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Innovative Mathematical Model for Earthquake Prediction

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ABSTRACT

An Innovative Mathematical Model analysis was carried out based on twenty years of earthquake data from California, Central USA, Northeast USA, Hawaii, Turkey, and Japan fault zones using Latitude, Longitude and Magnitude as variables. Using Poisson's distribution and spatial connection model, an identifiable pattern was found within the random occurrences of the earthquakes around each fault zone. This research provides an effective contribution to seismology by improving probability of successful prediction.

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1. Introduction and previous work

Innovative Mathematical Model was used to find an identifiable pattern within each fault zone based on spatial connection theory: earthquakes occurring within a fault zone are related to one another.

Current methods of predictions of earthquakes are based on land deformations, tectonic movements, seismic activity, differences in seismic wave velocities in different world regions, and geomagnetic and geoelectric phenomenons [1].

Due to the presence of Indo-Eurasian plate boundary zone, China has intense seismic activity. The researcher built a computer model to study Coulomb stress effect and analyzed 49 earthquakes of at least 6.5 magnitude that occurred in China. Consistent with the findings in the computer model, 80% of actual events were due to the stress build-up caused by previous earthquakes [2].

Extreme events, such as high-magnitude earthquakes, are clustered in the form of random patterns. Seismologists from the International Institute of Earthquake Prediction and Geophysical Mathematics at Moscow, Russia have developed an efficient stochastic-based M8 algorithm with a 99.71% confidence level for predicting location, time, and magnitude range of earthquakes in Armenia region and were able to predict six of seven major earthquakes [3].

Stochastic earthquake prediction models can be combined utilizing differential equations resulting in a more accurate earthquake prediction. Analyzing and interpreting various models, increases the reliability and validity of the prediction [4].

The stochastic CN algorithm has been utilized to predict earthquakes in the Italian region. It utilizes arcs and curves, geological patterns, and past earthquake history to predict earthquakes. The CN algorithm has an accuracy of 96% since it has 67 accurate forecasts out of 70 attempts [5].

2. Theory

The spatial connection theory used in this research is based on the assumption that earthquakes are related to previous earthquakes that occurred within a fault zone.

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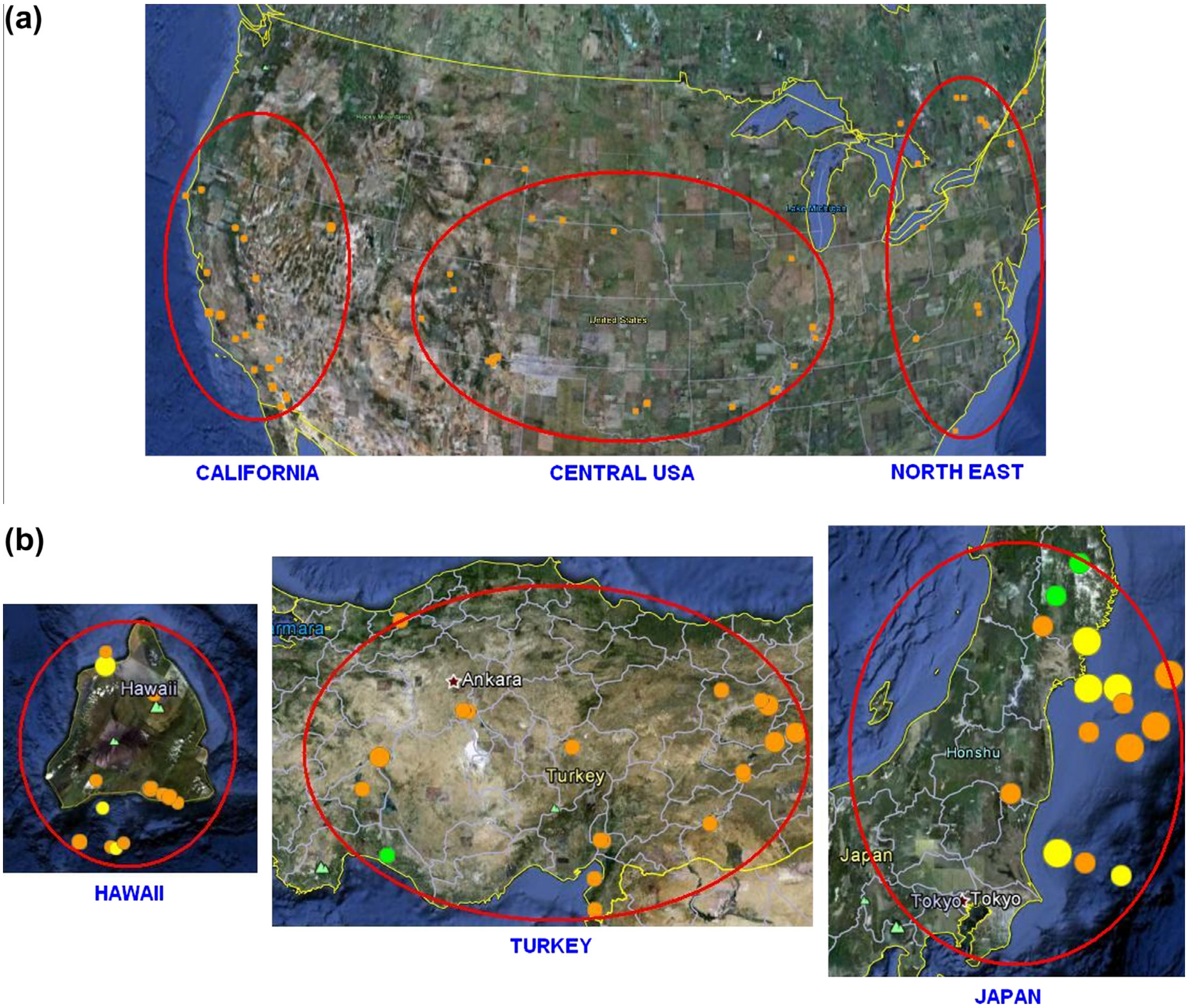

Fig. 1. Earthquake zones.

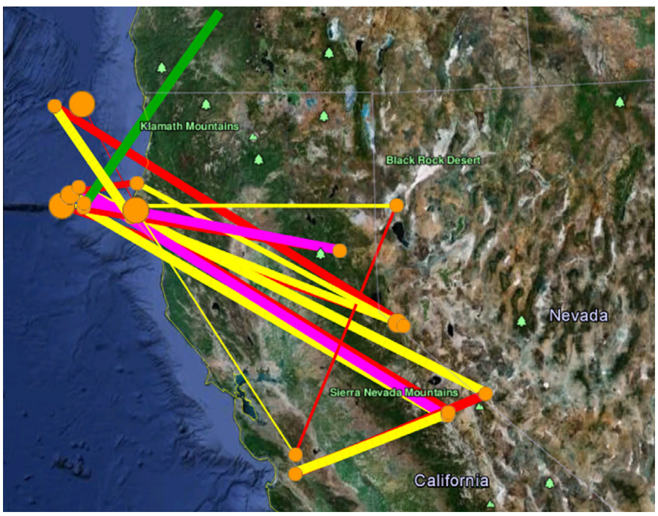

Fig. 2. California earthquakes (1991–2001) spatial connections.

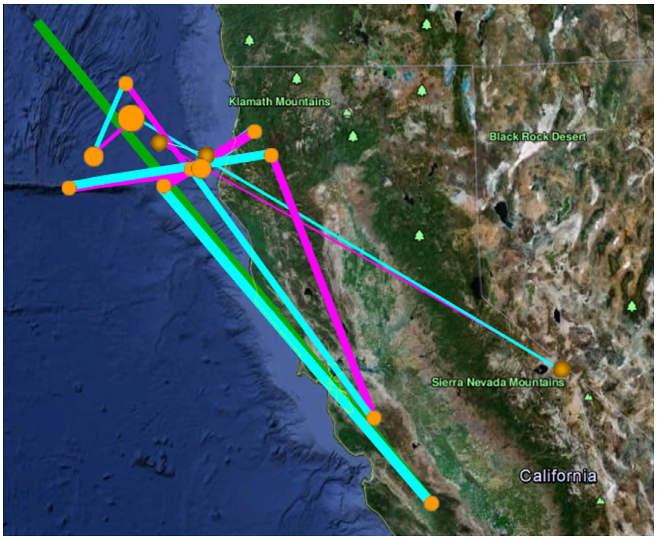

Fig. 3. California earthquakes (2002–2012) spatial connections.

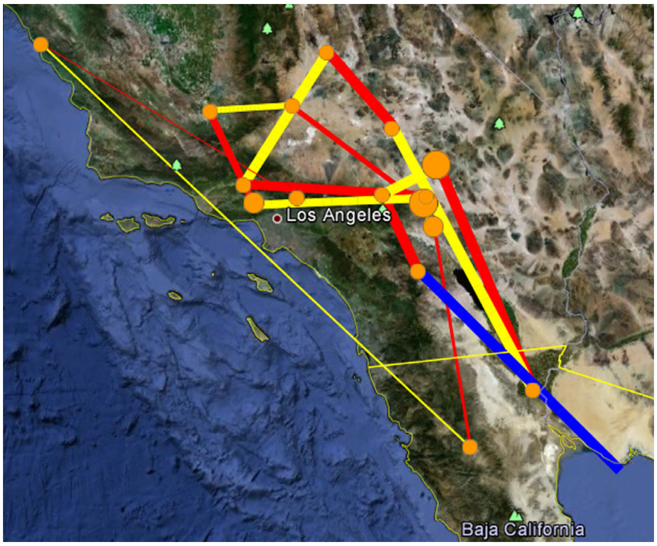

Fig. 4. California earthquakes (1991–2001) spatial connections.

This theory utilizes principles involving stratum and stress to predict different locations for earthquake epicentres. In high-density stratum, it was observed that there were acute angles between subsequent epicentres. In low-density stratum, it was observed that there were obtuse angles of return between subsequent epicentres.

This theory was developed into a model utilizing Google Earth program and model building tools. The data in the form of KML files were inserted into the Google Earth program and spatial connection models were built.

Poisson's distribution is utilized to predict future occurrences of an event where the past occurrences of the event are independent of each other. In this research, poisson's distribution was applied to the Pri values for each of the six earthquake zones to arrive at a distance factor. Reverse poisson's distribution is utilized to predict future occurrences of an event where the past occurrences of the event are dependent of each other. In this research reverse poisson's distribution theory was applied to the distance factor of each earthquake zone to arrive at a prediction distance and time.

Earthquakes occur in narrow and well-defined belts. The location and timing of earthquakes were assumed to be dependent of past earthquakes within the zone, and thus comply with the reverse poisson's distribution.

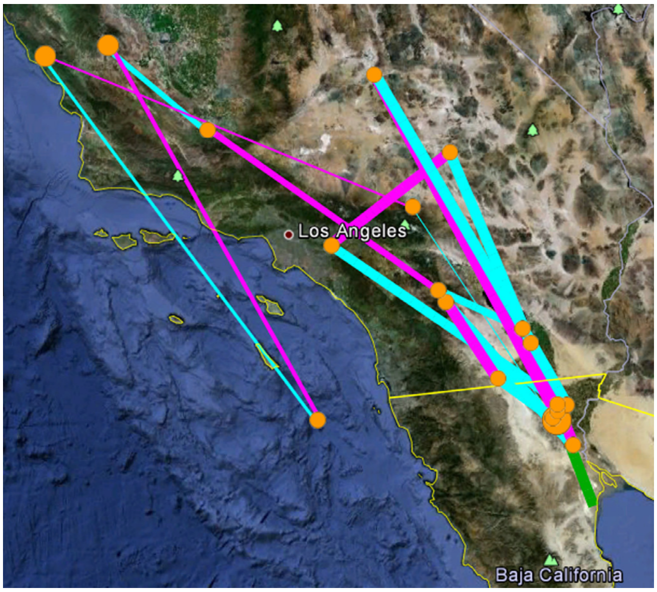

Fig. 5. California earthquakes (2002–2012) spatial connections.

3. Method

In this research, six major earthquake zones were identified based on their tectonic setting. These are California, Central USA, North East USA, Hawaii, Turkey, and Japan. Please see Fig. 1a and b. KML data files for two periods of ten-years were imported onto Google Earth program and spatial connection models were built. Using the epicentres, spatial connection lines were drawn connecting the earthquakes within a zone. Please see Figs. 2–5.

Significant amount of earthquake data exists in global earthquake databases such as those by the NEIC and USGS. For this research, different earthquake zones were identified based on different tectonic settings. According to Incorporated Research Institutions for Seismology, California and Turkey are strike-slip fault zones [6]. According to Wolfe, Hawaii is a volcanic fault zone [7]. According to Kafka, Northeast USA is an intraplate earthquake zone [8]. According to Natural Resources Department of Canada, Japan is a megathrust earthquake fault zone [9]. According to Central United States Earthquake Consortium, Central United States is a thrust fault zone [10].

Mathematical functions utilized in this research were the poisson range identifier function, poisson's distribution, and reverse poisson's distribution. The Pri function utilizes the data from the spatial connection model to derive pri values for each earthquake zone. Then, a distance factor was derived using the poisson's distribution. The prediction was carried out by using the reverse poisson's distribution and the distance factor for the earthquake zone.

To validate the theory, the models were built for first half of the data and predictions were developed. Then the models for second half of the data were built, validating the predictions from the initial models.

There is a relationship between the earthquake occurrences with respect to distance, direction, and time between two earthquakes. An equation for the relationship between angle of turn and difference in time was developed to predict a distance range for the next earthquake. See Fig. 7.

$$\text{Poisson's Range Identifier (Pri)} = [(x1 * \text{time lag } 2)/[(\text{Cos}(\text{theta}) * x2 * \text{time lag } 1)]$$

where $x1$ = distance between first and second epicentre, time lag 2 = difference of time between second and third earthquake, theta = angle between first spatial connection model line and the second line, Cos theta = cosine of angle theta, $x2$ = distance between second and third epicentre, and time lag 1 = difference of time between first and second earthquake.

To arrive at a statistically robust group for finding the average (Pri) for the zone, two of the highest values are omitted and cumulative value and mean for rest of the values are found.

Applying Poisson's distribution to the Pri Data,

$$\text{Df} = \text{POISSON DIST } [\text{Pri}; \text{Pri(mean)}; \text{Pri(cu)}]$$

Using distance factor (Df) and reverse Poisson's function future predictions were carried out and listed in the results table.

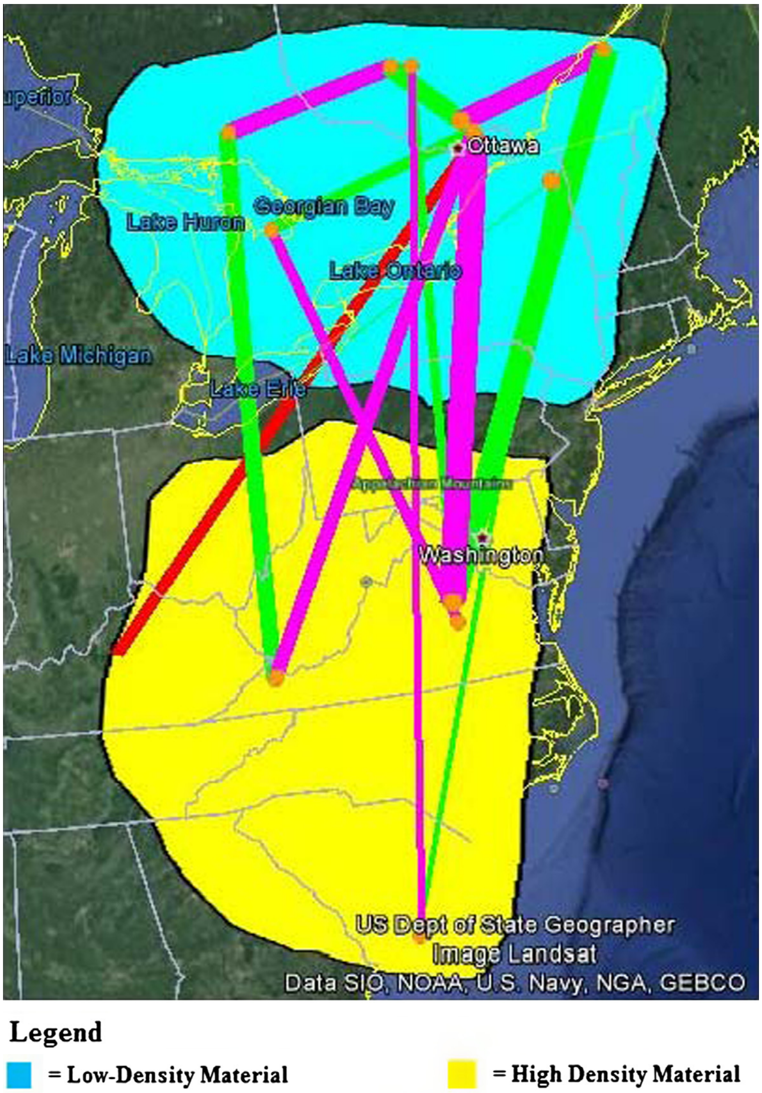

Fig. 6. Stratum in Northeast USA.

4. Data

Using National Earthquake Information Center database, data for six zones California, Central USA, North East USA, Hawaii, Turkey, and Japan were collected using past earthquake data. Depending on the occurrences of earthquakes, their magnitudes, and fault tectonic settings, the rectangular area or radius for the data collection for each zone was chosen as shown in the Meta-Data table.

5. Analysis

Data analysis was carried out to evaluate statistical significance between the different sets of earthquake data. See Appendix for T-Test Values Graph and T-Test Values Table. All of the *T*-Test values were well below the 2.20 limit. By the reverse *T*-Test concept or the null hypothesis, researcher proves that there is no difference between these data groups, supporting the theory that earthquakes within a fault zone are related to one another.

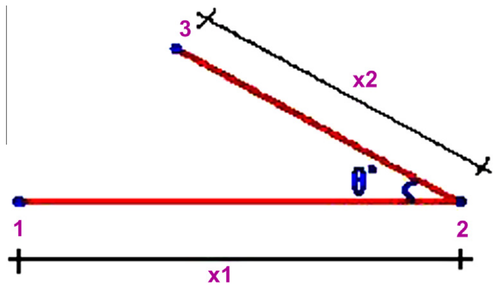

Fig. 7. Relationship between Angle of Travel and Distance

6. Discussion

Innovative Mathematical Model analyses of the California fault zone data showed the seismic forces travelling long distances along the San Andreas Fault. In California, the predictions were located 60 km (2013), 12 km (South 2002), and 22 km (North 2002) away from actual earthquake locations.

In Central USA, seismic force travel patterns were much more predictable since the earthquake occurrences created similar patterns. In Central USA, the prediction was located 100 km from the actual earthquake location.

In North-east USA, analyses showed that seismic forces were covering large distances from south to north. Within the northern end of the spectrum (near Ottawa region), the forces travelled slow and made obtuse turns due to low-density material in the stratum. According to Natural Resources Department of Canada and Maine Geological Survey, New England and the surrounding regions are made up of predominantly sedimentary rocks [11,12]. This confirms the assumption that there is low-density material in the stratum causing obtuse angles.

In the southern end of the spectrum (Virginia region), the forces travelled fast and made acute return angles due to high-density material. According to the Virginia Department of Mine, Minerals and Energy, many of the rocks located in Virginia are igneous and metamorphic [13]. Igneous and metamorphic rocks are denser than sedimentary rocks, clarifying that Ottawa region has lower density material than Virginia region. This confirms the assumption that there is high-density material causing acute angles. Please see Fig. 6. In Northeast USA, the prediction was located 17 km (2001) away from the actual earthquake location.

To validate the theory, two zones outside of United States were analyzed. Within the European zone Turkey faults, the prediction was located 6 km (2001) away from the actual earthquake location.

In the Japan fault zone, seismic forces travelled large distances in short periods of time showing clear fault line movements. The prediction is located 20 km away (2001) from the actual earthquake location.

7. Conclusion

The research results show that there is an identifiable pattern in random earthquake occurrences and provides an effective contribution to seismology by improving probability of prediction. This Innovative Mathematical Model predicts locations of earthquakes by using past earthquake data for six earthquake zones. To increase the accuracy of the predictions from this model, it will be combined with other prediction models by means of triangulation. The triangulation is dividing the prediction points of different models into 3-point sets and identifying the centroid of the triangles formed in these sets. By continuing this process till there is one point left, the prediction of the model will be vastly improved. The Spatial Connection Model, the Pri function, and the reverse poisson's distribution show that earthquakes within a fault zone are related to each other, supporting the basis of this model and earthquake prediction.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.engfailanal.2013.10.016. These data include Google maps of the most important areas described in this article.

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