Applied Seismology for Engineers

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Week – 12 Lecture - 02

Lecture – 29

Hello everyone, welcome to lecture 29 of the course Applied Seismology for Engineers. In earlier lectures, we have discussed, started with earthquake occurrence, how to distinguish between active faults and inactive faults, and how to quantify earthquake-based loading in terms of seismic hazard. Later on, we discussed how this loading, which is going to be generated because of seismic waves at the bedrock level, will get modified by local soil in terms of ground response analysis, particularly related to numerical methods of assessing the local soil effect. Later on, we discussed liquefaction assessment as well as landslide occurrence. Later on, we have also discussed seismic microzonation practice, how one can quantify the hazard index values, taking into account various geological, geotechnical, tectonic, and other parameters of a particular region and its possible variation, which will help us in understanding what are the locations within your study area that can be considered as relatively lesser affected by earthquakes and their induced effects and what are the areas that are more likely to be affected by means of earthquake occurrence in a specific exposure time.

This information can be used further in order to go for the planning of cities and site selection for important structures such as hospitals, schools, and relief camps, which can be used as shelters in case there is an earthquake hitting a particular site or a particular region for which suitable microzonation maps are available. In lecture 28, that whenever earthquakes are hitting a particular infrastructure, there are case studies in which fatalities in terms of maybe 10,000 people to as high as maybe 1 lakh people have lost their lives primarily because of earthquake occurrence and the response of the infrastructure to those earthquake occurrences. In addition, we have also seen that a significant portion of fatalities is also reported. In addition, there will be economic losses also. Whenever we are talking about economic losses, these are in terms of maybe hundreds of millions to several billions of dollars. That is the amount of money at the same time one has to pump into in order to go for rehabilitation work, to supply medicine, essential items, and even to supply food to affected areas during a particular earthquake. So, in the last class, that means lecture 28, we discussed seismic vulnerability and risk studies.

In an earlier lecture, we discussed that whenever earthquake-based hazard is there, which will be exposed or which will be applied to a particular infrastructure, depending upon the infrastructure capability, depending upon its intended use, sometimes the infrastructure may undergo partial damage, complete damage, or collapse. So, that is going to reduce its withstanding capacity for earthquake-induced loading conditions, which will come under vulnerability. Definitely, whenever we are going with risk assessment, that means what is the risk involved if a particular infrastructure undergoes failure. So, whenever risk is coming into the picture, we have three components. The first one is related to vulnerability, which will get input from seismic hazard analysis. So, you will have seismic hazard analysis, you will have vulnerability, and the third part is exposure. Whenever we are talking about whether it is about the building, what is the hazard corresponding to what exposure period the hazard is given, and in that particular exposure period, what are the buildings available, what is the design life of those buildings? So, collectively, based on these three parameters, one can assess the risk part. In lecture 28, we also discussed that whenever we go for vulnerability studies, primarily, we will be using two methods. One is the empirical method, which is primarily based on rapid visual screening. That means you will go around a particular site of interest or a particular building of interest for which you are interested in performing vulnerability studies. So generally, a screener will be there who will go around the building. If possible, you can go inside. If you get inside, then you will get maybe some more ideas about the building classification and the building characteristics. Later on, that can be clubbed with respect to the type of building and the associated score, which is given in the standard charts. So, in today's class also, we will be discussing how to assess the score, both the building base score as well as the score modifier, depending upon the type of building, depending upon the type of construction material, then depending upon the number of stories, whether the building has some kind of regularity in plan or in vertical dimensions, and subsequently many more details, which will help in getting modifiers with respect to the base score in order to come to a score that is rapid visual screening-based score in order to get the vulnerability of a particular building.

So, this we have discussed. This is just a brush-up of whatever we have discussed in lecture 28. So, rapid visual screening (RVS), this is an empirical method to go for vulnerability studies. Here, it is one of the most popular empirical methods because, firstly, you can find out the vulnerability or the score of a building very quickly. So, it is a kind of empirical method to find out the vulnerability of a particular building. It is developed by the Forensic Emergency Management Agency, that is FEMA, in the year 1998. The second edition of these guidelines, primarily related to rapid visual screening, was given in the year 2002. Subsequently, it was revised in the year 2015. It is a cost-effective tool because the guidelines are very much defined. So, you can just go around a building, find out, specific to those guidelines, what are the details that are available in the building, and then go ahead with the development of the score, base score, as well as score modifier. It is based on visual screening of the building by means of a sidewalk around the building, which will take a maximum of maybe 15 to 20 minutes, maximum 30 minutes. In case an expert is there, it is fine. Otherwise, if an expert is not there, you can train people about specific details, which one has to look into in order to go around and get the information about the building. And interior, if it is accessible, it is very good. If it is not accessible, we can avoid the interior and then go ahead with the information that can be accessed, that can be seen from the outside of the building just by roaming around the building.

Primarily, the objective here in rapid visual screening is to find out maybe irregularities and in terms of what type of soil medium the building is constructed on because we know based on earlier discussions that whenever ground motions, whenever a building is located on a hard rock medium, whenever it is located on a stiff soil, whether it is located on soft soil, in all three cases, the ground motion, even if the site is located at an equal distance from your focus or epicenter, the ground motion in all three conditions will be significantly different from each other. When the ground motion is significantly varying with respect to site characteristics, definitely, this will have a direct impact on defining the vulnerability of a particular building. So, that is also one piece of information which, in addition to irregularity, one should look into.

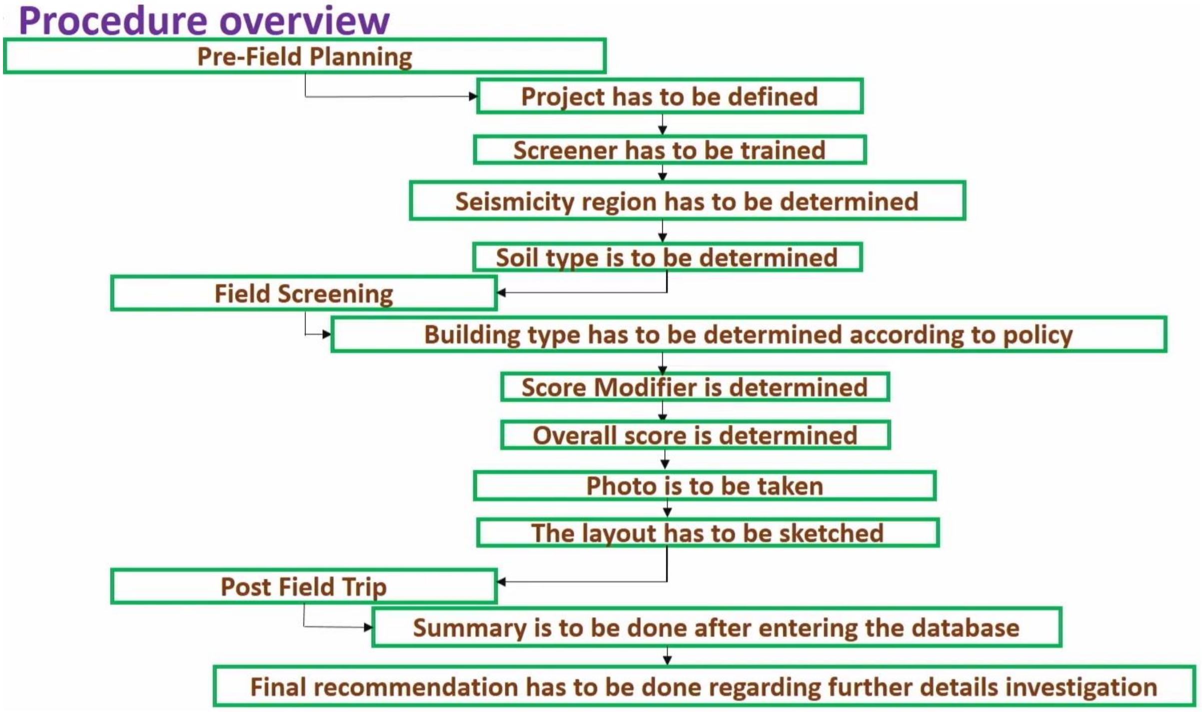
So, the interior need not be accessed, but if it is available, it can definitely give you confidence about what details you are looking for in terms of vulnerability study.

The purpose of rapid visual screening is that it is a preliminary screening process, based on which one can eliminate the need for a detailed investigation for certain kinds of structures, and then you can emphasize more on maybe more important structures or the structures that, based on preliminary investigation such as rapid visual screening, have been indicated as vulnerable. So, you can go ahead with maybe more important structures or the structures that are defined or found as more vulnerable based on rapid visual screening, and you can eliminate the structures that perhaps are not important as far as the study is concerned or are found as non-hazardous, non-vulnerable based on this particular part when, as far as earthquake occurrence is concerned. So, the limitation here is that, because in this particular method, you are trying to find out or assess the vulnerability of the building just by looking at specific details of the building.

So, what happened many a time is you are searching for some details of the building based on which the building is identified as vulnerable, but in actuality, the building is not vulnerable. Or, many a time, the building is actually vulnerable, but based on the scores—basic score as well as the score modified after the modifications based on different parameters—you find out that the building is not vulnerable. So, the actual building is vulnerable, but you are finding the building is not at all vulnerable based on the calculation. These are the limitations with respect to rapid visual screening. Some buildings, which are found vulnerable based on the study, may not be identified. So, that means there is a limitation. You are finding out the vulnerability based on some criteria, but actually, whether that particular building is vulnerable or not can vary from building to building and case to case. Similarly, there might be some buildings that are not vulnerable but are identified as vulnerable, primarily because that is how the guidelines are. But mostly, the objective here is to find out vulnerable buildings based on more specific details about the building, which we will come across further.

The experience of the person who is screening, as I mentioned, does not require any expert. But many a time, the screener can be trained for some time, and then the person can go and start screening the buildings that are there in a particular region or specific buildings that you are looking for as far as the vulnerability of important structures is concerned from a seismic point of view. So, the experience of the person who is going to screen the building is crucial as far as in-situ investigation is concerned. Because based on these identifications, based on these marks or understanding of the characteristics of the building, finally, you will be getting the score, and based on the score, you will be finding out the vulnerability of a particular building. If you recall lecture 28, we had decided to divide the building into two types. One is masonry buildings; the other one is framed structures, which are more or less covering the majority of the types of buildings nowadays. Then, in each of those building types, you have grade 1 to grade 5. So, grade 1 starts with almost no damages, and grade 5 is almost complete collapse for each kind of building. So, that is going to give us the kind of vulnerability each of these buildings corresponds to.

Whenever we are going with the base score or score modifier, we will take further details in order to arrive at the same parameter corresponding to the type of building. You can assign whether the building is highly vulnerable, or has low vulnerability corresponding to the given characteristics. Later on, you also take into account, whenever you go for risk assessment, that this vulnerability will be clouded with respect to the spatial distribution of seismic hazards, which is already in terms of a certain exposure period, primarily if you are going with probabilistic seismic hazard analysis. So, the procedure here, as far as he score modifier is concerned, is as follows.



Firstly, you go for pre-field planning. That means whatever information one has to look into when you are going to the field or to the site or a particular location or in a particular region, when you are going and assessing the specific details of various buildings in a location, you have to go with pre-field planning. What do you look into in pre-field planning? First, you have to define what type of project you are dealing with. Then, the screener has to be trained. It need not be an expert, but still, people can be trained with respect to the type of details one has to look into while going around different buildings. Mark the latitude and longitude, mark the address of those buildings, and mark the seismic zone in which the buildings are located because you are looking from a seismic vulnerability point of view. Then, you can go ahead with the seismicity of the region because later on, you will be determining the seismic vulnerability. That means determining the vulnerability of the building while keeping in mind the seismic aspect of a particular region. If you go ahead with seismic zonation map of the country, particularly for India, the entire country has been divided into four zones, starting with zones 2, 3, 4, and 5. The higher the seismic hazard of a particular zone, the higher the chances that your building is exposed to a larger level of ground motion. The building characteristics also indicate that the building is quite vulnerable and the loading characteristics also suggest that the chances of earthquake-induced loading are going to be significantly higher, it is collectively controlling the risk of the building and its intended user against failure. So, seismicity has to be defined.

Then, the next part will be soil type. As I mentioned, many a time, buildings are located on outcrops, buildings are located on weathered rock, and buildings are located on stiff mediums or there is some kind of utility that also exists in the case of a soft medium. If you go with the IS code (Indian Standard Code), again, the building classification and soil type classification are also given there. So, referring to that, if you are going for vulnerability studies for the Indian subcontinent, one can refer to those site classifications or site types, which are defined as per IS 1893:2016. So, you can go ahead with seismicity determination or seismic zone determination. You can go with soil type or the characteristics of the soil. So, it's like hard rock, stiff soil, and soft soil—these are the three types of soil defined in the Indian Standard Code IS 1893:2016. Then, you can start with field screening. Now, you know where your site is located, you have trained the person, you know what seismic zone your building or study area is located in, and, in addition, you also know the type of building you are targeting to perform a vulnerability study on and what the site conditions at which this particular building is located are.

Then, you start with field screening. That means the building type has to be determined. What type of building you are located in, which you can find out based on the type of construction material used for the building construction. In addition, you can refer to the policies in place to classify a particular building. Depending upon the type of building, one can determine what the base score is and then the score modifier, which will help in understanding how the base modifier or the base score has to be modified, taking into account characteristics—maybe the irregularities, maybe the number of stories, and many more things which we will discuss in the coming slide. So, firstly, you will determine the base score, and this will also give you, depending upon the building type, the factors one has to take into account in order to go for a score modifier. So, the score modifier means there was some base score corresponding to the type of building. Now, this base score has to be modified, taking different parameters into account, which are part of the score modifier as given in your form. Maybe whenever you are going for a field investigation, you will have a form, which I will show here. So, specific to that particular form, what details are asked? You look for those details and apply the score modifier according to your base score. So, you determine the overall score. So, you have a base score, and you apply a score modifier to that. Collectively, you will get an overall score based on which you can say, "Based on rapid visual screening, this is my overall score for a particular building or for n number of buildings separately."

A photo has to be taken. Many a time, irregularities present in the buildings may not be visible in terms of the site map or the building plan. But if there are irregularities present, maybe in terms of the in-situ condition of the building, irregularities present in the vertical direction, which may not be visible in plan, or irregularities that are identified based on site investigation and collecting information from the site, you get to know which were not there in terms of its plan, section, or elevation. That means you can go ahead with taking more photographs, getting additional details related to the score modifier. The layout has to be checked, as well as the sketch, to find out again what are the irregularities in terms of plan and what are the irregularities in terms of vertical elevation.

Post-field trips, that means initially, you decided what are the conditions you will look into based on the project you are looking for. Then, you went for field investigation, looked for a score modifier, looked for the building type, collected some photos, and also looked for the layout of the building in order to check whether whatever information about a particular building you have collected is also matching with the layout of the building. Then, post-field trips, what you will do is summarize whatever work you have done in terms of entering the database for different kinds of buildings. So, in these specific forms related to that form, you can actually note down the specific details which will be helpful in determining the base score as well as the score modifier. Then, final recommendation—that means based on your base score and your modified score, now you are having a score value. Based on this score value, you can categorize or grade whether it is about a masonry building, whether it is about a framed structure, what is the vulnerability of that building, whether it is not vulnerable, whether it is vulnerable, or whether it is highly vulnerable. So, you can identify or establish that understanding about a particular building.

For data collection, in this explanation, I have referred to documents which are given on the Ministry of Home Affairs webpage, referring to the forms generated by Sinha and Goyal (2004), which are again referring to FEMA 154/ATC 21-based forms. So, that was the basic guideline based on which one can perform vulnerability studies for a particular building, which has been referred to in the Ministry of Home Affairs, Government of India. This particular form can also be downloaded from that particular website. Now, here, the data collection form consists of—particularly, the first one is seismicity. That means, whatever building, whatever study area you are need to look into what the seismic zone is in which the particular study area is located. Accordingly, the form is to be taken according to IS 1893:2002. Subsequently, in 2016, the seismic zonation map of the country was given for the Indian subcontinent. So, in total, the country has been divided into four zones: seismic zone two, minimal seismic hazard, and seismic zone five, corresponding to the highest seismic hazard.

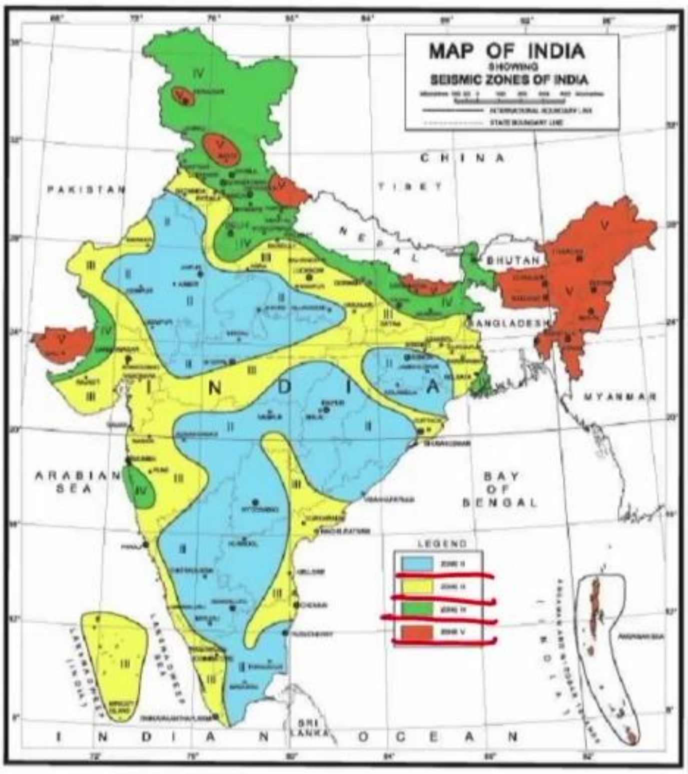


Figure 1: Seismic Zonation of India ((IS:1893-1(2016))

This is a map of the country. So, you can see here the regions which are marked and what the zone is in which each of these regions is located. Go ahead with the legends given in the right-side corner. You can see different color codes given—green, red, blue, and yellow.

Correspondingly, if your study area is located somewhere over here, that means you are talking about seismic zone two. Similarly, if you go to the northeastern part somewhere over here, you are looking into seismic zone five as far as the seismic zonation of your study area is concerned, which is asked in the seismicity condition. So, the entire country is divided into different seismic zones. Wherever your building is located, wherever your study area is located, for which one has to perform a seismic vulnerability study, you can refer to this code and get the seismic zonation information for that particular study area.

Then, building information. The seismic zone is spreading over a larger area, so whenever it comes to a specific building, you have to note down the details and finally submit the report corresponding to the vulnerability assessment. So, go ahead with finding out detailed information about the building, primarily the address. You have to find out where exactly the building is located. In addition, you can also give the latitude and longitude. Latitude and longitude will help in locating the building over the map, and the address will help in locating the building in actual field conditions. Then, ground motions—whenever we are going for vulnerability studies, what is the ground motion that we are expecting the building to be exposed to? One can refer to seismic zonation maps, and for each of these zonation maps, again in IS 1893:2016, the average horizontal design coefficient is given. One can refer to those and subsequently determine what the expected ground motion is, taking the natural period of the structure into account. Corresponding to this, you can go ahead with the design response spectra. Again, corresponding to the site condition, you can pick up what the spectral acceleration will be, take into account the importance, take into account the response reduction factor, and then you will be able to determine the ground motion to be considered. If you are using a seismic hazard-based map for a particular building, then you can directly pick up the value of seismic hazard and then proceed with ground motion determination.

Since ground motions are primarily determined in seismic hazard analysis, most studies determine the seismic hazard values for site class A or B, which correspond to very hard rock conditions. If your building is not located in that particular site condition but rather on strip soil or soft soil, that has to be noted. Also, whenever we are gathering building information, where the foundation of the building is actually located must also be looked into and reported as soil type. That has also to be reported in the form. So, you have the building information, the seismicity information, and the ground motion information to which the building is likely to be exposed. Based on this, you will be interested in determining the vulnerability of a particular building. Then, what code has been used to design this particular building? There are different codes. Which particular code has been referred to in order to design the particular component? If you are primarily talking about a framed structure, what codal provisions have been followed? That also has to be reported in the form. Then, information about the architecture of the building also has to be reported, primarily to take into account irregularities—whether in terms of plan or elevation—so that they can also be considered. These are the pieces of information corresponding to building type, which must be taken into consideration for the data collection for vulnerability assessment of a particular building.

So, we have information about the seismicity, information about the building, and soil type. We have started from the zone and reached the site, then the building type. What is the type of the building you are targeting? Corresponding to that building type, what is the basic score or base score? The base score means the score of the building depending on the type of the building. What type of building is it? Corresponding to that type, you can establish or get a value for the base score from the next slide, take that into account, and successfully modify it by considering other characteristics, which will also be shown in the next slide. So, when we are talking about building type, it means what has been constructed. Similarly, what are the guidelines that have been avoided while constructing a particular building? There might be some guidelines by the district administration, which must also be followed in addition to codal provisions whenever we are constructing a particular building. Those can also be noted down, in addition to the design code as well as architectural details.

At the same time, you should also report if there are irregularities or if there are no irregularities present in the building. Primarily, when we go for a basic score, it solely depends on the type of the building. So, it will not take into account any kind of irregularity present in the building. It will only consider the type of building. So, building type and basic score—that means, based on the pre-field investigation, you have decided what area to survey to determine vulnerability. Then, you narrowed down the study area, went to the site, and, referring to the building type and the basic score mentioned over here, you can assign a particular building the type of construction that has occurred for that particular building.

So, as per the National Policy of 2004, 10 building types are fixed for which the basic score was evaluated. That means, following the National Policy of 2004, primarily 10 types of buildings can be found in the field, and corresponding to each of these types of buildings, the basic score has been estimated or evaluated, which one can take into account while going into the field and finding a building. So, if I am going to a particular location and there are 10 buildings that I have to survey, what I can do is refer to this particular new National Policy of 2004 and assign a basic score to each of those 10 buildings that I am supposed to survey.

Building Type	Basic score (Seismic Zone II)	Basic score (Seismic Zone III)	Basic score (Seismic Zone IV and V)
Wood	6	4.4	3.8
S1 (FRAME)	4.6	3.6	2.8
S2 (LM)	4.6	3.8	3.2
C1 (MRF)	4.4	3	2.5
C2 (SW)	4.8	3.6	2.8
C3 (INF)	4.4	3.2	2.6
URM 1 (BAND +RD)	4.6	3.4	2.8
URM 2 (BAND + FD)	4.8	3.6	2.8
URM 3	4.6	3	1.8
URM 4	3.6	2.4	1.4

FRAME	Steel Frame
LM	Light Metal
MRF	Moment-Resisting Frame
SW	Shear Wall
INF	Burnt Brick Masonry Infill Wall
BAND	Seismic Band
FD	Flexible Diaphragm
RD	Rigid Diaphragm
URM 3	Unreinforced Burnt Brick
URM4	Unreinforced Masonry

So, these are the 10 types of building types, starting with wooden structures. Now, here we can see, again, depending upon the type of building and the seismic zone in which the building is located, you can get different values of the basic score. If you are taking vulnerability into account, that means the lower the basic score, the more vulnerable the building may be. So, you go with wood. If the building type is wooden, you can go with the basic score corresponding to 6. The basic score corresponding to seismic zone 2 will be 6. Similarly, if you are going with seismic zone 3, the building remains the wooden one, and your basic score will reduce to 4.4. If you are talking about seismic zones 4 and 5, your basic score again for the wooden building will be 3.8. So, the building remains the same, but depending upon where your building is located, if it is located in seismic zone 2, your basic score will be 6. If it is located in seismic zone 3, it will be 4.4. If it is located in seismic zones 4 and 5, the basic score will be 3.8.

So there are a number of terminologies given over here. After wood, one can refer to this kind of chart, which is given on the right-hand side. So, whenever a frame is coming into the picture, which is given over here. That means you are talking about a steel frame. Wherever LM is coming, that means you are talking about some light material, which is given over here also. Similarly, MRF is there. Mostly, you will find moment-resisting frame buildings. So, then you can go with MRF, moment-resisting frame. So, these are the expanded forms for different abbreviations given over here. So, you can see, at the site, you can have a wooden frame, you can have a steel frame, you can have a light metal building constructed, and you can have frame structures. Then, in case shear walls are present, SW can be there. So, you can say C1, C2, and INF (used for burnt bricks are used as far as the masonry infill is concerned). If, for masonry infill, burnt bricks are used, then you can say INF.

So, corresponding to INF, the basic score will be 4.4 in seismic zone 2. In seismic zone 3, it will be 3.2, and in seismic zones 4 and 5, it will be 2.6. Similarly, "BAND plus RD," which is given over here as "BAND," means seismic bands are provided at different levels in the building, and then RD means rigid diaphragms are also provided. So, that means you need not only look for one specific detail in a particular building but the majority of the details, which, based on walking around the building, can give a lot of information, primarily about what type of building it is. You can get more information primarily from getting more data about the building—maybe the plan also, if it is available, and maybe the design details, if available for a building. If you are talking about a recent building, then corresponding to the details that are there with us, we can find out if shear walls are provided in the building, if there are seismic bands in the building, if there is a diaphragm wall—rigid diaphragm wall or flexible diaphragm. Those also can be referred to while determining the building type or, more than building type, other details. Then, URM is there, that means unreinforced burnt bricks are used for construction. URM 4 means unreinforced masonry has been used for construction.

In case, in addition to this, you have more than one type of detail matching your building type, you can refer to this and get what should be your basic score. You cannot have a combination of this. So, if you find that shear walls are available, then you can go ahead with C2. Depending upon where your building is located, whether it is in C2, zone 2, 3, 4, or 5, collectively, you can determine the value of the base score. The base score is primarily based on the building construction—how the construction has happened and what details are primarily related to offering resistance to earthquake-induced loading conditions. So, if you see here, "shear wall" means shear walls are provided in order to avoid the kind of failure primarily caused by earthquake loading conditions. Similarly, diaphragms are provided, or unreinforced burnt bricks are used, or unreinforced masonry is used, which has been the primary source of building type. This itself is going to give you an understanding of what type of resistance the building is going to offer during a particular earthquake loading condition in order to understand the vulnerability of that particular building.

So, this is going to give you a basic score for the building type. You go to a particular site, 10 buildings are there. Look at each of these buildings and compare the type of construction material and construction practice, which is given over here, and come up with the basic score of a particular building. Then, you can go ahead with further details, more specific details about the building, which will be part of the score modifier.

Score Modifiers for seismic Zone IV and V (Sinha and Goyal (2004), Ministry of Home Affairs, Government of India (FEMA-154/ATC-21 based form))										
Building Type / Parameters	Wood	S1 (FRAME)	S2 (LM)	C1 (MRF)	C2 (SW)	C3 (INF)	URM1 (BAND+RD)	URM2 (BAND+FD)	URM3	URM4
Mid Rise (4-7 stories	N/A	+0.2	N/A	+0.4	+0.4	+0.2	+0.4	+0.4	-0.2	-0.4
High Rise >7 stories	N/A	+0.6	N/A	+0.6	+0.8	+0.3	N/A	N/A	N/A	N/A
Vertical Irregularity	-2.0	-1.0	N/A	-1.5	-1.0	-1.0	-1.0	-1.0	-1.0	-1.0
Plan Irregularity	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
Code Detailing	N/A	+0.4	N/A	+0.2	+1.4	+0.2	N/A	N/A	N/A	N/A
*Soil Type I	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4	-0.4
*Soil Type II	-0.8	-0.6	-0.6	-0.6	-0.6	-0.4	-0.6	-0.6	-0.6	-0.6
Liquefiable Soil	-0.8	-1.2	-1.0	-1.2	-0.8	-0.8	-0.6	-0.6	-0.8	-0.8

So, "score modifier" means now I have achieved, based on the type of building, a basic score. That means, depending upon the type of construction the building has undergone, you have established a basic score. Then, corresponding to further details, this basic score will undergo revisions or modifications. That is why it is called a score modifier. So, what you will do in this particular part is observe the building for specific parameters or specific characteristics. Accordingly, the basic score will be modified. What are the specific details? Based on the type of building, if you found that it is a moment-resisting frame and it corresponds to mid-rise (meaning 4 to 7 stories are present in the building), then, if it is a modern building, there will not be any modifier. If it is a frame building, a 0.2 additional modification in the basic score will happen. If it corresponds to light metal, again, there will not be any modification in the basic score. If it corresponds to a frame-resisting frame, then you will have an additional modifier corresponding to 0.4, and so on.

So, it is like your building is there, based on which you have found the basic score. When you go for modification, the first line itself will, depending upon the type of building, allow you to pick a modifier appropriately. If your building height is somewhere between 4 to 7 stories, if the building height is greater than 7 stories, then you can go with the third row, which is going to give you a score modifier over a basic score for buildings corresponding to greater than 7 stories. If the building is greater than 7 stories and corresponds to a framed structure, you can go ahead with a 0.6 increase in your basic score. If it corresponds to INF, you can find the building type in the previous slide. You will get a 0.3 increase in your basic score. If you are going with the last type of buildings, there will be no further change in the score, so the score will remain as the basic score.

Similarly, if there is irregularity in vertical dimensions, you can visit a building. If you can get an idea about vertical irregularity just by looking at the elevation of the building, you can mark a modifier accordingly. Depending upon the type of irregularity present, you can find the corresponding score modifier from this particular figure. Again, there is irregularity in terms of the plan, which most of the time will not be visible in site details unless specific details—whether it is related to the plan of the building or some major irregularity in the plan—might be visible while going for screening around the building. Then, again, you can go ahead with the score modifier, referring to this particular chart. Code detailing—how much detailing given in the code has been followed while designing and constructing the building—so, corresponding to that, you can again pick up the score modifier.

Now, there is a difference between the basic score and the score modifier. Whenever we go for a basic score, that means, primarily, for a building, more or less, it will be of one type of building, or you can say the building type cannot be more than one. So, corresponding to that building type, you can assign the basic score. Now, whenever you are coming to the score modifier, then, corresponding to each of these characteristics and the type of building, you can pick up more than one set of score modifiers. That means, if there is irregularity present in the building and you are talking about MRF, a -1.5 factor or score modifier will come alone from vertical irregularities. Corresponding to plan irregularity, again, -0.5 will come corresponding to the MRF type of building. Similarly, if the building is corresponding to 4 to 7 stories, 0.4 plus 0.4 will be an additional modifier in your basic score. So, it is not only one factor that will come into the picture. With respect to these factors in the background, you will search for the details during field investigation, note down these details on the form given, and then, once you go for a score assessment, you can keep referring to these parameters and this particular chart, keeping in mind to modify the basic score. That will help in getting the final score, which will be called the overall score of a particular building or set of buildings for which one has to determine the vulnerability.

So, the score modifier continues here. According to IS 1893-2002, there are primarily three types of soil that are present, so you can refer to the design response spectrum given in IS 1893-2002 and later on in 2016 also. Hard rock is there, so that means, corresponding to the soil type or corresponding to the site condition on which the building is located or the foundation of the building is located, your response spectra will change. So, what are the three types? Hard soil—this is primarily defined as a soil medium having strength or having in-situ investigation-based assessment, where the SPT value or standard penetration test value is greater than 30 in the medium. That means you are talking about the building and the site condition. The site condition is such that the SPT value is greater than 30, which you are referring to as a hard soil condition. Similarly, you can go ahead with the medium soil condition. That means, again, the building foundation is located on another site or any other site on which the building is located. So, if you do borehole drilling and perform a standard penetration test at that particular site, your SPT (standard penetration test) value will be ranging between 15 and less than 30.

Based on in-situ investigation, you can find out the site condition on which your building and its foundation are going to rest or have rested. Either you can go with in-situ investigation to narrow down this particular detail, or you can refer to earlier performed investigations before the laying of the foundation for that particular building had started. Primarily, whenever we go for any kind of construction, we conduct in-situ investigations to find out whether the overcoming load from the superstructure on the base of the building, which is the foundation medium, will be able to withstand it or not. So, in order to understand the in-situ strength characteristics, most of the time, for important structures, there might have been some kind of in-situ investigation. It can be a geophysical investigation or a geotechnical investigation that might have happened. Based on those investigation reports, you can find out the SPT-N value or the standard penetration test value. If standard penetration test values are not available, you can refer to other details—maybe cone penetration test-based results, such as cone tip resistance as well as slip friction. You can refer to shear velocity profiling, which is available for that particular site, and correspondingly, you can assess an understanding of the site.

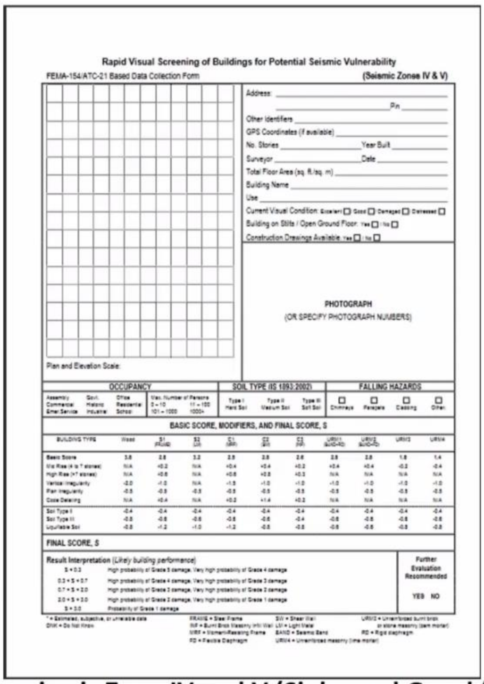
You can also convert the shear velocity to the standard penetration test value based on regional correlation. Again, that will help in identifying what type of soil condition is available at your site of interest, for which you have to take into account the site condition. If you recall, whenever we are going for building addresses and latitude-longitude, we have also mentioned that the type of soil condition on which the building is located has also to be informed and noted down. Again, soft soil is where the SPT-N value is less than 15. So, if the SPT-N value is less than 15, field investigation suggests that your site is located on a soft soil medium. So, the basic score must be defined based on the type of building, and you can modify that basic score based on the score modifier, referring to the previous slide. Also, refer to the site condition at which the building is located.

RVS Score	Damage Potential
S<0.3	High probability of *Grade 5 damage; Very high probability of *Grade 4 damage
0.3<S<0.7	High probability of *Grade 4 damage; Very high probability of *Grade 3 damage
0.7<S<2	High probability of *Grade 3 damage; Very high probability of *Grade 2 damage
2.0<S<3.0	High probability of *Grade 2 damage; Very high probability of *Grade 1 damage
S>3	Probability of *Grade 1 damage

So, the final score will be equal to the basic score plus the summation of the number of score modifiers, referring to the previous chart. The final score, S, is evaluated. So, the basic score plus the summation of all score modifiers will give you the S value. Once you have that S value, you can refer to the damage potential or vulnerability of a particular building. That means, if your S value—rapid visual screening-based—is less than 0.3, then there is a high probability of grade 5 damage, particularly if you are referring to a masonry building. If you are referring to framed structures, there is a very high probability of grade 4 damage if you are referring to masonry buildings. Similarly, if the S value ranges between 0.3 and 0.7, then there is a very high probability that grade 3 damage can happen in an RC building and a very high probability that grade 4 damage may happen in a masonry building.

So, in general two types of construction that have happened—masonry construction or concrete construction. Here, you are referring to both. Then, you can say either there is a high probability of grade 3 or a very high probability of grade 2 kinds of damages. This provides an understanding of vulnerability-based assessment. If the S value is greater than 0.7 but less than 2, you can say there is a high probability that grade 3 damage may occur to the building because this is correlated with respect to the damage. If you are interested in finding out the meaning of grade 2 damage or grade 3 damage, you can refer to lecture 28. Similarly, there is a very high probability that grade 2 damage may occur to your building for which you have found the RVS-based S score. If the S value is greater than 3, then there is a probability of grade 1 damage. That means the lower the S score, the higher the probability that the building may undergo grade 5 to grade 4 damages for a particular seismic zone.

Now, we have taken the seismic zone into account, the site condition into account, irregularities into account, storage into account, shear bands into account, and diaphragm into account. Collectively, based on that, you have determined the score modifier and then determined the value of S, which is the final score. Based on the final score, you have determined the damage potential.


Rapid Visual Screening of Buildings for Potential Seismic Vulnerability

FEMA-154/ATC-21 Based Data Collection Form (Seismic Zones IV & V)

PHOTOGRAPH

(OR SPECIFY PHOTOGRAPH NUMBERS)

OCCUPANCY | SOIL TYPE (IS 1893:2002) | FALLING HAZARDS

BASIC SCORE, MODIFIERS, AND FINAL SCORE, S

FINAL SCORE, S

Figure 2: Score Modifiers for seismic Zone IV and V (Sinha and Goyal (2004), Ministry of Home Affairs, Government of India (FEMA-154/ATC-21 based form))

Now, this is the form I was referring to. Here, you can find out the basic score depending on the type of building. This form has been taken from the Ministry of Home Affairs, Government of India's website for seismic zones 4 and 5, referring to Sinha and Goyal (2004). So, here you can see, based on rapid visual screening, you just go there, find out the address, give the address of the building, GPS coordinate (that is, latitude and longitude of the building), number of stories, how many stories are there when the building was built, who surveyed here, what is the date on which it was surveyed, total floor area, building name (if it is there). If you are talking about some important building, then current visual condition of the building (it was excellent, good, damage, or other things are also given). Then, you go to the building type. All these building types, which we have discussed a couple of slides back, everything is given over here. Then, in terms of irregularity, in terms of number of stories, in terms of soil type, so here it is given as soil type 1, 2, and 3. So, all these conditions are already there. You just take this particular form, go to a particular site, fill up all these details, and your database corresponding to a particular building, for which the building coordinates and the name of the building has been reported over here, is now ready. So, if you are targeting for 100 buildings, collect the same information for all those 100 buildings, then sit in your laboratory and determine the S score corresponding to the S score. Now, you have a better understanding in terms of the damage potential of a particular building.

Figure 3: Example1

There is one building, randomly taken. So, you can see over this particular building, a screener went to the particular building to find out what is the detail you can extract from this particular building. So, you can find out what is the seismic zone in which the building is located. Then, you can find out other details about the building. That means the address of the building, latitude, longitude of the building, all these things you can enter, you can report it here. Then, the building is a moment-resting frame structure (that is, MRF type of building), we have established. Building type would be C1, which is given again if you refer to the building type chart. So, basic score was corresponding to 2.5. Then, go with score modifier.

Mid Rise (4-7 stories	+0.4
High Rise >7 stories	+0.6
Vertical Irregularity	-1.5
Plan Irregularity	-0.5
Code Detailing	+0.2
Soil Type I	-0.4
Soil Type II	-0.6
Liquefiable Soil	-1.2

What are the score modifiers? The building rise or the number of stories, 4 to 7. So, you go over here, ground 1, 2, 3, so total 4 are there, including ground. So, you can pick up the score modifier. Here, it is a midrise building, so 0.4 + 0.4 will be the score modifier corresponding to the rise. Then, in terms of vertical as well as irregularity at plan level, there are available. So, accordingly, you can pick up corresponding to vertical and plan irregularity, what are the modifiers. It has been built with core detailing, so again you can take score modifier that can be decided based on the design of the building and comparing with respect to the exercise condition. Soil type is soil type 2, which is again, you can refer to different investigations done or maybe subsurface investigation at the site you can refer to and then assign this as corresponding to soil type 2. So, corresponding to soil type 2, you can pick up score modifier.

Final Score S = 2.5+0.4-1.5-0.5+0.2-0.6=0.5

Now, this was your basic score of 2.5. This is corresponding to mid-story or midrise. This is corresponding to vertical irregularity, plan irregularity, codal provisions, and then soil type or soil condition. And all these things you are getting a value of 0.5. If you refer this to corresponding to the chart, which was given one slide back, so 0.5 means you are talking about somewhere over here. That means your building has a high probability of grade 4 damage or very high probability of grade 3 damages. That is the damage potential of the building. Just by looking around the building, just by looking at the specific details of the particular building, we have come across. Similarly, we can collect for another type of building. So, according to the final score (that is, S value), the damage potential of the building is very high, with a high probability of grade 4 damage or very high probability of grade 3 damage. The screener can suggest a detailed investigation before proceeding with the risk assessment.

Figure 4: Example2

Similarly, another example is there. There is another building where again, the screener will go around the building and get the details. So, here also, following the same procedure which was there in the previous slide, the building is located in seismic zone 4. Note down the address of the building, coordinates of the building. The building is having burnt build infill wall structures that can be used. The building type would be C3. Basic score corresponding to C3 is

2.6. You can refer to the specific slide where the basic score corresponding to each of the building types was given.

Mid Rise (4-7 stories	+0.4
High Rise >7 stories	+0.6
Vertical Irregularity	-1.5
Plan Irregularity	-0.5
Code Detailing	+0.2
Soil Type I	-0.4
Soil Type II	-0.6
Liquefiable Soil	-1.2

And then, score modifiers are updated accordingly, corresponding to different stories. So, if you go here, it is corresponding to there being no vertical irregularities because the building is very much in level condition. It is more or less, you can see there are no irregularities, whether it is in vertical dimension or in plan. It is built with codal provision. So, corresponding to that, the score modifier of 0.2 will be taken into account. Soil type again, it will be corresponding to soil type 2 that can be estimated based on.

Final Score S =2.6+0.2-0.6=2.2

So, the final score in this particular case will be corresponding to 2.2. That means the basic score, soil type and codal provision are only available here and other information are not applicable. This is going to give you a final score here corresponding to the basic score corresponding to 2.6, okay? So, according to the final score, the damage potential, based on the S value, is high, with potential for grade 2 or very high potential corresponding to grade 1 damage for this particular building which is appearing on the screen. The screener may or may not suggest a detailed investigation because the type of damage potential highlighted here is relatively low based on rapid visual screening. This was about the empirical method, and we can start about the analytical method.

So, analytical method, as I mentioned earlier means you will be having numerical modeling of a particular structure. You will also try to find out based on laboratory investigation or push-over analysis, the demand capacity of a particular building, and then subjecting the building to different sets of input motion characteristics. We can have an understanding about the damage characteristics of the building corresponding to different ground motions. So, how you start with, you firstly perform the seismic performance assessment, has to be done, and then based on this, you can go ahead with fragility curve development. That is going to give you what is the cumulative probability of damages at different levels of ground motions. Taking that into account, you can get an idea about the damage potential and correspondingly, the vulnerability assessment can be performed for a particular building based on the analytical method.

Gravity Load	Earthquake Load
Direction does not change	Directions may change within a fraction of second.
There is always stretching of members at a particular location and that location does not change.	The location of the stretch may change due to changes in direction.
Tension and compression in members does not change.	The shaking reverses the tension and compressions in members. Hence, reinforcement is provided on both faces.
Bending Moment Diagram is constant	Bending Moment Diagram changes
Analysis can be done by hand calculation	Computational effort is needed to perform the analysis.

So, primarily, the structures are designed for gravity loads. Whenever you are going with earthquake loads, additional components of forces have to be taken into consideration. So, if you take into account what is the variation between gravity load and earthquake load, the first one is the direction of the loading. In gravity load, it is always vertical, acting downward. But in earthquake, the direction of loading is primarily in horizontal direction, changing within fractions of a second. These are always stretching of members at a particular location when we are talking about gravity load. But in case of dynamic loading, primarily the earthquake loading, this location of members undergoing more deformation, it keeps changing, tension and compression in the member does not change in case of gravity load. The shaking reverses, that means sometime there is compression, sometime it is tension in the medium or the material comes back from compression, and the compression will be generated to the other end or diagonally opposite end of the building. So, then this can be considered as tension. The bending moment diagram is constant whenever we are talking about static loading condition. However, in case of dynamic loading condition, that may vary. Analysis can be done relatively easy when we are going with gravity load in comparison to if you are taking earthquake loading into account.

Structural Model / Seismic Loading	Linear	Nonlinear
Static	• Equivalent Lateral Force Procedure	• Several Pushover Analysis Methods or Nonlinear Static Procedures (NSPs)
Dynamic	• Modal Response History (or Time History) Analysis Procedure (Modal RHA/THA) • Linear Response History (or Time History) Analysis Procedure (Direct Integration Linear RHA/LTHA)	• Nonlinear Modal Response History Analysis or Fast Nonlinear Analysis (FNA) • Nonlinear Response History (or Time History) Analysis Procedure (Direct Integration Nonlinear RHA/THA)

RHA-Response History Analysis

THA-Time History Analysis

Further, if you are going primarily with the understanding of the demand capacity of the system, there are different methods you can go with linear analysis, where you can find out what are the linear forces, equivalent linear forces which will be applicable in terms of earthquake loading condition. If you are going with non-linear analysis, you can see once you start applying the load, what are the components which have almost yielded or reached the state of failure? Then, there will be redistribution of loading characteristics, and that is how you can progress with non-linear analysis. I will not be covering all these details; this is just to give you an overview about what are the different methods which can be used for static as well as dynamic conditions to find out the demand or the capacity of a building and what are the external loading conditions. So, based on these two comparisons, one can have an understanding about the damage potential. So, pushover analysis can be performed to find out, corresponding to different values of shear, what is the tentative displacement which is going to be generated in a particular medium. If you are going with dynamic analysis, you can perform model response analysis or time history analysis procedure or response history analysis procedure in order to find out the dynamic loading corresponding behavior of a particular structure. This is corresponding to linear; if you are going with non-linear analysis, you can again go with fast non-linear response analysis or model response analysis.

So, I will stop here, and then we will continue this part in the next lecture, that is, lecture 30. Thank you, everyone.