Introduction to Engineering Seismology

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Lecture No-28
Prediction Relationships

Vanakkam, so we will start our engineering seismology lecture. So, as I told you that last class we will be discussing about the predictive equations in engineering seismology. So last class we have discussed the stochastic simulation model. So basically the stochastic simulation model we have seen that you can generate a synthetically the ground motion data. So those data's are generally used for getting your acceleration time history and thereby you can also go for developing a ground motion simulation, ground motion prediction equation.

So we are going to talk about the ground motion prediction equation in general, the predictive relations in the engineering seismology. So what is mean by the predictive relation? So this is the predictive equation or relation or model. So both are mean all of them are I mean pinpoint finally the same kind of meaning only. So the predictive model, or predictive equation or predictive relation is basically we try to give you the time domain or frequency domain parameter as the function of;

So the generalized parameters, so what are the generalized parameters? So, you can see that if you want to get any parameters;

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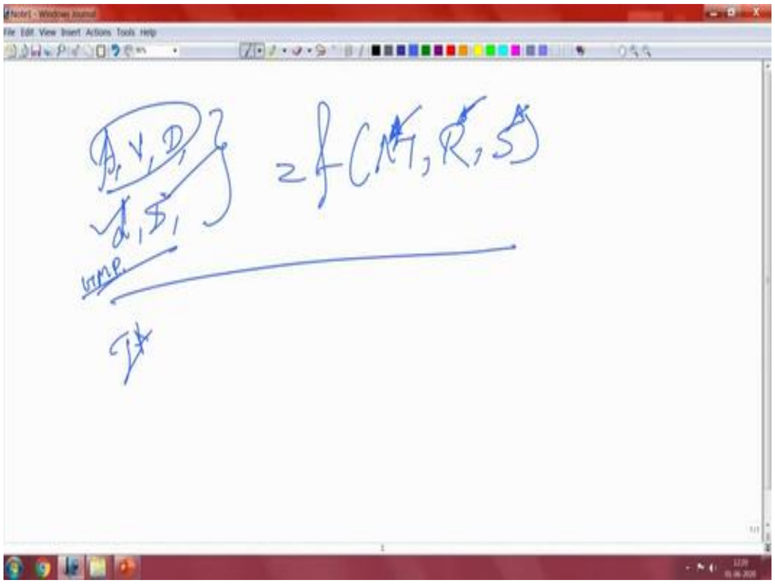

So the any parameters means basically acceleration values or velocity, so or the displacement, so or the duration, so duration, so or intensity, so anything, these are all the ground motion parameters correct that is what we have seen; these are all the ground motion parameters. So one earthquake you will get a one parameter. In a given region, you do not know what type of magnitude and distant earthquake are going to come.

So in order to get a wide range of parameters as the function of M, magnitude and distance some relation is developed this is the equation is the function of M and the R and the site. So there is M is basically a magnitude which represents your source, the R is basically the path and this is a site. So this kind of equation is called as a predictive equation, predictive model, and predictive relation.

So, the depends upon the what ground motion parameters, you are interested depends on that you might have seen that during the intensity I told there is a intensity predictive equation during the discussion of the duration, I told duration predictive equation during the RDS scale, I also told that the RDS scale is linked with the M and R where that is also some kind of predictive equation.

Similarly, the acceleration, velocity, displacement, predictive equations, also available that is called as a ground motion prediction equation, this is the ground motion parameter, acceleration, velocity, general predictive equation includes this three intensity, duration are given arias intensity or anything which you can interpret and useful for engineering application from the earthquake data in time domain or frequency domain.

So that is what it does in the predictive models, so today we are going to talk about those predictive models.

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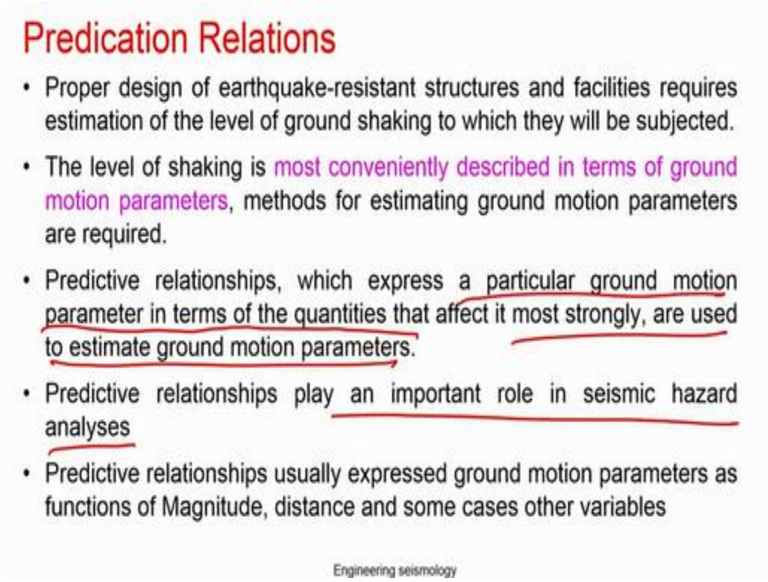

So, what those models? How it is basically used in that? What are the different state of art knowledge in the predictive relation? So the predictive relation proper design of earthquake resistance structure and facilities requires estimation of the level of ground shaking at which it will be subjected or even a damaged level, the intensity one. The level of shaking most conveniently described in term of ground motion parameters the method of our estimate in the ground motion parameters are required.

So, the predictive relationship which express a particular ground motion parameters, which may be acceleration, velocity, displacement, duration, arias intensity, that affect most strongly and are used to estimate to the engineering design parameters or estimation of the ground motion parameters. Predictive relation plays a very important role in a seismic hazard analysis, so this is mostly used to predict the hazard values for the future.

This is what based on the past earthquake develop your equation using that you can predict further future earthquake what is the acceleration expected, velocity expected, displacement expected, duration expected. Predictive equations are usually expressed ground motion parameters as a function of magnitude and distance and some cases other variables, which I told as a site.

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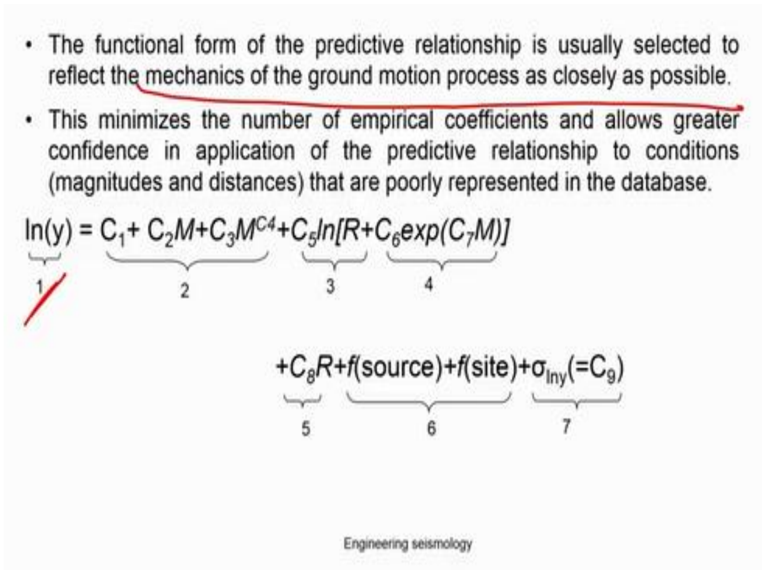

So the functional form of predictive equation usually selected to reflect a mechanics of the ground motion process as closely as possible in the region. So, the functional form for a particular ground motion prediction equation, even though it is said M and R is the predominant factor but the functional form varies with respect to region to region. So, you cannot use the same functional form for developing predictive equation in southern India and in northern India because of the seismicity difference similarly Western America and Eastern America like that.

The seismo tectonic regional parameters go has to be considered to make a functional form so this minimizes number of empirical coefficient allows greater confidence on application of the predictive equation to conditions, magnitude and distance that are poorly represented in the database. So the any predictive equation should be this is a left site, the ln of y and then C + CM + C3 M C4 + C 5 ln R + C 6 M, so, exponential of C7 M and C8 R the function of source and the site factors and then the C9.

So this entire equation has been segmented as here 7 parts we will discuss each part what it means. So that when you are going to develop a predictive equation, you need to consider this, as I told you in the last class I work on research on simulation of the ground motion and developing a prediction equation for the different parameters. So far I have developed the equation already for the duration prediction equation and ground motion prediction equation for north India.

And, ground motion prediction equation for the south India, Peninsular India, which already I published available in the publication.

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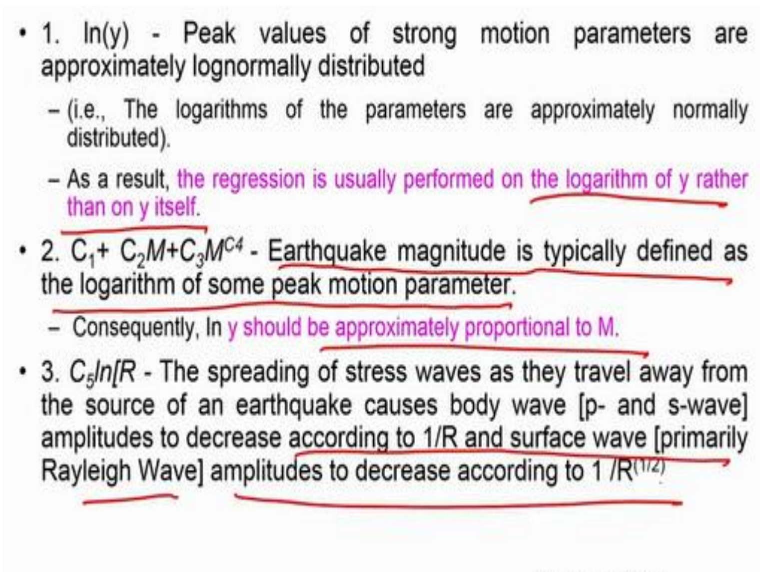

So the term one the ln, so basically here the peak values of strong motion parameters are approximately logarithmically distributed. So as we have seen that the magnitude one scale to other to other scale basically log base 10, the same way the predictive equation also should have the function of logarithm distribution that is why ln is used. The logarithmic of parameters are approximately normally distributed as a result the regression is usually performed a logarithmic of y rather than y itself that is why you use a ly.

So the term two which is C + C2 M and C3 M C4, so this earthquake take care the earthquake magnitude it typically defined as a logarithmic of some peak motion parameters. So this part taking care of the earthquake magnitude in the function. So the consequently y should be approximately proportional to the M. So the y should be approximately proportional to the M the C5 ln R the spreading of stress wave as they travel away from the source.

An earthquake causes a body wave P and S wave the amplitude decrease according to the 1 by R in the surface wave and the then amplitude decrease 1 by root R in the Rayleigh wave. So these kind of phenomena wave propagation has been modelled in the term 3, which we have discussed in the here term 3 is this one.

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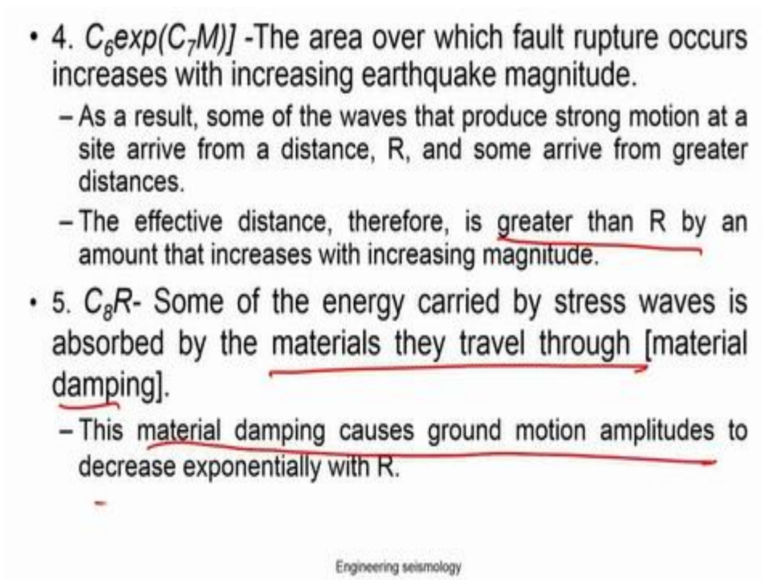

So the term 4, basically the area over which the fault ruptures occurs increases with increasing in the earthquake magnitude. So as a result some of the wave that to produce a strong motion at a site arrives from the distance R some arrives from the greater distance the effective distance therefore is a greater than R, so by account the increase in the increase in the magnitude. So, this term is modelled in the 4 part equation 4.

The 5, equation 5 is modelled some energy carried by stress wave absorbed by the material as a travel through which is like material damping, the material damping causes a ground motion amplitude to decrease exponentially with R, which is modelled in the term 5.

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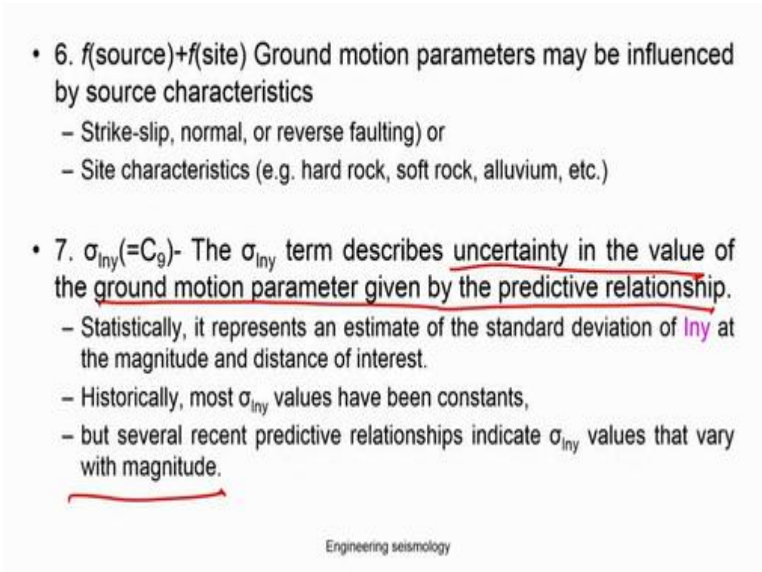

So the term 6, basically the function of source and site the ground motion parameters may influence by the source characteristics like the fault type strike-slip, normal reverse faulting and the size characteristic like rock site, soft site, alluvium site that part has to be taken care in the portion 6 in the equation. The 7 is basically the, so sigma ln y so this is basically term describe uncertainty values, in the ground motion parameter given by the predictive equation here are term.

Statistically, it represents an estimated standard deviation ly at the magnitude and distance interest. Historically, the most ln y values have been constant but several reason predictive equations indicated that the sigma ln y values are varying with the magnitude. This is basically error term how the equation is associated with the error. So plus or minus value, so this is will be the function of sometime constant value sometime it may be also variable value with respect to the magnitude.

So this 7 major component of the equation should be considered to develop any predictive equations.

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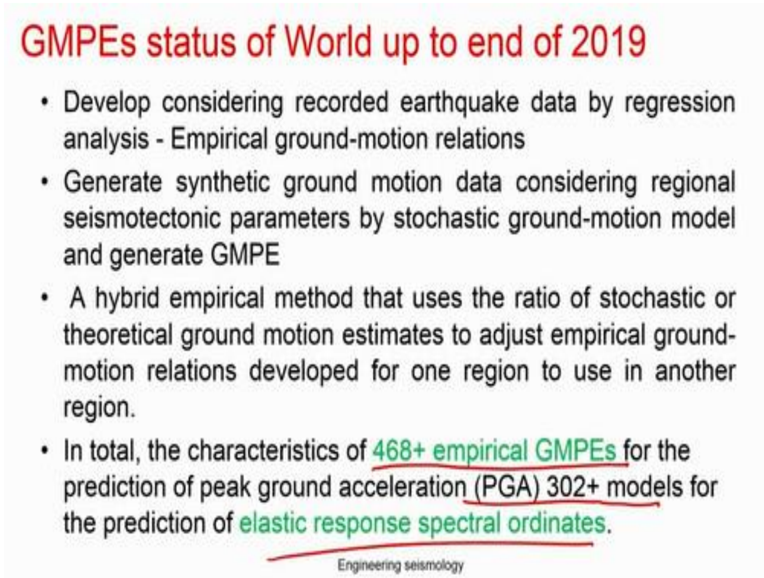

So the ground motion prediction status of the world, so let us see what the ground motion predictive equations are available as on today. So at the end of the 2019 so the scientist called Douglas, so this person so when I was doing my PhD itself so during the 2004 when I started my PhD so the scientists the Douglas actually what he did so he took steps to read a different ground motion prediction equation developed by different people and to go through that paper and try to summarize that and develop a ground motion prediction equation report.

So which is called as a GMP report so this report is first released on the during 2004, then subsequently he keep updating this report a very time. So, he considers some criteria and discusses what is the limitation advantages and disadvantages it is validity and applicability, range of magnitude applicable, range of distance applicable, so everything he will try to compile and presented as a book.

So, if you want to find out is book you just to go to the Google and find out GMPE report by Douglas, then you will get that book you can see how book big volume which is summarized since historic term, what are the equations are developed. So the develop, development of GMPE is considering the recorded earthquake data by regression analysis. So there are different way the GMPE the ground motion prediction can be developed.

So one is that you take a recorded data with their plenty of data's are available you can make M and R combination and then you can use that functional form and do a multiple regression analysis, so then you will end up with the empirical ground motion relation which is called as a empirical ground motion relation. So, generally synthetic ground motion data's are considered when there is no recorded data are available.

So that kind of ground motions equations are called stochastic ground motion model to where the stochastic data has been used to arrive the functional form, functional form constant values, so the hybrid is actually they develop a model for one region adjust for the other region by taking some kind of consideration that kind of model is called as a hybrid empirical models. So that means the ground motion itself there are three ways you can develop.

One is that empirical ground motion, which is just a fitting of the data. Second is stochastic model which is where the stochastic ground motions are predominantly used to model, hybrid is you develop for the data which is one region and then modify that further your region. For example; north India developed a ground motion prediction equation and a modify to south India that kind of relation is called as a hybrid empirical models.

So, why it is hybrid? Because you are basically converting according to your convenient hybriding that is why this hybrid is there. So as on today, the 2000 end of 2019, so about 468 empirical ground motion models are available for the prediction peak ground acceleration about 320+ models are available. So for the prediction of elastic response spectrum ordinates, so basically 468 empirical GMPEs are available for prediction of the peak ground acceleration and 302+ models are available to predict a elastic spectrum.

So what is these two differentiate we are trying to discuss here basically there are equation which gives only a PGA that means you cannot get the equations at a different spectral period, so as we have discussed in the response spectrum;

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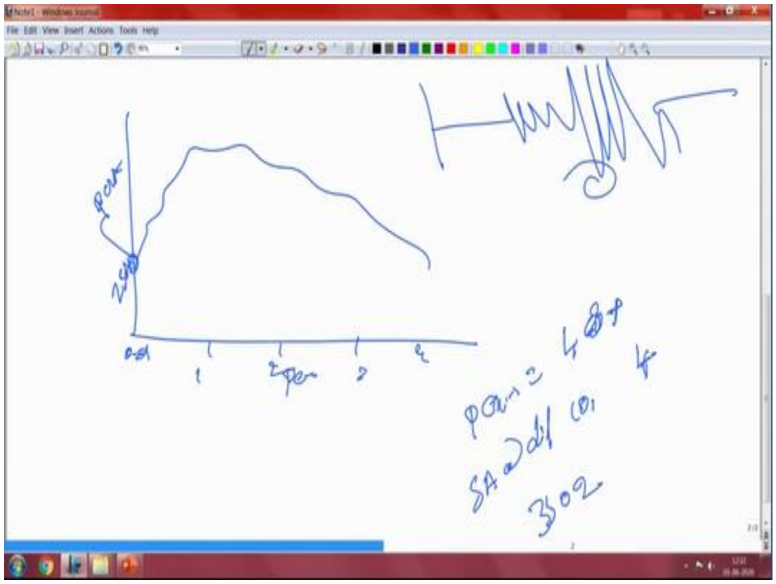

We have seen that you have the two type of data one is that response spectrum, this is the basically your period, this will be your ZSA which is also equal to PGA which we have discussed, so this is with the time. So 1, 2, 1 second, 2 second, 3 second, 4 second something like that, so then another data is you are acceleration time still varying you get a peak values, so the peak value the equation which predicts only the PGA is you have 462+ models 68+ models.

So the response spectrum that is like the SA at a different period, so starting from 0 to 4, so that kind of data we have 302 models. So far developing the world up to end of the 2019, so that is what the Douglas given the summary of the same.

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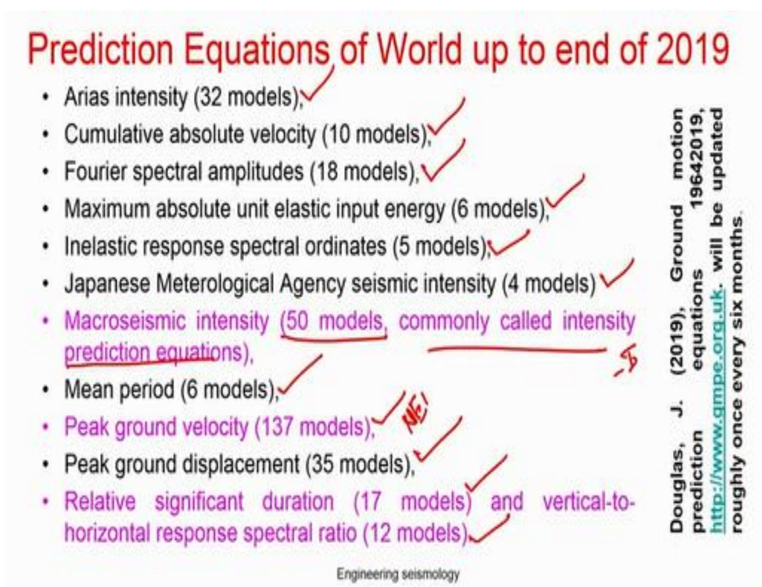

So for a different ground motion parameters, what are those parameters about arias intensity, we discussed what is the arias there are 32 models are available to predict arias intensity. So which region where it is developed all those things one has to be careful to use this models, then cumulative absolute velocity about 10 models are developed. Fourier spectral amplitude 18 models are developed; maximum absolute unit elastic input energy 6 models are developed.

Inelastic response spectrum ordinates 5 models are developed. Japanese meteorological agency seismic intensity 4 models are available; this is actually intensity only applicable to the Japan region. Micro seismic intensity like the predictive equation for intensity values 50 models are available commonly called as the intensity predictive equation. So, then the mean period 6 models are available, peak ground velocity 137 models are available.

Peak ground displacement 35 models are available, relative significant duration 17 models and the vertical to horizontal spectrum ratio 12 models, so we have seen that the significant duration equations 17 models are there and horizontal response spectrum 12 models are there. So, what you can do basically you can this is actually Douglas I was telling know this is the Douglas references so you can go to the Google and type this reference or click this link.

You will take to the page this pdf file, where he described each and a very equation and a given a functional form how it is developed what data is considered where it is applicable where it is not applicable kind of things he has discussed in detail. So among this many equation models are there India, we have intensity predictive equation; right now we have one intensity predictive equation in India.

So, we have few ground peak ground velocity models also but that is only developed for the northeast region as per my knowledge and then the relative significant duration we have few models particularly peninsular India, this model was developed by me and then vertical to horizontal spectrum which is not developed but which may be record in the future. Like how the vertical horizontal spectrums are various per different period that is that kind of models are one can develop.

And then general motion prediction models, so there are several models are developed in north India and limited models are developed in peninsular India. So as I told that my research group my students PhD student others are keep working on this so they will be like developing this models and then try to so publish that so this published letters are also reported here, so when you download that the page or go to that page with this report you just type my name and give you a search then you can see how many pages my equations are listed.

So since I find there are many things are not appropriate after I mean doing the steady as well as research then I started working on that and try to develop some of my students are working on developing the intensity predictive equation, duration predictive equation and ground motion prediction equation, which we have done very recently. So this is the kind of work which is need large number like country like us as we told that we have a complex seismo tectonic set up.

So we have where the peninsular India major southern part is covered. So as a different type of seismic tectonic behaviour within the peninsular India of Bhuj, Kutch and Bhuj region as a different seismo tectonic this one then the central peninsular India has a different seismo tectonic behaviour then the North-East where the boundary and the intra-plane, so as a different way of creating earthquake there and then the northern part.

So, where lot of seismic gaps are there particularly the Indo-Nepal border and those regions where active regions are there and then the western India, so there is a some kind of seismic activities there so these are all the different complex seismic phenomena, so even though the simplicity many of them are compiled them as a single part like India is consider as a one in some of the models.

So India as a considers two part in some of the model so like that, they make it a very simplified way but at least those are all the work at least people are started working but we have to basically focus more at a regional scale level what I discussed the different seismo tectonic things, so one has to focus on those kind of models development which is required for the country. So this model as I told you that the prediction of PGA.

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- The prediction of PGA and/or response spectral ordinates that were derived by the regression analysis on strong-motion data.
- GMPEs derived based on simulated ground motions, often the stochastic method
- Complete (source, path and site terms) stochastic models that could be used within the stochastic method (e.g. Boore, 2003)
- GMPEs derived using the hybrid stochastic empirical method (e.g. Campbell, 2003b)
- GMPEs derived by converting equations for the prediction of macroseismic intensity to the prediction of PGA and response spectral ordinates
- GMPEs derived using the referenced-empirical method (e.g. Atkinson, 2008) that adjusts coefficients of published GMPEs for one region to provide a better match to observations from another
- Studies where one or more coefficients of previously published GMPEs are altered following additional analysis (completely new GMPEs are not derived in these studies)
- Non-parametric ground-motion models, i.e. models without an associated close-form equation, which are more difficult to use within seismic hazard assessments

Engineering seismology

And, are the response spectral ordinate that were derived by the regression analysis of strong motion data, so generally, they take recorded data or regular, the simulated data and the pickup a peak values and with respect to magnitude and distance and per the similar conditions, similar conditions means the data from bedrock has to be used only for the bedrock, so you cannot mix here soil site and rock site.

So in India many of the seismic station the classification of station based on the seismic data itself very rare, so we are done some attempt we try to classify the different seismic stations in India using recorded data, you can find that publication in the soil dynamics and earthquake engineering general, so where you are to compile a similar kind of site and seismic tectonic region and take different M and R combination using that you can develop a regression equation that kind of regression equations are you can call it as a ground motion prediction model.

There is a the GMPE is derived based on the simulated which we have seen that a stochastic based model the complete source, path and site terms stochastic models could be used which is stochastic method when you use that you should be basically account the source and path site terms properly using the regional parameter, so GMPEs derived using the hybrid stochastic empirical model.

Basically, the Campbell was working on that he given some kind of GMPE ground motion prediction models using the hybrid stochastic empirical models, Boore was doing with the stochastic simulation model. So GMPE derived by converting the equation and prediction, micro seismic intensity is a PGA and response spectrum also has been developed. So GMPE is derived using the reference empirical model.

So there are from the emigrant model which was done by Atkinson in 2008, adjust coefficient published GMPE is one region to provide better match observation from the other region. Studies where one or more coefficient of previously published GMPs are altered by following additional analysis completely new GMPE are not derived. This kind of studies also people do, they take a voltage GMPs and try to adjust the coefficients, those kind of.

Non-parametric ground motion models model without association with the close form equation, which are more difficult to use within the seismic hazard analysis. So these kinds of equations are also available in the Douglas summary of GMPs. So the GMP ground motion prediction models are the predictive equations are the backbone for the any hazard analysis are further future hazard parameter estimation.

So without predictive model it very difficult to get into the any kind of analysis and predict a what type of hazard you can expect not earthquake. As I told that it is not possible to predict earthquake size and time and location very precisely it is only easiest way to predict is a earthquake hazard. So earthquake hazard in terms of earthquake parameters, like intensity you can predict, duration you can predict, ground motion parameter PGV, PGD, PGA you can predict and the spectral parameters you can predict, arias intensity you can predict, if you have the your predictive equation.

So the developments of predictive equations are very important for getting a reliable hazard prediction of the particular region. As I told you that in India this area very less research has been carried out. You can see very few papers so of a majority of them come from IIsc, some of them come from IIT Roorkee and here and there one or two papers people have published. So the number of equation developed was very less.

Particularly, the most of the equation considered and developed with respect to the prediction of acceleration, and a very few equation for the duration and very less equation for the intensity. So similarly for the PGV flexure and there is no equation for vertical to horizontal ratio, there is no equation for arias intensity. So these are all the one of the potential area provided if you have the mathematical skill and a proper guidance.

So that I can see there are a lot of people develop this kind of empirical ground motion prediction equation without understanding what they are doing given they get degree doing that and then also publish some paper but there are a lot of limitation because of the understanding of the misunderstanding of the engineering seismology. So when you want to do this kind of simulation, you have to be go through proper literature, get a proper guidance to develop a most reliable predictive equation, which will be useful for getting a proper this one.

So we have discussed overall about the predictive equation which is basically record for the any region for hazard estimation, but in specific we will also discuss a different predictive equation applicable for a different part of India I also compiled that, so this predictive equation as I told you that there are several things are associated one is that before developing any predictive equation, first of all you identify a suitable functional form.

So suitable functional form means what is the functional form you are using you should use a better for your region or not using the recorded data, so we have been done some research where we identified basically here best suitable functional form for the Himalayan region and then used that functional form to derive a GMPE that was published as a paper, so in the bulletin of earthquake engineering you can refer that paper from my website.

Then followed by we also developed a empirical model by combining the recorded and simulated data, which is calibrated adjusted for the regional seismo tectonic parameters which is like source, path parameters are estimated from the earthquake recorded data and then that parameters are compiled and we consider basically the condition of bedrock condition for same for all that data, we do not mix here soil site data with the bedrock site.

For that purpose even the available data we use and try to separate which are the sites or soil which are the sites are rock, so again the soil 1, 2, 3 different classification, we have done you can also find here that kind of paper is that, so apart from that as I told you that when you look at this report you have the large number of ground motion data prediction equations are available like 302+ equation which equation applicable to which region how it is reliable so that process is called as a selection of ground motion prediction equation.

That also I do research on that we have published a couple of papers on selecting best suitable ground motion prediction equation per a region. For example, as I told you that peninsular India there are about 3, 4 regional equations and then the outside regional equation totally around 13, 14 GMPEs are available but all of them may not be applicable to your region, but that kind of study also is important.

Similarly, north India some of the equation may not even suitable to use for hazard analysis that kind of study also we do selection of ground motion prediction equation by doing the efficacy test like log likelihood method, log likelihood analysis. So, where you do systematic, mathematical, statistical analysis using available data, and then find out which are the equations are suitable for what distance range and magnitude, that kind of data are you can further use for the hazard prediction so that the hazard analysis are more accurate.

So that is what we also done in some of the this one those who are maybe next class and future we will discuss about all these GMPEs available for the India and all are followed by that, so before going to maybe we should first discuss about the seismicity of the India then followed by we will discuss about the different seismo tectonics and then GMPE is available and then the zonation map-up India and then followed by the hazard analysis, how you can do the hazard analysis, those are all the things we can discuss in the coming classes.

So with this I will close the today class so today we have seen about the ground motion prediction models, what is meant by the ground motion prediction, what are different models are available and which are the models developed in India so and then how this models are useful for application also I given a glimpse of idea, so we will also discuss further those things in the near future classes.

So with this I will close today class thank you very much for watching this video, so we look forward to meeting you in the next class you have any doubt on all this analysis, models and this one you please approach me or my TA they will be keep explaining you because the TA basically who involved on this kind of they do research on that, some people done analysis to select GMPEs, select suitable GMPEs are particular regions.

Understand how the GMPE is varies with the different part of region based on the rock and geological formation in the region, so all those things they do. So you can interact with them they will produce give you a valuable information for and guidance for you, if you need any further you can approach me as you Google it and find out my website and contact details, so thank you very much for watching this video, we will see you in the next class, thank you.