Desktop Toys for Educational Seismology
- Random or Periodic? Before or After?

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Background

• The misunderstanding of natural disasters, particularly for earthquakes, is mainly caused by the gap between seismologists and the public.

• In Japan, there are many “earthquake prediction sites” by amateurs, most of which have no scientific basis.

• In the Japanese high-school textbooks, they treat <High-spec seismology> such as “the Asperity model (Lay & Kanamori, 1982)” or “the Characteristic earthquake model (Schwartz et al, 1984)”.

• The Japanese gov. has made “the national seismic hazard maps” based on the above model for a long time.

• But, the above models are now in controversy by seismologists.

• On the other hand, statistic behaviors of earthquakes such as famous “The Gutenberg-Richter’s law” is omitted.
“Hi-spec” sometimes causes too much of a good.
弧一海溝系の地震 日本のような弧一海溝系では、p.66 図2のように非常に多くの地震が発生している。地球上で発生している地震は、このようにプレートの沈み込み境界で発生するものが中心である。特に注目すべきものの一つとして、海溝やトラフのすぐ陸側でゆっくり返し発生しているマグニチュード8クラスの巨大地震がある。図8は南海トラフ沿いに発生した地震についてまとめたものであるが、ここではフィリピン海プレートがユーラシアプレートの下に沈み込むのに伴い、図8のようにゆっくり返し地震が発生していると考えられている。この地震の発生機構は逆断層型である。

プレートの収束境界である海満の陸側では、図9のように沈み込みに伴いゆっくりと沈降し、地震の際は急激に起るような地殻変動が起こるのが特徴である。ただし、海満からある程度離れた地域では上に沈降する場合もある（図10）。このような地震は海満型地震とよばれる。

震源深度が浅いため津波（p.270）の発生を伴う。南海地震の際には、大きな被害をもたらしていった。

参考 アスペリティーとゆっくりすべり

プレートの沈み込みに伴い大陸プレートと海洋プレートの境界で蓄積した歪みが、瞬時に解放されるのが海満型の巨大地震である。その境界面は断層面には固着している部分（アスペリティー）と、普段からゆっくりとすべっている部分があると考えられている。アスペリティーが急激に大きくすべるとときに巨大地震が発生する。プレートの年間数10cmほど動いているので、例えば50年間に蓄積した歪みが解放される場合、アスペリティーでは瞬時に数mもすべることになる。ゆっくりすべりの例としては2000～2005年に若松市付近で観測された「東海スロースリップ」がある。5年間に10～20cmほどプレート境界面に沿ってゆっくりすべりが起こり、マグニチュード7.1の地震に相当するエネルギーが解放されたと考えられている。

2011年3月11日に起きた東北地方太平洋沖地震（マグニチュード9.0）では、ふたたびゆっくりすべりが起きている領域で地震すべリが起き、大きな歪みが蓄積される。これが突然、ゆっくりとすべきを走らせ、マグニチュード9.0の大地震とゆっくりすべりの蓄積だけでは、地震規模の歪みの蓄積をも完全に解约していないことを示し、今後の課題となっている。
Seismic Hazard Map
By Japanese Gov, 2016

REALITY CHECK
The Japanese government publishes a national seismic hazard map like this every year. But since 1979, earthquakes that have caused 10 or more fatalities in Japan have occurred in places it designates low risk.

Geller, 2011 Nature
denied this hazard map!
Kagan et al., 2012 SRL also contradicts “the characteristic EQ model”

**Characteristic Earthquake Model, 1884–2011, R.I.P.**

A precept of science is that theories unsupported by observations and experiments must be corrected or rejected, however intuitively appealing they might be. Unfortunately, working scientists sometimes reflexively continue to use buzz phrases grounded in once-prevalent paradigms that have been subsequently refuted. This can impede both earthquake research and hazard mitigation.

Well-worn seismological buzz phrases include “earthquake cycle” (66 instances recorded in the ISI Web of Science database for the period 2009–2012), “seismic gap” (84), and “characteristic earthquake” (22). And the grand prize goes to... “seismic cycle,” with 88 hits. Each phrase carries heavy baggage of implicit assumptions. The primary assumption loading these phrases is that there are sequences of earthquakes that are nearly identical except for the times of their occurrence. If so, the complex process of earthquake occurrence could be reduced to a description of one characteristic earthquake plus the times of the others in the sequence. Often, such a characteristic earthquake sequence is assumed to be an “invariant feature” of the region, such as the San Andreas fault,” “near Parkfield,” and “about magnitude 6.” Much attention was paid to the fact that no qualifying event occurred before 2004 (11 years after the end of the prediction window), but little was focused on the ambiguities of what was predicted. Any event with magnitude between 5.5 and 7.5 and rupture length over 20 km would arguably have satisfied at least some of the published descriptions.

Jordan (2006) pointed out that a scientifically valid hypothesis must be prospectively testable. Ironically, his article made the untestable assertion that “the northern San Andreas is entering a mature stage of the Reid cycle.” Buzz phrases die hard. Retrospective analyses cannot provide a rigorous foundation for any model of earthquake occurrence including, but not limited to, the “seismic cycle.” Even the simplest spatial model, a circle, has three degrees of freedom for its characterization. The famous mathematician and physicist John von Neumann remarked that with four parameters he could “fit an elephant...” (Dyson, 2004). Furthermore, retrospective searches of seismicity patterns can usually find seemingly significant features in completely random simulations (Shearer and Stark, 2012).

The case of Parkfield shows how retrospective analysis can mislead. The presumed characteristic earthquakes were
Earthquake!

Before/on
Non-linear Process
Rock failure
Chaotic and Unpredictable!

After
Linear Process
Wave equation
Predictable
Source mechanism!

Stochastic methods

Deterministic methods

Time
Origin of misunderstandings

• If an earthquake occurs. *(After quake)*
• Reversely, We estimate the focus/focal mechanism/fault dimension/etc..
• We also forecast the wave *(tsunami)* propagation and seismic hazard!
• *But this is not the prediction of an EQ!*
• However, these processes sometimes confound with each other.
• *And this is one of origin of misunderstanding.*
Apart from ‘Hi-spec’
We should teach
‘Fundamental’ seismology!

i) Fault dislocations
ii) Propagation of seismic waves
iii) Power law behaviors
Previous studies:

• Flour & cocoa fault model (Okamoto, 2003)
• 3D seismic maps using ChromaDepth Glasses (Okamoto, 2008)
Seismic fault + Slinky model

“Three Desktop Toys!!
For Fundamental Seismology

Piggy Bank model

Spring-Block model
Q_1: How does an earthquake occur?

• How and Why does an earthquake occur?
• Fault and Earthquake
• How do seismic waves propagate?
• What is a quadratic pattern of P-arrival phases?
A seismic fault model using two transparent spheres + four slinky springs

Bolt (1999)
P-arrival phases: a quadrant pattern and a fault geometry
地震を起こした断層はどのように動いたかというと、地震波が発生し、断層を通過するメカニズムのことを震源メカニズムという。一般に、断層運動は、地震の原因である地殻の力の変化を反映している。断層が地表に到達している場合、地表調査により、どのような断層かを調査することができる。

しかし、断層は地表に到達していない場合が多く、地表調査からは断層運動について推定することは困難である。このようなときは、地震波形を用いるような断層運動を推定することができる。

図Bのように断層が動いたときについて考える。

まず、領域AとCを通るP波を考えると、断層のずれにより、押し出すされる圧縮が異なる。領域AとCを通るP波の初動は、外に押し出される圧縮を示す。逆に、領域BとDを通るP波の初動は、中に押しこまれるような形になる。つまり、押し出し分布により、4つの領域に分けることができる。

断層運動は3次元で考えることも必要である。地震波を中心とする球（震源球）を考える。

震源球に押し出し分布をプロットすると、4つの領域に分けることができる。4つの領域を分ける面は2つあるが、そのうちの2つが断層面となる。もう1つの面は、補助面とよばれる。この結果を下から見て、2次元に投影したものを震源メカニズム解とよぶ。

この震源メカニズム解からは、2つの断層面が求まるが、実際にどの断層面が動いたかは判断できない。しかし、この震源メカニズム解から、正断層・逆断層・横ずれ断層のいずれであるかを判断することができる。

震源から押し出しされる領域の中心を結ぶ軸をT軸、震源へ押し込まれる領域の中心を結ぶ軸をP軸とよぶ。震源はT軸方向に押し出されており、P軸方向に圧縮されている。
Fault plane (source) and Slinkys (wave)
Normal speed movie
Slow play
What this model shows:

• Unfortunately, the movie is too fast to recognize the initial P-phases!!

• The relation between the focal dislocation and the seismic wave generation is introduced.

• A theoretical (wholly predictable) wave propagation is shown after an earthquake shocked.
Q_2: Are the earthquakes on a same fault periodic?

• If “the characteristic earthquake model” is reasonable.
• The earthquakes on a same fault are periodic!
• Periodic means: the next event is predictable!
• Simplified conditions →
• An interesting prior study:
  Hall-Wallace: Can earthquake be predicted?, JGE 46, 439-449, 1998
Toy_2: “Piggy Bank” as a fault slip model

Neodium magnets
“Piggy Bank”: Before Slip
Stress accumulates

Coins -> Marbless
“Piggy Bank”: After Slip

Then an earthquake happens!
Piggy Bank Movie!
Overburden weights vs. trials

- **pure acrylic**
- **tape (both side)**
- **detached tape**
- **6mm+13mm Magnet (marbles)**

Values are scattered!
An Irregular distribution is appeared.
This results show even a simple friction model dose not behave pure periodic pattern!
Q_3: How do faults affect each other

- Even a simple model shows a little bit complicated pattern.
- If many faults affect each other, what kind of thing happens??

**Spring-block model**

- What happens in **a multi-block model**?
- Theses models are originated by Burridge and Knopoff(1967), This S-B model is inspired by Kato(2011)

**Spring-block model:**
8 thick iron plates lined up in a straight are connected to a surrounding wooden frame with rubber bands. The frame is driven by hand.

- Rubber bands
- Steel blocks
Cutting Iron Blocks by a “cheap” Band Saw

Steel block
Shaving surface by a milling machine

Four pull-tags are attached
Spring-block model Movie!!
Spring-Block model exercise

• The exercise is carried out on the classroom floor, students are watching and counting the slips of each blocks enjoyably. (Occurrence of earthquakes)

• The wooden rim is driving slowly in one direction (a mimic of plate and/or fault motion).
The Gutenberg-Richter’s Law

Natural earthquakes

Earthquake sizes VS. Frequency
25-48N, 125-150E, 1961-2010, JMA

One dimensional S-B model
Co-Slipped Blocks VS. Frequency

Co-slipped blocks number
Let’s count slipped blocks on two-dimension model!
Co-Slipped blocks and frequency on two dimensional model

Longitudinal Pulling

Diagonal Pulling

Peak?
Time sequential slips of each block
On one-dimensional model

Another feature of this model is lateral shifts of the blocks
The earthquake likely occurred on a branch of the North Anatolian fault. Although this is the largest earthquake in the epicentral region in this century, the region of the earthquake has a long history of destructive earthquakes. In 1967, a magnitude 7.1 earthquake caused extensive damage along the North Anatolian fault just east of the current shock.

The 900 kilometer-long North Anatolian fault has many characteristics similar to California’s San Andreas fault. These two faults are right-lateral, strike-slip faults having similar lengths and similar long-term rates of movement. If a person is looking across a right-lateral, strike-slip fault during such an earthquake, that person would see the opposite side move to the right.

The North Anatolian fault has produced seven large (MS >= 7.0) earthquakes in the period from 1939 through 1999. These earthquakes have ruptured the fault progressively from east to west. The seismic gap on the western part of the North Anatolian fault led Turkish and American seismologists to specify, in published papers, that the zone ruptured by the August 17, 1999, earthquake was a zone of special concern.
A PC simulation of Spring-Block model
PC Simulation
Black: position
Purple: force
Green: force-friction
PC simulation results

Frequency

Co-Slipped blocks number
Conclusion

• Three desktop toys are developed to inspire students for seismology.
• These models show two aspects of earthquakes; simple and complicated.
• Also the models are introducing two compensative approaches for nature; deterministic and stochastic; linear and non-linear.
• Our students fully enjoyed these demonstrations.
Conclusions

• All models can be made from DIY store materials. Also tools are easily assembled and can be used as a class room demonstration.

• These toys are useful for students to learn a complicated earthquake process, by discussing the following themes;

  - Are the occurrence of large earthquakes in a single fault system "random or periodic"?
  - Why is the earthquake prediction so difficult?
  - If can, which situation is physics able to describe an earthquake, "before or after"?

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Please come to my Poster: #PB06
Low-Cost and Easy-Made Horizontal Seismometer with Arduino for Educational Use - Demonstration and Observation

http://www.osaka-kyoiku.ac.jp/~yossi

References: