

REMOTE SENSING FOR NATURAL HAZARD STUDIES

Course Instructor: Dr. Rishikesh Bharti
Associate Professor
Department of Civil Engineering
Indian Institute of Technology Guwahati
North Guwahati, Guwahati, Assam 781 039, India
e-mail: rbharti@iitg.ac.in
Website: <https://fac.iitg.ac.in/rbharti/>

Lec 33a: Remote Sensing for Liquefaction Studies - II Part A

Hello everyone, today we will continue our discussion on liquefaction. So, this is the third lecture on liquefaction; this is module 9, and today's lecture number is 33. So, before I continue, I would like to summarize what we have learned and discussed in the last two lectures. So that you will be able to perceive exactly what I mean by using geospatial technologies in liquefaction studies. Because once you understand the pros and cons and what parameters govern this liquefaction hazard, you will be able to understand how to utilize your geospatial techniques in this study. So, as we know, liquefaction is a phenomenon observed in soil due to earthquake loading, and here you have also seen this video.

In the last two lectures, this explains how liquefaction occurs for a particular given reason. So, liquefaction is a phenomenon in which soil loses its shear strength, and because of this shear strength reduction, there will be failure under this loading. Excess pore pressure generation results in a decrease in shear strength. So, if you have seen this video because of the shear strength reduction and how it decreases due to the excess pore pressure, and the decrease in shear strength.

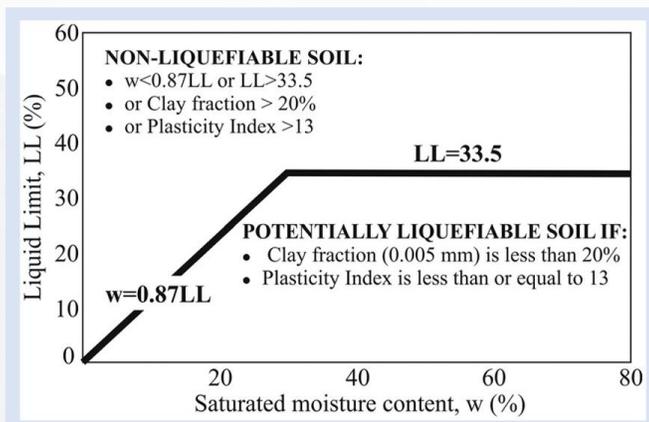
It is unable to bear any kind of load. So, because of that, this building will fail here. Liquefaction is observed in loose granular deposits with a high groundwater table because, unless you have water coming and interacting with this loose granular sediment, the shear strength will not change. And, since shear strength is reducing because of the interaction of this water with loose granular sediment, this load will not be sustained over this material. So, liquefaction occurs only in cohesionless soils, which is one of the parameters that is very, very important; soils that do not have cohesion are more susceptible to liquefaction.

Cohesionless soils are a type of soil whose particles do not stick together. So, when we talk about this cohesionless soil, let us try to understand what I mean by cohesionless. So, cohesionless soils are a type of soil whose particles do not stick together. Their strength primarily comes from the friction between individual grains rather than from any binding agent. So, once you have the interaction with the groundwater, and this is the loose

granular sediment, and here you have the groundwater, which is very near, and during the earthquake event, what happens is these come together, and the shear strength of this particular layer will be reduced substantially, and then the building or any load that is here will try to fail.

So, the role of groundwater is very important here. Now, why am I discussing it again? Now we will be identifying some of the critical parameters that we will be investigating through geospatial techniques. Then, for the initial assessment of any area for any site,

Chinese Criteria (Wang et al, 1979)



Chinese criteria for susceptibility to liquefaction adapted to ASTM definitions of soil properties (after Perlea et al., 1999)

What we do is refer to Chinese criteria, and here we have also discussed that W is equal to 0.87 liquid limit. And this line is where the liquid limit is equal to 33.5 . So, for the non-liquefiable soil, the liquid limit is greater than 33.5 , the clay fraction is greater than 20 percent, or the plasticity index is greater than 13. So, if your soil has any of these parameters, then it is non-liquefiable soil. And, if your soil satisfies this criterion that the liquid limit is less than 33.5 , the clay fraction is less than 20 percent, or the plasticity index is less than or equal to 13, these soils will have the liquefaction potential.

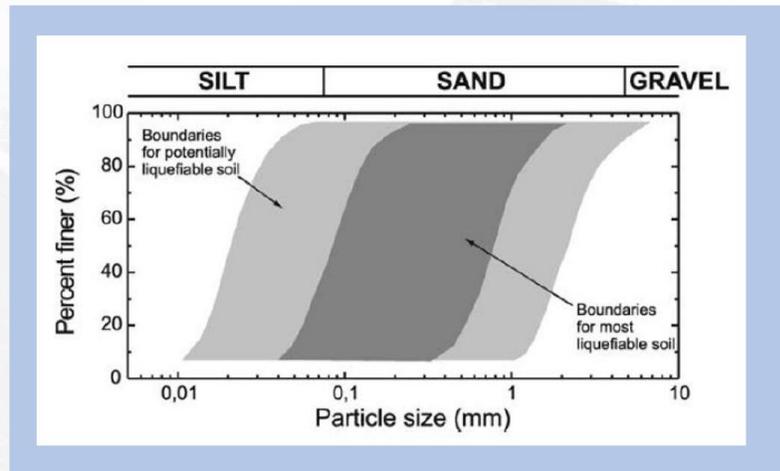
So, here the x and y axes are both given. So, I hope this is easy to understand. So, here is the initial assessment. Before we go for any kind of analysis, we simply derive the clay fraction, plasticity index, and liquid limit, and once we identify them, we will be able to tell whether this soil is susceptible to liquefaction or not. Like the Chinese criteria, we also have the Andrew and Martin criteria.

Here, the clay fraction is less than 10 percent, and the liquid limit is less than or equal to 32 percent, which has the potential to liquefy. For non-liquefiable soil, the clay fraction

will be greater than 10 percent, and the liquid limit will be greater than 32 percent. So these soils will be non-liquefiable.

Tsuchida Criteria (1970)

Ranges of grain size distribution for liquefiable soils (Tsuchida., 1970)



Similarly, we have the Tsuchida criteria. So, here you can see the particle size and the percentage of finer material that is used on the x and y axes.

So, what we do here is try to generate the particle size distribution for our soil sample, and then we see whether it is confined to a particular category or has this kind of distribution. If it is running across these sizes, then this is non-liquefiable, and if this is confined to one sector, say sand, gravel, or silt, then they have more potential to liquefy. So, this is how we try to assess the soils of any given region for liquefaction. Now, once we identify whether our soil is susceptible to liquefaction, we will go for further analysis. If it has the potential, then we will evaluate the liquefaction potential; otherwise, no further evaluation is needed.

This is very simple. So, initially using these two or three criteria, Chinese or Tsuchida, we try to identify whether the material or the soil is susceptible or not. If yes, we proceed and check for these parameters. The earthquake intensity of that area, earthquake duration, building load, groundwater, earthquake intensities of the table, depositional environment, aging and cementation, then confining pressure, drainage condition, soil type, soil relative density, particle shape, particle size distribution, and all these factors combined contribute to the chance of soil undergoing liquefaction. So, now we will try to investigate these parameters or any other parameters that can tell us the potential of liquefaction in our soil.

So, we have also seen that there are many laboratory-based methods that have disadvantages because they are time-consuming. And we should have the apparatus; we should have lab access; then only will you be able to generate all these parameters. If not, then we have to find an alternative. Similarly, Seed and Idriss in 1971 came up with the stress-based approach, and they found that the liquefaction potential is related to the standard penetration test and the SPT-N value. They investigated it further and came up with this liquefaction potential index.

So, before that, they tried to investigate this CSR and CRR. CSR characterizes the loading, and CRR tells us at what CSR the soil is susceptible to liquefaction.

STRESS BASED APPROACH



$$\text{Liquefaction Potential Index (LPI)} = \int_0^{20} F(z) \times w(z)$$

Where,

$$F(z) = 1 - FOS \text{ when } FOS < 0.95$$

$$F(z) = 2 \times 10^6 \times e^{-18.427 \times FOS} \text{ when } 0.95 < FOS < 1.2$$

$$F(z) = 0 \text{ when } FOS > 1.2$$

$$W(z) = 10 - 0.5 \times Z \text{ when } Z \text{ (depth below ground level is equal to or less than 20 m.)}$$

$$\text{Or else } W(z) = 0.$$

So, we utilize this CRR and CSR together to evaluate the liquefaction potential of soil or a particular site. So, this is the expression for liquefaction potential, where the F(z) value is 1 minus the factor of safety when the factor of safety is less than 0.95. When the factor of safety is within this range, we refer to this. When the FOS is greater than 1.2, then F(z) is 0 and W(z) is between 0 and 20 meters. And then we use this expression; otherwise, for all other depths, W(z) is equal to 0, and then we try to evaluate the liquefaction potential of that soil. So, using this liquefaction potential, we will have some numbers.

So, how do we interpret these numbers? So, when (LPI) is 0, liquefaction risk is very low. If (LPI) is between 0 and 5, liquefaction risk is low; if (LPI) is between 5 and 15, liquefaction risk is high; if (LPI) is greater than 15, liquefaction risk is very, very high. So, this is how we utilize this liquefaction potential index to determine the status of our soil. whether it is highly susceptible, moderate, low, or very low. So, with this, we will try to take some of the inputs from this understanding, and then we will try to utilize geospatial techniques in the liquefaction study. So, let us start with the very, very basic.

So, there are numerous approaches to evaluate liquefaction potential. So, we have seen lab-based, stress-based; now we are going with the geospatial technique-based. All the approaches require field investigations. So, there is no alternative to the field investigation that you need in the analysis. Field investigation is not always feasible because of accessibility issues; sometimes the site is not accessible, sometimes the apparatus is not accessible, and sometimes it is not feasible for other reasons.

Also, it requires a lot of money and manpower, which is not possible for everyone to bear. Geospatial techniques can be handy in narrowing down the area for field investigation, which can save a lot of time and money. Let us say this is a particular reason; it may be 100 thousand square kilometers. Now, where to start this investigation if there is no historical evidence of liquefaction or none of the researchers have reported any liquefaction problems here? Then, how to start your investigation? So, this geospatial technique can help you identify such hotspots to go for the field investigation. Liquefaction happens because of the excess pore pressure generation that we have understood from the previous lectures.

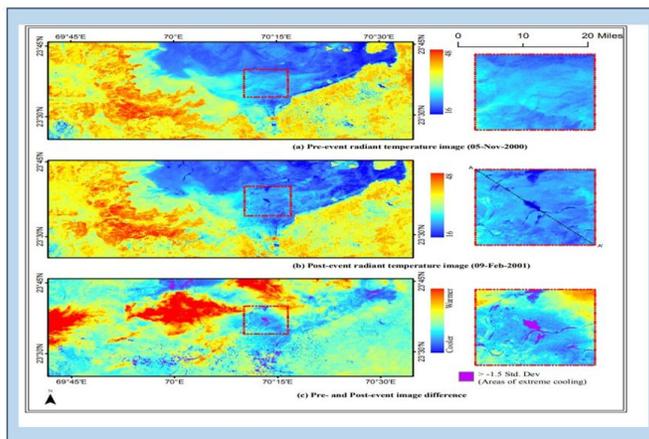
This would, in turn, increase the wetness of the surface. So, what is ultimately happening? If this is the surface, let us say this is the column and this is the groundwater table. So, during an earthquake event, what is happening? We have loose granular sand or soil here, and the groundwater table is very near the surface. So, during this event, saturate this particular layer, and during this, the wetness of the surface will change. Liquefaction locations can be identified by increased wetness or moisture in the soil because of an earthquake.

Now, since we are looking from space, what parameters can we identify? We can see how a particular area is showing the changes in wetness or soil moisture before and after an earthquake. So, the approach will be something like this: we have satellite data, and we will have pre-earthquake satellite images and post-earthquake satellite images, and then we will capture the wetness through different methods. We have various methods for optical and microwave remote sensing; similarly, we will go for the post-earthquake event. So, once we have these two wetness measurements before and after the earthquake event, we can find the difference in wetness to identify the liquefied location or the locations that have a high chance of liquefaction. So, there are different remote sensing methods.

So, we can talk about thermal remote sensing, then we have microwave remote sensing, and then we have optical remote sensing. So, when we talk about this optical, it covers both. It has the reflective and thermal domains. So, here I mean only the reflective domain. So, utilizing the 400 to 2500 nanometer wavelength bands, this is between 3 and 16 micrometers, and this is completely in the microwave remote sensing region.

So, here we have different techniques, and there are different studies available for thermal remote sensing, microwave remote sensing, and optical remote sensing. In today's lecture, I will be referring to some examples from such published literature. So, when we talk about this thermal remote sensing, the satellite data is collected for pre- and post-earthquakes because one very important thing to note is that this liquefaction happens only during the earthquake event, and then we have this groundwater and this granular or loose material interacting with the Material, and then we have this liquefaction problem. So, by using this thermal remote sensing, we can also map the increased moisture content or the change in moisture content before and after the earthquake. Using thermal remote sensing, temperature can be captured, and this can provide you with more information about the surface characteristics.

THERMAL REMOTE SENSING (CASE STUDY)



Landsat ETM+ radiant temperature image in Degree Celsius ($^{\circ}\text{C}$) (a) pre-event (05-Nov-2000), (b) post-event (09-Feb-2001), (c) pre- and post-event radiant temperature image difference corrected for the seasonal changes and overlaid by regions of extreme decrease in temperature, i.e. > -1.5 standard deviation filtered (inset shows zoom of the region within the study area) (Oomen et al., 2010).

So, Oomen et al. (2010) used thermal remote sensing to detect liquefied locations. So, the study area was the Kutch region, and he used this Landsat ETM+ data set. The analysis was cross-checked with the field investigation results from Singh et al. (2002). So, they had the field information. So, he validated his analysis, which is derived from Landsat ETM+. With this published literature, they found that satellite remote sensing provides an alternative to identify the liquefied or liquefaction potential zone. The Oomen et al. (2010) analysis was based on the hypothesis that, due to liquefaction, soil moisture increases and, in turn, decreases the sensible heat. Because during the liquefaction, the groundwater comes in contact with the surface, and as a result, the moisture condition

will change, and the sensible heat will also change. So, he used this approach, and then he identified the locations of liquefaction. So, the Landsat ETM+ radiant temperature image is in degrees Celsius. So, here you can see that the degrees Celsius are given. The pre-

event is on 5th November 2000, and the post-event is on 9th February 2001. These two images were used. Pre- and post-event radiant temperature image differences were corrected for seasonal change and overlaid due to an extreme decrease in temperature greater than minus 1.5 standard deviations filtered. Zoom in on the region within the study area, and this is from Oman et al. 2010. So, here you can see that these images can tell you A, B, and C, which will help you understand the potential of geospatial techniques. Limitations, as we have seen in the application of geospatial techniques, also present a few limitations. So, let us talk about the limitations of thermal remote sensing. So, the first one is the coarse resolution that, if you remember, at the beginning of this course, I discussed why thermal remote sensing has a coarser spatial resolution, which is one of the limitations. And, if your study area has one liquefied zone, that is, let us say, 60 by 60 meters, and the spatial resolution itself is in the order of 60 to 90 meters. So, in such cases, these locations will not be easy to detect.

Rainfall occurred between the periods of pre- and post-earthquake image acquisition dates. So, what happens? We are talking about the reflective and thermal domains, which are influenced by atmospheric scattering. And, it is also disturbed because of the presence of cloud cover, as we are talking about the shorter wavelength range of 400 to 1600 nanometers.

Here, specifically, we are talking about the thermal 3000 to 16000 nanometers. So, this is greatly influenced by your surface and atmospheric characteristics. So, that is one of the major disadvantages the cloud cover. So, this will restrict you to using thermal remote sensing data, but in case there are cloud-free and very good images of thermal remote sensing available for your study area, you can utilize them to identify the liquefaction potential. Then let us talk about the microwave because optics have limitations with cloud cover, haze, aerosol, and rainfall, but microwaves come with all these advantages. So, satellite data is again collected here for pre- and post-earthquake events, and ground subsidence is noticed because we know that microwave remote sensing can be utilized to identify surface deformation.

And, if there is liquefaction happening in some areas, this subsidence or uplift, anything can be identified easily with high spatial resolution using this active microwave remote sensing. Liquefaction locations are identified from the ground subsidence because when we talk about this area, and it has subsidence or liquefaction, there will be subsidence. So, these can be easily identified using microwave remote sensing. So, there are two approaches to microwave remote sensing. The first one is differential interferometry of synthetic aperture radar data, and the second one is the coherence image.

So, we will see in detail how these two techniques are used in liquefaction potential studies. We will continue this discussion in the second part of this lecture. In the second

part, we will further discuss the application of geospatial techniques in the liquefaction study.

Thank you.