Earthquake Forecasting System (EQFS)

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Real-time Integrated Systems Engineering (ISE) Earthquake Forecasting

General Information

It is well known that every earthquake fault is different in many ways such as size, location, soil type, rock type, water chemistry, weather conditions etc., and therefore every earthquake fault has different characteristics and different associated functionality that is constantly changing. The functions acting on the earthquake faults are also actively different and constantly changing. This is fundamentally why forecasting catastrophic earthquakes are extremely complex and difficult to achieve. It is because of this huge matrix of constantly changing variables that using real time data measurements is best for earthquake forecasting. We propose that by employing earthquake fault simulation models with real time data combined with using probability quantification figures in place of physics parameters the complexity of earthquake fault forecasting can be greatly simplified and improved. The difficulty of accomplishing adequate detailed models may be a very difficult task initially. However, earthquake fault models may be created that are good enough to begin improvement in earthquake forecasting and can be updated and improved upon with experience developing them and perhaps narrow the earthquake forecasting time gradually. The earthquake forecasting systems approach may become easier to use as the details and data are exchanged between various institutions, gathered and stored more efficiently, and become better understood in the integrative systems process. This integrated systems approach will incorporate the historical prediction methods that have been accomplished by others and utilize those prediction methods as a foundation to build upon for simulation modeling and analysis. Earthquakes are not predictable, but this cannot be the last word. With this Systems Engineering approach we propose to move earthquake forecasting out of the realm of controversy that has marred so many of the interactions in the past between seismologists and non-seismologists. Some recommended relevant reference material to coincide with the development of the integrated earthquake forecasting systems modeling process are the following:

Peter Bormann, From Earthquake Prediction Research to Time-Variable Seismic Hazard Assessment Applications
Vladimir Keilis-Borok, Alexandre A. Soloviev, Nonlinear Dynamics of the Lithosphere and Earthquake Prediction
Ragnar Stefansson, Advances in Earthquake Prediction: Seismic Research and Risk Mitigation
C. Thanassoulas, Short-term Earthquake Prediction
Francesco Mulargia, Robert J. Geller, Earthquake Science and Seismic Risk Reduction
C. Kisslinger, T. Rikitake, Practical Approaches To Earthquake Prediction And Warning
Sergey Pulinets, Kirill Boyarchuk, Ionospheric Precursors of Earthquakes
M. Hayakawa, Electromagnetic phenomena associated with earthquakes
H. Chesnut, Systems Engineering Methods
Goode & Machol, Control Systems Engineering
F. Beer and E. Russell Johnston, Dynamics
J.L. Meriam, Dynamics

Abstract

Being able to recognize earthquakes (EQ) before they strike has been an elusive goal. This capacity is slowly coming into focus, thanks to advances in elucidating the physical processes underlying a wide range of pre-EQ phenomena. Here we present an architecture for EQ forecasting on the scale of days to weeks, possibly months or even years. It is based on NASA's integrated systems engineering (ISE) approach to evaluate failure risks in complex systems.

We propose a robust methodology using the latest in technology tools available with an integrative process approach that includes the use of quantifiable probability figures to establish a process platform for easy analysis and understanding of complex nature built earthquakes faults as systems with many subsystems.

The integrated systems approach encompasses a function flow energy transfer of events methodology that views the earthquake fault and its input activity and output reactivity as a complete probabilistic non-deterministic earthquake forecasting system (EQFS). This method converts the temporally very slow input physics parameters acting on earthquake faults and compressed rocks into probability of failure data. Then the ISE approach integrates that data with the failure modes and the reactive energy output of earthquake faults with compressed rocks, thereby rendering additional probability of failure data about the EQFS. Many earthquake precursors are manifested from the activity of these earthquake faults with compressed rocks. These earthquake precursors are an intrinsic subsystem of the EQFS the probability of failure model. The earthquake precursors temporally precede earthquake events, but the have less energy and last longer than earthquakes.

By using an integrated systems engineering process, with a generic model that is easily modifiable to include data from any earthquake fault by simply changing the failure rate data/parameters, precursor data, etc., of any given earthquake fault within the EQFS model, we hope to develop and demonstrate various earthquake fault scenarios. The ultimate objective is for the EQFS model to be used as a plug and play tool that can ultimately be used to develop a real-time prognostic tool for earthquake forecasting that has real-time precursor sensory input data.

Predicting earthquakes has been and continues to be seismology's "Holy Grail". Unfortunately, the tools used by seismologists are limited and ill suited to reach this goal. The reason is that seismologists approach the question of earthquake prediction by looking at past (historical) events and then calculating the probability of events in the future. Additional input may come from geodesy, e.g. from information on how the Earth's surface deforms and how sections of the plates move relative to each other.

In this paper we present an architecture for a fundamentally new approach to earthquake forecasting. This approach encompasses three fundamental key aspects. This approach involves focusing on the utilization of all possible "real-time" precursors that can precede an impending hazardous earthquake in an integrated fashion, as part of a complete earthquake forecasting system model to aid in the certainty and increased accuracy of earthquake forecasting. Some "real-time" precursors that are used as prognostic indicators to an impending earthquake in the EQFS forecasting model are thermal infra-red glow, air ionization perturbation, ultra-low frequency electromagnetic emission, radio-frequency noise, earthquake lights, geo-electric waves, atmospheric gravity waves, radar reflectivity, radon readings, water chemistry changes, human and animal behavior changes.

Secondly, this approach utilizes a stochastic, non-deterministic, modeling methodology that converts the earthquake fault integrated subsystems and components functional physics parameters and physical characteristics into probability of failure numbers, based on all of an earthquake "real-time" fault input, output functions and physical characteristics. A big advantage to using probability is that when physics parameters are converted into continuous probability variables, time is implicit and automatically taken into account with the probability figure for easy mathematical calculations.

With this systems integration engineering approach earthquake faults are viewed as “real-time” functional energy flow systems enacting on earthquake fault physical failure modes, and integrated subsystems with input and output functional energy contributors, all working together, that can generate probabilistic data earthquake predicting precursors events to impending earthquakes as well as cause a dramatic hazardous failure, namely an earthquake with a magnitude of 5.0 or higher.

Introduction

The main purpose of this paper is to present a “real-time” systems engineering approach to earthquake prediction. The work presented here is highly theoretical and based on a number of assumptions. This paper attempts to establish a concept for a baseline methodology or template to be used and followed up on, and to perhaps build and achieve a real-time, usable, early warning with timely forecasting, system that has a non-deterministic stochastic higher confidence of certainty in hazardous earthquake forecasting.

Seismologists and geophysicists base the stochastic earthquake probability forecasting calculations on past occurrence, recurrence, epicenter migration extrapolation, seismic gaps, and interpretation of earthquake precursor information. This has not worked. Earthquake event probability forecasting presented here is based on earthquake precursor data, the causal input functions to earthquake faults data, the earthquake faults characteristic physical makeup, the earthquake faults failure modes data, and the earthquake faults output functions reaction response effects data, all in a matrix together forming an integrated system. It is important to note that the earthquake fault forecasting system (EQFS) model used also includes a portion of the earthquake faults output positive (in phase) functions going back into earthquake faults are added to the input functions and failure producing forces to account for the increase in enormous earthquake energy buildup forces and great instability in earthquake events caused by the regeneration effects that are similar in nature to the regeneration forces that are in tornados, prior to physical characteristic deformation changes in the earthquake faults that cause the earthquake events to cease.

In this System Engineering Approach we allow inputs from every long-term or short-term energy source that can have an effect on information about processes deep in the Earth’s crust and external to the earth's crust, which occur during the build-up of stress on earthquake faults, e.g. before catastrophic failure of a fault that could lead to an earthquake. The System Engineering Approach focuses on using probability theory in an attempt to have a reliable and quantifiable stochastic method for understanding stress accumulation and behavior, as well as a more accurate approach to increase certainty in forecasting catastrophic failures. Our goal is to establish forecasting confidence, with a model containing a matrix of as many input parameters as possible, including seismological (historical) information along with real-time sensor information provided by integrated functional processes. It is hoped that this methodology will inspire a new, different, and improved way to describe and forecast earthquakes.

It is important to note that this is a simulated System Engineering modeling process, using simulated numbers, for concept development only. It is also important to note that with probability quantification this System Engineering Approach will attempt to simplify the complexity of analyzing an earthquake forecasting system completely built by nature that is constantly changing, by modeling an earthquake fault as a system and using a multi-signal testability analysis tool.

Our primary goal is to illustrate that Systems Integration Engineering (SIE) may be used to reduce the complexity of a very complex problem. Another goal is to offer a tool or methodology to support the work that is already in progress and capitalize upon the work that is being accomplished with many different types of earthquake faults and earthquake forecasting precursors. We want to support the work that has already been done, by developing another method to be used for easy validation, and another approach for review and discussion of a complex problem.

It is also our intent to develop an earthquake fault model to be used as a tool that is flexible. We are developing a template, a method, or a boilerplate to be used and built upon. Our goal, at this point, is not focused upon producing an accurate output of our model. We are concerned here with developing a platform using a systems engineering approach to help solve a very complex problem or complex problem set. It is hoped that our approach will be a useful method to coincide with the work done by others, along with increasing developments in contemporary knowledge of earthquake precursors.

We use an integrated systems engineering process for development of a probability model that looks at an earthquake fault as an unstable nonlinear earthquake forecasting system made up of many integrated subsystems comprised of subsystem failure modes probabilities and earthquake forecasting precursors for a given time period. This is accomplished by quantifying the integrated functional effects of each subsystem that make up the complete system by using a systems functional flow model, also known as a probability of success or failure model. With this Earthquake Forecasting systems real-time model, it can readily be shown that the more precursors that are indicated real-time and used, during a given time period, the more likely there is a higher chance or probability of forecasting an earthquake event occurring for that given time period. It can also readily be shown to have quantifiable probability numbers that anyone (scientists, engineers, business men, and the general public) can understand and respond to.
A top level Earthquake Forecasting block diagram that illustrates how the "real-time" Earthquake Forecasting System (EQFS) will be designed and developed is depicted in Figure 5.0. The EQFS will be a hardware and software product that will be easy to comprehend, easily updated and maintained, and very easy to operate.

GOALS

Our primary goal is to illustrate that an integrated systems approach may be used to reduce the complexity of a very complex problem. Another goal is to offer a tool or methodology to support the work that is already in progress and capitalize upon the work that is being accomplished with many different types of earthquake faults and earthquake forecasting precursors. We want to support the work that has already been done, by developing another method to be used for easy validation, as well as another approach for review and discussion of a complex problem. Our goal is to demonstrate that with quantifiable probability numbers anyone (scientists, engineers, businessmen, and the general public) can understand and respond to geologic event forecasting.

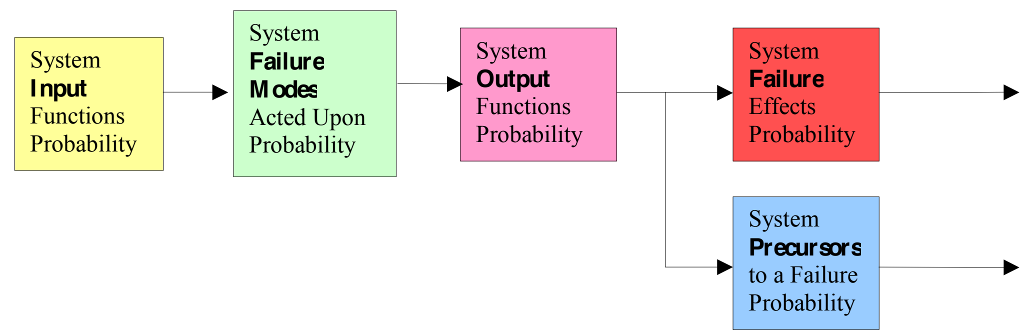
It is also our intent to develop an earthquake fault model to be used as a tool that is flexible. We are developing a template, a method, or a boilerplate to be used and built upon. Our goal, at this point, is not focused upon producing an accurate output of our model. We are concerned here with developing a platform, using an integrated systems approach to solve a complex problem or complex problem set.

It is our vision to use an integrated systems process for development of a probability model viewing earthquake faults, as unstable nonlinear earthquake forecasting systems, containing many integrated subsystems that have failure mode probabilities and earthquake forecasting precursors. This will be accomplished by quantifying the integrated functional energy exchange effects of each subsystem that makes up the complete system, by using a systems functional flow model, also known as a probability of success or probability of failure model as is depicted in figure 1.0. With real-time Earthquake Forecasting Systems, it will be shown that the more earthquake precursors that are indicated with real-time data, during a given time period, the more likely there is a higher chance, higher probability, of forecasting catastrophic earthquake events for that given time period.

Earthquake Forecasting System (EQFS) Probability Modeling

Before attempting to develop the EQFS probability of failure model or EQFS earthquake forecasting reliability model of an earthquake fault system, a generic systems functional flow block diagram of the earthquake fault system using pre-earthquake signals had to be developed. To understand and use probability theory in a functional flow sense, the generic probability flow diagram as depicted in figure 1.0 was developed as a template for development of the systems functional flow diagram to show sequences, relationships and signal paths as depicted in figure 2.0. It is important to note that even with the very best forecasting system, using the probability of continuous variables implies non-deterministic quantification with a limited degree of certainty, and a time element being involved.

Figure 1.0 Generic System Probability of Failure Block Diagram



The Earthquake Forecasting System (EQFS) Model is based on a number of assumptions:

1) Earthquakes are not viewed as accidents or random events that just happen for no reason.
2) Over an infinite period of time almost every fault will cause an earthquake, somewhere between very small (infinitesimal) and extremely large in magnitude.
3) Each fault is capable of having an EQ Probability Profile over a given period of time.
4) Nothing in nature can be predicted with 100% certainty; therefore our earthquake forecasting models are non-deterministic.
5) Each fault generates different pre-earthquake signals that have a physical reality that can be used for forecasting earthquakes.
6) A fault's behavior can be predicted with probability number figures over a given period of time with some degree of certainty and some level of accuracy based on the accuracy of a non-deterministic probability model.
7) Each fault can be characterized differently, based on the fault's history, geometry, physicality, and surrounding influential physics parameters effects. And this characterization can be put into some probability numbers leading to an earthquake event based on time.
8) An earthquake fault's stability can be modeled with the failure modes caused by external input forces and stresses applied to that earthquake fault.
9) For our modeling purposes, only earthquake faults such as the Hayward and San Andreas faults cause earthquakes. i.e. not volcanic activity, etc.

Using the Generic probability block diagram in figure 1.0, the systems functional flow reliability analysis block diagram of an earthquake fault as an unstable nonlinear system in figure 2.0 was developed to clarify the energy functional flow needed for development of an earthquake fault system earthquake forecasting system model.

Earthquake Forecasting System Input Functions that can cause an increase in probability of Earthquake Fault system failure are: Temperature, Humidity, Gravity, and Weather Conditions

The Earthquake Fault Source Acted Upon has Failure Modes with associated probabilities of system failure Earthquake Forecasting System Output Functions that can cause a probability of system failure are: Output performance effects probabilities

Earthquake Forecasting System Precursors to a system failure are: Observations and Indicators that indicate probability of system failure is imminent

Figure 2.0 Earthquake Forecasting System (EQFS)
Top Level Functional Flow Diagram of an Unstable Nonlinear Geosystem without Sensor Placement that is used to develop the TEAMS Earthquake Forecasting Testability Model

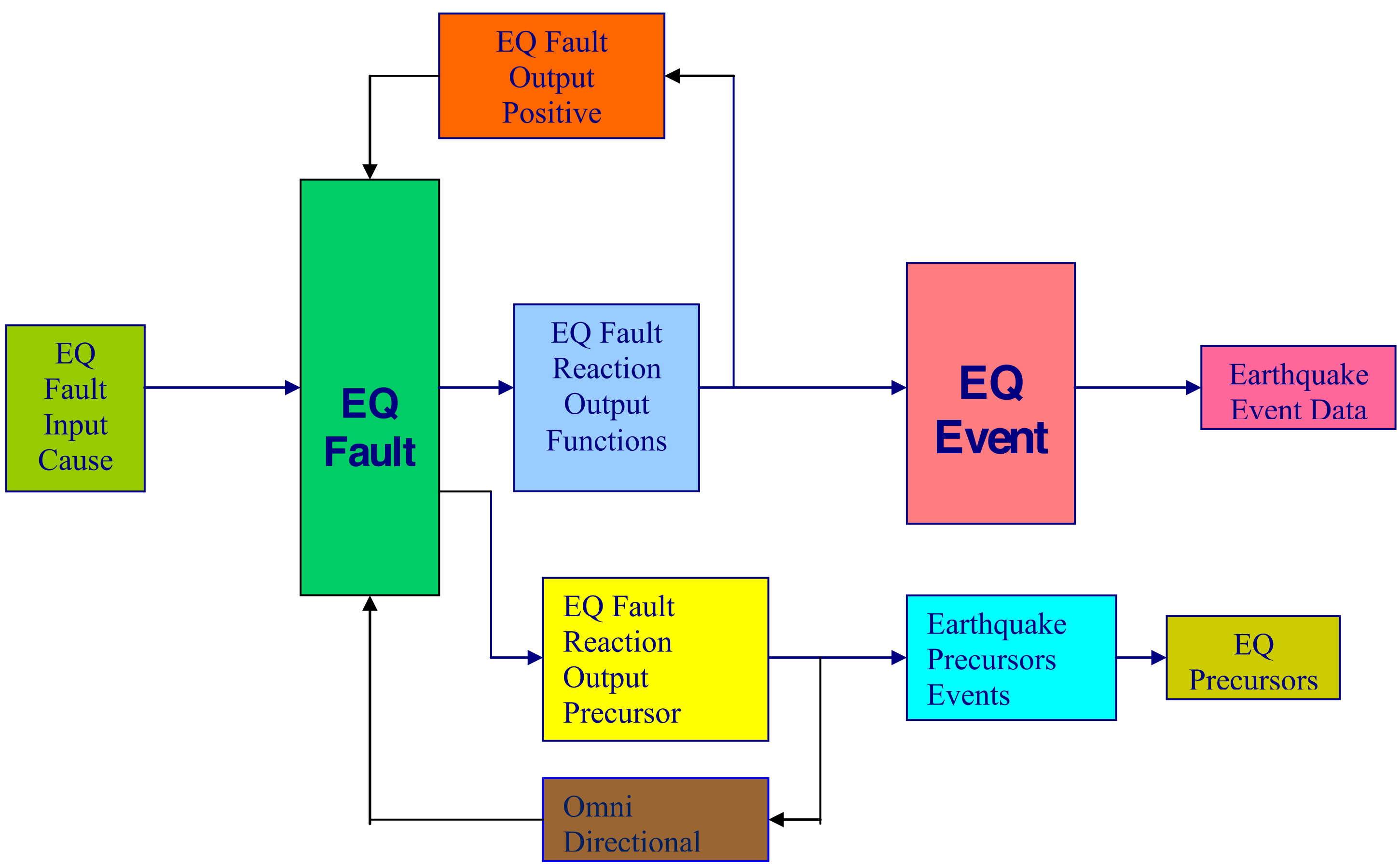
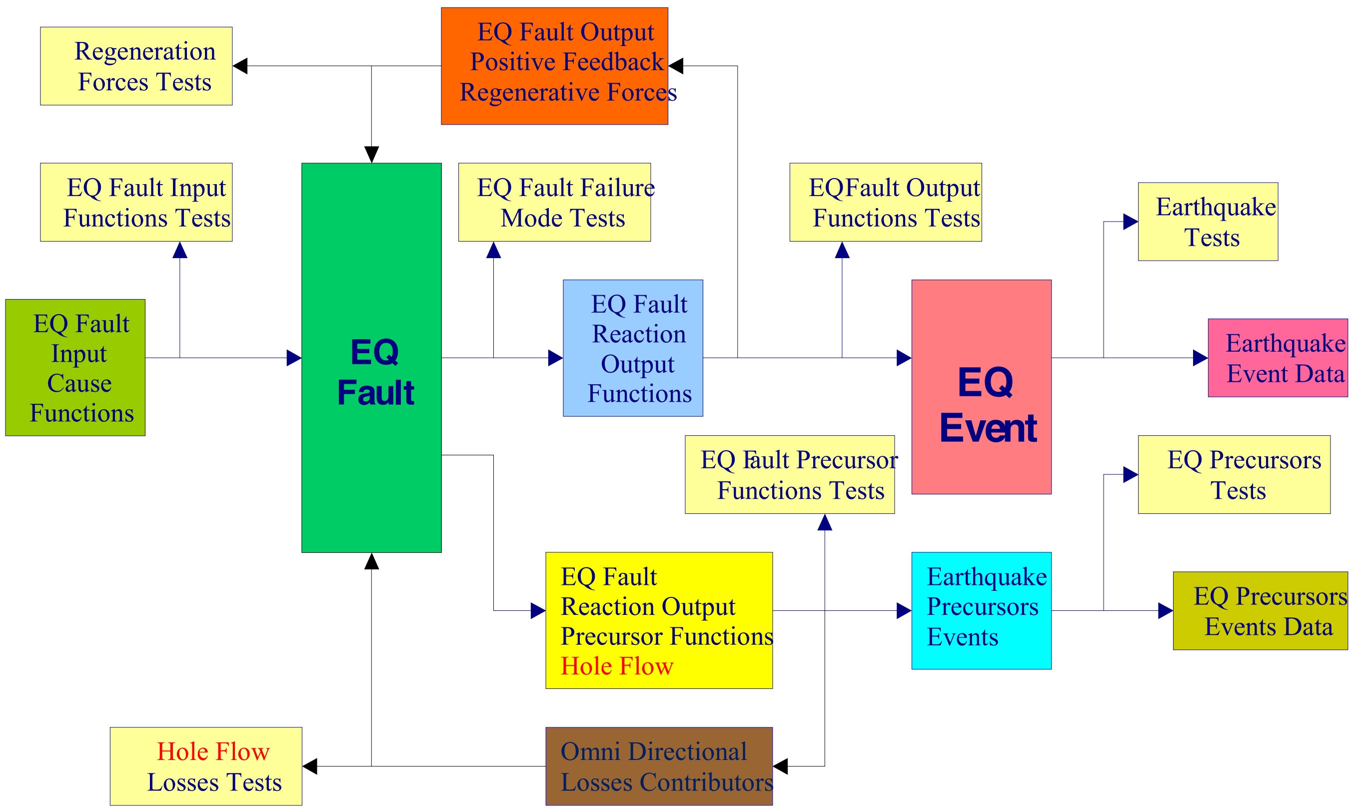
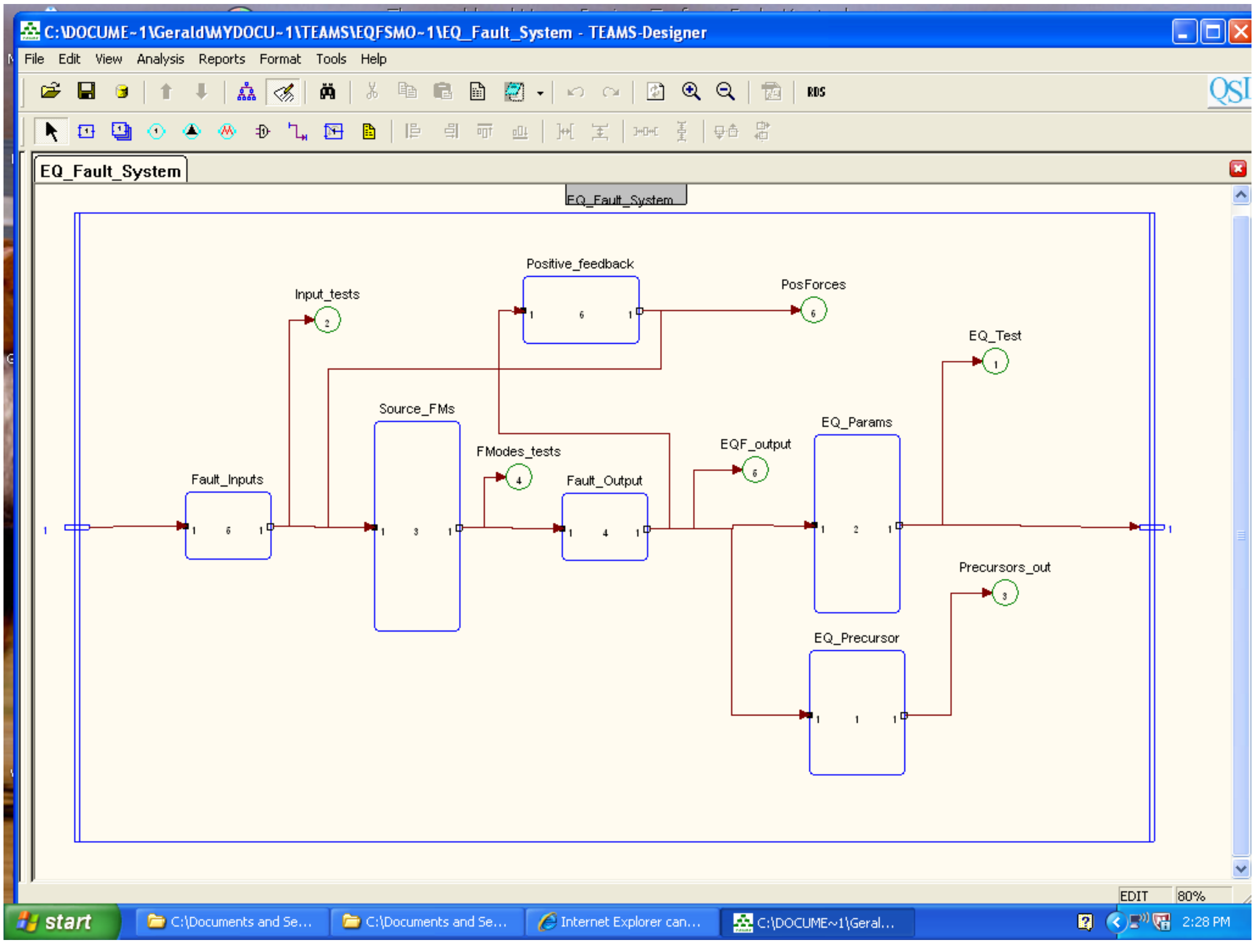


Figure 3.0 Top Level EQFS Testability Analysis Functional Flow Diagram of an Unstable Nonlinear Geosystem used to develop the TEAMS Testability Earthquake Forecasting Model with Real-time Sensor Placement for Measurement



The unstable nonlinear system functional flow block diagram seen in figure 2.0 was used to develop the system functional flow testability block diagram seen in figure 3.0. Then the testability earthquake forecasting block diagram was used to develop the TEAMS EQFS reliability and probability of failure functional flow testability model in figure 4.0. Before developing the reliability earthquake forecasting model, a tool had to be chosen for the development and the analysis. We chose to use the Qualtech Systems, Inc. TEAMS Designer diagnostic and reliability analysis tool, because we are familiar with it, and the excellent support that we get from QSI when developing complex models.

Figure 4.0
EQFS Top Level TEAMS Earthquake Forecasting Model

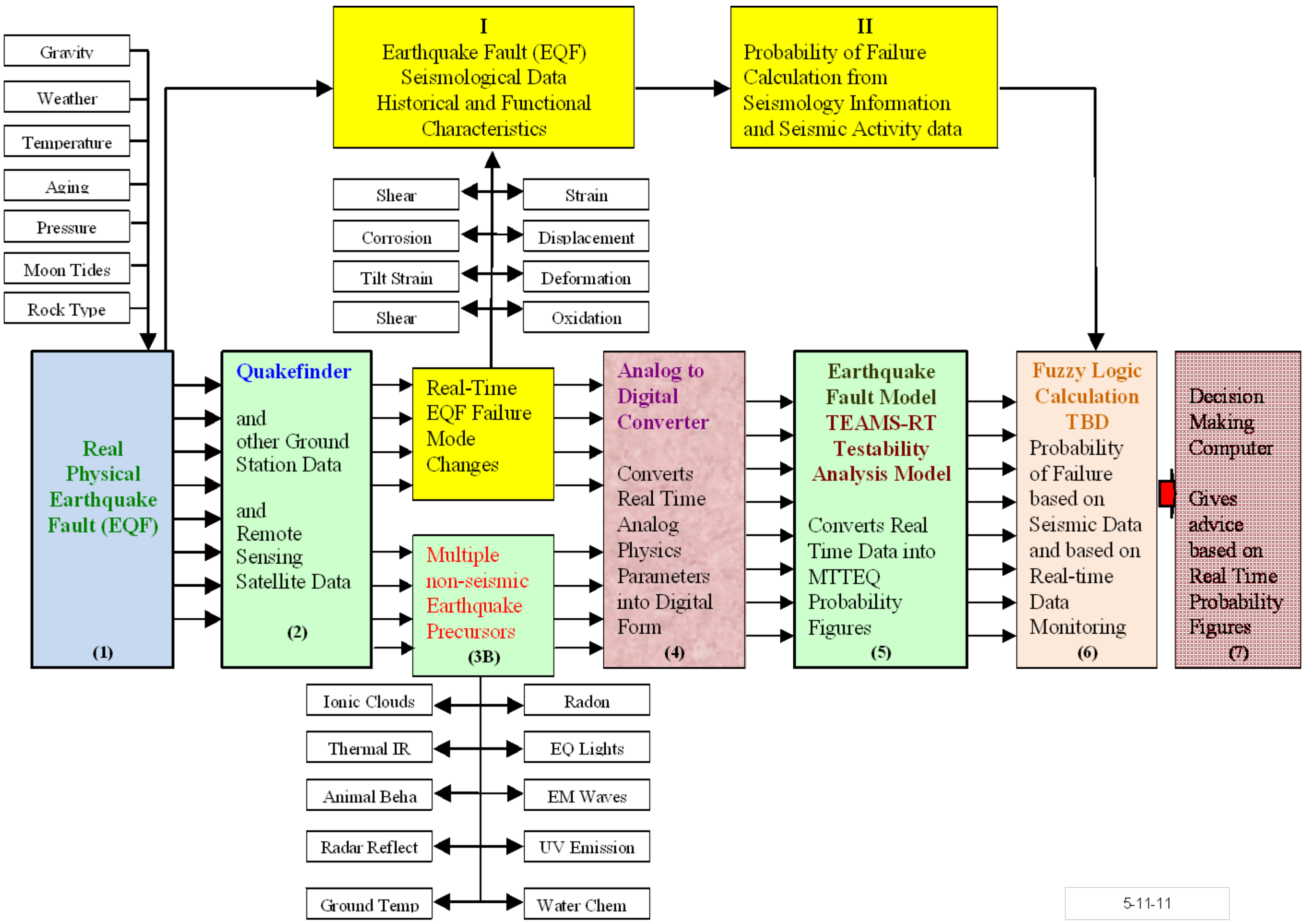


The Real Time Fully Developed Earthquake Forecasting System (EQFS) Model Diagram

A top level Earthquake Forecasting block diagram, with some sublevel functions and subsystems, illustrating how the "real-time" Earthquake Forecasting System (EQFS) can be designed and developed is depicted in Figure 5.0. The EQFS will be a hardware and software system that will be easy to comprehend, very easy to operate, and easily updated and maintained.

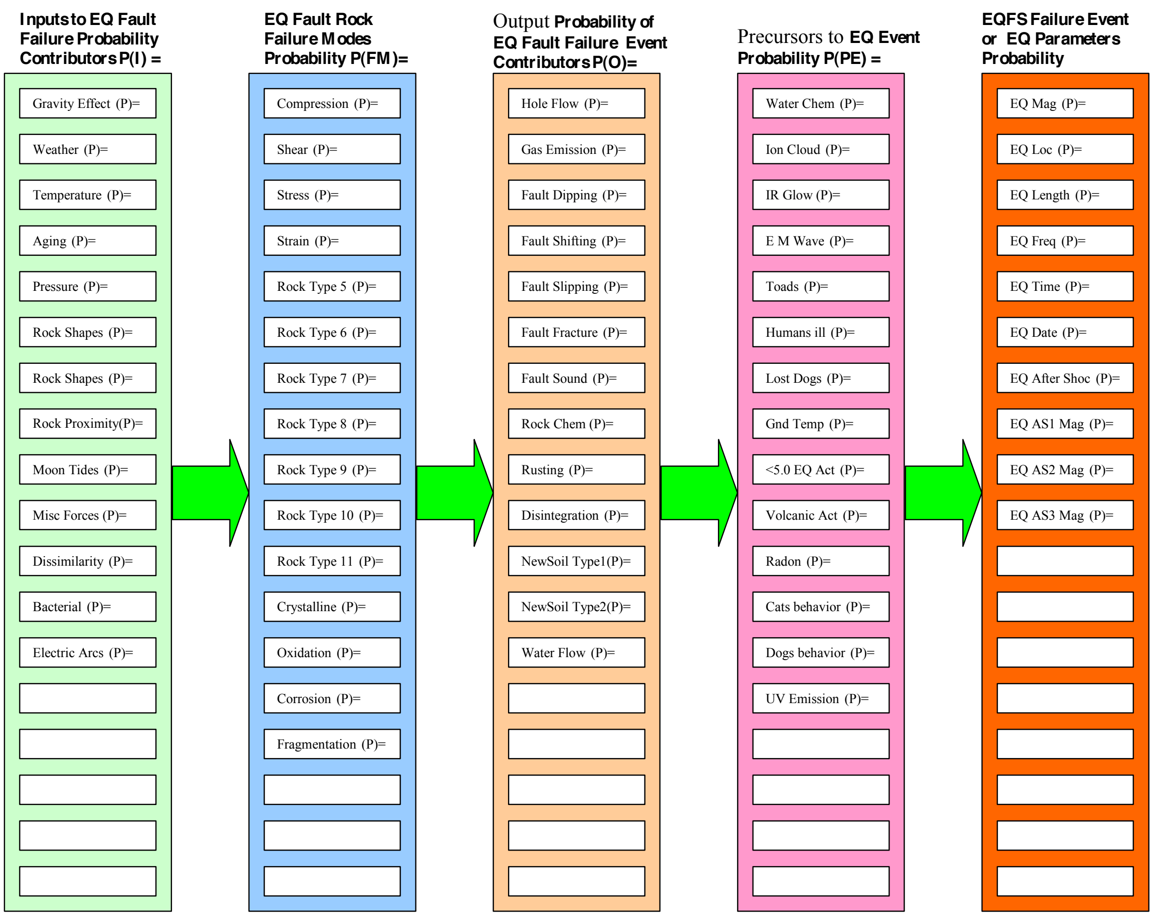
Figure 5.0 NASA-SETI

Real Time Earthquake Forecasting System (EQFS) Diagram showing a Real Physical EQ Fault, with Quakefinder Data, and a Fuzzy Logic Computer



Real Time Earthquake Forecasting System (EQFS) Model Diagram Details Each of the TEAMS Reliability earthquake forecasting model top level elements has more defined sublevels that have the associated probability failure rate data in terms of mean-time-to-fail (MTTF). Sublevel block diagrams, as in figure 6.0, were created to define them prior to model development.

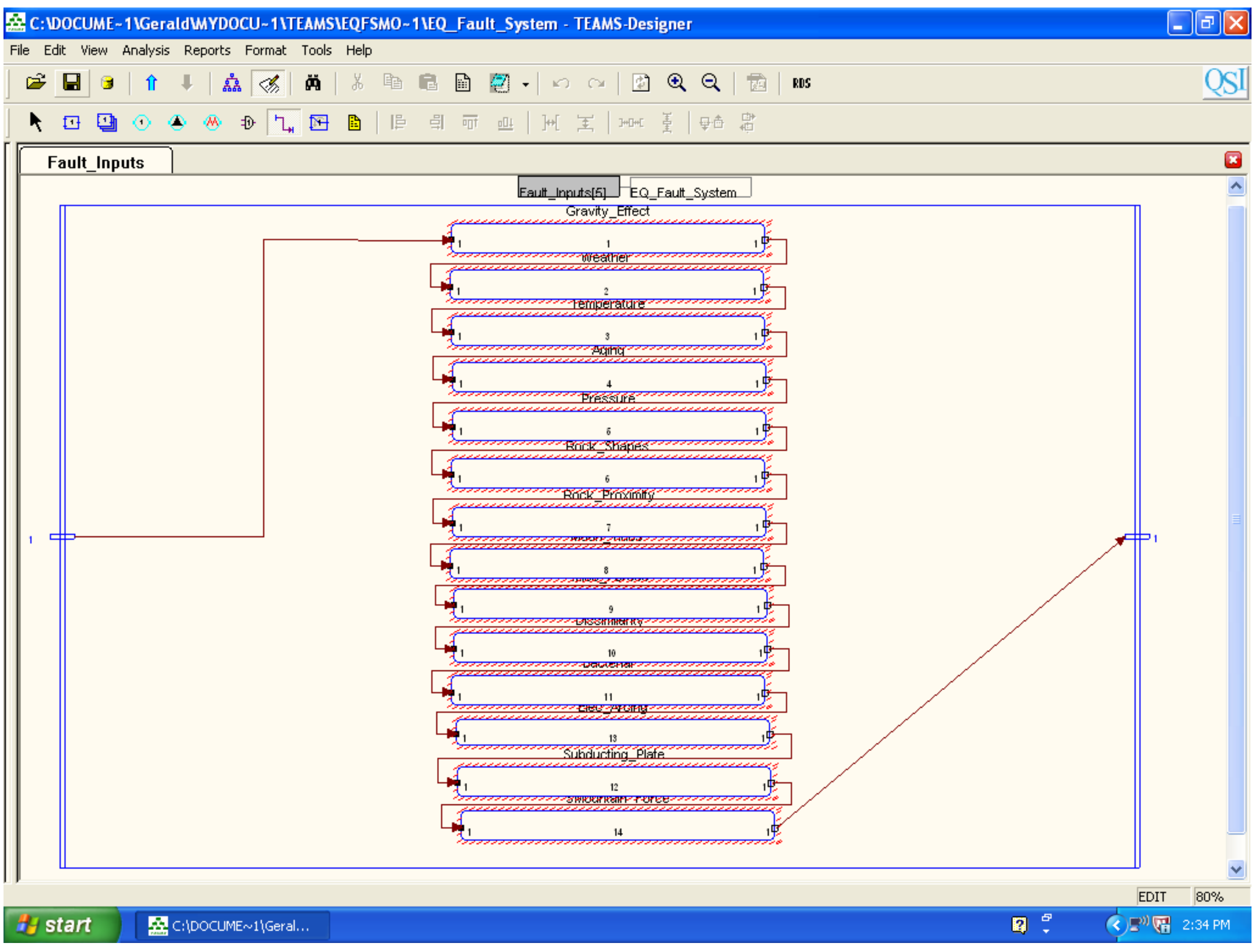
Figure 6.0 an Integrated Probabilistic Functions Flow Diagram of an EQFS (EQF Probability of Failure Model Block Diagram)



The TEAMS Earthquake Fault (EQF) Integrated Earthquake Forecasting System Input Function Forces Model (figure 7.0)

1) These system functions are external input forces that act on the EQF source rocks.
2) The more input forces there are stressing the EQF source rocks, the more likely (higher the probability) a failure will occur; the less reliable the source rock will remain stable, before shifting due to fracture, oxidation, etc.
3) These integrated input functions lower the reliability of the EQF when they are functioning together
4) Any single one of these input functions can cause an EQF system failure.
5) These integrated input functions must be modeled as series elements.

Figure 7.0
Integrated System Input Function Forces TEAMS Earthquake Forecasting Model

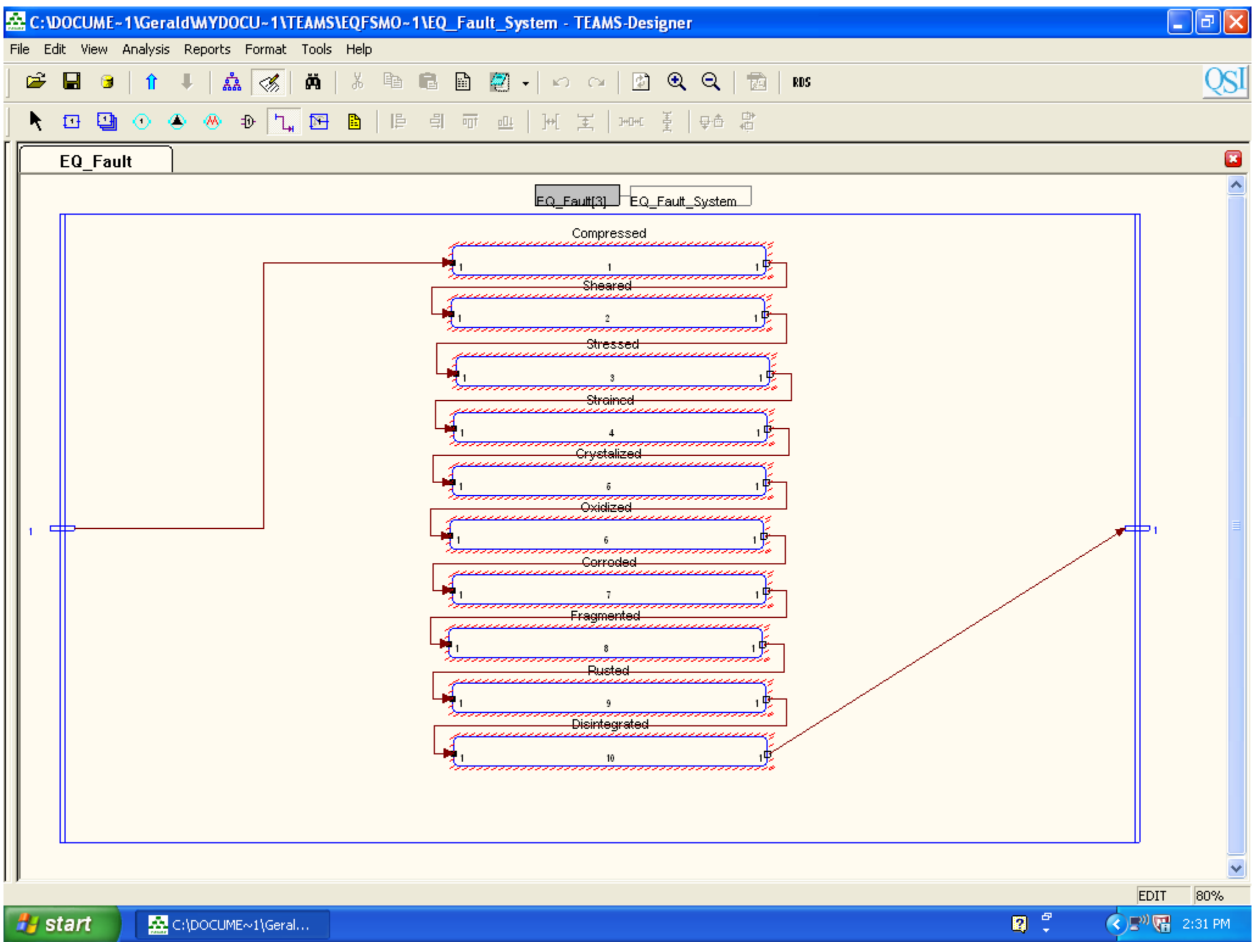


The TEAMS Earthquake Fault (EQF) Integrated Earthquake Forecasting System Failure Modes Model (figure 8.0)

1) The failure modes model consists of an integration of elements that are how the source rocks actually fail.
2) The more failure modes there are available to cause a complete EQF failure, the more likely (higher the probability) of a complete failure.
3) Any single one of these failure modes can cause a complete EQF system failure.
4) These integrated failure modes must be modeled as series elements, as seen in figure 8.0.

Figure 8.0

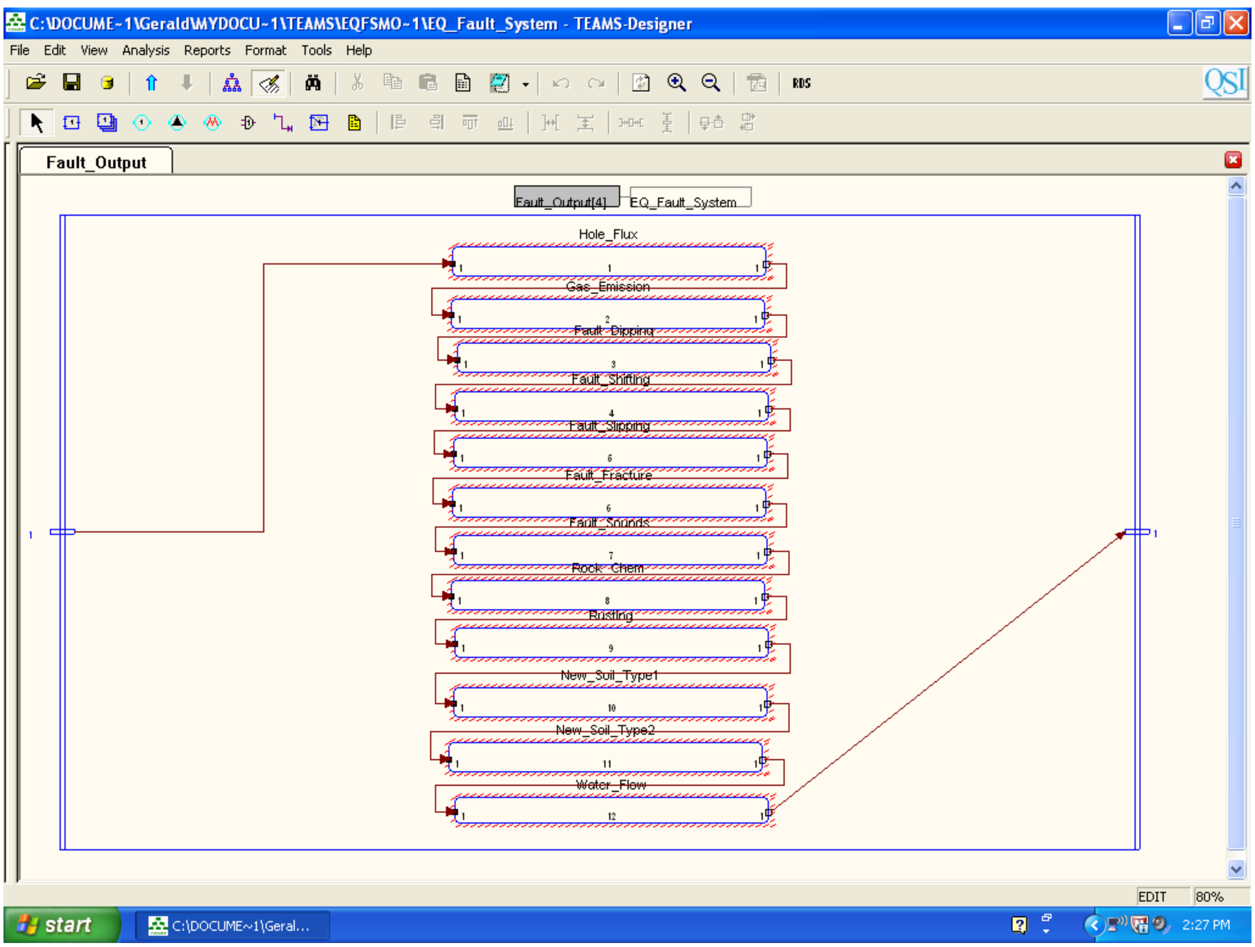
Integrated System Source Rocks Failure Modes TEAMS Earthquake Forecasting Model



The TEAMS Earthquake Fault (EQF) Integrated Earthquake Forecasting System Output Functions Model (figure 9.0)

1) These functions are reactions coming from the rocks sources that were caused by the input forces acting on them.
2) Depending on the physical characteristics of the EQF source rocks, these functions change or have an effect on the probability of failure.
3) The more output functions there are available to cause a complete EQF failure, the higher the probability of a hazardous failure.
3) Any single one of these output functions can cause a complete EQF system failure.
4) These integrated output functions must be modeled as series elements, as seen in figure 9.0.

Figure 9.0
Integrated System Output Function Forces TEAMS Earthquake Forecasting Model



Earthquake Precursor Modeling Assumptions

Because Earthquake Precursor events are extremely important to Real Time Earthquake Prediction and Forecasting, some discussion about our assumptions about how Earthquake Precursor events are generated and how they are modeled in the EQFS model is necessary.

Earthquake Precursor events are independent events created by changes that occur in Earthquake Faults, just as Earthquakes events are.

Earthquake Precursor events have completely different characteristics than Earthquake events.

Earthquake Precursor events are detectable, observable, measurable, and deterministic.

Earthquake Precursors events are events that precede Earthquake events and can be used as prognostic indicators for impending hazardous Earthquake events, because of the associated timelines that exist for earthquakes and earthquake precursors.

Earthquake Precursor events early portion of its life cycle are determined by the causal input stress functions on Earthquake Faults and the Earthquake Faults physical characteristics.

Earthquake Precursor events late portion of its life cycle are determined by the causal effects of hazardous Earthquake events changing the physical characteristics of the Earthquake Faults that created the Earthquake Precursors events.

Earthquake Precursor events are created before Earthquake events and cease to exist after Earthquake events.

Earthquake Precursor events have relatively short time intervals prior to Earthquake events.

Earthquake Precursor events last longer than Earthquake events.

Earthquake Precursor events allow excellent stochastic non-deterministic probability analysis and prediction capability for forecasting Earthquake events.

Earthquake Precursor events life cycle models are based on an exponential probability distribution, because most things with long-term stresses fail with an exponential probability of failure distribution.

Earthquake Precursor events are not hazardous.

Some Examples of how these Real Time Earthquake Precursors are generated are depicted in Figure 10.0:

- Tectonic stresses build-up deep below the surface of the Earth and rocks become electrified.
- Highly mobile electronic charge carriers in the rocks are activated.
- The electronic charge carriers travel fast and far, kilometers through unstressed rocks.
- Some resultant effects of the electronic charge carriers at Earth’s surface are shown in Figure 10.1.
- Ionization in the atmosphere.
- Lightning in the mesosphere.
- Perturbations in the ionosphere.

Figure 10.0
Various Earthquake Forecasting Precursors are Generated Beneath the Earth Surface

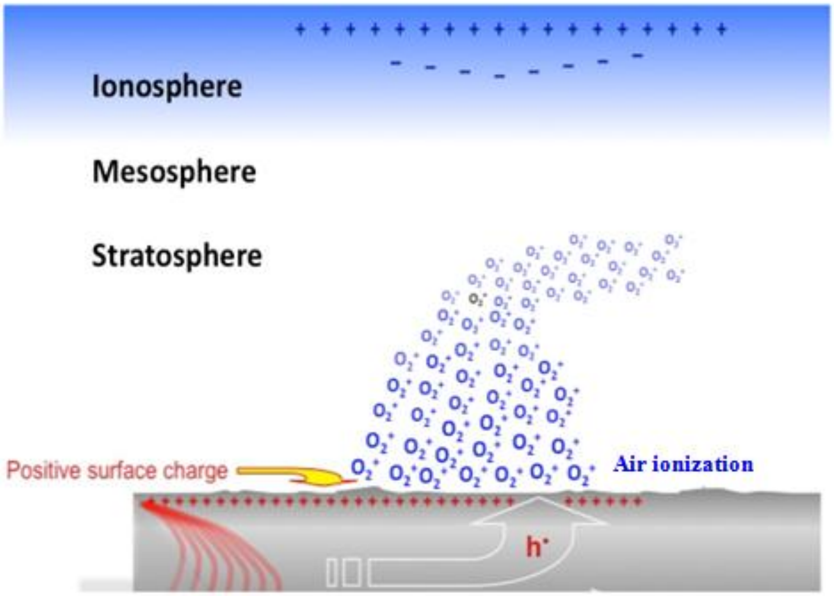


Figure 10.1
Earthquake Forecasting Precursors Generated Effects

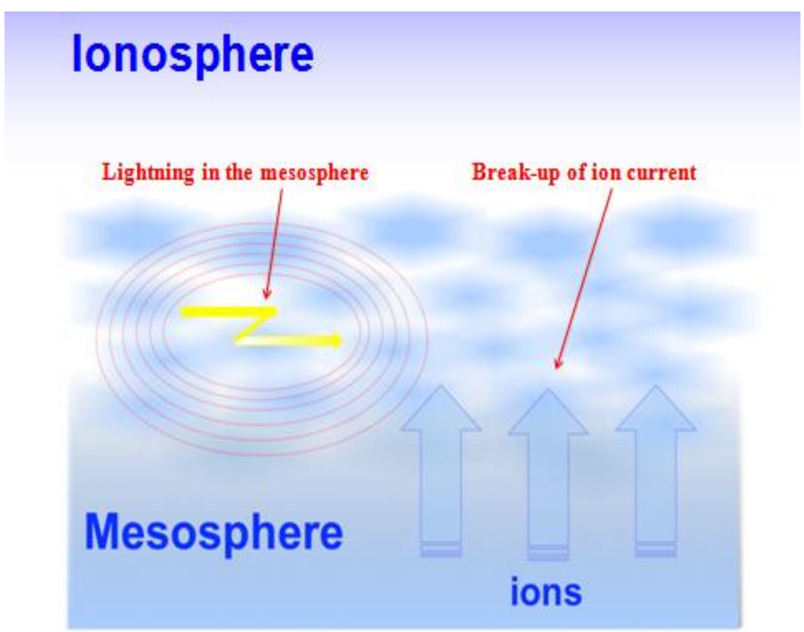
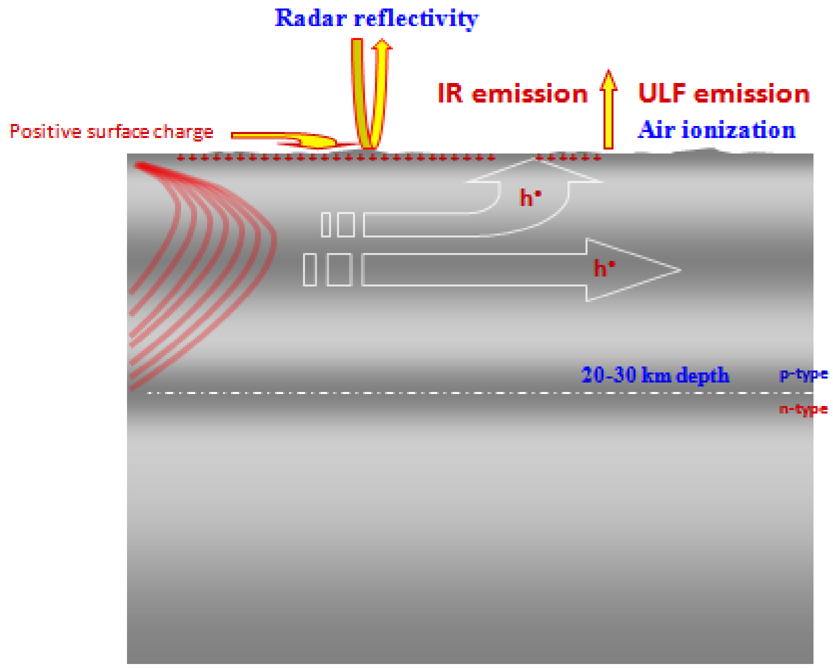


Figure 10.2
Earthquake Forecasting Precursors Effects Measured



As Real Time Precursors to Earthquakes, we propose to measure the following along the flight path of suborbital vehicles:

(i) Electric Fields
(ii) Electron Concentrations
(iii) Ion Concentrations
(iv) Ion Drift velocities
(v) HF Emissions

Collectable Satellite Data:

(i) Infrared emission, spectrally resolved, primarily during night
(ii) Thermal IR
(iii) Top-of-the-atmosphere temperature
(iv) Trace gas release from ground (CO)
(v) Ionospheric data

Figure 11.0 is a diagram that depicts how Dr. Friedemann Freund's use of Hole Flow generation leading to important earthquake precursors can be implemented into the systems integrated engineering probabilistic earthquake fault forecasting system (EQFS) model. The mean time to earthquake (MTTEQ) precursor data is taken from actual pre-earthquake signals.

Figure 11.0 Dr. Friedemann Freund Hole Source System Diagram
Top Level Diagram of an Earthquake Fault with an Earthquake Forecasting Precursors Subsystem

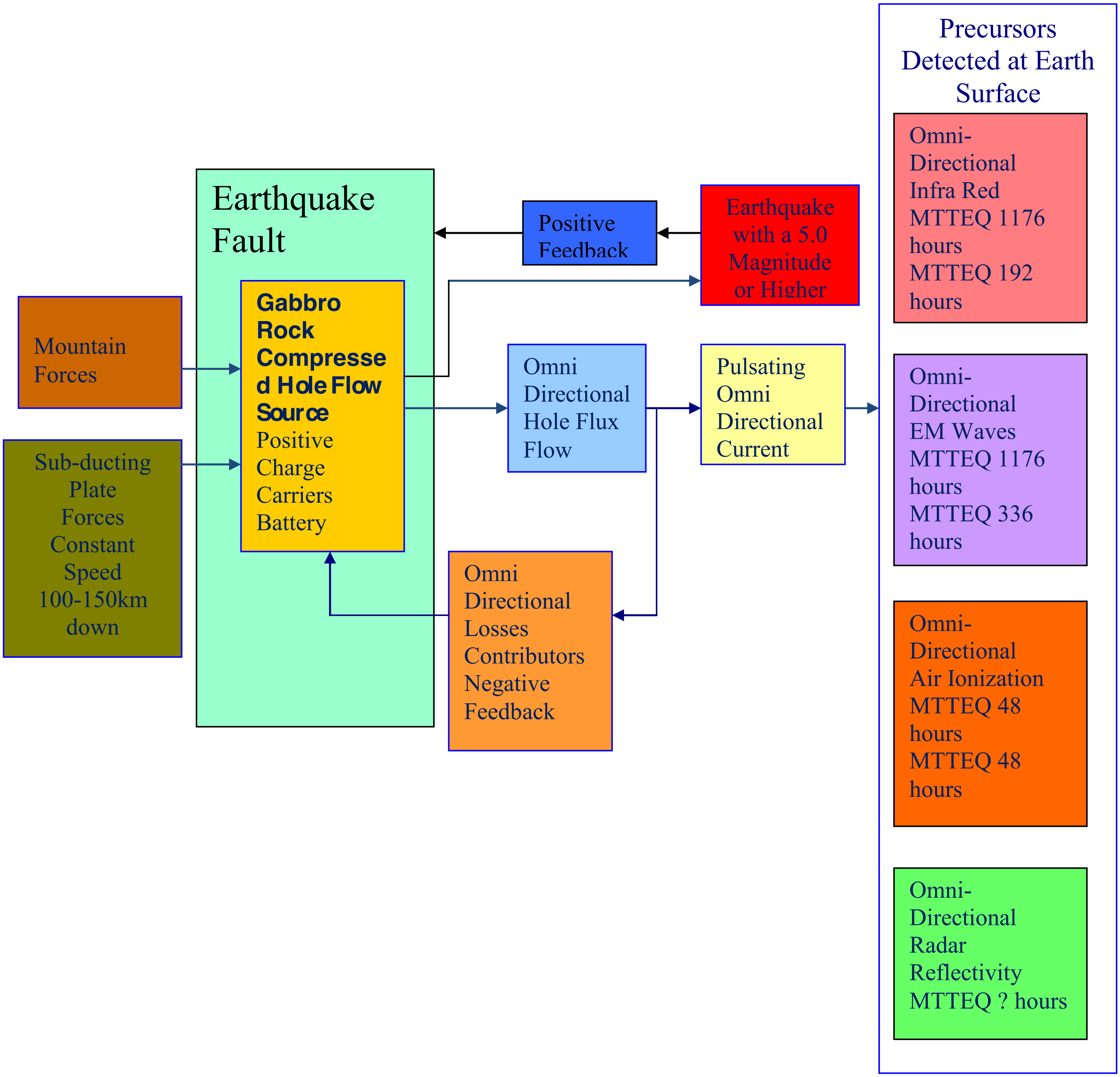
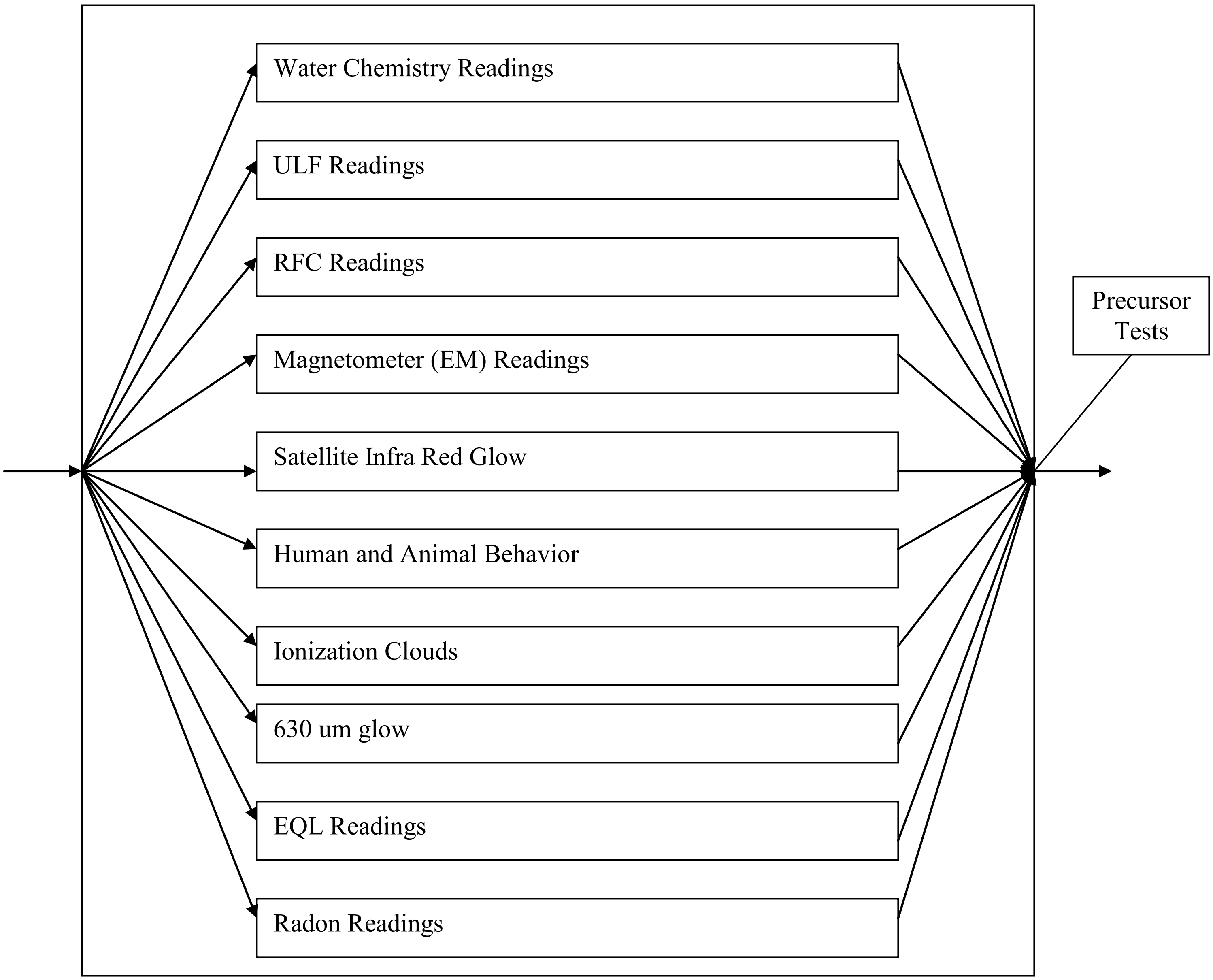


Figure 12.0
Precursors to Earthquake Magnitude 5.0 Diagram used to Develop Earthquake Forecasting Models



The TEAMS sublevel model of the earthquake forecasting precursors to a magnitude of 5.0 or greater earthquake is depicted in figure 13.0

1) These precursors are indicators or predictors of an impending earthquake within a time period; they don't cause failures.
2) These precursors are modeled as a probability of success, or reliability of a prediction of impending earthquake.
3) These precursors can be modeled as reliable up to about 100% correct.
4) These precursors can be used as reliable forecasting parameters.
5) These precursors are modeled in parallel, because the more precursors there are to predict an impending earthquake, the higher the probability of success or the higher the reliability of the prediction.

Figure 13.0
EQFS Integrated System Earthquake Forecasting <u>Precursors</u>
in the TEAMS Earthquake Forecasting Model

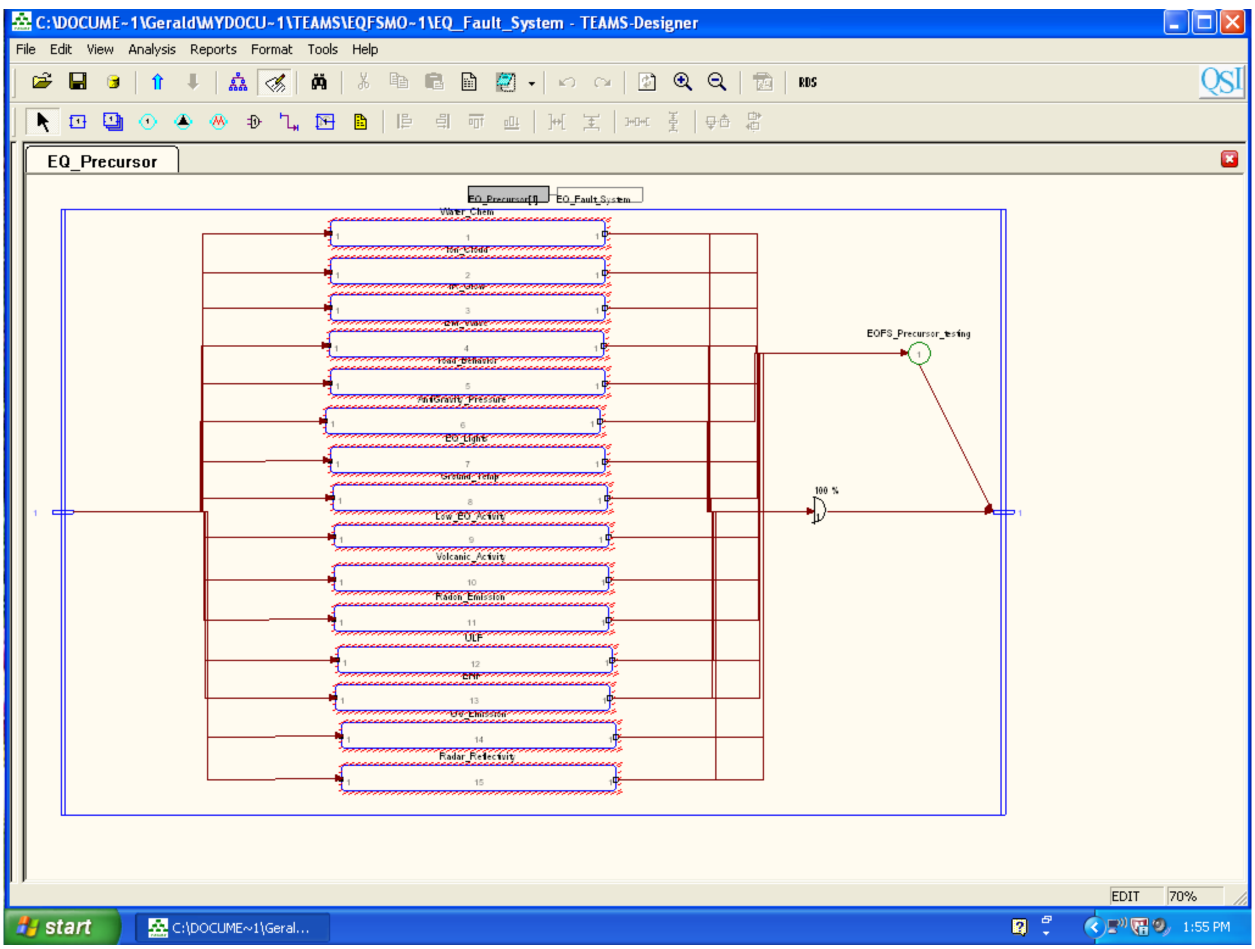
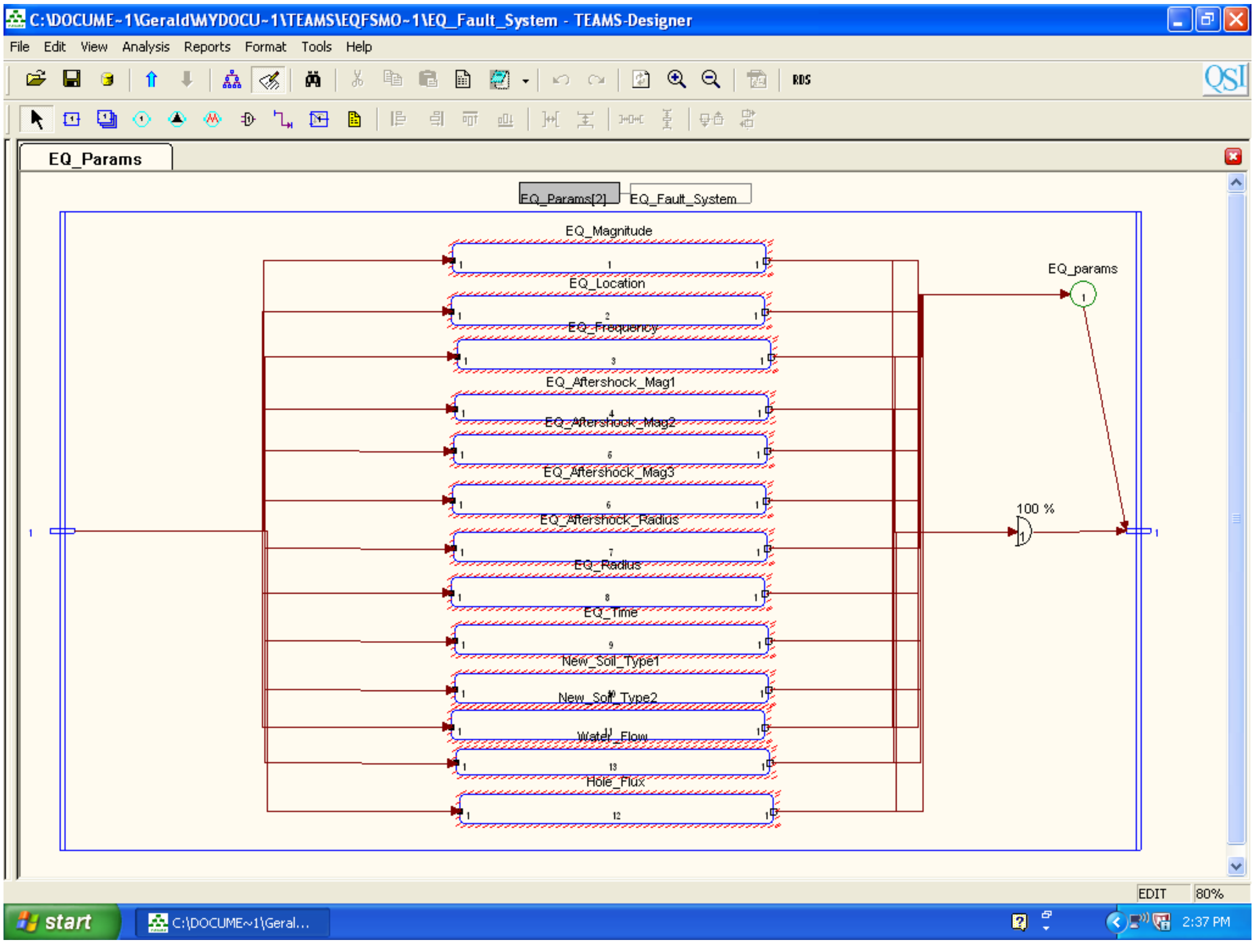


Figure 14.0
EQFS Integrated System Earthquake Parameters
in the TEAMS Earthquake Forecasting Model



The EQFS Model Calculation Basis

The Reliability model calculations used by the TEAMS Designer testability diagnostic tool are based on an exponential probability distribution, because most things that fail in nature fail over a long period of time. Therefore, using the exponential probability distribution closely matches the actual failure rates of the earthquake fault forecasting physics parameters and the associated earthquake forecasting precursors that precede hazardous earthquake fault failures. The basic formulas for the exponential reliability calculations are:

$$R = e^{-\lambda t} = e^{-\frac{t}{\theta}} \quad \text{and,} \quad PF = 1 - R$$

Where: R = Reliability of the Component, System, or Subsystem
λ = Failure Rate of Component, System, or Subsystem
t = Operating Time or Mission Time of Calculation (current model: 100,000 hours)
PF = Probability of Failure or Unreliability of the Component, System, or Subsystem
θ = MTTF (Mean-Time-To-Fail) of the Subsystem Elements
(for the current model: θ = 140 years or 1,226,400 hours)

The Earthquake Fault System Model Scenarios

The EQFS scenarios, for demonstration of the TEAMS EQFS integrated systems reliability analysis model, can be done by simply changing the reliability probability data in the model. The USGS has stated that the Hayward Fault fails every 140 to 150 years. This was the MTTF reliability data used in the TEAMS model for simulation and conceptual modeling purposes.

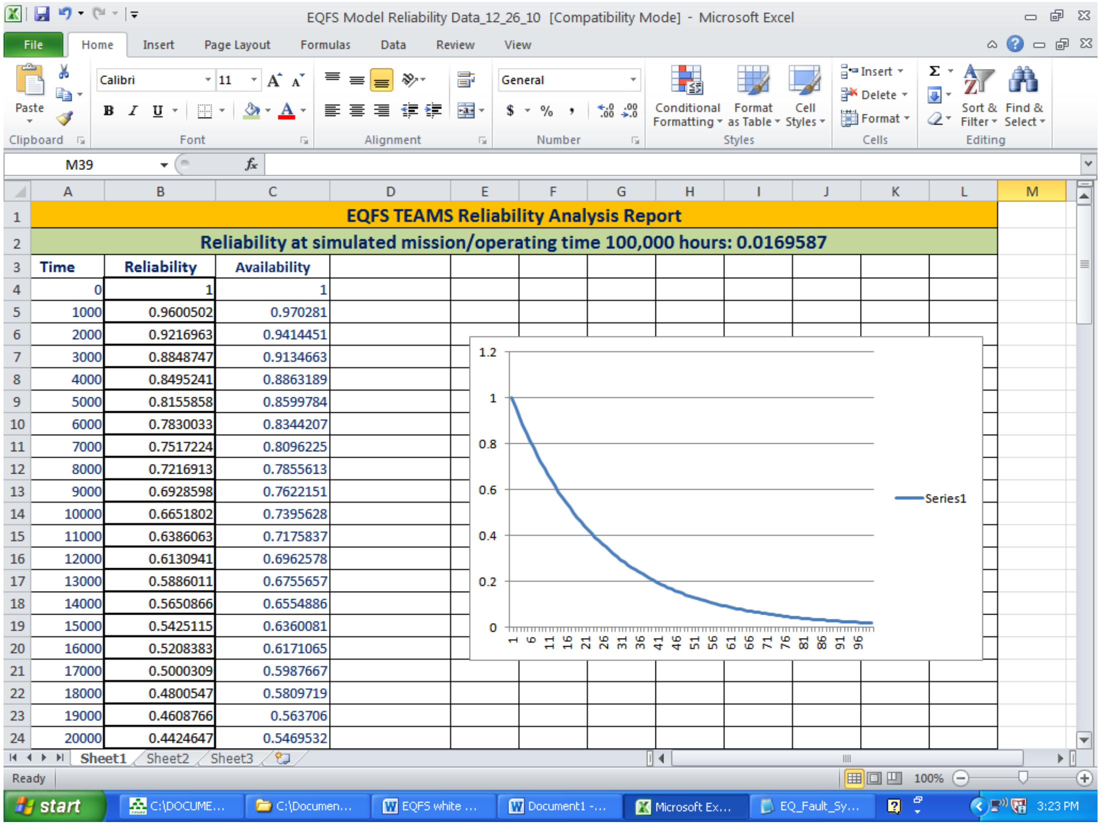
Procedure for Operating the EQFS

To use the earthquake forecasting system is fairly easy, because all of the difficult work for confident forecasting was already accomplished in the integrated systems engineering design and development combined with knowledge about earthquakes.
At a given operator input time t1, data from all of the subsystems parameters is taken from real-time sensors that are automatically dynamically polled, or statically input manually, is inserted into the EQFS computer for analysis. This data could be telemetered from sensors through out the world as well as from satellites and other computers.
In the EQFS all subsystems physics parameters sensors data is converted into an integrated systems earthquake fault probability of failure and effects matrix.
The probability of effects toward earthquake fault failure data is passed on to the EQFS model for an integrated simulation analysis.
The output data from the EQFS is non-deterministic probability figures for an impending earthquake event, including a number of tables, charts and graphs. The tables will contain probability of earthquake fault not failing from time, t1, until a predicted lowest level of reliability. An associated reliability graph will be based on the table data. Another table will be a probability of earthquake fault failure from time, t1, versus some operating/mission time with an associated graph. An approximate earthquake magnitude range and an approximate epicenter location will be given.
Some output data can also be accessed from the individual EQFS subsystems as well as the complete EQFS.
The output data is routed to another computer algorithm that performs analysis estimates of damage and costs.
Another computer added to the system could be a decision-making computer that advises evacuation, etc.

The Earthquake Fault Integrated System Model Data

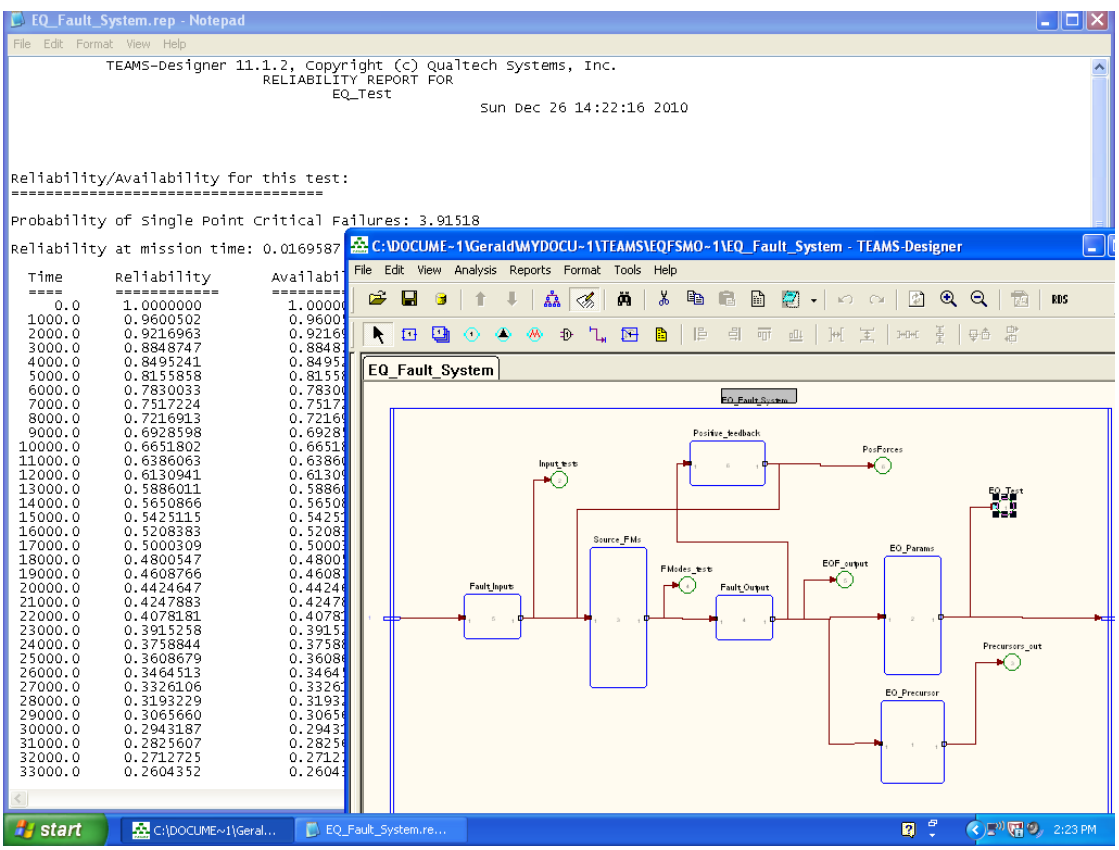
The TEAMS output reliability data is based on the accuracy of the model, the MTTF, and the input operating time.
There is a similarity in the failure rate data of the compressed rock experiments done by Dr. Friedemann Freund and the TEAMS EQFS integrated systems reliability model analysis data. The compressed rock begins to exponentially fail around the 36.8% mark that is used as the reliability where MTTF (reciprocal of the failure rate) is defined to be calculated from being a constant probability of failure distribution to begin an exponential probability of failure distribution. The failure rate of the compressed rock is approximately a mirror image, even though the data is in physics parameters, not probability of failure data. See figures 15.0 and 16.0.

Figure 15.0
Earthquake Fault Integrated System TEAMS Earthquake Forecasting Model Reliability Data



Time	Reliability	Availability
0	1	1
1000	0.9600502	0.970281
2000	0.9216963	0.9414451
3000	0.8848747	0.9134663
4000	0.8495241	0.8863189
5000	0.8155858	0.8599784
6000	0.7830033	0.8344207
7000	0.7517224	0.8096225
8000	0.7216913	0.7855613
9000	0.6928598	0.7622151
10000	0.6651802	0.7395628
11000	0.6386063	0.7175837
12000	0.6130941	0.6962578
13000	0.5886011	0.6755657
14000	0.5650866	0.6554886
15000	0.5425115	0.6360081
16000	0.5208383	0.6171065
17000	0.5000309	0.5987667
18000	0.4800547	0.5809719
19000	0.4608766	0.563706
20000	0.4424647	0.5469532

Figure 16.0 TEAMS EQFS Model and Reliability Report
Also Shown are the Test Points used for the Analysis and the Data Reports



Time	Reliability
0.0	1.0000000
1000.0	0.9600502
2000.0	0.9216963
3000.0	0.8848747
4000.0	0.8495241
5000.0	0.8155858
6000.0	0.7830033
7000.0	0.7517224
8000.0	0.7216913
9000.0	0.6928598
10000.0	0.6651802
11000.0	0.6386063
12000.0	0.6130941
13000.0	0.5886011
14000.0	0.5650866
15000.0	0.5425115
16000.0	0.5208383
17000.0	0.5000309
18000.0	0.4800547
19000.0	0.4608766
20000.0	0.4424647
21000.0	0.4247883
22000.0	0.4078181
23000.0	0.3915258
24000.0	0.3758844
25000.0	0.3608679
26000.0	0.3464513
27000.0	0.3326106
28000.0	0.3193229
29000.0	0.3065660
30000.0	0.2943187
31000.0	0.2825607
32000.0	0.2712725
33000.0	0.2604352

Summary

In summarizing our earthquake prediction/forecasting theoretical methodology, our reliability transfer function system model is a simulation of an energy exchange or an energy transference from a very long time slow moving stored potential energy source into a very short time rapid release transform into kinetic energy in motion with enormous/tremendous power. We have an energy transfer function conversion integrated system model based on the conservation of energy in physics terms and incorporating probability quantification. The model shows that the potential energy equals the kinetic energy minus the losses in the energy conversion process. The losses that occur prior to and during the energy exchange from stored potential energy to kinetic energy can be in the form of heat, magnetic effects, out of phase energy forces that were generated during the potential energy build-up before a complete release of the stored potential energy sources, etc.

Newton's formula f=ma becomes very important in our model, because the enormous energy transfer acting on a huge mass generates a tremendous amount of force, with the mass being the earthquake fault and the acceleration being the dynamic impulse motion involved. Some of the losses may be precursors to the very unstable nonlinear energy release process. These losses don't contribute to the large mass movement/motion. They may be indicators that precede and exceed, in terms of time (temporally) not in energy, the large force earthquake or mass in motion. The earthquake precursors may be thought of as losses in the energy exchange transference from stored potential energy to the quick released kinetic energy. Measuring the energy exchange is done with physics parameters. However, quantifying the energy exchange may be easier with non-deterministic probabilistic figures than with physics parameters for our modeling purposes and easier to relate to. Quantifying the effects of the energy exchange can be in financial terms and/or physics parameters. If it were possible to understand and interrupt, redirect, or change the positive feedback energy momentum forces based on energy release calculated using: $\sum F(\Delta t) + mV_1 = mV_2$, where mV equals the momentum and F equals the initial forces over a period of time, Δt, that reinforce the earthquake fault as it is releasing the stored energy, or before it releases the stored potential energy, it may be possible to reduce the number of large catastrophic earthquakes.

Conclusions

There is a difference between seismic hazard and seismic risk. Seismic hazard describes the potential for dangerous earthquake-related phenomena, such as ground shaking, fault rupture, or soil liquefaction. These phenomena could result in adverse consequences to society. Seismic risk is the probability of occurrence of these consequences. The output of a seismic hazard analysis could be a description of the intensity of a magnitude eight earthquake or a map showing levels of ground shaking. The output of a seismic risk analysis could be the probability of damage (in dollars) from a magnitude eight earthquake or the probability of fatalities due to seismically induced nuclear power-plant accidents. Seismic risk is a probabilistic expression of the product of seismic hazard and its consequences. The ultimate goal of seismic hazard estimation is reduction of seismic risk. One needs to know the seismic hazard in order to calculate the seismic risk. If it is not known, defining the seismic hazard becomes a part of the risk estimation process. Earthquake engineers are no strangers to this challenge, but many earthquake specialists are. The reason for this lies in the different ways that scientists and engineers view themselves. Scientists see themselves as explorers trying to unlock the physics of nature. The answers to their questions usually lead to new and better questions. Engineers see themselves as practitioners, who put to good use, what the scientists have discovered. Engineers tend to be concerned with solving problems. Of course, the boundary between science and engineering is fuzzy and there is a great deal of overlap. As engineers and scientists working together, it is our vision to have a more reliable and more cost effective earthquake forecasting philosophy and methodology. We have developed a geosystem model based on this vision. The great work on this very difficult and complex problem of earthquake forecasting by seismologists has not been enough. We feel that the work of non-seismologists and non-specialists should be synthesized with the work of earthquake specialists.

Our proposal is to establish a bond with seismologists and geophysicists, and along with their expertise, build on what they have already accomplished. We would like to use their expertise along with integrated systems engineering to improve earthquake forecasting certainty. Seismologists and geophysicists have traditionally used two fundamental ways to predict earthquakes. They have used some form of trending or extrapolation analysis based on past historical earthquake events in certain locations. This method has not worked. More recently they have used earthquake precursors to do earthquake forecasting. This has worked occasionally, but not good enough to establish any degree of certainty, when predicting earthquakes.

We are proposing to build upon the use of real-time earthquake precursory data, and synthesize with the technique of using historical event trending together in an integrated systems engineering approach, viewing an earthquake fault as a geosystem composed of many subsystems intrinsically linked together to form a single system.

Because nature built geosystems are constantly changing, there will never be the possibility of forecasting earthquakes with one hundred percent certainty. However, we believe that we can improve upon the degree of certainty and approach one hundred percent certainty by using "real-time" data in our earthquake forecasting models. The approach of using all of the "real-time" earthquake precursors that are available in a given time period, and viewing earthquake faults as integrated systems composed of many subsystems working together in "real-time", can greatly improve earthquake forecasting. Also, testability analysis tools can play an important role in analyzing and forecasting the nature built earthquake fault systems as well as man-made systems. Testability tools that generate probability and reliability figures, based on "real-time integrated earthquake precursory information and earthquake failure mode data combined in a stochastic matrix, may not be deterministic. However, these testability tools can reduce the complexity of earthquake forecasting and allow for greater confidence when forecasting earthquakes.

Concerns

1) Accuracy of the Real-time, Manual, or Simulated Data
2) Accuracy of the Model
3) Correctness of Assumptions
4) Constraints of the TEAMS tool
5) Adequate Earthquake and Earthquake Fault Knowledge
6) EQFS Model Development Time and Budget
7) The EQFS Model Concept Experts Opinions

Future Work

Continued work on the current Earthquake Forecasting System (EQFS)Development of a real-time dynamic EQFS that produces reliability data for forecasting earthquakes, by interfacing with many different types of sensory data and a decision making computer system

Glossary of Terms

DFT - Design for Testability
EQ - Earthquake - A functional event with an impulse magnitude, location, and frequency components
FM - Failure Mode
EQ - Earthquake
EQF - Earthquake Fault
EQFS - Earthquake Forecasting System
EQFSS - Earthquake Fault Subsystem
EQFSF - Earthquake Fault System Failure

EQFSFM - Earthquake Fault System Failure Mode
EQFSSF - Earthquake Fault Subsystem Failure
EQFSSFM - Earthquake Fault Subsystem Failure Mode
Earthquake Forecasting - a probabilistic estimate of an earthquake event occurrence with an approximate magnitude, in an approximate location, at an approximate time; an advanced indication
Earthquake Prediction - the probability that an earthquake event will occur at a definite time, location and magnitude; a prophesy
FM - Failure Mode(s)
ISE - Integrated Systems Engineering, the same as SIE
ISEHM - Integrated Systems Engineering Health Management
ISHM - Integrated Systems Health Management
ISR - Integrated Systems Reliability
IVHM - Integrated Vehicle Health Management
MTBF - Mean-Time-Between-Failure
MTTF - Mean-Time-To-Fail
MTTEQ - Mean-Time-To-Earthquake
MTTPQ - Mean-Time-To-Earthquake Precursor
PDF - Probability Density Function
PF - Probability of Failure or Unreliability
PS - Probability of Success or Reliability
QSI - Qualtech Systems, Inc
RAC - Reliability Analysis Center
Systems Engineering (SE) - a top level managerial engineering philosophy used to develop a system. It is project management from the engineering perspective. It involves developing plans, system concepts, system requirements, system reviews, system tests, system operations validation to meet performance specifications, etc
Systems Integration Engineering (SIE) - an engineering design and development philosophy that views a system as a functional interaction of subsystems and components all functioning together to form a complete system. It involves detailed design and **TEAMS** (Testability Engineering and Management System) – a testability simulation analysis tool developed by Qualtech Systems, Inc.

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