EXTENDED SOURCE SIMULATION AS SEISMIC EARLY WARNING TOOL FOR PAKISTAN

Junaid Khan
Researcher, Department of Civil Engineering
UET Peshawar
Peshawar, Pakistan
reafathal@gmail.com

Awais Ali
Researcher, Department of Civil Engineering
UET Peshawar
Peshawar, Pakistan
awaiscivil928@gmail.com

Shahid Ullah
Assistant Professor, Department of Civil Engineering
UET Peshawar
Peshawar, Pakistan
shahid.ullah@uetpeshawar.edu.pk

Adeed Khan
Lecturer, Department of Civil Engineering
Iqra National University Peshawar
Peshawar, Pakistan
adeedkhan@hotmail.com

Mohammad Adil
Assistant Professor, Department of Civil Engineering
UET Peshawar
Peshawar, Pakistan
adil@uetpeshawar.edu.pk

Irfan Jamil
Researcher, Department of Civil Engineering
UET Peshawar
Peshawar, Pakistan
irfanuop@hotmail.com

Abstract

Pakistan is one of the seismically active regions, continuously being under threat of seismic activities. Seismic early warning system can be very useful in directing rescue efforts in proper direction. There is a need to step into sustainability and avoid the spring backs of development, like 2005 Earthquake, we need focus on this undeniable need, and so to keep in the race as different earthquake early warning systems have evolved and are evolving throughout the world.

This study demonstrates an approach, that is feasible, economical and a good starter, to implement an earthquake early warning system in Peshawar, Pakistan. Historical data of earthquakes was obtained and the relevant data was extracted according to our requirements along with defining an approach for selecting the Grid points, to house the sensors, using QGIS. Furthermore, the data is refined for input into the simulation code EXIM (Boore), which is used because of its good comparison with the results obtained from a ground motion prediction equation. At last, an exceedance time code, to calculate exceedance time between grid points and the target city, is developed. The use of micro genetic algorithm will make the system affordable.

Finally, unlike many of the early warning systems throughout the world, this allows choosing sparse number of station's locations with more reliability to bring in easy modification, if needed in future, and economy, however, to carry out this approach with high resolution require quite high computational power.

Keywords— Earthquake Early Warning, EXIM_dmb, Micro Genetic Algorithm

I. INTRODUCTION

The world is continuously engaged in developing earthquake early warning systems to ensure the sustainability of their progress, economy and safety of the human race. One of such systems is "Earthquake early warning system in Fujian, China", which was implemented in 2009, with online testing carried out in 2012 that bore the warning time of almost 6.5sec for onshore events and 13.7sec, with uncertainty of 3sec, for offshore events. Overall, 41 stations hold velocity meters along with 40 stations occupied with acceleration meters and 41 station house both acceleration meters and velocity meters. The data detected by sensors is transmitted to the processing center to estimate different parameters like, real time location, magnitude and available lead time. After this, information is released through mobile apps and on TV spots [1].

Another similar system is developed to issue warnings for Bishkek (Kyrgyzstan) and Almaty (Kazakhstan). In this study an early warning system is developed, with the analysis based on an arbitrarily generated one hundred and eight events along the active tectonic region, with fourteen events below the moment magnitude of 5.5. For both of the cities, seismic traces are simulated for each different event along with the computation of traces for each grid point, which are obtained by defining 0.2 degree spacing between 41.6 degree and 43 degree North , and72.8 degree and 79 degree east. After this, the simulated events are divided into different classes, Class 0, Class 1, class 2 and class 3, according to their maximum ground acceleration. The threshold for these classes is optimized along with the station location by making use of Micro Genetic Algorithm. According to results, if more than five stations are available for a single target, it is good to construct a separate network for both cities rather than combine one. Most efficient system of 8 stations was obtained for Bishkek with the warning time of 10sec achieved [2].

Similarly in an earthquake early warning system developed for turkey, Istanbul, which is under continuous seismic activity from the faults located under the sea of Marmara, an effort is made to develop more efficient and reliable system with minimal number of stations, enough lead time and less false alarms, however, in this study a point is raised that increase in lead time is not of much significant if it surpasses a value that is enough to perform our operations, say, shutting down of power lines, but what is more important is the reliability of the warning information. The Finite Fault Stochastic Simulation approach is adopted to generate synthetic seismograms at the target city and Grid points (spaced at 0.1 degree, with 128 onshore and 112 offshore sites). Moreover, in this study proper and elaborative focus is made on the network optimization along with obtaining optimized trigger threshold values, the existing thresholds values were 0.02g, 0.05g and 0.1g for three warning classes; class1, class2 and class 3 respectively. These trigger thresholds were optimized to 0.03g, 0.12g and 0.2g moving from class 1 to class 3. Furthermore, a cost function, for use in Micro genetic algorithm, special to this application was developed. In results, six onshore and three ocean bottom seismometers are suggested that could be used in effect to reducing the false alarms of the existing systems for class 3 events, however, the existing lead time, which was 17 sec, was going to reduce by almost 2.5sec [3].

With regards to optimization approach, Simple genetic algorithms have proved useful for various optimization problems; however, the issue with simple genetic algorithm is that it requires large initial population, which would result, ultimately, in quite more numbers of outputs that requires further refining and selection. Besides this, in our case, we need such a method that will result small number of outputs to design the more reliable and economic network. This issue can be overcome by making use of Micro Genetic Algorithm, which are special variation of Simple genetic Algorithm and it requires a lot lesser initial population as compared to Simple genetic algorithm [4].

Similarly, estimation of accurate parameter of an earthquake prior to dissemination of a warning is of real interest and different approaches have been adopted to compute different parameters from the initial traces of the P-waves, special to the applications of an Earthquake early warning system. A method to estimate magnitude using first three seconds P-wave amplitude has been developed [5]. One of the several methods, developed for estimation of parameters in early warning, is given below; it is developed under the china Earthquake administration [6].

This method follows six steps:

1. P-arrival is sensed, using Short-term-average and Akaik information criterion, automatically from traces records.
2. Consider different spectrum of frequency records, ground motion record is generated by various natural periods and single degree of freedom system response to acceleration, velocity and displacement respectively, with the natural time period being 1, 3, 5 and 10sec. However, damping ratio is 0.707.
3. Three period parameters and three amplitude parameters are calculated at P-wave record segment.
4. Two-layer-feed-forward artificial neural network is used, 3 period parameters and 3 amplitude parameters of P-wave trace for four various frequency bands and focal distance are provided as input, with total 25 parameters. The PGA, PGV and PGD are obtained as output.
5. The early stopping training function is used in the neural network to avoid over fit. The data is divided in three sets, with the 60 percent data as check or training set, which is used for computing change and updating weight and biases. The other subset of 20 percent is validation set, with the error on validation set monitored during training process.

Trained artificial neural network is applied to obtain forthcoming S-wave Shaking (PGA, PGV and PGD) from the first P-waves traces.

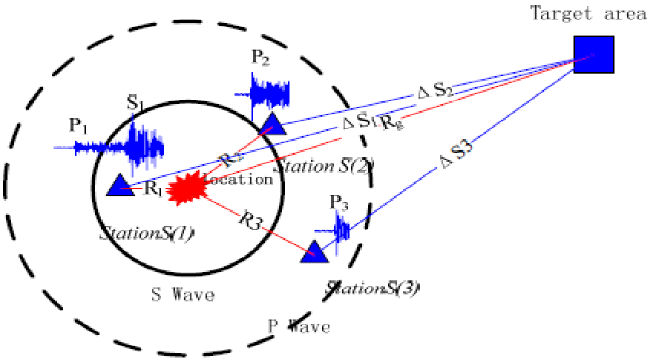

Figure 1: Schematic plot for ground motion prediction for any field [6].

as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. METHODOLOGY AND RESULTS

This section explains the complete step wise procedure, adopted for carrying out the prescribed operations for a regional earthquake early warning system for Peshawar, from data collection to plotting, refining, simulations and station optimization. Earthquake data is obtained from Global Earthquake Model (GEM). The data, obtained from Global Earthquake Model, is plotted on QGIS to extract data of interest and carry out other relevant spatial analysis. A Grid is defined and coordinates obtained using QGIS.

This data is further adjusted as input to program used for simulation. The program we used for simulation is EXIM_DMB by David. M. Boore (USGS). Simulation results are required as input for the optimization process. The optimization is not as simple and linear like a typical optimization processes and so different approaches like, simulated annealing, particle swarm optimization and Genetic Algorithms can be helpful. The micro genetic algorithm (special variation of simple genetic algorithm) is adopted for the evaluation and optimization of seismic network for the case of Istanbul [3]

A. Data source

In this work, we have explained the use of historical data in an earthquake early warning system rather than the use of artificially generated events. To obtain data about the past event, we approached Global Earthquake Model (GEM). Different Data sources are available for providing data about earthquakes, but making use of Global Earthquake Model has a special implication, that it contains earthquake events of higher magnitude. Focusing on higher magnitude is essential due to the nature of the applications of the data, if smaller magnitude events are taken into consideration, they would not result in significant ground motion at the target of interest, thus resulting in a warning that is, otherwise, not needed. Such insignificant warning can result in two issues:

- It can lead to economic losses by stopping activities that doesn't need to be stopped for such warnings. However, stopping activities like nuclear activities, industrial process, Shutting down electricity and transportation services can really result in an economic loss, which is an overhead caused by our improper design.
- In seismically active regions, small and insignificant earthquakes are abundant, if warning is issued for such insignificant ground motions, like a routine activity, it can become a wolf cry and the system is an unreliable system.

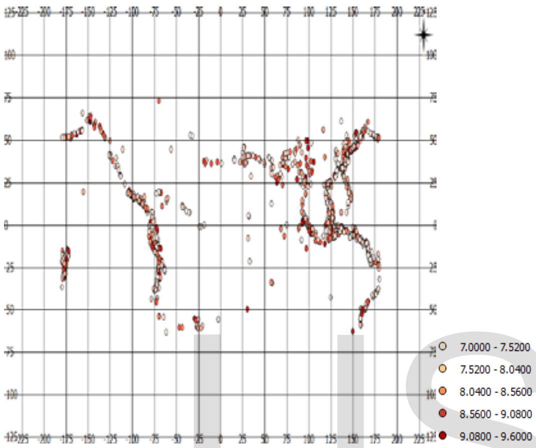

Figure 2: The figure shows distribution of major earthquakes worldwide. The red color is showing earthquakes of higher magnitude, with the light color running down to smaller values.

The GEM model, we adopted, contains events having Moment magnitude of above 5. The catalogue contains 1184 events and their different properties like latitude longitude, strike angle, focal depth and magnitude etc.

B. Data Extraction

To extract significant, that causes strong ground motion at site, and local data from the globally distributed events we made use of Geo processing tools in QGIS. To capture the events of interest, events falling over the region of Pakistan as well as those outside the boundaries of Pakistan, those which can contribute significant ground motion, are selected by defining a 200km buffer around the boundaries of Pakistan.

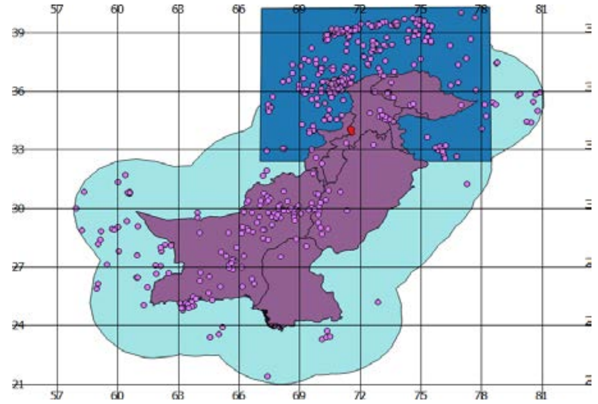

Figure 3: The figure is showing the clipped events, with rectangular portion to extract events clustered around Peshawar. The other events lying out of the rectangular portion are discarded. The red zone is showing Peshawar, while the blue boundaries represents the buffer.

The 200km buffer is more than enough to capture all the events, this statement is further supported by the simulation results, as the ground motions, at the target city, contributed by the events lying on the boundaries of the buffer are small enough. Furthermore, the events for northern regions that would have impacts on our target city are further separated from the events lying away from Peshawar. This would result in reduction of computational efforts. To show an example, the events were further scanned to select those above moment magnitude 7, summarized in Table 1.

Table 1: it shows details of the selected, seventeen, events.

Date	Coordinates		Magnitude (Mw)	Depth(Km)	Strike	Soil type
	lat	Long				
8/22/1902	40	77	7.69	0		C
4/4/1905	32.636	76.788	7.9	20	32.7	C
10/21/1907	39.179	70.585	7.41	20	28.5	C
7/7/1909	35.387	70.251	7.7	200	34.3	C
2/18/1911	38.331	72.628	7.26	15	12.5	C
11/15/1921	36.199	70.676	7.8	240	21.3	B
3/4/1949	36.563	70.698	7.5	228.7	36.3	A
7/10/1949	39.178	70.835	7.5	20	37.7	A
6/9/1956	35.155	67.607	7.27	25	34.4	A
4/13/1961	39.762	77.712	7.04	35	32.4	A
3/14/1965	36.405	70.724	7.44	207.8	32.5	A
7/30/1974	36.319	70.782	7.01	211.6	32.1	A
8/11/1974	39.355	73.823	7.1	10	175.3	A
12/30/1983	36.396	70.682	7.4	212.8	17.9	A
7/29/1985	36.12	70.911	7.38	99.2	24.3	A
3/3/2002	36.369	70.593	7.34	205	14.9	A
10/8/2005	34.451	73.649	7.59	15	27	A

C. Grid points

To locate the sensors, accelerometers for sensing ground motion, certain points are needed to be considered on the ground. As there are infinite points that can locate the sensors, however, we need such a location that provide maximum lead time and reliable information about the parameters (Magnitude, Distance, Frequency content etc.) of the impending events, as these parameters are really important and can play a major role in the future applications of earthquake early warning systems.

Considering finer grid spacing will result in more computational efforts, however, the grid spacing needs be such that in between two grid points, there should be very small difference of the Exceedance time i.e. the difference between the arrival time of S-waves at two neighboring grid points should be minimum and same applies to the maximum acceleration values recorded at the two neighboring points. While selecting grid points special attention should be given to the accessibility of the locations, which may be needed in future for maintenance purposes, if a sensor is deployed at such a location. The first priority is to be given to vicinity of the earthquake sources, these locations are the first one to sense the shocks and great gaps are available between detection of the event and arrival of the severe wave at the farther site of interest.

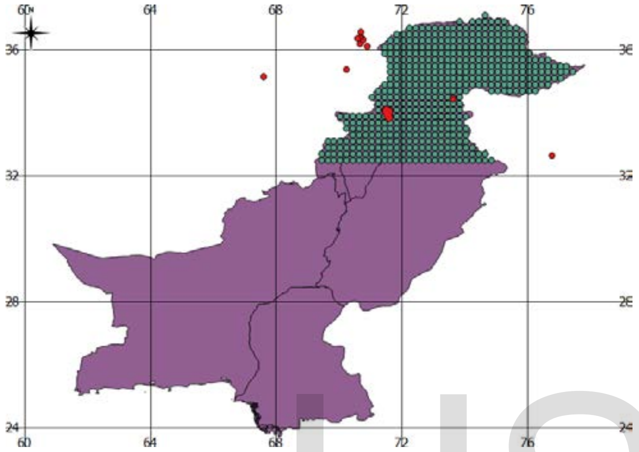

Figure 4: The green dots are showing 503 grid points, which are considered for housing the sensors. The red dots are showing the epicenters of the seventeen events, with the red polygon showing the target city, Peshawar

In our case, it can be seen from Figure 3 that grid points are not lying, closely, in the vicinity of the epicenters (Red Dots), it is because of the restriction imposed by the country boundaries. The grid points falling out of the country boundaries are discarded. These points are drawn by making use of the Regular Points Tool in QGIS, which is a vector research tool.

D. Simulations

To simulate the seismograms at the target city and the 503 Grid points we used extended source simulation code provided by David. M. Boore (URL). We have seventeen events and 503 grid points, which result into total of 8551 seismograms. This particular program, EXIM_dmb, considers a range of different inputs like parameters covering details of Source, Spectral shapes, Parameters related to frequency and other parameters required for the filtering of seismogram. The site amplification effects are considered by the code. The program assume segments over a long faults and considers random foci for simulation purposes, results from these foci are subjected to statistical processes to result in a single seismogram for a single source, divided into different small segments, at single point.

The input, to EXIM_dmb, used in this scenario is that of Distance (R) and Azimuth (Z). For the purpose of simulations at target city, the site location is fixed and the location of sources vary for calculation of Azimuth, however, opposite is true for calculating Azimuth to be used in simulations at the grid points. It helps to simplify the calculations, as the target city is a single point and considering a single or minimum no of origins, in other case, helps to manage data easily and make the computer code, for calculating Distance and Azimuth, simple. The line showing zero degree, if it is assumed as North direction, the Bearing is termed as Azimuth, while the blue line shows the distance calculated by distance formula. The Azimuth is calculated by finding tangent of a line and adding zero, 90, 180 and 270, if the line falls in first, fourth, third and second quadrant respectively. The points, (X2, Y2) and (X1, Y1) are at the end and start of a line, respectively.

```
peshawar=[71.52 34.01] ;
target=peshawar;
sourcef=importdata('files.dat')
r=length(sourcef);
long=zeros(r,1); lat=zeros(r,1);
long=sourcef(:,1);
lat=sourcef(:,2);
RAZ=zeros(r,2);
for i=1:r
    x=long(i,1)-target(1,1);
    y=lat(i,1)-target(1,2);
    R= 111*sqrt((x^2)+((y^2)));
    RAZ(i,1)=R;
    if x>0 && y>0
        AZ=(57.29)*atan(x/y);
        RAZ(i,2)=AZ;
    elseif x>0 && y<0
        AZ=90+((atan(-y/x))*57.29);
        RAZ(i,2)=AZ;
    elseif x<0 && y<0
        AZ=180+((atan(x/y))*57.29);
        RAZ(i,2)=AZ;
    else
        AZ=270+((atan(-y/x))*57.29);
        RAZ(i,2)=AZ;
    end
```

$$D = \sqrt{((x_2 - x_1)^2 + (y_2 - y_1)^2)}$$

Figure 5: It is the code used to calculate R and Z.

Mw	R(km)	Z	Mw	R(km)	Z
7.69	901.15	42.44	7.04	937.79	47.10
7.9	604.41	104.57	7.44	279.75	341.48
7.41	583.27	349.68	7.01	269.24	342.23
7.7	207.35	317.16	7.1	645.38	23.29
7.26	495.09	14.40	7.4	280.15	340.55
7.8	260.75	338.78	7.38	243.80	343.86
7.5	297.66	341.96	7.34	281.56	338.48
7.5	578.95	352.38	7.59	241.42	78.32
7.27	453.14	286.21			

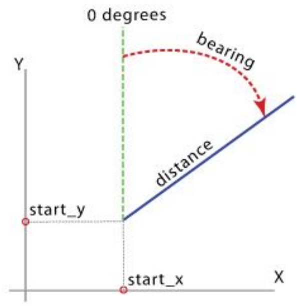

Figure 6: Results of the aforementioned code.

E. Results of Simulation

The simulation of seismograms, through EXIM_dmb, includes a lot number of inputs. One of the most important inputs is the value of stress release during the movement of a fault. Different approaches are available for determining this particular value. However, due to scarcity of research for our region, we ran different trails over the simulations and compared our results, from simulation, with values calculated from ground motion prediction equation. The ground motion prediction equation (1) defined by Cornell is used in this case, which is an old model and doesn't involve different advance parameters like variation for different site conditions, using this model gives peak ground acceleration (PGA) in close agreement with that from the simulation, if an advance Ground motion prediction equation is used our results can enhance, further, to a much closer and better approximation.

$$\ln(Ap)=a+bxM+c\ln(R+25) \qquad (1)$$

While a, b and c is constant having values 6.74, 0.859 and -1.80 respectively. Where, Ap, M and R show Amplitude, Magnitude and distance from source, respectively.

The difference in the results is so small that even if it is added to the significant ground motion from history it does not result in any major event that would, otherwise, result in significant ground motion.

Table 2: The table shows comparison of the results from Equation and simulation.

S.No	Magnitude	PGA from Model (g)	PGA from EXIM (g)	Difference (g)
1	7.69	0.00291	0.00259	0.00031
2	7.9	0.007	0.00728	0.00028
3	7.41	0.00488	0.00311	0.00176
4	7.70	0.03547	0.01846	0.01701
5	7.26	0.00569	0.00315	0.00254
6	7.80	0.02663	0.01584	0.01079
7	7.50	0.01653	0.00947	0.00706
8	7.50	0.00534	0.00424	0.00110
9	7.59	0.02522	0.01814	0.00708
10	7.04	0.00155	0.00141	0.00013
11	7.44	0.01740	0.01079	0.00661
12	7.01	0.01281	0.00767	0.00513
13	7.10	0.00314	0.00199	0.00114
14	7.40	0.01677	0.01018	0.00659
15	7.38	0.02072	0.01090	0.00981
16	7.34	0.01580	0.01042	0.00537

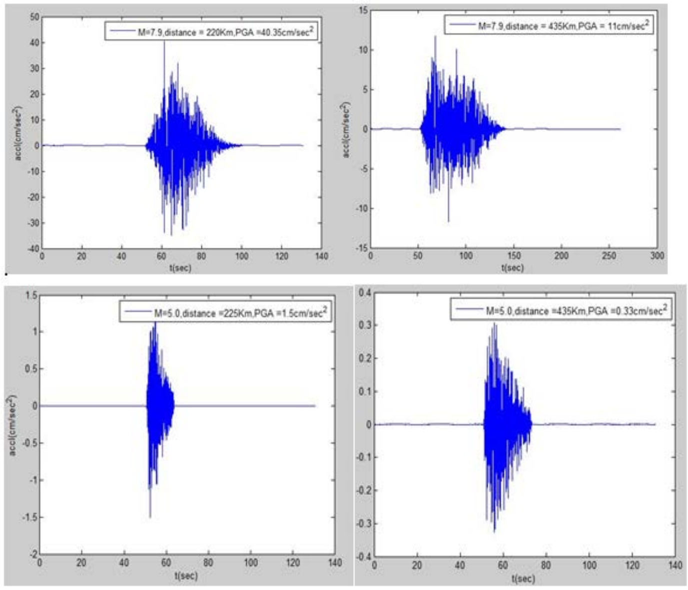

Figure 7: The figure shows simulated PGA (S-Wave) using Exim_dmb

F. Optimization

The approach recommended for optimization is that of Micro Genetic Algorithm as it has resulted in good results for such application like in case of Turkey [3]. However, in our work, we have written a code for calculating exceedence time at the target site. The sensor's trigger threshold values given in this code are as example and obtained from the case of Turkey, however, these values can also be optimized by running different trails.

G. Exceedance time

The simulated seismogram gives time histories as they are detected at the site under consideration. Thus, for a seismogram having P-waves and S-waves amplitudes, Exceedance time will be the time at which Peak ground acceleration occurs, at the site, minus zero. The other term is zero because the origin of the simulated time history, at a site, is the site itself i.e. time history starts as the motion is detected at the site. Following is the Code for Exceedance time.

```
function [Exceedence_time]= ComputeET(Noofevents) %Rows
%inputfile=importdata('array.dat');
load Array;
inputfile=Array;
TH= abs(inputfile);
N=Noofevents;
maxarray=zeros(1,N);
maxval=max(TH,[],1);
maxarray=(1/980)*maxval(:,2:end)
indicies=zeros(1,N);
Accel=zeros(length(TH),N);  %ONLY Accelration values of time_history
Accel=(1/980)*TH(:,2:end);
for i=1:N
    if maxarray(1,i)>=.1
    indicies(1,i)=find(Accel(:,i)>=0.1,1); %We are calculating Indicies
    elseif maxarray(1,i) >= 0.05
        indicies(1,i)=find(Accel(:,i)>=0.05,1);
    elseif maxarray(1,i) >=0.01
     indicies(1,i)=find(Accel(:,i)>=0.01,1);
%     else
%     disp('hi')
    end
end
 disp(indicies);
% Finding warrning classes, the approch we are using is:if
% event falls in upper classes we calculate time for all the classes
% However if there are no values we assign a random of -10000
% /for colom we always put 1 as 1st colom includes time,
% Multiply 980 to convert g to cm/sec^2, we alo need to take abs
ET=zeros(3,N);
```

```
for i=1:N
    if maxarray(1,i)>=.1
        ET(3,i)=TH(indicies(1,i),1);
        if2=find(Accel(:,i)>=0.05,1);    % 2ndT
        ET(2,i)=TH(if2,1);
        if1=find(Accel(:,i)>=0.01,1);    %1st T
        ET(1,i)=TH(if1,1);
    elseif maxarray(1,i)>=0.05 && maxarray<=(0.1)
        ET(3,i)=-10000;
        ET(2,i)=TH(indicies(1,i),1);
        if1=find(Accel(:,i)>=0.01,1);    %1st T
        ET(1,i)=TH(if1,1);
    elseif maxarray(1,i)>=0.01 && maxarray(1,i)<=0.05
        ET(3,i)=-10000;
        ET(2,i)=-10000;
        ET(1,i)=TH(indicies(1,i),1);
    else
        ET(3,i)=-10000;
        ET(2,i)=-10000;
        ET(1,i)=-10000;
    end
end
Exceedence_time=ET;  % 1st row=exceedence time for all event of class 1st
                     % And so on
end
```

The Exceedance is used for the calculation of S-waves at the site for each source under consideration. This will help us to find the expected class of optimization for warning. Threshold may vary which depends upon on each class.

- Total Number of time values = Number of sources under consideration
- The resulting matrix is of order (I,N)
- I=Number of classes
- N=Number of considered sources
- If an event falls in the uppermost class
- It gets three actual time values, no dummy values
- The dummy values for a particular class are:
- No of dummy values= Upper class – current class

This will to give us expected warning class, importance factor for each class and future comparison with the results of Micro genetic algorithm.

CONCLUSION

This study aimed at looking background scenario for an earthquake early warning system in Pakistan. It has been already mentioned that Pakistan is one of the seismically active regions, with no such study or approach carried out before. The approach that is selected should provide for a good starter and must be an economical approach. In this regard, the aforementioned approach has been explained having the gist or conclusions given below.

- The approach being selected is based on theory rather than a lot number of field trails and deploying sensors to carryout trials for selection of station's location. However, performance trails are obviously needed to be performed once the system is developed.
- The Simulation results from Cornell's Equation and EXIM_dmb are in close agreement, especially, for this application, however, further finesse can be incorporated by using new advanced and refined equations for comparison.
- Across the world, there are different early warning systems based on different algorithms but one weak point is often founded in them that is a large number of sensors and due to this, it is often difficult and uneconomical to deploy any major change in such systems. While in the aforementioned approach, the optimization has a key role to calculate the sparse number of best locations and proceed with small number of locations, and hence sensors, ensuring economy and ease with future changes, if to be made.
- The approach also considers exclusion of such locations that are anticipated to provide future problems with the grounding or future maintenance of sensors.
- This method has a special application of Micro genetic algorithm, for optimization, which is a modification of ordinary genetic algorithm, requires large initial population. While, Micro genetic algorithm requires a scant initial population, hence, providing small number of best locations.

Finally, this approach is a good and economical step towards implementing an earthquake early warning system in the developing country, and convincing the authorities to focus their focus and part of finances towards such implementations.

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