Natural Hazards
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Lecture - 22
Liquefaction and Related Geological Features

Welcome back, so this was the last slide. Now, historical liquefaction features from Kachchh. So, this is one kind of investigations which we do to look for the past signatures or the signatures of the past earthquake or liquefaction preserved in the ceramic successions.

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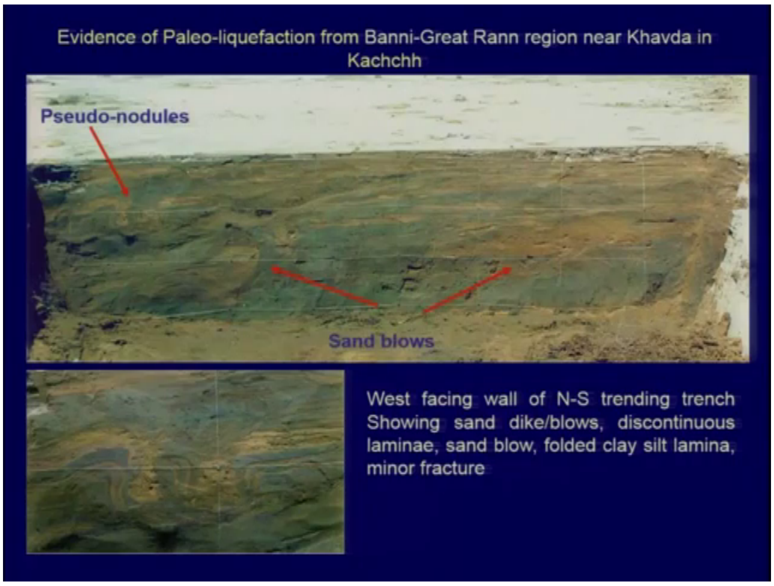

So, this was the trench which we did in 1999 and maybe before at 1996 or 98. And what we found was this sand blows here. There is an typical sand blow and deformational features ok. So, convolutions:~~;~~ so this convolutions are also considered as an load structures or and folding in the very fine sediments.

And this happens because of strong ground shaking and sand blow which I was explaining in the last previous slide is because of the strong ground shaking,~~.~~ ~~Increasing~~ increasing pore water pressure and releasing the liquefiable sand at the surface. So, you also call this as an pseudo nodules and these are typically the sand blows.

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Modified Mercalli Scale

Intensity Value and Description	Average Peak Acceleration (g is Gravity = 9.80 m/sec²
I. Not felt except by a very few under especially favourable circumstances. II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.	
IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.	0.015g-0.02g
V. Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.	0.03g-0.04g
VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.	0.06g-0.07g
VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.	0.10g-0.15g

Now, this is one table which we have prepared which talks about the instant intensity values and descriptions. And this is after the intensity scale is also being given here. So, 1 3 and 2 and 3 and so on which talks about that what will be the approximate ground acceleration. So, if you are having for example, the intensity 4 here, then the peak ground acceleration will be around point 032.04g.

But the issue or the you know at the where we should bother is may be somewhere over here that is where having the intensity of ground shaking at 7 and then it reaches 0.1 to 0.15g. And this is what happens and mainly most of us will experience. Now we will have damage will be negligible in the building, but yes of course, everybody will be will these the shaking will force us to run outdoors ok. So, if the building is could well design, then the damage will be negligible. But like to moderate in the wall built ordinary structure if you are having.

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VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stack, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed. (~M 6)	0.25g-0.30g
IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (~M 7 to 7.5)	0.50g-0.55g
X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.	More than 0.60g
XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly. XII. Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.	

And then if you have for example, the peak ground acceleration above 0.5 and then more than 0.6g, then you make experience that. Well built wooden structures will also be destroyed most missionary and frame structure destroyed with foundations.

So, this will result into the major damage. And of course, if you are having greater than point g 6g, then you will have a major damage or total damage in that case.

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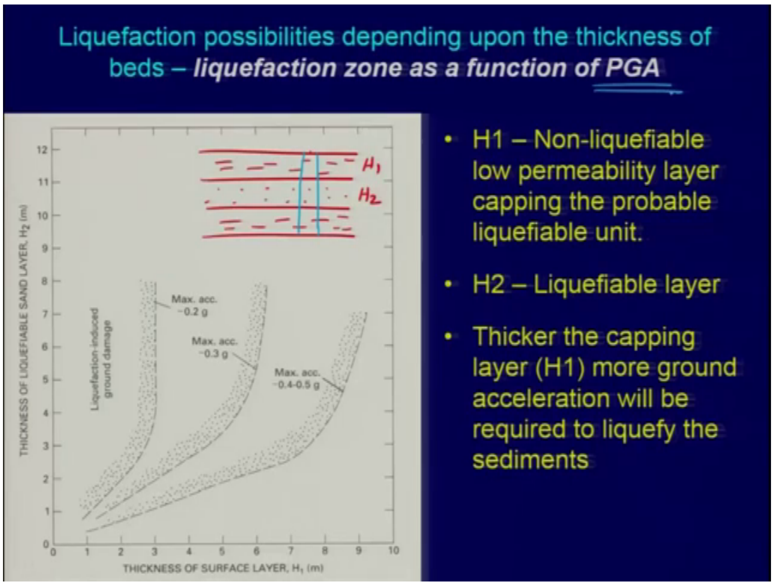

So, liquefaction possibility depends upon on the thickness of bits as I was talking in the previous slide and that is mainly a function of peak ground acceleration. So, suppose we are having the thickness this is what we were talking about the H1 and H2. So, you have like units. So, unit one you are having and then you having the liquefiable unit and you are having another one here.

See if the liquefiable unit is sandwich between the non liquefiable unit and what happens. So, this is your liquefiable sand this is your H2 and this is your H1. So, H1 is your liquefiable and non liquefiable unit and this is your H1 H2 is here liquefiable. So, H1 is non liquefiable no permeability layer capping the probable unit liquefiable unit that is your H2, so H2 is your liquefiable layer.

Now if the thickness of your H1 this is an over lying unit is higher anything that is your capping unit is more. ~~so~~ So more ground acceleration will be required to liquefy the H2 unit. So, we have for example, we have very ideal conditions, but this is cohesion less and also it is water saturated, but if the thickness of H1 is larger or thicker then you require much more ground acceleration.

So, the ground acceleration which will be required if you are having the thickness for example 8 meter or so~~. Then~~ then you have the maximum ground acceleration which will be required will be approximately around 0.4 to 0.5 g. So, this is another important part.

So, what the geotechnical engineers and the geophysicist and geologists they do; is that they will have they will take the borehole and then try to study the deposits here. So, based on this and they will conclude whether this unit will liquefy at the time of the earthquake from a particular source. So, they also need to know that what will be the peak ground acceleration at the site of interest.

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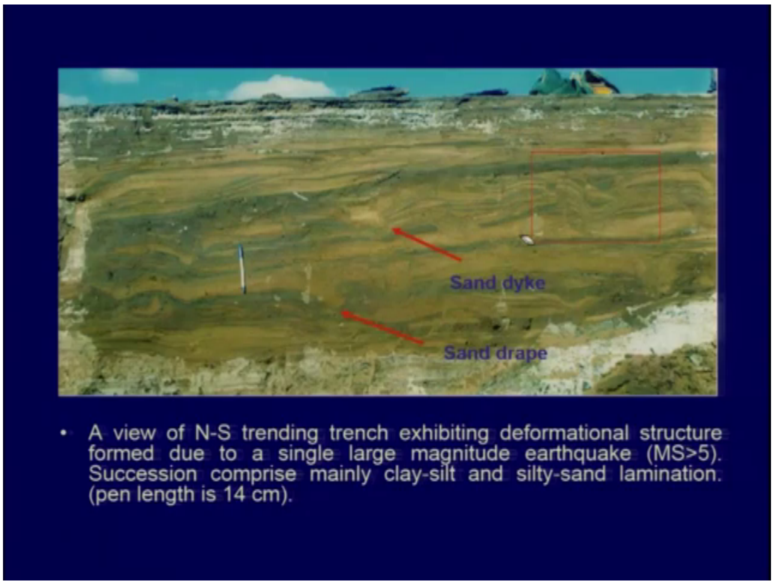

So, this is another trench which it did in the Great Rann of Kutch which also showed us that not all liquefiable units or the units where they have been able to reach or break the surface. So, this example if you see here is a very tiny sand blow which was unable to reach right up to the surface, but it deformed the units overlying it and just stopped there.

So, this is another example. Other than that what we found was and very interesting micro faulting in this region. So, this type of deformations also will be seen in most of the places where one either the thickness is quite large there is an overlying thickness of the bed which will not be able to liquefy. And another point is that I was talking about the dimension of the liquefaction features.

So, if the magnitude is less then you may not have the large liquefaction features as I we were looking in one of the site in Great Rann of Kutch. So, this is an sand dyke and then this portion which is in marked here is here sand drape and this your micro faulting area.

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So, this is a close up of that which you can easily make out at this portion has moved down with respect to the side walls here. And there is some down faulting the normal faults which can be seen here. Those another normal fault here another normal fault here. So, typically this unit is horizontally laminated unit.

So, micro faulting in Banni sediments. So, if sit suchphenomena happens and we have the micro faulting, we have small sand dikes, and the sand blows of course, this will disturb in terms of the shear strength. So, the material it will lose the shear strength and you may have or you may experience the collapsing of your structure which is sitting on the surface.

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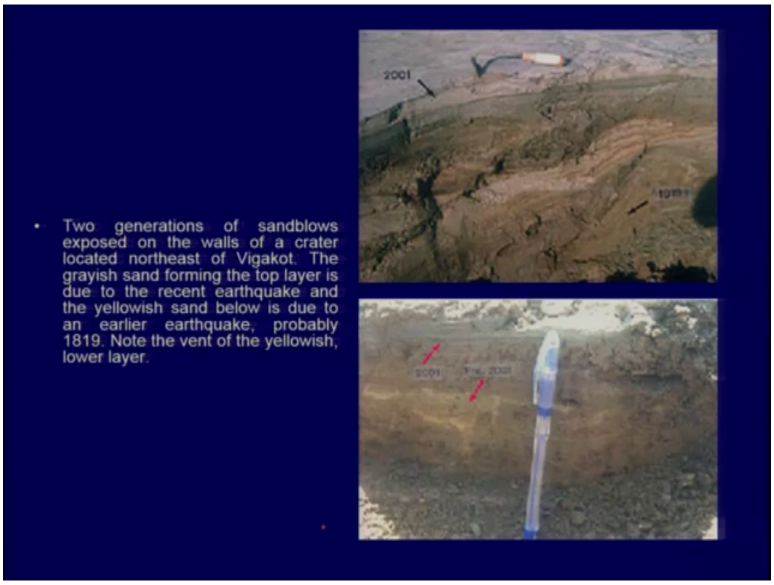

So, people have done the studies which also shows the pre 2001 earthquake signatures in terms of the liquefaction. Then another very common phenomena which usually is observed is of lateral spreading. And then lateral spreading can also.

Or I would say that it can even occur if you are having a slope of around 2 degree also or even less than that. So, the main process which is involved in lateral spreading is your liquefaction, but since it is the material is sitting along this slope it will slide down or the blocks will the because of the fracturing the blocks will float on the liquefiable sand.

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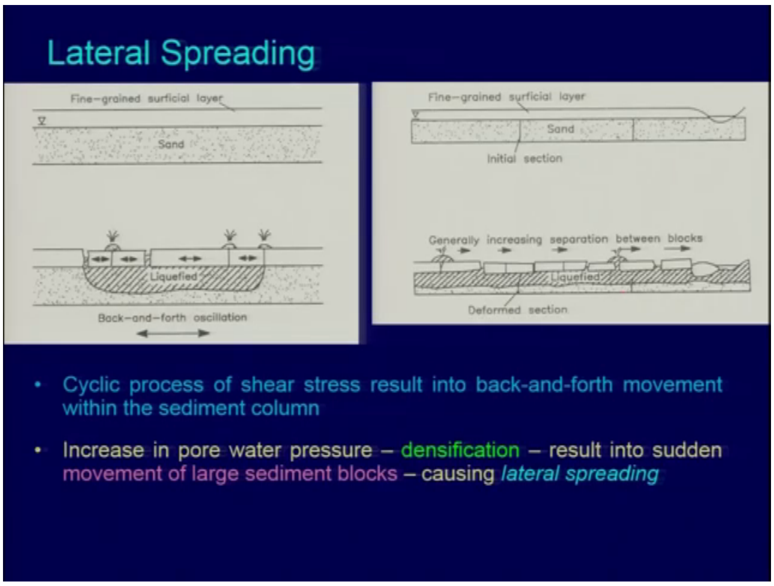

So, lateral spreading what we see is that we have it is because of the again the cyclic processes as we were talk talking about the shear stress. The results into the back and forth movement within the sediment column. Soso, you will have an back and forth movement within the sediment column.

And this is the potential unit which will liquefy this is the un--liquefiable unit or non leak viable unit, but this will of course, will fracture. And this blocks will float on the on surface and the separation point will be your fractures whic-h will develop or the fissures which will develop because of the breaking up of this flux on the surface.

So, increase in pore water pressure densification will take place and that will result into sudden moment of large sediment blocks causing lateral spread. So, this will start moving in an in it is the along the gradient or the slope and result into the complete landslide also ok. So, lateral spread will also can also result into the landslide in many of the regions.

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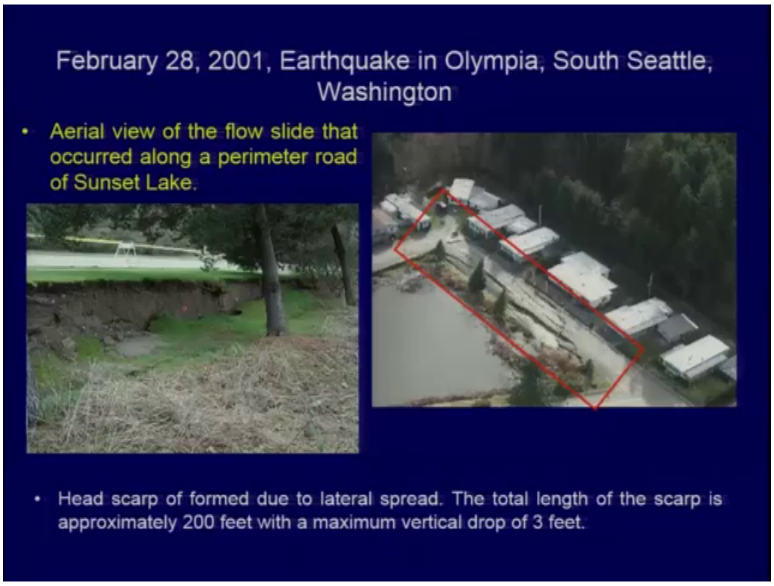

So, example this is from again Seattle Washington DC. I am unable to play the movie here, but we can put it later on. So, there is one example of lateral spread here which was triggered in 2001 on 20th of February 2001 because of the earthquake in Seattle. And the displacement which was been observed for here was around 1.5 to 2 meters.

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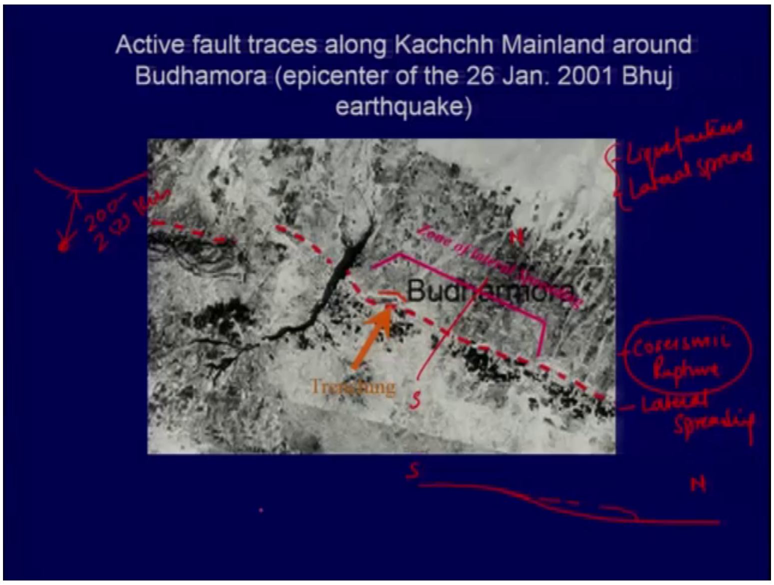

Now, coming to the Kachchh region so this was the area which was been marked as an zone of the epicentral zone. The rupture did not come right up to the surface-, but of course, what we feel is that there was not surface deformation which_accompanied the ground shaking. And the area over here we did trenching and then the details survey in this region which showed us the zone of lateral spreading.

So, if I take the cross section here probably next slide we have the cross section. But if you take the cross section here this is a my south this is north then there is the very gently sloping surface here. So, this is my south and this is my north here and the sediments here this is in close to the bunny plane and this is on rocky mainland. And this portion is mostly covered by a loose sediments.

So, this portion slipped over here. So, what we did was we studied this whole area in detail and try to understand that what exactly happened at the time of the earthquake. And whether this was the, what we say is the co seismic rupture or this was and purely lateral spreading. Now when we say liquefaction and lateral spreading then this goes as in secondary features these are not the primary one. Primary one is the co seismic rupture that is the displacement which is coming right up to the surface along the along ~~default ,~~default, but this one will be in side effects ok.

So, these are all secondary co seismic will be close to the fault, but this can happen like lateral spreading or liquefaction they can take place quite far it may cover more than 200 kilometers of the area. And if there is an idle condition you will face an liquefaction. So, what we keep talking about not if even though we are sitting like far away from the Himalaya, if you are even sitting in the indo-gangetic plain and the distance is not much maybe are on to 200 to 250 kilometers. Then we are likely to be hit by the liquefaction.

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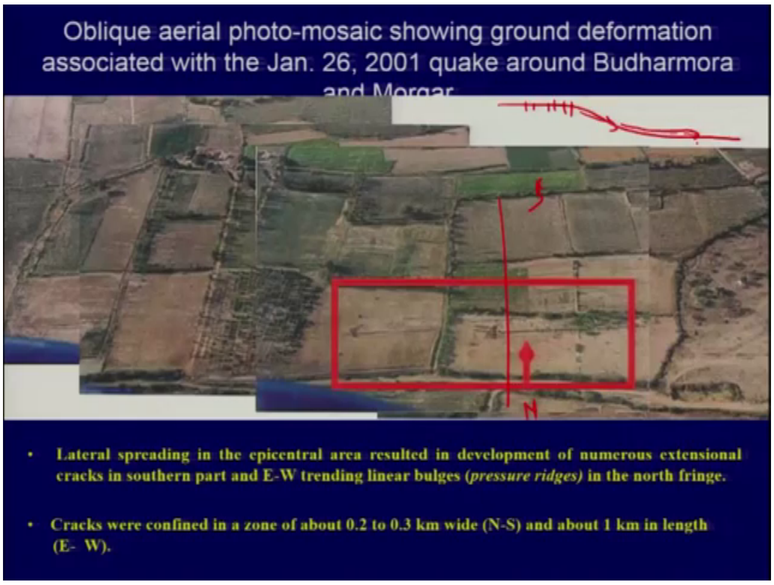

So, with that aerial survey here and we found in the a very prominent east west aligned ridge lines here very small ridge lines. And of course, it was bit difficult differentiate between the agricultural field boundaries and theand the recently formed this ridge lines because of the 2001 bhuj a earthquake, but yes we flew very low and then we tooked very close photographs aerial photographs to understand this.

So, what we found was at this area this is your north sorry south and this side is north. So, we are looking towards south from the aircraft. So, what we found that this area the southern part whoa shows as extension and the northern part at the toe of the slope break we were able to see and the deformation. So, if you if I take the cross section here it looks something like this ok.

So, what we found was not they were extensional cracks here and this land completely moved down and then was bulldozed on the surface. So, there is an typical of the lateral spread and the landslide and we also say this as an rotational landslide.

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So, this is the north from. So, from south we mapped all cracks or the fissures which were been developed in this zone of almost 1 kilometer. And this was the maximum a deformation which we were able to pick up. So, the bold lines which has been shown is your be the linear bulges; bulges which have been formed.

And this where the open cracks or the fissures which were developed;. ~~And~~ and the slope is in this direction it is in this direction towards north. So, the we have the profiles topographic profiles which we took across this. So, A B and C D and what we found is; this one ok.

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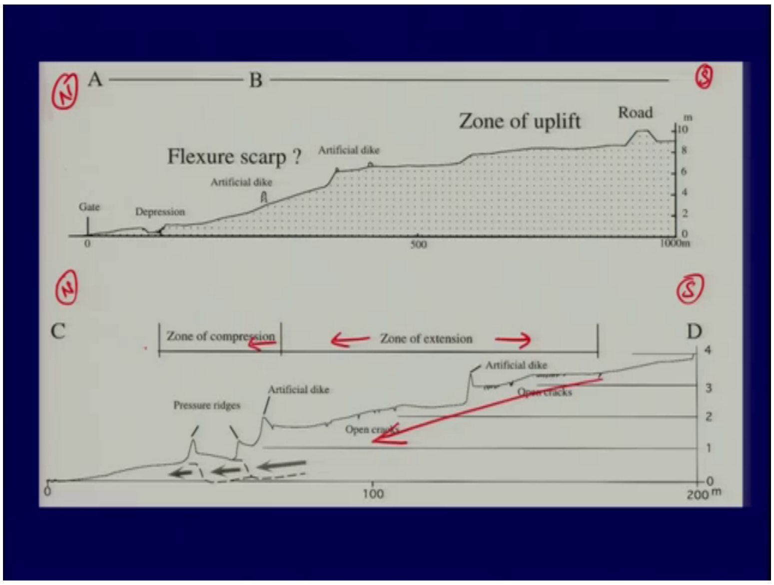

So, we have the A B is here. So, we see this as an uplift zone. So, this is your south and this is your north and same is over here. So, we found in an A B what we found is the uplift zone and then few sand dykes or there or the artificial dykes and then depression. Whereas, over here we found at there was an extension in the southern side.

So, this is your south this is your north here and the slope was not so much ok. So, if you take this slope here will be something like this and slope was not much then also the slit across the condition where very ideal to have this type of deformation secondary deformation. So, the pressure edge or the bulges which were formed because of the movement of this mass.

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So, close above this if you see this it looks like something like this. So, very thin fissures or the fractures which were formed and these are all extensional fractures. So, if you look at here what happened basically is that this area opened up the extinction. And then this portion came as in compression here because of the material which moved to the on the flat surface.

So, close up of this one extensional cracks and the bulges which we have been formed. Now the you know issue will be that suppose if you were having and building here sitting on the top of this and it must have it would have been damaged because of the bulging which has been seen here.

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Now, cross section of the bulge if you see what we found was something like this ok. So, we have the extension here in the southern side and we have the bulging. So, this that this the material moved or was bulldozed on the present surface. So, some people thought that this is an primary or the co seismic or rupture, but when we did the detail survey we found that this is nothing to do with the primary rupture, but this was and secondary phenomena.

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And we also observed at some location this is because of the extension this, the water ditch which was or the small cannel which was also literally shifted over here. So, these are the two piercing point of this one this got lateral shifted along this fracture.

Again this was nothing to do with the primary one. So, this moved like that and this moved in this direction. So, this was a lateral shift right lateral shift here even the pond boundaries we are also it moved because of the lateral shift.

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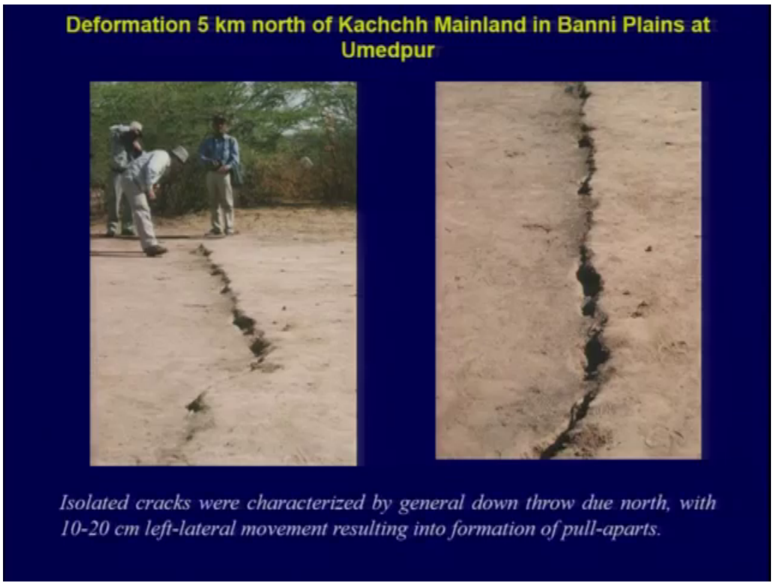

And it was typical the formation which was observed in the money plane.

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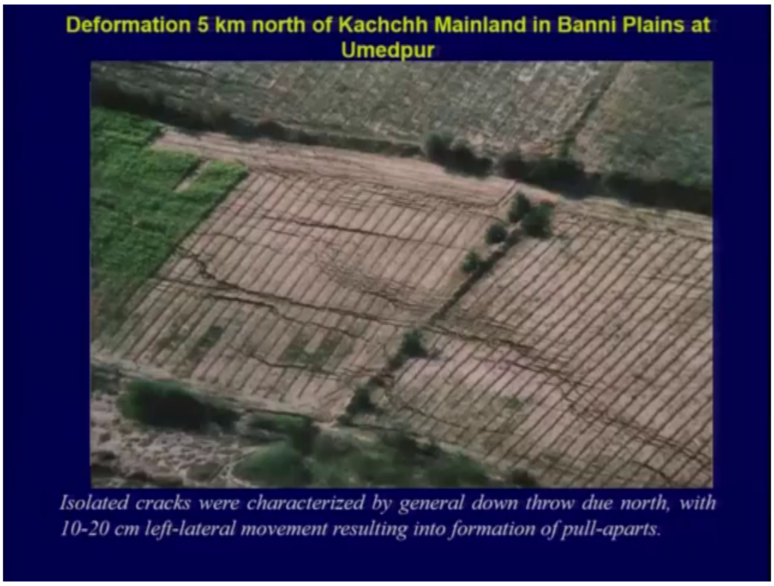

The same photograph period photograph showing the extensional.

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Now, this one effect from 1995 Kobe earthquake again the magnitude was not so large, but yes of course, the damage which was been experienced during1995 and 1994 Niigata earthquake was massive because of the liquefaction.

So, these are some pictures which shows the effect of the liquefaction and the tilting of the building complete tilt. Because of the loss of shear strength of the liquefiable soil this is from 1964 Niigata.

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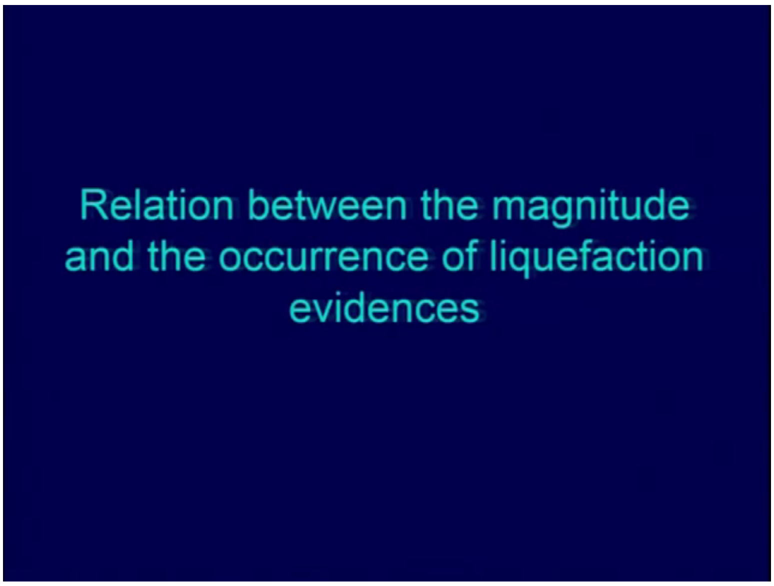

Another picture of the similar phenomena: so, this is the relationship between the magnitude and the occurrence of liquefaction evidence as I was talking about that. We can look at the old liquefaction features and even try to understand that which area have a maximum intensity or the impact because of the liquefaction.

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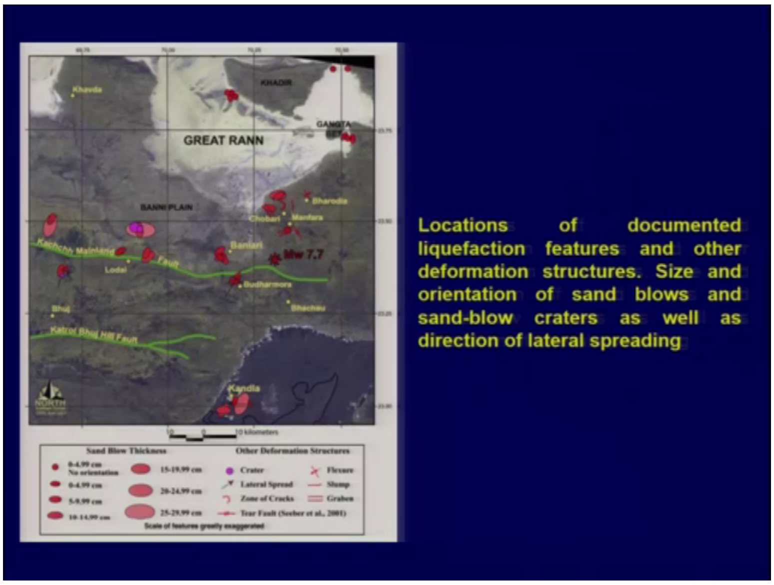

So, this was another excise done by one of the teamafter 2001 Bhuj earthquake looking at the dimension of the on the features. So, this is the sand blow thickness 1 ok. And even they along with the thickness what type of features where have been formed either it was crater, the lateral spread, or the cracks, or the tear falls, or the fracturing, slumping, rabbing or that is the depression which have been formed.

So, if you if you come close to the previous like slide which I was showing this area was having a very large features. The dimension was almost 25 also this is a sand thickness ok. But as they moved away from the epicenter the size reduced. So, there is another advantage which one can take and then type of the features which will be experienced or observed in the epicentral area.

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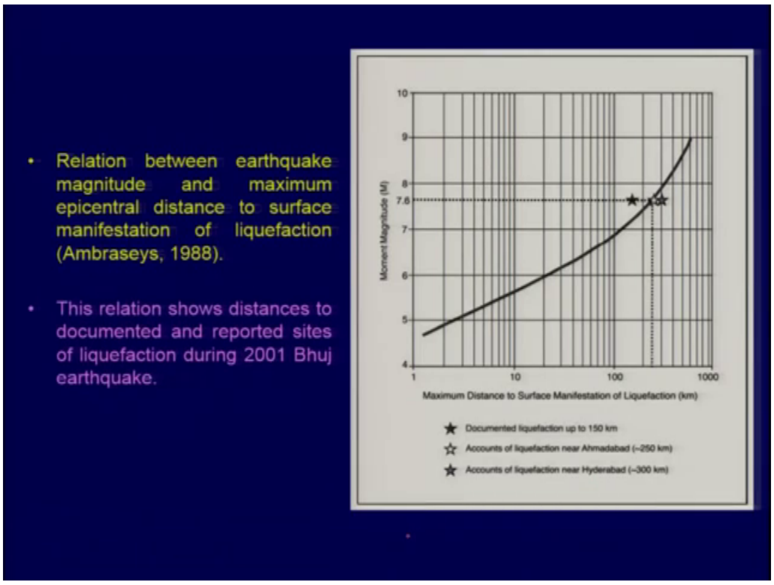

So, design relationship which talks about that the moment magnitude which has been given on the y axis here~~. And~~ and then maximum distance to surface manifestation of the liquefaction. So, how form you can expect the liquefaction features if you are having in particular magnitude triggered in the region. So, even if you are sitting up way this is what I was talking about. So, this is an logarithmic scale which shows up to it. So, 7.6 was or 7.7 was here now 2001 bhuj earthquake.

So, what one can expect if the ideal condition prevail that you will have an liquefaction which is more than 200 kilometers away you can you can experience. So, this is an documented liquefaction which was observed up to 150 kilometers within the filled star. And then the another one is the will white star you are having count of liquefaction near and above which is sitting almost 250 kilometers. And this was the far this near Hyderabad that is 300 kilometers.

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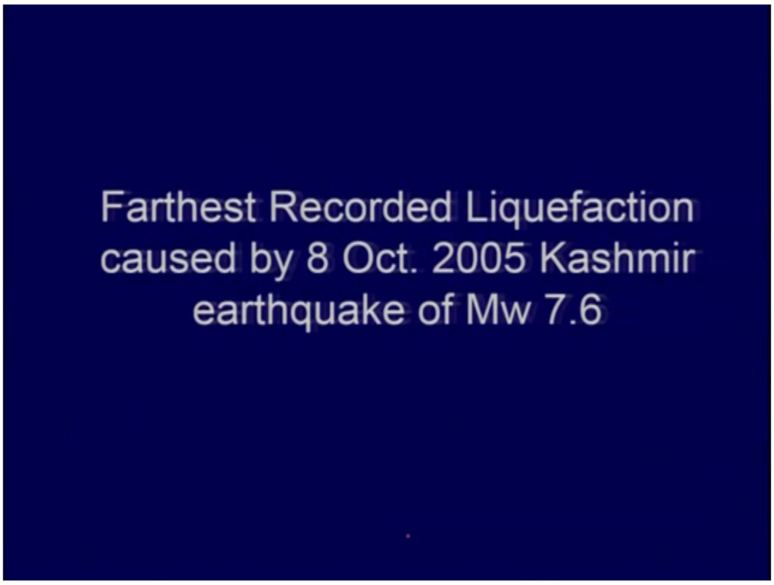

So, we also did one small exercise after 2005 Kashmir earthquake or you can say Muzaffarabad earthquake. The epicenter was in Pakistan the magnitude was 6 7.6.

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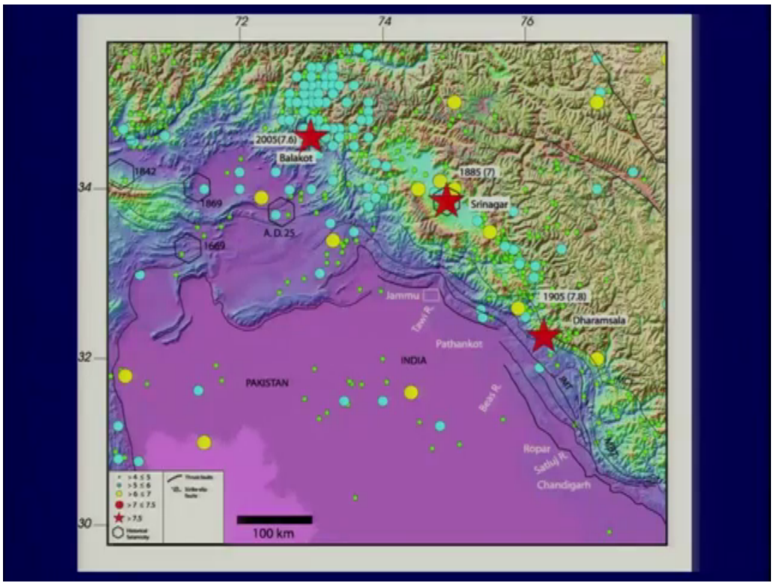

So, when we were doing field somewhere in the close region we found that there was a news talking about that there is an liquefaction or fissures or the cracks which were formed close to Jammu.

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So, we immediatelywent there and then did a very small one day fieldwork to look for the liquefaction features. So, we also observed some cracks or the openings which developed in pakka houses. And then typical fissure sand blows which were have been observed close to the riverbank of TAVI.

And there were very small sand blows here and very deep crack which was also observed. And then what we found was this crack was along the boundary wall ofpond. And this is an typical of a lateral spread.

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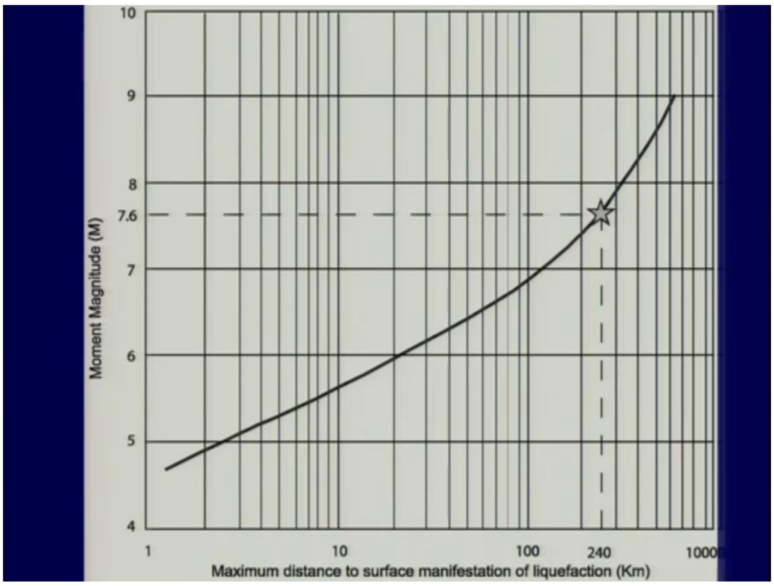

So, when we compared with the magnitude again at the location of the Jammu from the epicenter was almost 240 kilometers. So, this is what we say the for this recorded liquefaction during 2005 Muzaffarabad or Kashmir earthquake. So, what I can do is I could stop here and maybe we will continue in the next lecture talking about monitoring seismic activities.

Thank you so much.