CRITICAL DESIGN REVIEW

Faculty Mentor:
Dr. Ramancharla Pradeep Kumar

TA Mentors

Chetna Gupta

Abhishek Bharadwaj

Group Leaders
Saurabh Kathpalia
Gayatri Nair

Subgroup Leaders
Saurabh Kathpalia
Hari Narayana
Rohan Bhatial

EARTHQUAKE FORECASTING AND FAULT MODELLING

1. System Definition And Overview

Mission Objective:-

The aim of our project is to try to analyze earthquake data relevant to the areas of the states of Himachal Pradesh, Gujarat and the seven northern states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Tripura and Nagaland and implement a practically usable system with a Graphical User Interface that interacts with users to provide information about the probabilities of earthquakes of different magnitudes occurring in a chosen area and advice about the safety of building structures such as skyscrapers, dams, etc. Depending on the calculated probability of earthquake occurrence and the damage the respective structures are likely to sustain, over a certain period of time.

We also developed 3D models of the earthquake faults for visualization and further analysis. The probabilities of the occurrence of earthquakes are calculated on the basis of the analyzed data and related equations .

We aim to achieve this by:

- Organizing data into a structured, human readable format that helps us retrieve the relevant information required for the project.

- Searching and retrieving useful data that is relevant to the individual subsystem goals . Data relevant to the concerned states of Himachal Pradesh, Gujarat and the seven northern states of Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Tripura and Nagaland was separated and organized according to sub-areas and faults.

- The data is further classified according to earthquakes that occurred in the above regions and the faults that caused them. The top five faults that have caused the majority of the earthquakes in a region have been separately tabulated.

Modelling the structure of faults using latitude and longitude data points of faults and coordinates of epicenter of the earthquakes caused by that fault. Surface 2d modelling, Impact Modelling and Depth Modelling is to be done.

Operational Objective:-

- We are considering the top 5 earthquake causing faults ordered by the magnitudes of the earthquakes that they have caused in each area of every state.

- Using the data about the latitude and longitude of faults and the depth of the epicenter of earthquake the 3-D models of the faults were created.

- Data taken into consideration has details of earthquakes from the past 200 years.

- Using the classified data we are calculating probability of recurrence of earthquakes of different magnitudes in the given areas.

- Depending on this probability user is advised as to the safety of building a structure in user selected area.

2. System Design

2.1 Design Requirements:-

2.1.1 Scope of the System:

1) The aim is to make the system reliable for making decisions regarding the building of structures in earthquake prone areas by providing information regarding the probabilities of occurrence of earthquakes of different magnitudes, and also provide a 3D modeling of the faults for further analysis.

2) The project currently works with the states of Gujarat, Himachal Pradesh, Arunachal Pradesh, Assam , Nagaland, Tripura, Mizoram, Manipur and Meghalaya.

3) The data used for the calculation of probabilities is data collected about earthquakes in the given regions over the past 200 years.

4) The result will be based on the probability of the occurrence of earthquakes of different magnitudes that can cause damage to structures.

5) The result will also depend on the type of the structure itself.

6) For the 3D modeling of the earthquake causing faults in each of the areas, the depth of the fault itself was not considered due to unavailability of data. Instead, the mapping was done according to the depth of the epicenter of the earthquake caused by the fault.

2.1.2 Operational Requirements:

1) There is a vast area to cover under all the different states. In order to organize the data efficiently, the states were divided into different areas.

2) The given input from the user will be one of the areas that have been designated for each state.

3) Since the result is dependent on the type of structure that is to be built, the structure is also taken as input. The structure that is given as input should be one of the listed few considered by us.

2.2 Design Characteristics:-

2.2.1 System Structure:

The system is divided into three sub-systems based on the category of work needed for the operational requirements :

1) Data ordered by earthquake magnitude and the faults that caused it, grouped by the states of Gujarat, Himachal Pradesh and the Seven Sisters. Also the data relevant to the top five earthquake causing faults in each region.

2) Analysis of the classified data and calculation of certain values required for equations, and final calculation of probabilities based on the data, and comparison of the probabilities to predict the safety of building a structure.

3) Using the fault related data such as longitude and latitude to plot the relevant faults for visualization and analysis. The depth for the 3D modeling of the faults has to be considered as the depth of the epicenter of the earthquake caused by the fault.

2.2.2 System Challenges:

1) There is a large amount of unorganized data that needs to be sorted and separated into relevant data as required for the different subsystems.

2) There is a possibility of inaccuracy in the data.

3) The probabilities are mere estimates and do not state anything definite. Any analysis and conclusions make the assumption that the probabilities are exact, but this may not be the case. Natural phenomenon can turn out to be unpredictable, so the final behavior may be completely unexpected.

4) Some of the data, such as the depths of the earthquake causing faults, may not be available.

2.2.3 System Success Criteria:

1) The data given should be utilized effectively and fully to be as precise and accurate as possible.

2) The calculation of the probabilities based on the equations should turn out to give a more or less correct representation of the actual events.

3) But since these are merely probabilities, there is no such guarantee as natural disasters can occur unexpectedly and behave in unpredictable patterns in certain anomalous cases.

4) However, the implemented system should be able to provide the best possible information for making informed decisions.

5) The 3D models of the faults should be able to capture all the relevant details, curvature, extent, etc. that could be required for further study.

2.3 System Organization:-

As specified in the system structure, the system is divided into three sub systems:

1. Organizing Relevant Data:

In this subsystem we categorize data of latitude and longitude of faults which were provided by EERC lab on basis of faults that lie within our concerned states which are Gujarat , Northern Seven Sisters And Himachal Pradesh .

We then choose faults based on number of earthquake that were caused by each of the faults and then out of all picking up top 5 for that state . Then we further organize data of the chosen 5 faults by creating a *seismicity* table which maps the magnitude to the no. of earthquakes caused by each of these faults for every state. In similar manner we choose top faults for all major metropolitan cities in our concerned states. Then for helping out forecasting subgroup we further we map the magnitude of the earthquake to the fault lines which caused them, specifying the frequency of the earthquake and the years when they occurred.

2. Calculation of the Probabilities:

In this subsystem, we make an estimation of number of earthquakes in future 100 years and plotting of the probability density curves.

3. 3D Modeling:

In this subsystem, we are generating various 3D models of the faults given a set of points that lie on that fault. Using these 3D Models we have tried to do an impact analysis of the faults within the scope of our project and also find out their approximate shapes. This helps us in getting the idea of where the earthquakes might occur in future.

2.3.1 System Flow Diagram:

(a) The given data is organized according to the states, earthquakes that have occurred in the past 200 years in the states, their magnitudes and the faults that caused them.

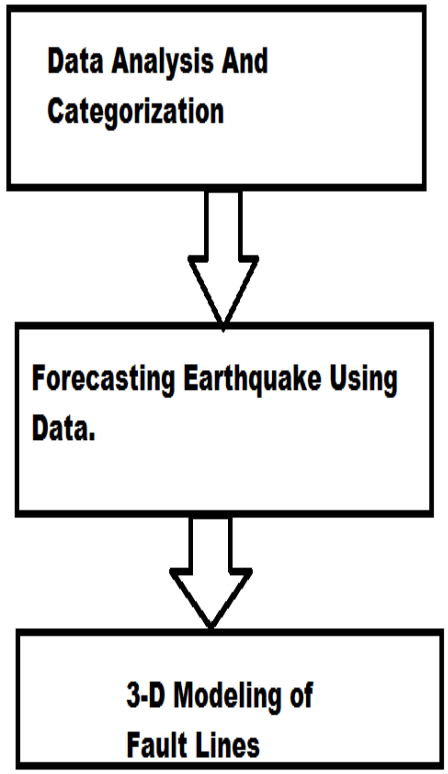
(b) The relevant details like the top five faults that have been responsible for the most number of earthquakes and the magnitudes of these earthquakes are tabulated for each of the regions.

(c) Data relevant to the faults such as their longitude, latitude and the depth of the epicenter of the earthquake caused by them, required for the 3D modeling, are tabulated.

(d) The data is organized and certain required values are calculated. These values and other relevant data (input such as the area and the type of structure to be built) is used to calculate the probabilities based on some equations.

(e) The fault data is used to create a 3D model in Matlab.

(f) The calculated probabilities are ordered by the magnitude of the expected earthquake for a certain period of time. Depending on these values, an estimate of the safety of building different structures in the concerned area is made.


Data Analysis And
Categorization
Forecasting Earthquake Using
Data.
3-D Modeling of
Fault Lines

Sub-System Details

1. Data Analysis

Objectives Of The Subsystem:-

Our subsystem aims at studying the earthquakes that have occurred in the past 200 years with their characteristics such as magnitude, fault lines causing them, etc. in our concerned three regions namely Gujarat, Himachal Pradesh and seven north eastern states. We extract data relevant to the probabilistic analysis of future earthquakes and send it to next subsystem which uses it to forecast possible earthquakes in near future, thereby helping authorities to make informed decisions about the building of large structures and also to take timely measures against such potential earthquakes so they can save lives and try to avoid damage caused to infrastructure. The main task is to group regions according to faults lines which caused earthquake in past years.

Requirement Analysis :-

Our requirement analysis includes classification of faults based on the area of the concerned states and sending it to next subsystem so that it can forecast earthquakes using equations and algorithms they have developed. We'll use data of fault lines that have caused earthquakes in India in the past 200 years which was given to us by the Earthquake Engineering and Research Centre lab. We group the data by the three given regions - this data includes latitude and longitude of the fault lines. We further classify faults based on number of earthquakes caused by them and select the top five faults and send the data relevant to these faults to the forecasting subsystem. We use the same classification as above for the major metropolitan cities in each of the three regions. The purpose of choosing major metropolitan cities is that these cities have a comparatively larger population and a more developed infrastructure.

Sub-levels Of This Sub-System :-

1) Grouping of faults according to states:-

- We first estimate the latitude and longitude of the center of the given states.
- Then we find the perpendicular distance of the farthest border of the state .
- Using this distance as radius, we choose all the faults that lie within the area of the circle thus created.

2) Classification based on magnitude

- After grouping the faults according to the states, we choose the top 5 faults after sorting them based on number of earthquake caused by each of them.

- We create a *seismicity* table which maps the magnitude to the no. of earthquakes caused by each of these faults for every state.

- This seismicity table would be required by the forecasting subgroup to accurately forecast earthquake for that particular region.

3) Categorizing and linking faults to the major metropolitan cities

- In this we compute the latitude and longitude of the center of these urban cities and then find the Euclidean distance to the latitude and longitude co-ordinate of the farthest border of the city.

- Using the above distance calculated as radius, we note all the faults that lie under this imaginary circle.

- Then we create a seismicity table mapping the magnitude of the earthquake to the frequency of the earthquake caused by each of these faults for every metropolitan city .

- This would further help the department of earthquake forecasting and infrastructure development in advising against creation of dams and infrastructure in a region of a particular city.

4) Classification based on the earthquake events of the past years.

- In this, we map the magnitude of the earthquake to the fault lines which caused them, specifying the frequency of the earthquake and the years when they occurred.

- This would be used in equations which are used to forecast earthquake and would be helpful for the authority to take measures against such potentially dangerous earthquakes

State : Gujarat

Seismic Table | Fault Modelling | City-Wise

Magnitude (Range)	Fault 915	Fault 689	Fault 949	Fault 690	Fault 749
3 - 3.5	11	5	0	4	0
3.5 - 4	41	13	8	7	2
4 - 4.5	46	12	8	14	4
4.5 - 5	32	14	10	6	4
5 - 5.5	10	6	5	3	2
5.5 - 6	8	7	2	0	2
6 - 6.5	4	4	2	0	1
6.5 - 7	3	0	0	0	0

Above is the seismic table created for Gujarat State . Here we take different earthquake magnitude ranges and link them to faults which caused them and also mentioning the number of earthquakes that have occurred in this magnitude range.

For eg. from the above table we can clearly see that there are 32 earthquakes that are caused by fault number 915 in magnitude range 4.5-5 in past 200 years.

Gujarat : Surat

Center : 21.1700° N, 72.8300° E

Radius : 10.65km (+ 140km)

Previous Data | Input Data | Earthquake Forecasting | Graphs

Magnitude (Range)	Fault 949	Fault 749	Fault 755	Fault 770	Fault 51
3 - 3.5	0	0	3 1896 1958 1961	2 1962 2008	1 1986
3.5 - 4	8 1987 1987 1997 1997 1997 1998 2002 2006	2 1861 1956	3 1896 1896 1960	2 1861 1891	0
4 - 4.5	8 1986 1987 1987 1987 1997 1997 1997 1998	4 1861 1870 1985 1985	4 1958 1960 1985 1987	4 1985 1986 1987 1996	3 1985 1985 1986
4.5 - 5	10 1985 1986 1987 1987 1987 1987 1994 1997 1997 2006	4 1985 1985 1985 2006	3 1985 1985 1985	2 1956 1985	4 1868 1986 1986 1986
5 - 5.5	5 1961 1986 1987 1987 1987	2 1955 2006	1 1960	3 1985 1985 1987	1 1986
5.5 - 6	2 1961 1987	2 1845 1960	0	1 1955	1 2010
6 - 6.5	2 1955 2007	1 1955	0	1 1963	1 2010
6.5 - 7	0	0	0	0	0

Above is an example of the mapping we created linking the magnitude of earthquake with the faults lines mentioning the frequency of the earthquake and the years during which they occurred.

For eg. - we can clearly see that in past 200 years fault number 949 has caused 2 earthquakes of magnitude range 6-6.5 in years 1955 and 2007.

2. Calculation of Probabilities

Objectives Of The Subsystem:-

This subsystem is responsible for the forecasting of earthquakes in the regions of consideration, namely, major urban areas in Gujarat, Himachal Pradesh and the North Eastern states over the next 100 years, based on details of earthquakes that have occurred there in the past 200 years. We find the probability density function of earthquakes for each area and for each magnitude range, from which the probability of an earthquake in that magnitude range occurring till a particular year can be found out. Based on the area and the type of structure, we specify the earthquakes that must be considered while deciding the peak ground acceleration in that place before building the structure.

Requirement Analysis :-

This subsystem requires the categorized and tabulated results of that of the subsystem that performs data extraction and analysis. Specifically, it would need, for each city, the five major earthquake causing faults, and the number of earthquakes these faults have resulted in the last 200 years in various magnitude ranges and the years these earthquakes have occurred. We also need the threshold values of probability that are to be considered for each type of building. Further, we will need the type of structure that is going to be built.

Approach/ Details of Subsystem levels / Procedure

The data here is assumed to follow a Poissonian sequence of occurrence, due to which we take into account the increase in the likelihood of an earthquake with time as more strain is built up. To find out the hazard, we first find out the mean and variance of the return period, then the probability distribution function and the probability density function for each fault. After this, the hazard is calculated and the number of earthquakes that would occur in the future is found. Then, based on the type of structure, we say which earthquakes must be considered. The process is explained in more detail below.

1) From a table such as the one in figure <x>, a table which gives the return period for one particular fault and one particular magnitude range is prepared. This return period is taken as the random variable, and the mean and standard deviation are calculated. From here on, we will represent them by λ_{lk} and ξ_{lk} respectively.

2) We then find out n, the expectancy, and find out the probability distribution function and the probability density function of n. n is calculated by the formula

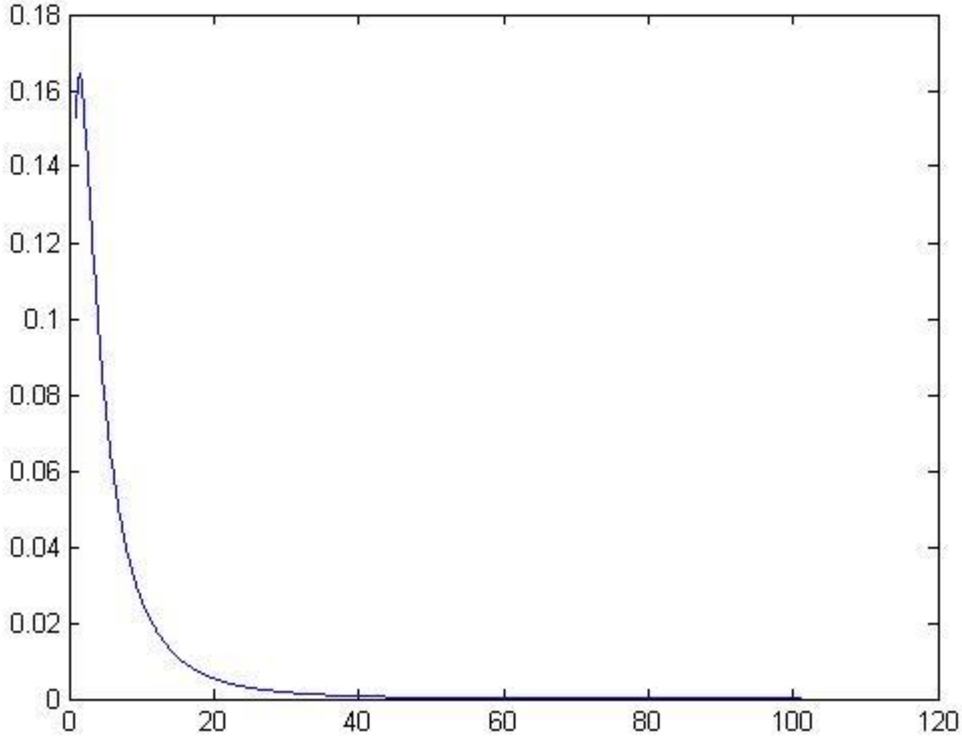
$$n = \frac{\ln t - \lambda_{lk}}{\xi_{lk}}$$

where λ_{lk} and ξ_{lk} are obtained from 1.

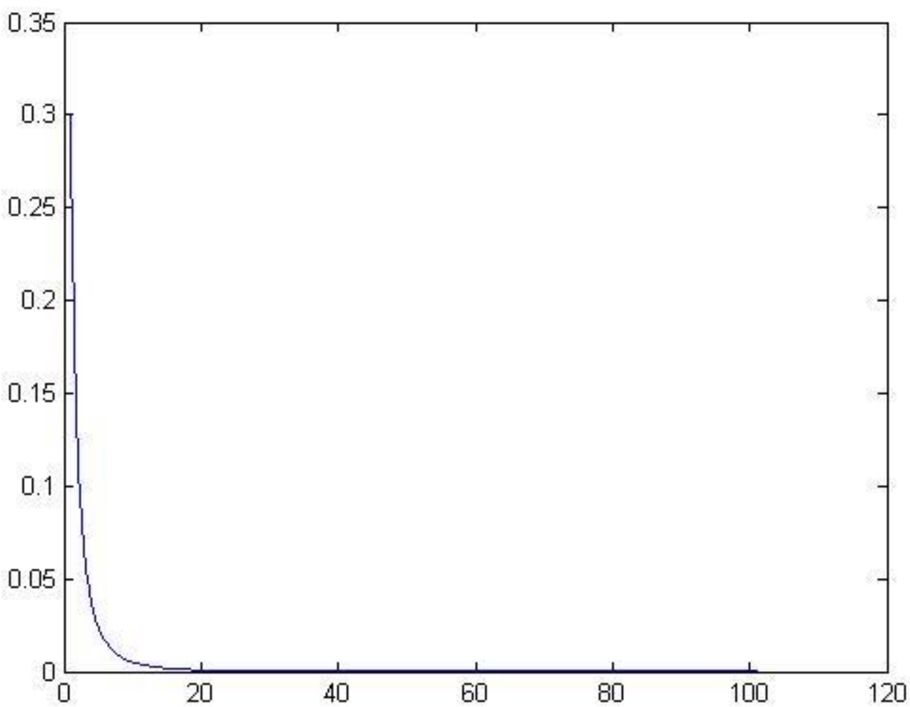
We find $\phi(n)$ and $\Phi(n)$ which represent the probability density function and the probability distribution function respectively.

These are the obtained graph plots obtained for the Guwahati area.

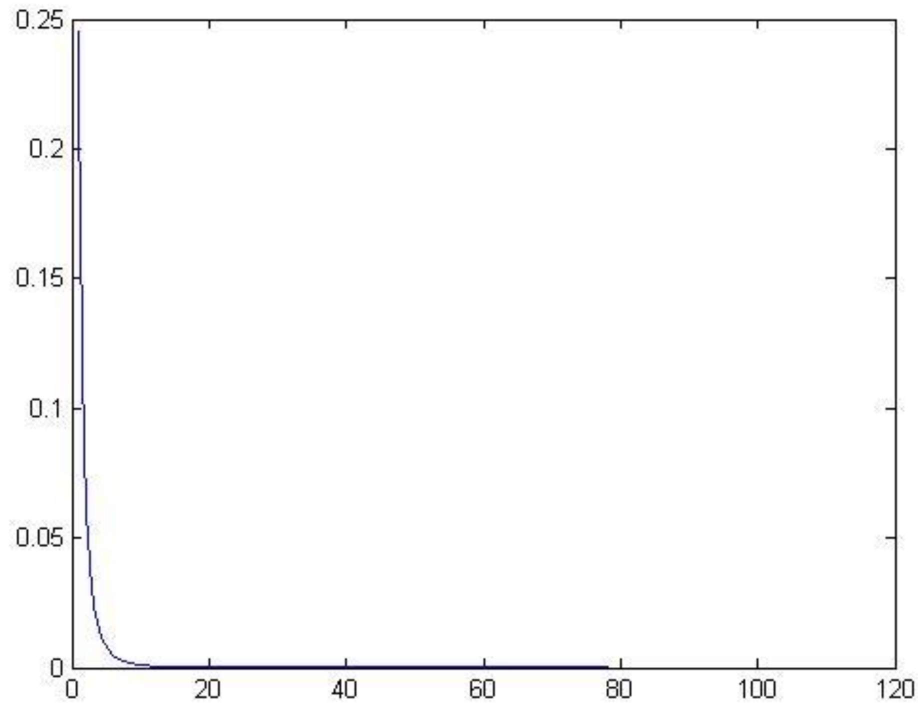
Magnitude range 3 – 3.5



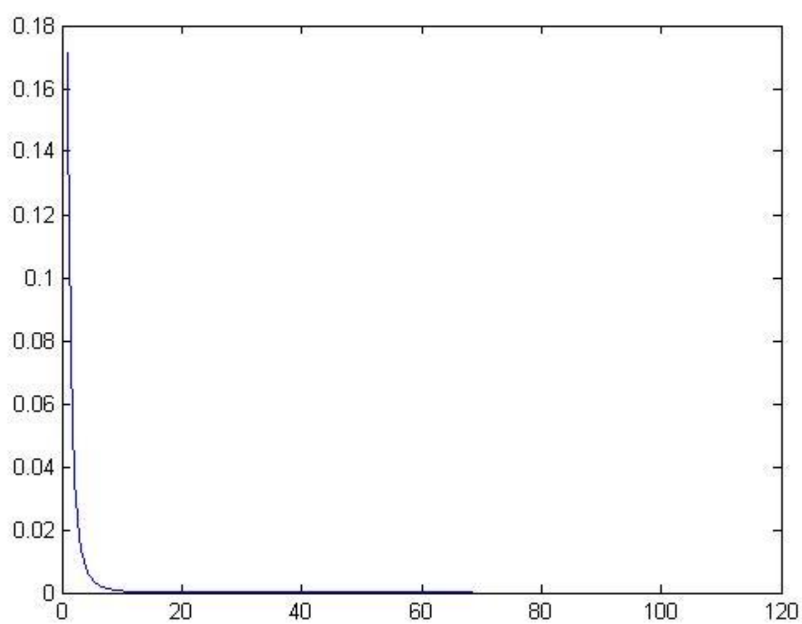
Magnitude range 3.5 – 4



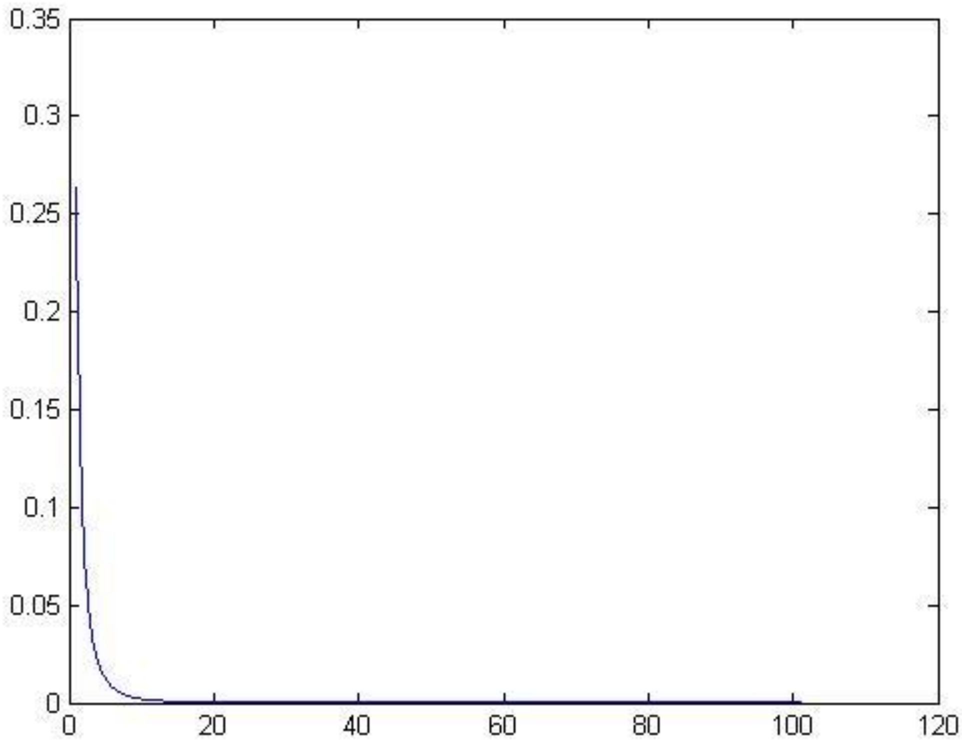
Magnitude range 4-4.5



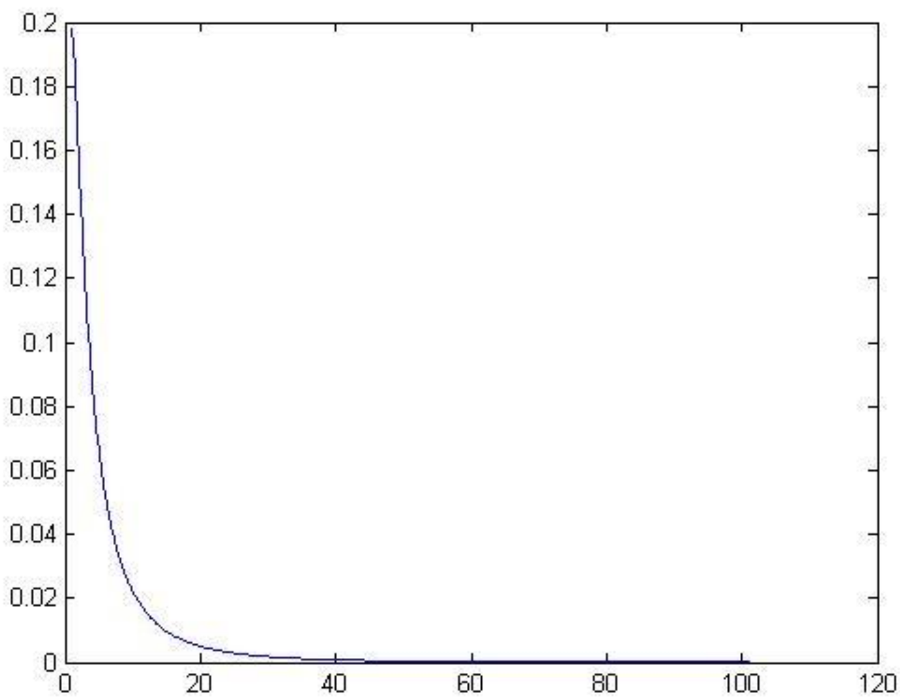
Magnitude range 4.5 – 5



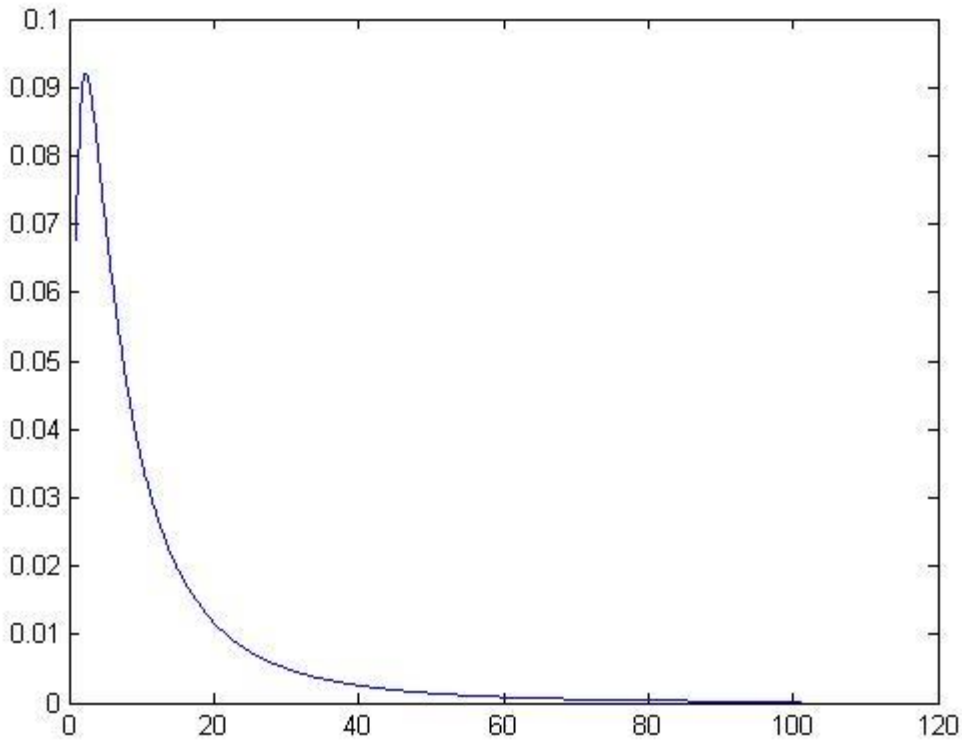
Magnitude range 5 – 5.5



Magnitude range 5.5 – 6



Magnitude range 6-6.5



In all these graphs, the x axis denotes the number of earthquakes while the y axis denotes the probability of an earthquake occurring at that specific year within the magnitude range

3) In the next stage, we find the hazard, given by . $h(t) = \frac{\phi(n)}{\xi t(1-\Phi(n))}$, where $\phi(n)$ and $\Phi(n)$ were found in step 2. This is a conditional probability.

4) Then we find out the number of earthquakes in the next Y years where Y is the design life of the building. The formula for this is given by

$$n_{lk}\left(T_0 + \frac{Y}{T_0}\right) = \int_{T_0}^{T_0+Y} h_{lk}(\tau)d\tau$$

Here, we find out, for the next 100 years (Y=100).

The obtained number of earthquakes for the Guwahati area in the next 100 years is

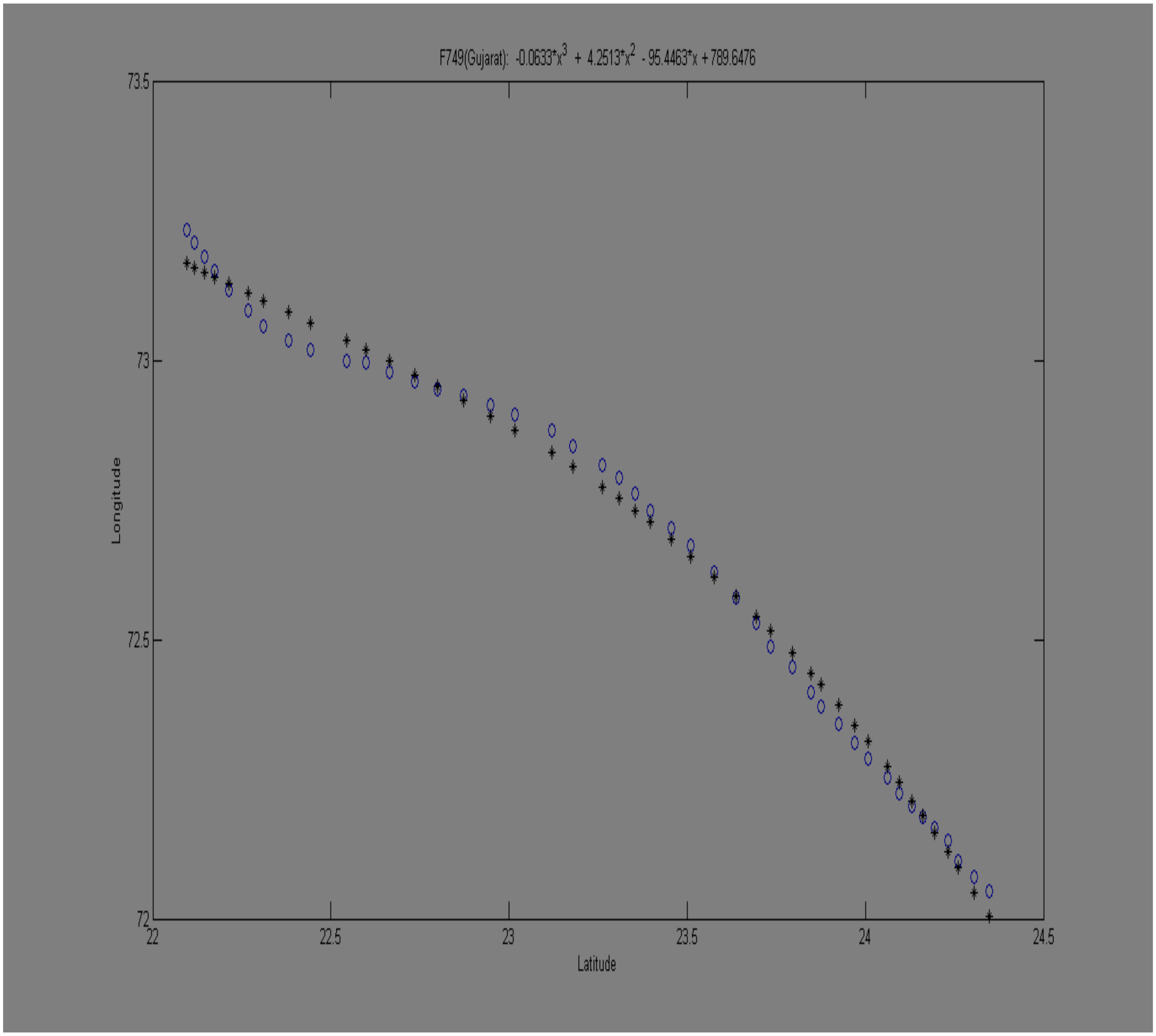
Magnitude (Range)	Fault 982	Fault 947	Fault 820	Fault 840	Fault 825
3 - 3.5	5	1	4	4	6
3.5 - 4	7	3	8	5	7
4 - 4.5	9	4	7	8	10
4.5 - 5	8	6	8	8	8
5 - 5.5	8	3	10	7	8
5.5 - 6	5	8	11	5	1
6 - 6.5	5	3	5	1	0
6.5 - 7	6	0	1	1	0

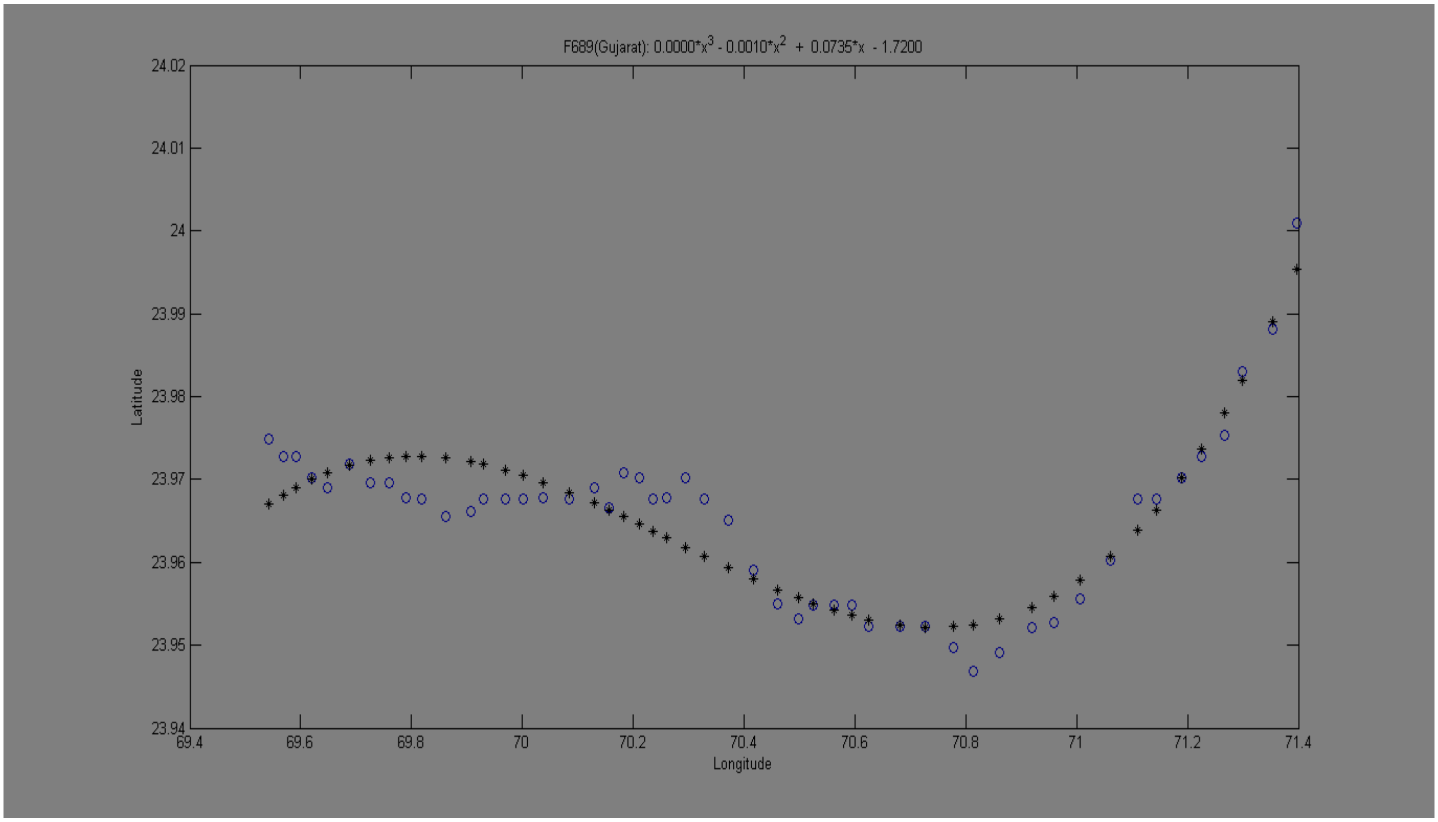
5) Then based on the type of the building and the number of years, a probability for damage is calculated. Based on the following specified thresholds, we say if the structure is advisable or not. The following are the thresholds we consider:

Structure	> Threshold percentage
Nuclear power plant	2%
Dam	5%
Skyscraper	10%
2-storeyed building	15%

3. Fault Modeling:

In this subsystem, we are generating models of the faults given a set of points that lie on that fault. For this, we plot the points on a 2D plane.





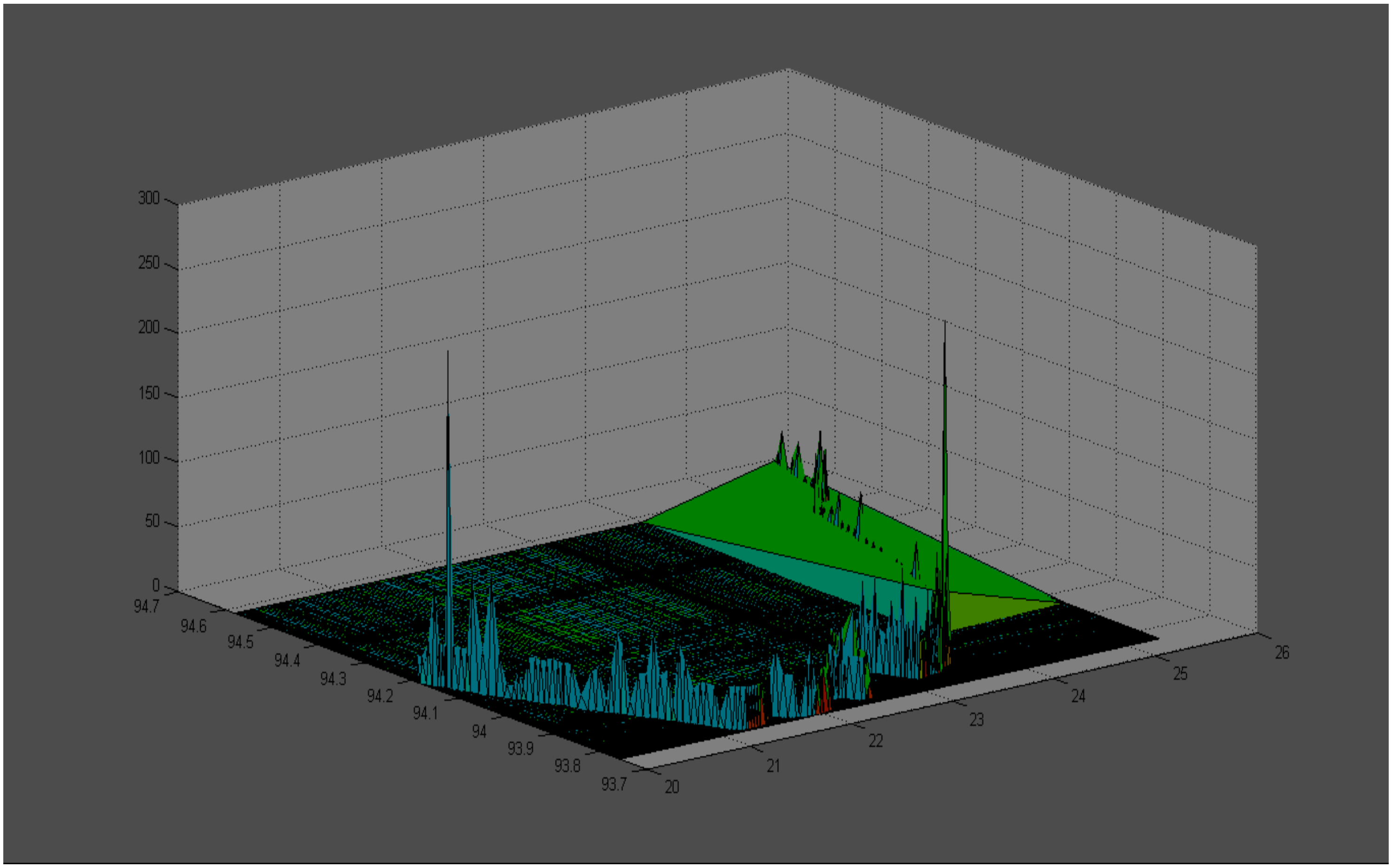
Using these 2D models we have created different models for the fault:

1) Impact Modeling:

For each of the faults in the scope of this project, we have modeled the latitude, longitude, and the depth of the epicenters. Using this data we have created a 3D 'Impact Model' which gives us an idea of the where and how the earthquake has impacted in the past. This would help us predict points of impact of the earthquakes in future.

Here is the Matlab script to get the Impact Model

```
filename = 'fault982.txt';
delimiterIn = ' ';
headerlinesIn = 1;
B = importdata(filename,delimiterIn,headerlinesIn);
X=(B.data(:,1));
Y=(B.data(:,2));
Z=(B.data(:,3));
xdata=[];
ydata=[];
for i=1:length(x)
    xdata(:,i)=x;
    ydata(:,i)=y;
end
xdata=xdata';
f=diag(Z(1:190));
surfl(xdata,ydata,f);
```

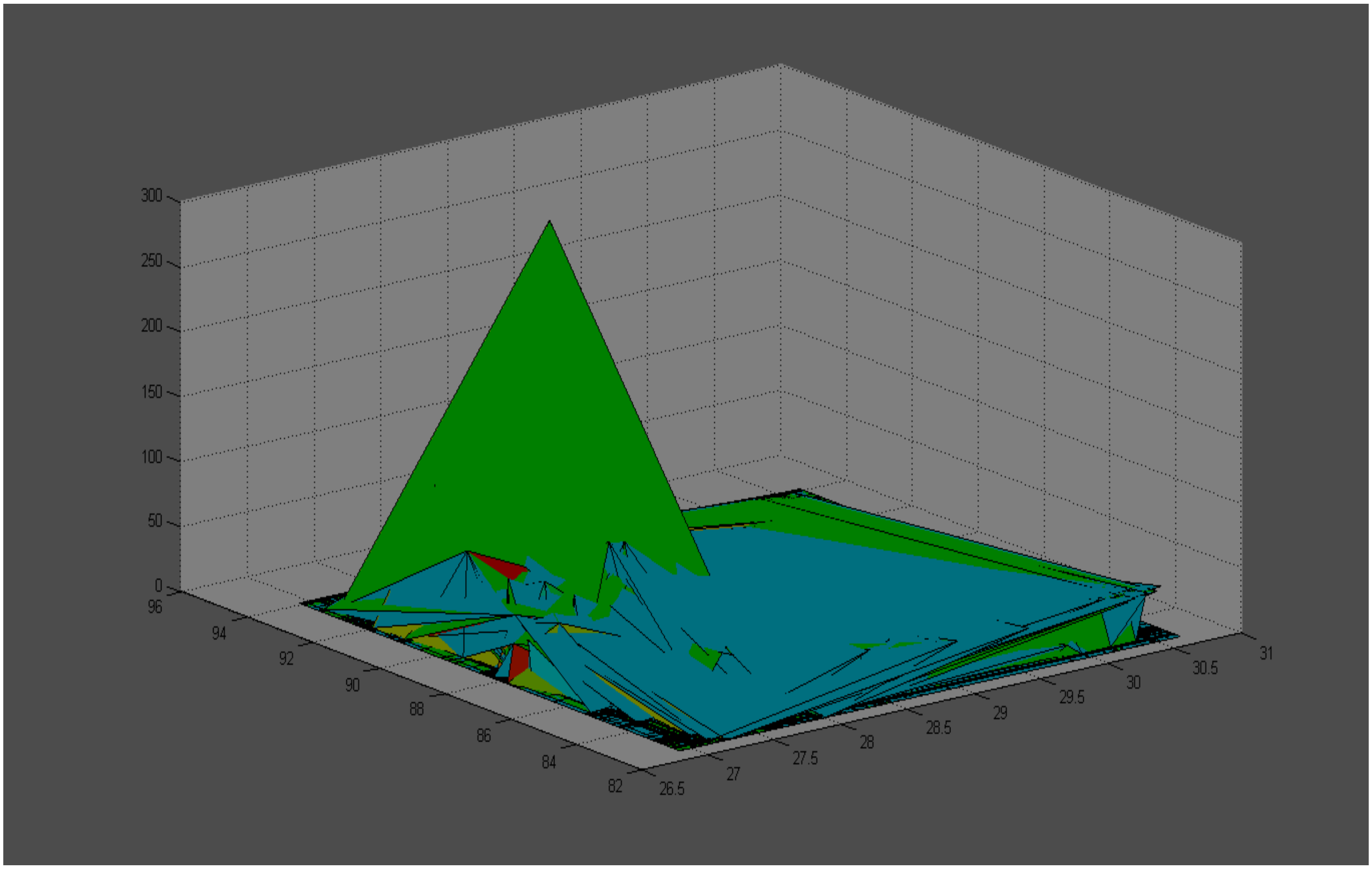


2) <u>Depth Model</u>:

This is another model that we have created using the points given in the fault. Here we have extended the 2D model using the depth of the epicenters to give us an approximate shape of the faults. This will help us know how the depth of each fault changes with the change in latitude and longitude.

Here is the Matlab script to get the Depth Model

```
filename = 'as.txt';
delimiterIn = ' ';
headerlinesIn = 1;
A = importdata(filename,delimiterIn,headerlinesIn);
x=(A.data(:,1));
y=(A.data(:,2));
p=polyfit(x,y,3);
f = polyval(p,x);
table=[x y f y-f];
plot(x,y,'o',x,f,'*');
```


300
250
200
150
100
50
0
96
94
92
90
88
86
84
82
26.5
27
27.5
28
28.5
29
29.5
30
30.5
31