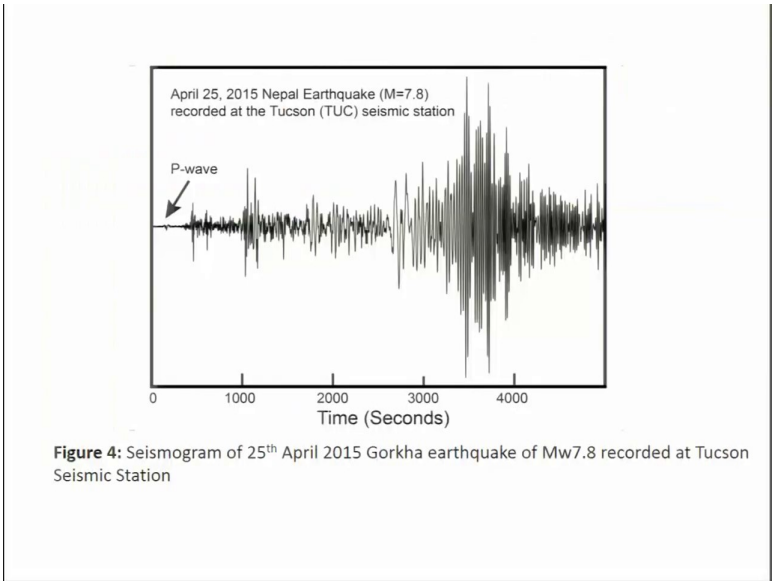

Figure 4: Seismogram of 25th April 2015 Gorkha earthquake of Mw7.8 recorded at Tucson Seismic Station

So, this is an Seismogram of 2015 Gorkha earthquake and so this was the event ah, which took place and record it at the Seismic station in Tucson.

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- The National Earthquake Information Centre (NEIC), USGS has given the following hypocentral parameters of the 25th April 2015 event.

➢ Origin Time:	06:11:26.270 UTC (11.41:26.270 IST)
➢ Epicentral Coordinates:	28.147°N: 84.708°E
➢ Magnitude (M_w):	M_w7.8; M_s8.1
➢ Depth:	15 km
➢ Moment Tensor Solution:	Nodal Plane Strike: 295°, Dip: 11°/N, Pure thrust type
➢ Seismic Moment Release:	8.1e + 27 dyne.cm

- The following are the parameters of 12th May 2015 major aftershock.

➢ Origin Time:	07:05:19.030 UTC (12:35:19.030 IST)
➢ Epicentral Coordinates:	27.837°N: 86.077°E
➢ Magnitude (M_w):	7.3
➢ Depth:	15 km ± 1.8
➢ Moment Tensor Solution:	295°, Dip: 10°/N, Pure thrust type

These are the information, which are available from NEIC, USGS about the origin time and the epicenter, what was the depth. Now, this is also extremely important for us, at what depth the earthquake is occurring, because that will have a lot of implication in terms of the damage. And of course, another important is what type of earthquake, this we will be talking later on, the thrusts type and the strike slip type and all that, but this is,

this part is important which were very shallow earthquake. Hence, the damage I was, could be, could have been more actually.

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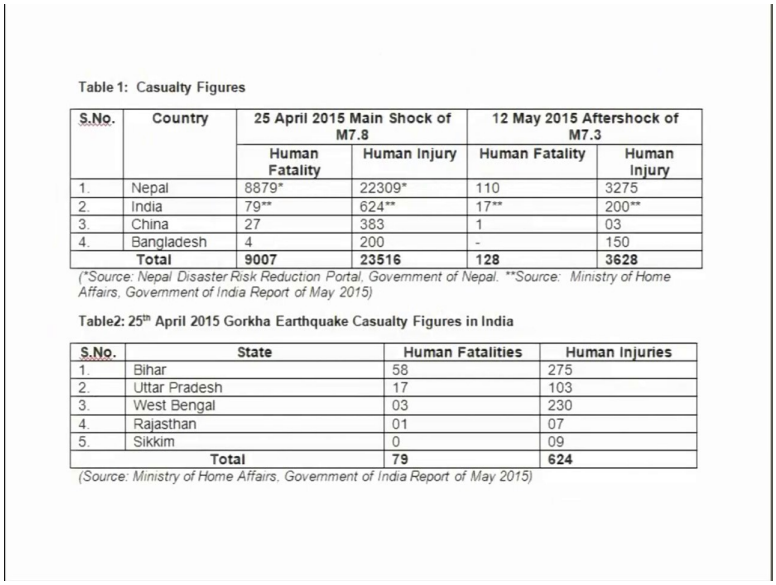

Table 1: Casualty Figures

S.No.	Country	25 April 2015 Main Shock of M7.8		12 May 2015 Aftershock of M7.3	
		Human Fatality	Human Injury	Human Fatality	Human Injury
1.	Nepal	8879*	22309*	110	3275
2.	India	79**	624**	17**	200**
3.	China	27	383	1	03
4.	Bangladesh	4	200	-	150
	Total	**9007**	**23516**	**128**	**3628**

*(*Source: Nepal Disaster Risk Reduction Portal, Government of Nepal. **Source: Ministry of Home Affairs, Government of India Report of May 2015)*

Table2: 25th April 2015 Gorkha Earthquake Casualty Figures in India

S.No.	State	Human Fatalities	Human Injuries
1.	Bihar	58	275
2.	Uttar Pradesh	17	103
3.	West Bengal	03	230
4.	Rajasthan	01	07
5.	Sikkim	0	09
	Total	**79**	**624**

(Source: Ministry of Home Affairs, Government of India Report of May 2015)

Now, casualty figures which we collected and we got the information from the local people as well as from the government, governmental organization so just that maximum number of human fatality was in Nepal and not only in Nepal, but few deaths were also been reported from India. Injury was more than like 22000 and in India, the injury was again and this were all mostly related to the, in the areas of Indo Gangetic plain.

So, if we take the casualty figures in India ah; Bihar, Uttar Pradesh, West Bengal, Rajasthan and Sikkim it definitely shocks were also felt up to Rajasthan. So, it is sitting very far. So, Bihar was maximum 58 people got killed in that region and so on. So, this was just like the figure, which we got from the M H R report.

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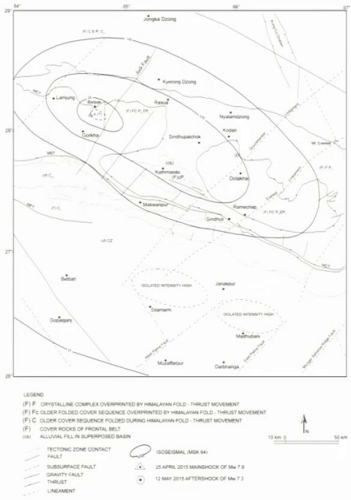

Fig. 5: Higher intensity isoseismal map of 25 April 2015 Gorkha (Nepal) earthquake of Mw 7.8 (*Tectonic Map based on: SEISAT, 2000*)

This is an shaking map, which was been was prepared based on the damage pattern. So, you can easily make out that this were the two epicenters ah, epicentral areas where maximum damage was been experienced, comparative maximum damage and then if we move further in the Indo Gangetic plain and the intensity of a ground shaking and damage pattern is reduced.

So, it was like here, it was up to 10 and then here comes around 9 and then further it is around 7 here and then in the Indo Gangetic plain is was almost like around 6.

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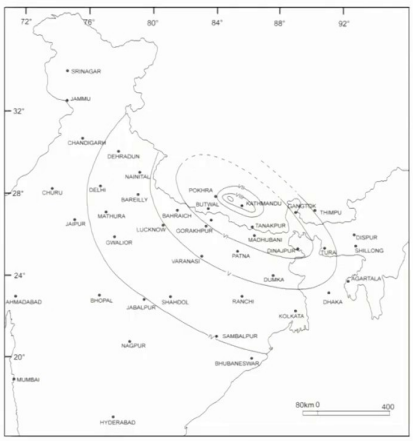

Fig. 6: Isoseismal map of 25th April 2015 Gorkha (Nepal) earthquake of Mw 7.8

So, this shows very, the clarity is more here in this map ah. So, here it was maximum then slowly it reduced and went down to up to 4 also in some part of the areas. So, this area particularly will be quite going to be affected, if you are having the large magnitude earthquake. So, one it occurred somewhere here, but next, if it suppose, it takes place somewhere in this area then along the, along the front then the damage pattern will vary.

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So, we slowly moved and from the Indo Gangetic plain even we, we tried to interview the people in India and in the border areas, where we were talking that what was the experience they had during the earthquake or before the main shock started, that is particularly the Seismic shaking started. So, we were talking to people and trying to understand that what was their experience. Some people told that there was like lightning and thunder storm, thunder and all that and some people told that there was a roaring sound.

So, that was very important for us to understand and as be moved further close to the epicentral area, we found that the damage was increasing slowly and we saw more of the building collapse and all that. Otherwise, at the initial stages when we started moving ah, from the Indo Gangetic plain and enter into the Nepal, we found some cracks which have been very visible and these structures, but no collapse was been seen.

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Photo 3: A brick masonry-mud mortar structure suffering damage of Grade 4 in Chebetar Village

Photo 4: Collapse of first floor stone masonry packed in mud-mortar and GI sheet roof of a house at Naya Sandhu village

Then, when we moved further ahead most of the houses with brick masonry and mud mortar, they suffered damage in the villages and this again then another figure, which has been shown photograph here, collapse of the first floor and this was stone masonry package. So, this also points out that most of the damage, which even though we say that it was in some villages experience massive damage was, because of the poor construction.

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Photo 5: A coseismic landslide triggered in terrace material at Naya Sandhu village.

Of course other than geological processes, we were able to observe was common and most of the areas experience landslide, because of the strong ground shaking or Seismic shaking. Then this was at Kathmandu main and it in the main city.

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Photo 6: Collapse of RCC framed structures due to failure of load bearing base columns of the stilts in Kathmandu Valley. Central region, Bagmati, Kathmandu, Chhauni, Nepal (27º42'45.0"N; 85º16'58.5"E).

Now, failure of those houses, the civil engineers and the software engineers can tell more about this, but this was the you the damage, because of the poor construction again.

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Photo 7: Collapse of brick masonry-mud mortar gable wall of a structure of the Temple Complex

Photo 8: Partial damage to the brick masonry structure at the entrance of the Pashupatinath Temple Complex. Yellow circle marks the portion showing minor damage.

This is at the Pashupatinath temple, even though very old construction, but it still remain as it is. Very light damage was been observed as you can see here and then so, this is the

part, which was damaged and again some structures, which are associated with the temple experience the damage. Otherwise there was no major collapse, which we observed in at this point.

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Photo 9: Failure of load bearing base column from beam junction, Thankot. Central region, Bagmati, Thankot, Tribhuvan Highway, Nepal (27º41'25.7"N; 85º13'20.7"E)

Photo 10: Development of fissures on the slump along the roadside at Malekhu Bazar.

The newly constructed structures experienced a huge damage and in some places what we found was the construction is taken place. Now, this construction of this house has been constructed over a artificial film and what you see here are the cracks, which had been developed in extensional crack. So, tired the, at some point of time, this whole mass which is been filled mass on the, on when the area close to the slope will slide down. So, this is not an good place to be selected for any construction.

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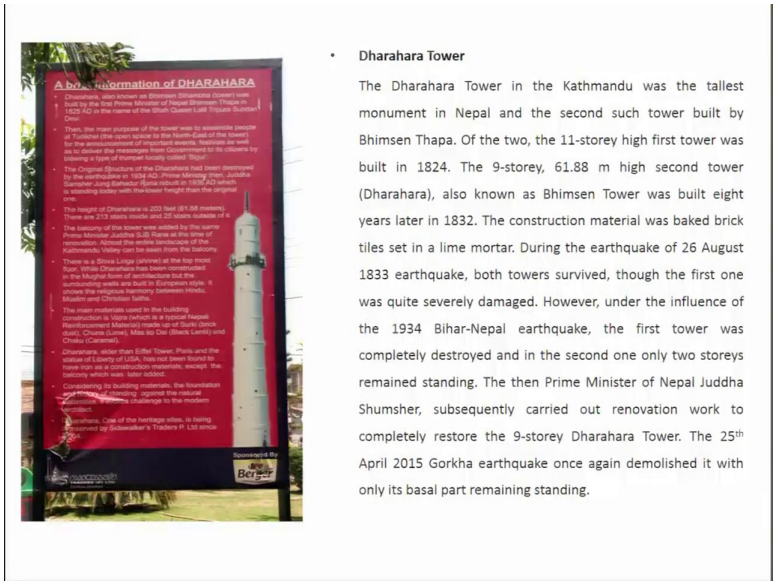

Another ah devastating and people mostly they got killed was at Toldhara Dharahara tower, in Kathmandu. Now, this tower was the tallest monument in Nepal and the second such tower built by Bhimsen Thapa and of the two the eleventh storey, high first tower was built in 1824. Now, there was an earthquake in 18 o 3 and later on there was an earthquake in 1833 also in this region. So, nine storey was almost like around 61.88 meter high, second tower of Dharahara also known as it was named as Bhimsen tower.

Now, this tower experience the massive damage or way I can say, total damage of that. Now, this is important point that during the earthquake of 26 August 1833 both towers survived. So, the first one was quite severely damaged; however, under the influence of 1934 Bihar, Nepal earthquake, this was an the earthquake above magnitude 8, the first tower was completely destroyed and in the second one only two storey remains standing.

Now, the question comes here that this people knew that this tower is getting affected every time in different earthquakes, then also they constructed without keeping in mind that it there will be earthquakes or there will be more number of earthquakes in near future and this occurred on April 2015 once again demolished, it completely up to it's and only the basal part remain standing.

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Photo 11: A view of the Dharahara Tower before 25th April 2015 Gorkha earthquake (Mw7.8).

Photo 12: Total damage to Dharahara Tower, Kathmandu after the25th April 2015 Gorkha earthquake (Mw7.8).

So, this is, the before Dharahara tower before the earthquake and this one is after the earthquake. So, it was completely destroyed that definitely, the construction was not up to the mark to withstand even the earthquake of 7.8 within very different acceleration.

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Now, what we observed was most of similar structures like what we see Dharahara, a this is an chimney ah, which most of the chimneys in this area got damaged and this was very much similar phenomena, which we observed or this area of Dharahara experienced in

the region. Along with this, the damage ah, we also saw some the land deformation, which occurred.

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Fig. 7: Google image showing the surface deformation caused by 25 April 2015 Gorkha earthquake (Mw7.8). It resulted into formation of en-echelon fractures developed striking in N60°-70°E. Factures/extensional cracks are associated with warping of the surface, which has caused relative uplift and subsidence in the deformational zone extending for about 400 m.

Now, there are two views again debate is there that this area or which is the area, it is the main highway and close to Katmandu. So, we found surface deformation which was resulted, because of 2015 Gorkha earthquake. What we was saw was that the area was subjected to the en-echelon and fracturing and the strike force, this actually. This was what we found and the en-echelon fracturing that some places resulted into the land uplift and subsidence, uplift subsidence and uplift like that. So, we did little bit detail survey and this area extended for almost like 400 meters.

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Photo 13: Fissures obliquely dissecting the road surface at Lokanthalli, Bhaktapur (Source: IAEG Report by Aydan and Ulusay, 2015)

So, this were the pictures which were been also available on the net, which shows the damage pattern, where the roads and the bridges were buckled up huge deep cracks were been formed, but our idea was that let us go and try to study, if possible to see subsurface, what exactly has happened.

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Photo 14: Land-level change observed

And of course, we were not able to go much deeper, but with the help of ground penetrating radar, we tried to see at some location that what is the ah, the features which we see in such pattern of deformation in subsurface.

So, this portion closely clearly shows a very well develops scarp here. The side is up, the side is down and close to the in the and the on the same line in the veranda, if we see this portion is up and you can see this portion is coming down here.

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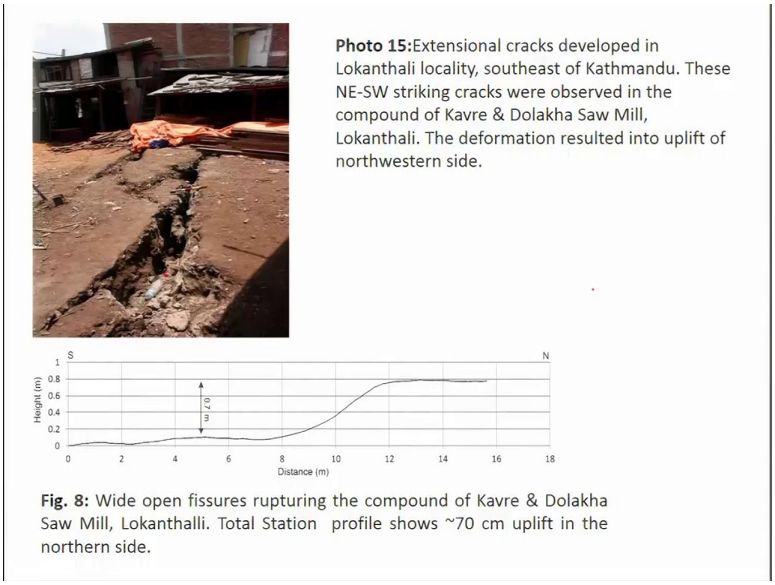

So, land level change was reported and on the crust of the warping, which we saw the area which was up and the, we saw the extensional cracks, which were developed an extensional crack where quite deep. So, what we decided that let us do ah G P R across this so that we can see that what how deep the cracks are and what is the deformation, which has occurred at greater depth.

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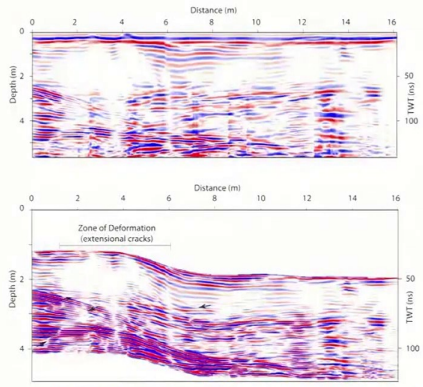

Fig.9: (a) Unprocessed 2D-GPR profile collected with 200 MHz antenna for a distance of 16 m across 0.70 m high southwest facing scarp. **(b)**Processed and topographically corrected GPR profile showing prominent warping. The zone of deformation extend for about 5-6 m. Black arrows mark probable plane along which slip occurred from NE to SW. Slip along these planes were responsible for the deformation, warping and formation of extensional carcks. These cracks are marked by irregular vertical whitish line within the zone of deformation.

So, we did G P R of course, as I told that we were not able to go deeper, but what we found was that; so this is an unprocessed profile, without topographic correction. The topographic correction is this one, we applied to it and what we found was there are the cracks, this was the zone of deformation the extension cracks are developed on the warping side. So, if you warp anything then the crust will show you some openings or the cracks will form the extensional cracks will be seen on the on the crust part. So, this is very common ah.

So, this extension cracks were observed here, but at the deeper portion what we saw that there is another similar deformation ah, which has occurred probably not due to this earthquake, but of the past event and this warping was experienced in the past also. So, this area must have experienced such type of deformation in the and the earthquakes during the historic time.

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Very commonly found secondary features or the secondary effect and most of the areas where the water table was very shallow, we found the formation of the sand dikes and sand blows.

So, this part again we will be talking in the ground effects, but of course, this I would like, I would wanted to show you when we are talking about the Gorkha earthquake. So, this was another important. So, this phenomena is going to be dangerous for the people, who are staying in the Indo Gangetic plain or the areas with thick alluvium, because liquefaction even the earthquake ah, occur at the distance from the site of interest or where you are staying, if you are the site conditions are ideal to trigger like faction, then you are going to face this type of issues.

So, this is ah typical of liquefaction sand dikes, which are coming up and this sand has been the liquefied sandwiches, which has broken this layers and coming right up to the surface, because of change in pore water pressure.

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Fig.10: Post earthquake Google image of Barpak village located within the epicentral tract

So, post earthquake google image of Barpak that was the village, which was in the epicentral area of Gorkha earthquake, maximum damage was been experienced. Now, because of the connectivity of the roads, we could not reach at this place, but the local people, the survivors, they told us that this Barpak village experience ah, the huge damage and that was mainly, because of the poor construction and the construction was done using this stone and mud masonry.

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Fig.11: Google image of Co-seismic landslides triggered by Gorkha earthquake around Barpak village

Landslides were very common in most of the valleys, close to Barpak and this area experience the maximum intensity in terms of the ground shaking.

So, thank you so much and we will continue in the next lecture, talk more about the different hazards.

Thank you.