10 September 2022 Sharing Yangon

Earthquakes Risk Reduction in MNBC Provisions

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Building Engineering Institute
Myanmar Earthquake Committee

Content

- Earthquakes
- Earthquake Engineering
- Earthquake Design in Myanmar National Building Code
- Living with Earthquake

မျက်ဖြေ လင်္ကာ (အနန္တသူရိယ)

သူတည်းတစ်ယောက်၊ ကောင်းဖို့ရောက်မူ
သူတစ်ယောက်မှာ၊ ပျက်လင့်ကာသာ
ဓမ္မတာတည်း။

ရွှေအိမ်နန်းနှင့်၊ ကြနန်းလည်းခံ
မတ်ပေါင်းရုံလျက်၊ ပျော်စံရိမ်ငြိမ်
စည်းစိမ်မကွာ၊ မင်းချမ်းသာကား
သမုဒ္ဒရာ၊ ရေမျက်နှာထက်
ခဏတက်သည့်၊ ရေပွက်ပမာ
တစ်သက်လျှာတည်း။

What is Our Earth anyway?

A tiny stone in space

Rotating itself daily

Circling around the SUN annually

Our Earth is NOT an STATIC object

Rotating itself daily

- 1 circle every day at about 1000 km/hr, **600 mph**
- about the speed of airplanes

Circling around the SUN

- 1 circle every year at 107,000 km/h, 67,000 mph
- 40 times faster than F15

Our Earth is NOT a STATIC object

5. McDonnell Douglas F-15 Eagle (1650 mph)

F-15 Eagle RIAT 2017

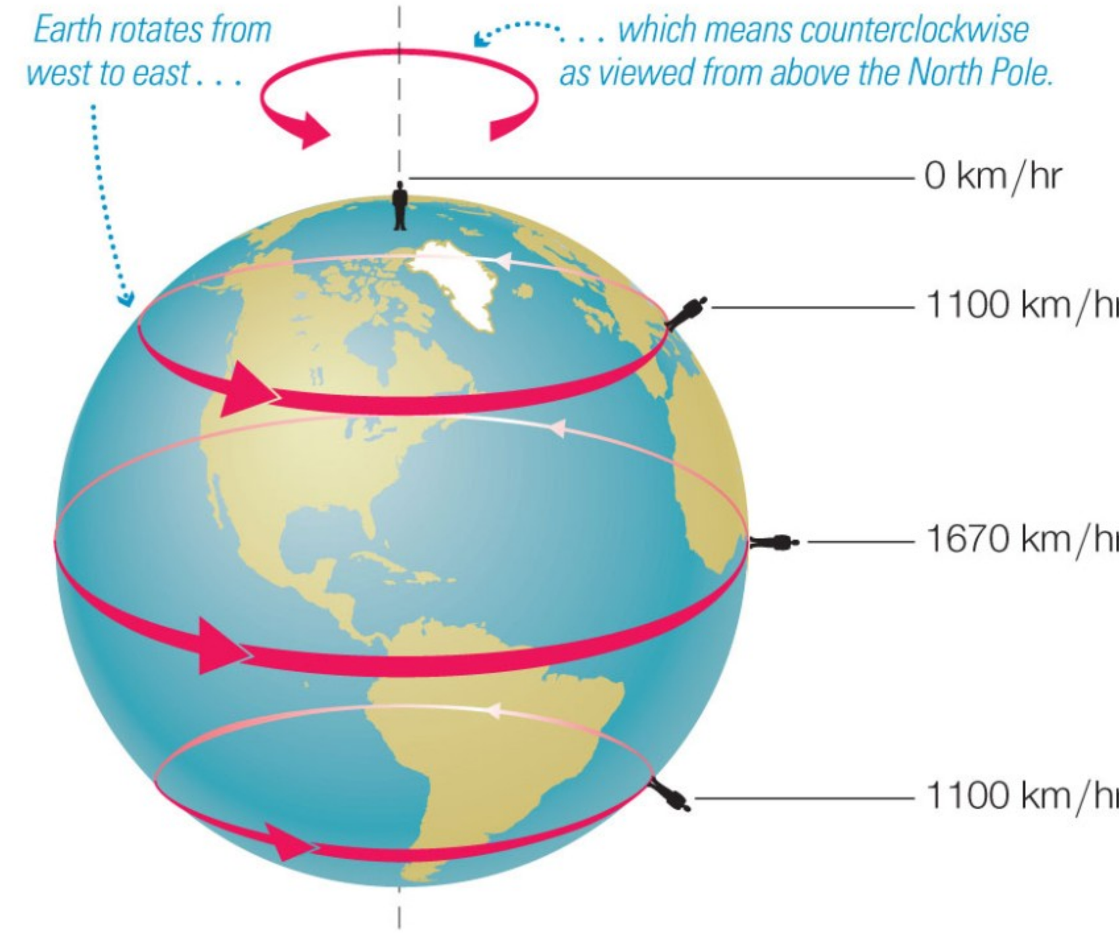


Figure 1.26 – As Earth rotates, your speed around Earth's axis depends on your location: The closer you are to the equator, the larger the path you move around each day, and therefore the faster you travel with Earth's rotation. *Credit: The Cosmic Perspective*

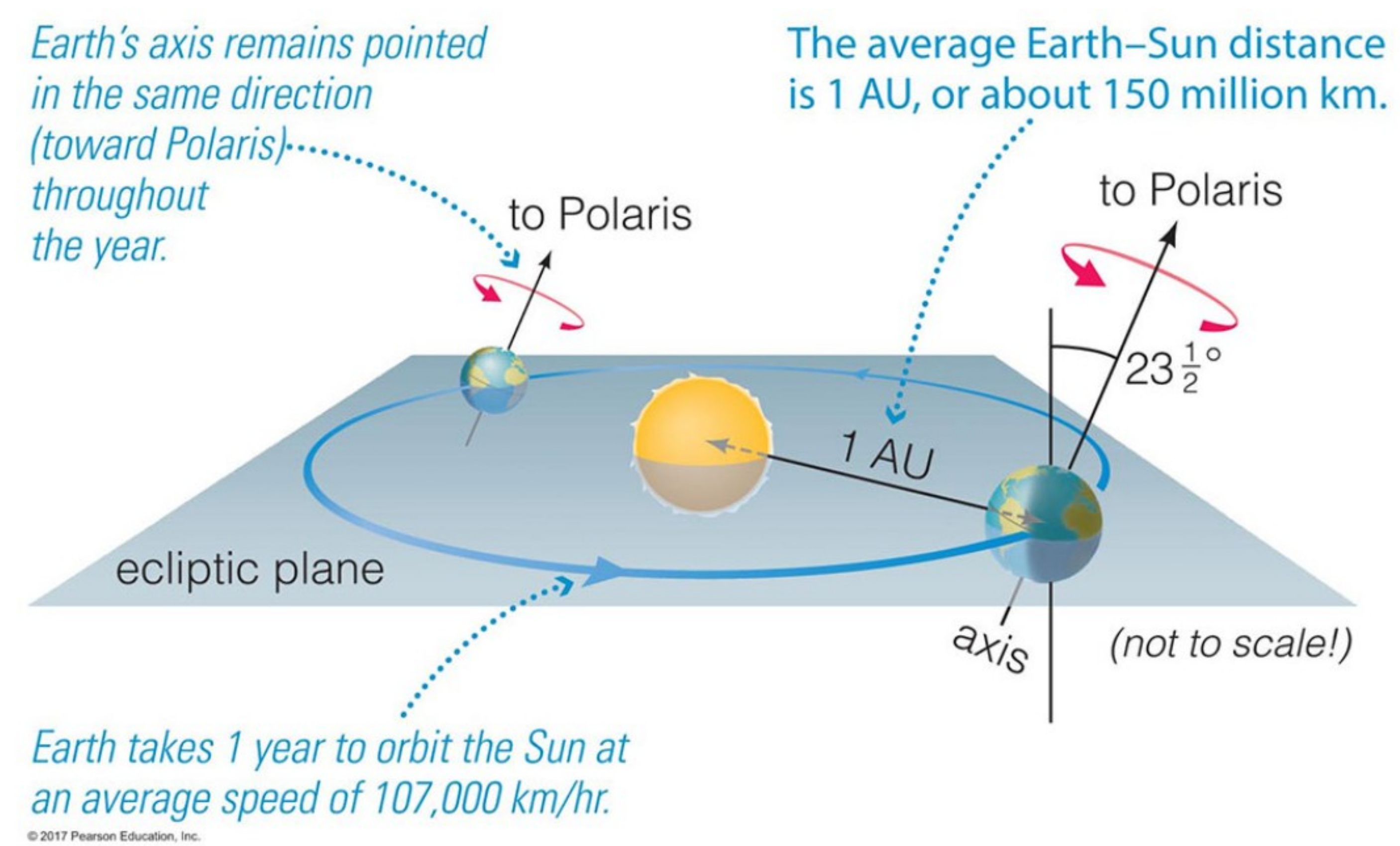
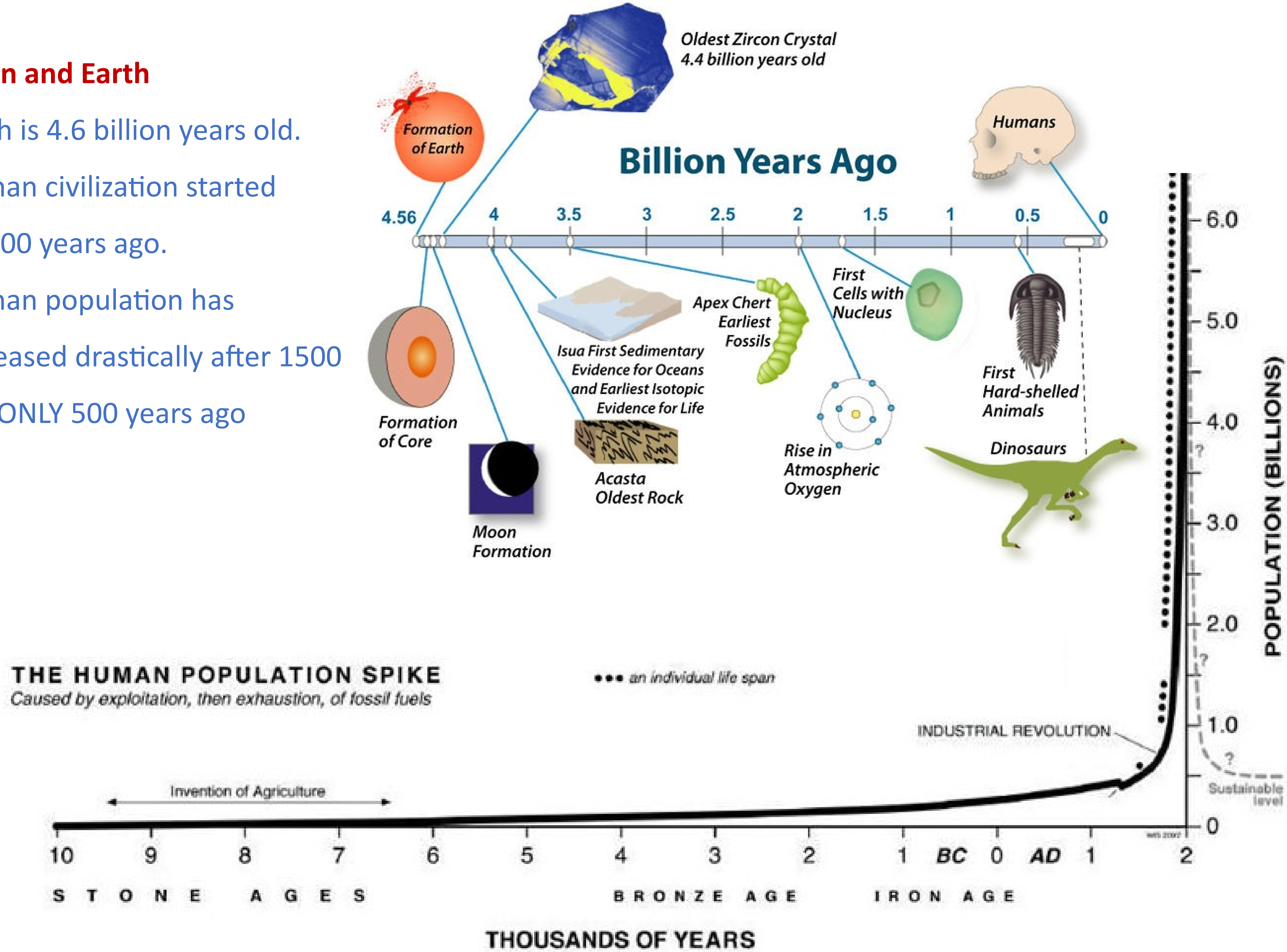


Figure 1.28 – This diagram shows key features of Earth's orbit around the Sun. *Credit: The Cosmic Perspective*

Human and Earth

- Earth is 4.6 billion years old.
- Human civilization started 10,000 years ago.
- Human population has increased drastically after 1500 AD, ONLY 500 years ago



Design Life

- Design life will vary according to the type and use of the element being considered. BS EN 1990, Eurocode - Basis of structural design, (Eurocode 0) gives indicative design lives for various types of structure:
- Category 1:

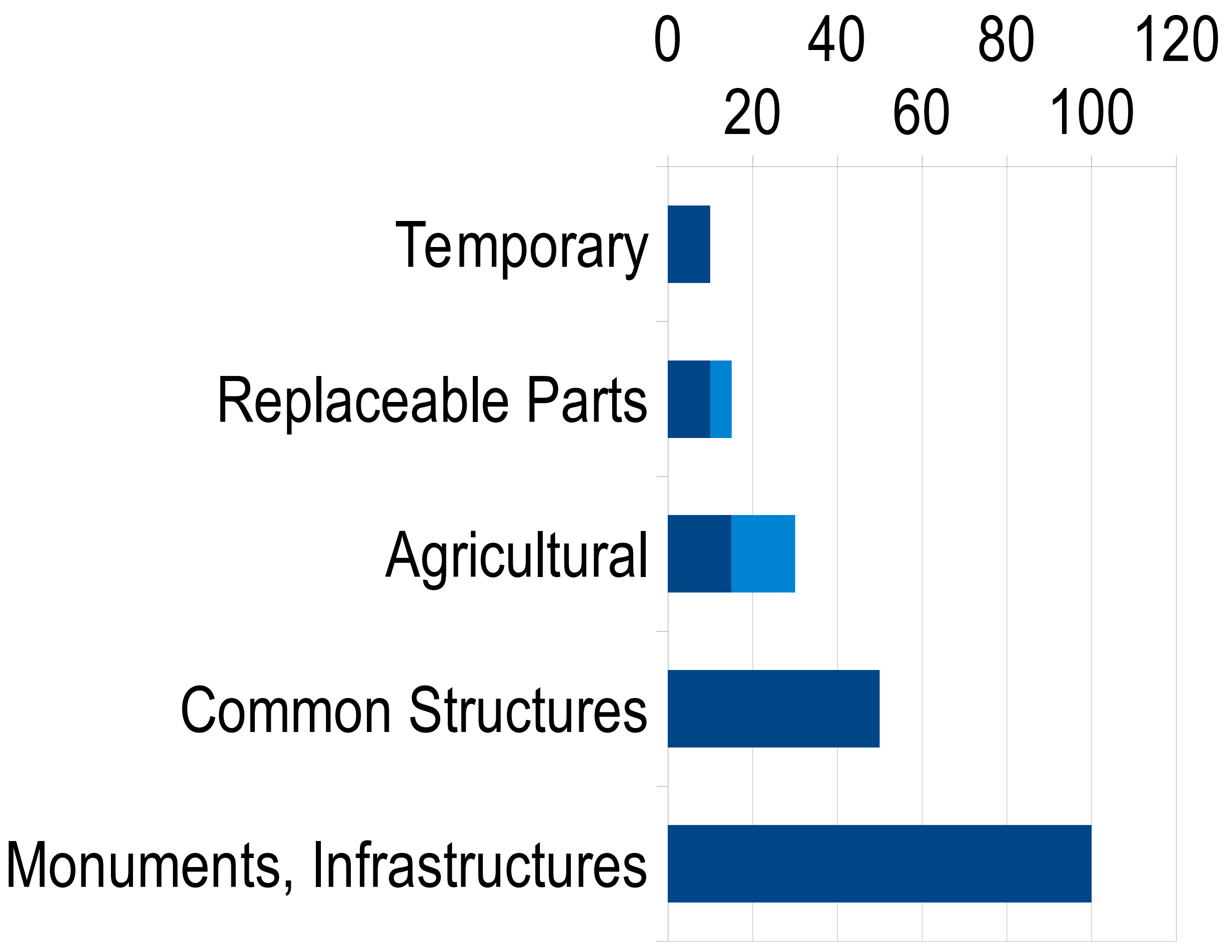
  Temporary structures, not including structures or parts of structures that can be dismantled with a view to being re-used – 10 years.
- Category 2:

  Replaceable structural parts, e.g. gantry girders, bearings – 10 to 25 years.
- Category 3:

  Agricultural and similar buildings – 15 to 30 years.
- Category 4:

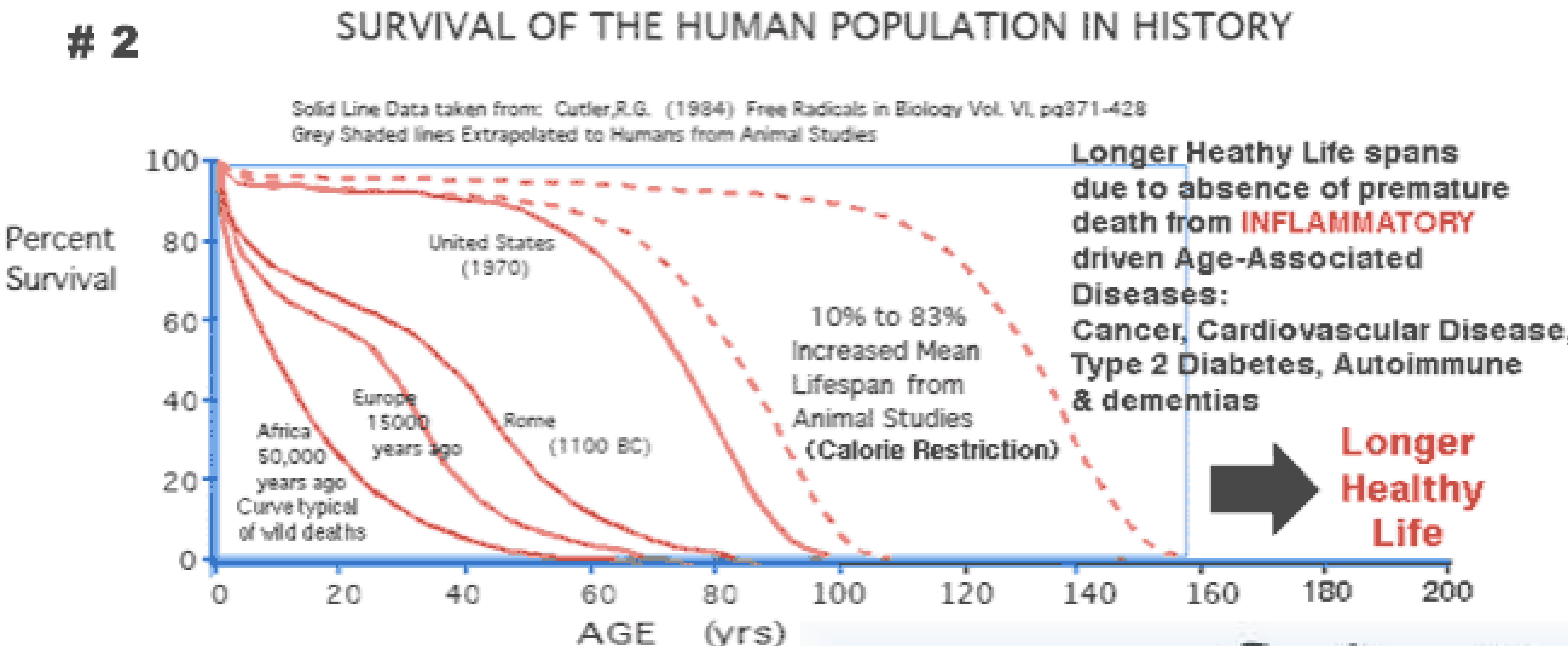
  Building structures and other common structures – 50 years.
- Category 5:

  Monumental building structures, bridges and other civil engineering structures – 100 years.

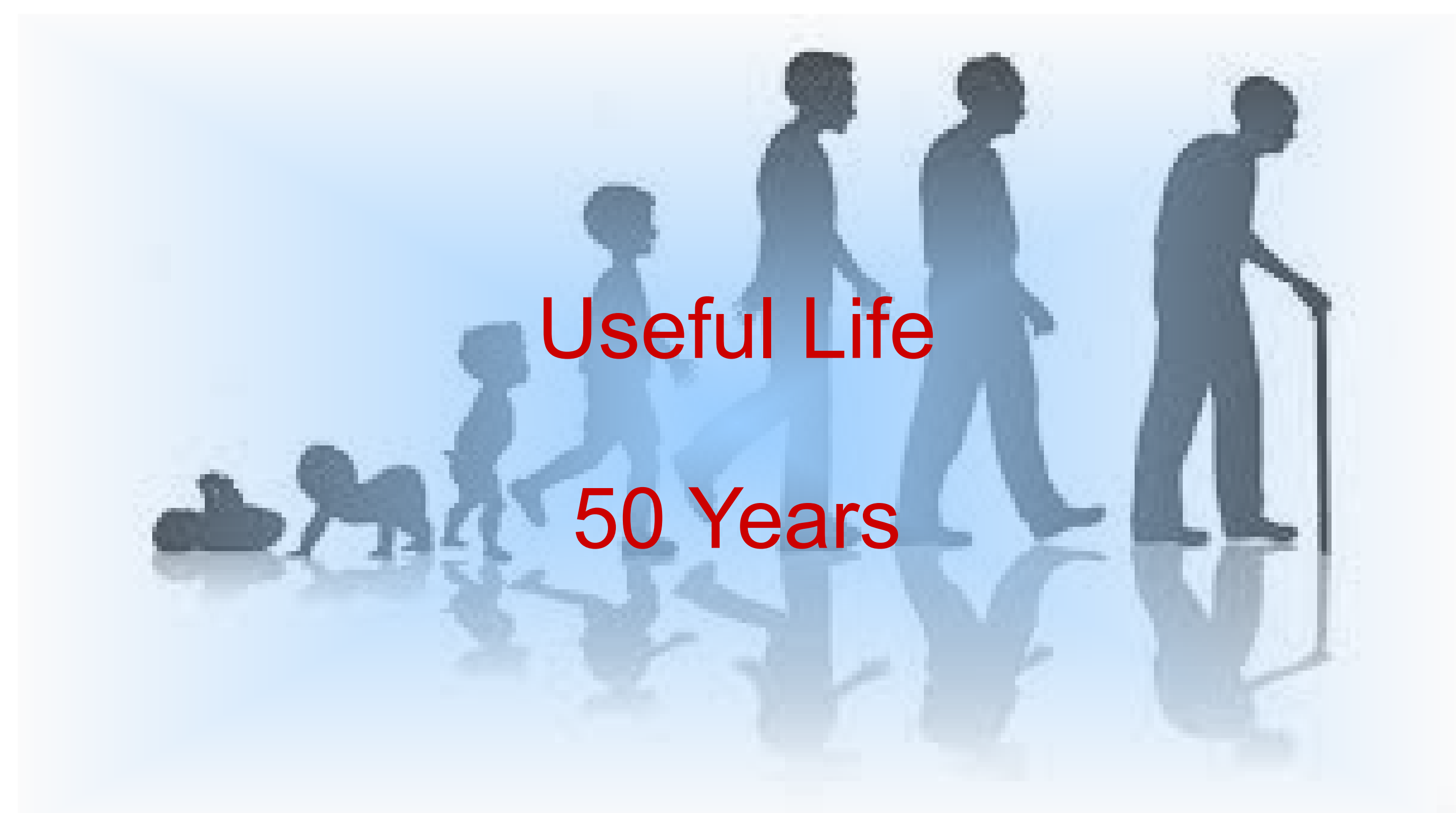


50 Years of Human Windows on 4 Billions Years of Earth

 # 2



Nearly 50,000 years back people were generally dead by age 20



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တစ်သက်လျာတည်း။

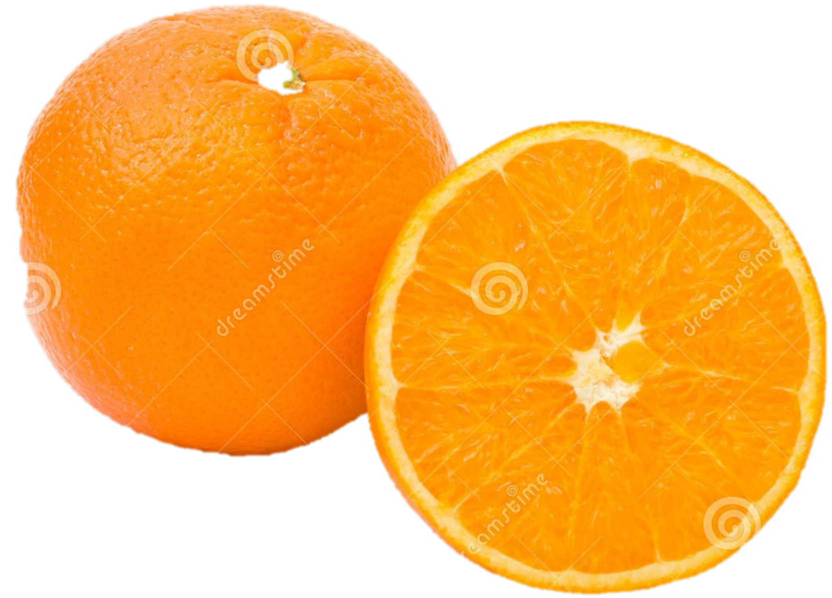
Our structures looks static because we are considering 50 years structural life span window over 4.6 billion years old planet

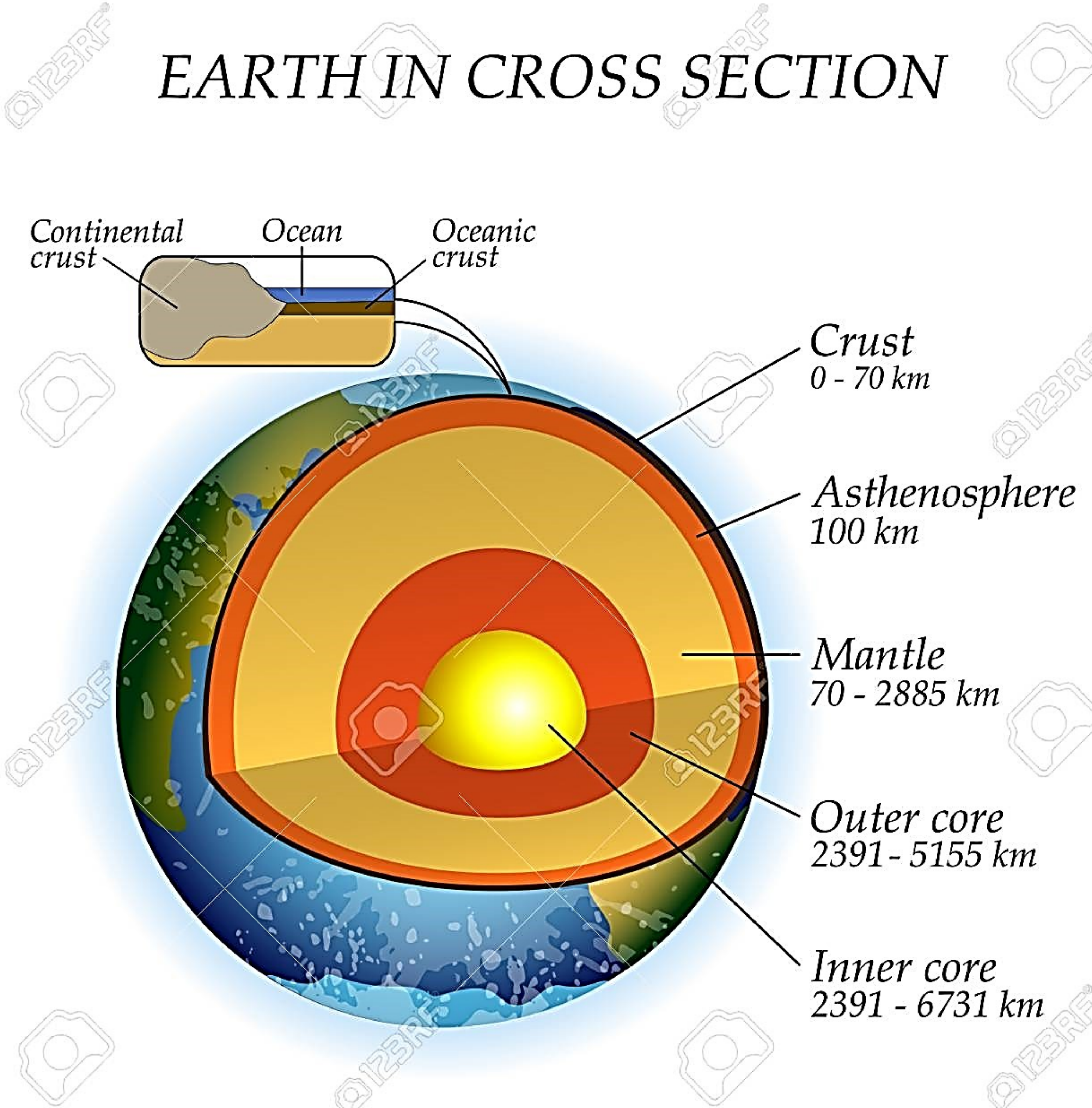
How the earth is made of?

Section Cut

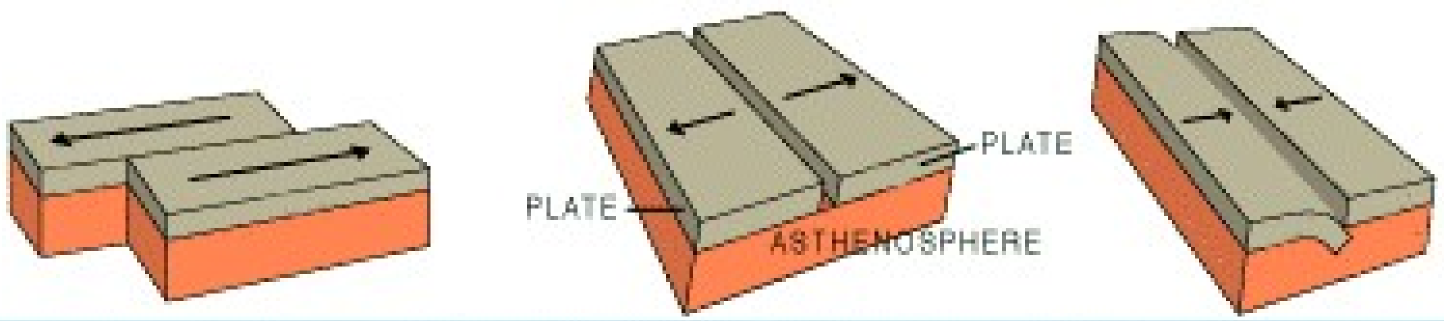
- **Crust** – uppermost thin layer, 3-44 miles thick
- **Upper Mantle** – 200-250 miles thick, 1600 F̊
- Lower Mantle – 1800 miles thick, 7000 F̊
- Fluid Core – 1,400 miles thick, 7000 F̊
- Solid Core – 760 miles thick, 9800F̊

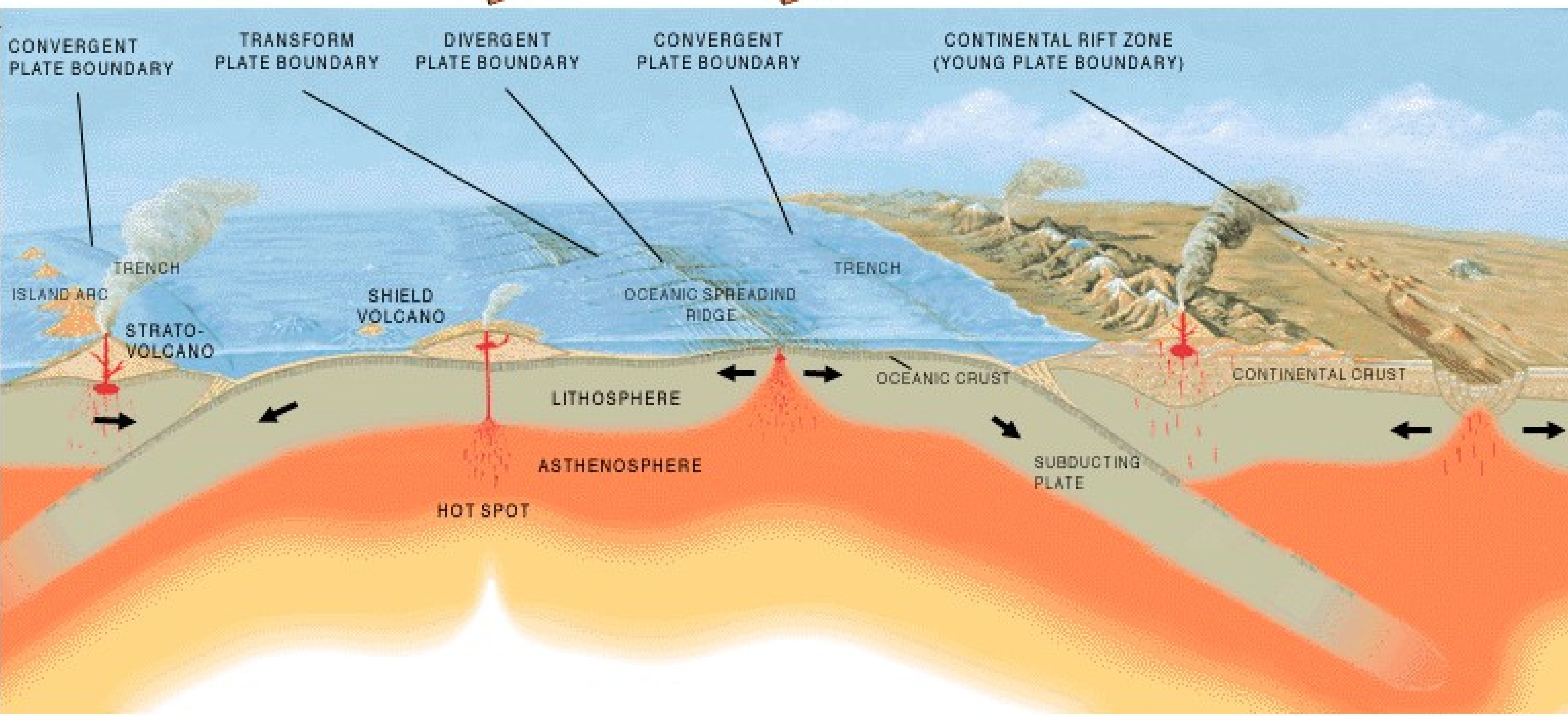
We are sitting on a boiling pot of LAVA

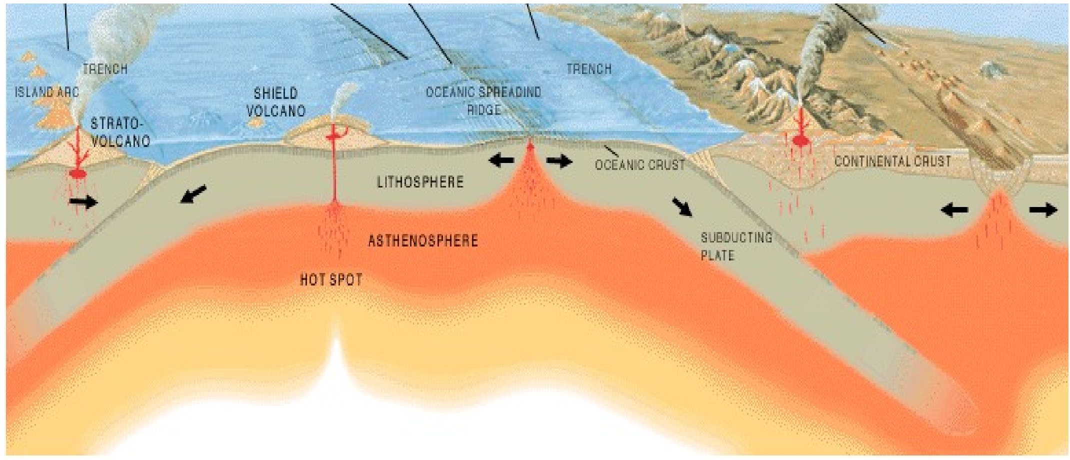


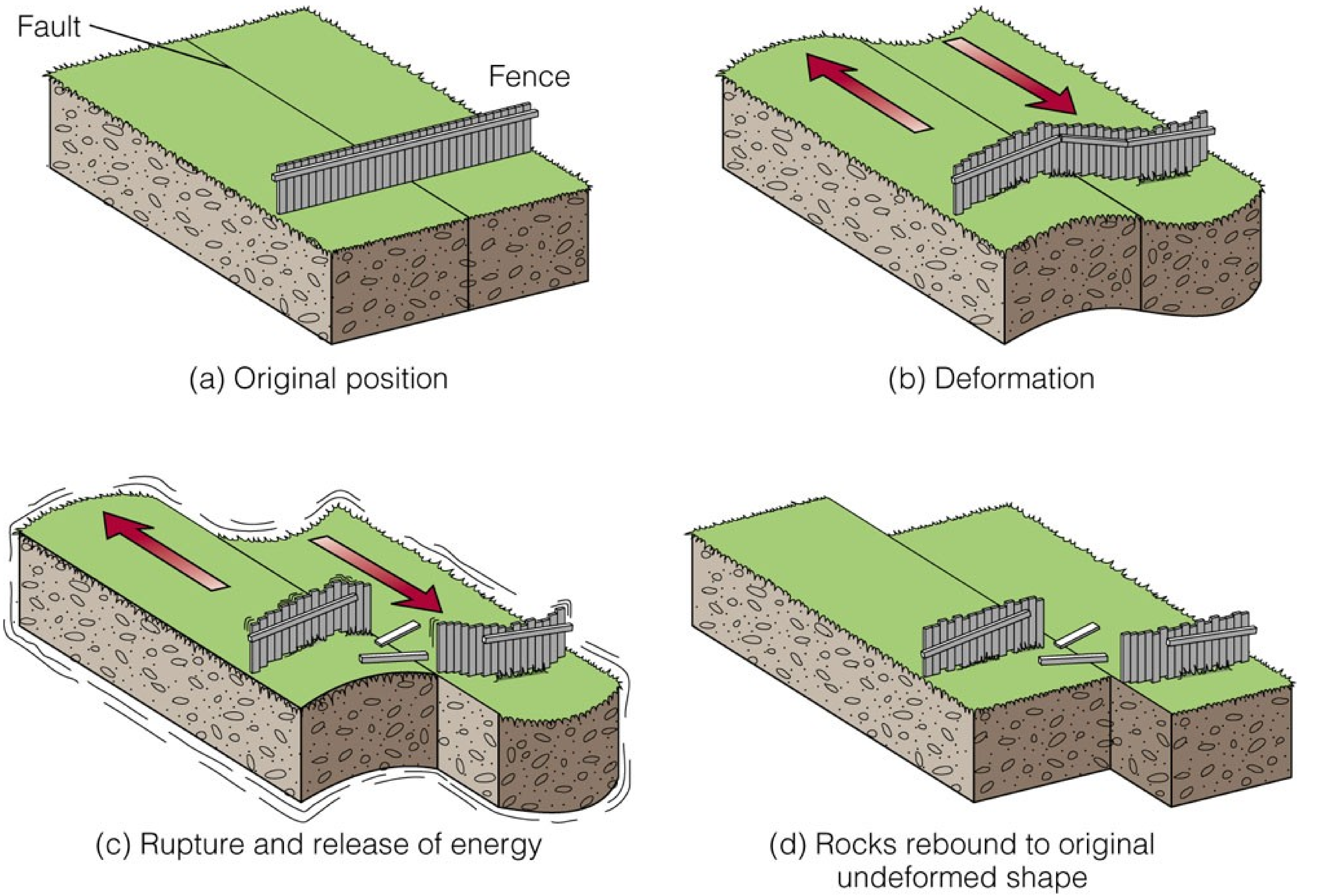


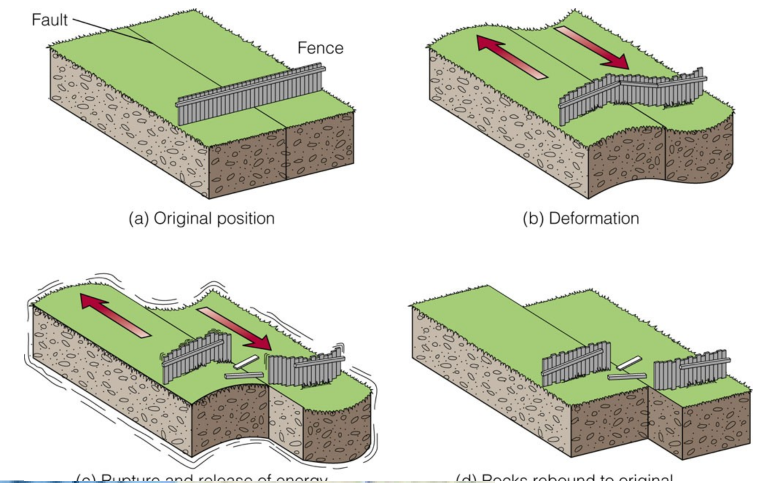
Why earthquakes happen?

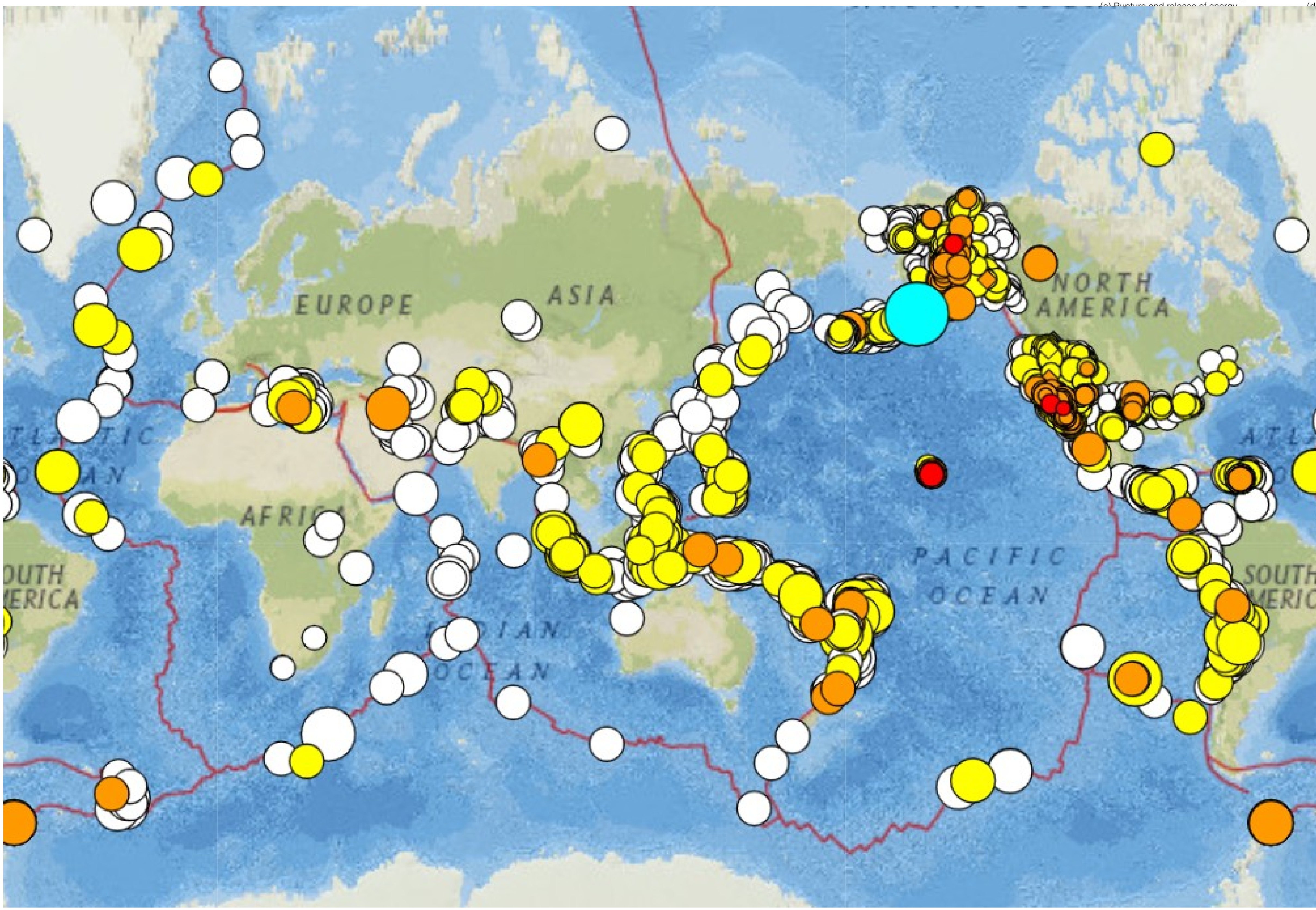





TRENCH
ISLAND ARC
STRATO-VOLCANO
SHIELD VOLCANO
OCEANIC SPREADING RIDGE
TRENCH
OCEANIC CRUST
CONTINENTAL CRUST
LITHOSPHERE
ASTHENOSPHERE
HOT SPOT
SUBDUCTING PLATE


Fault
Fence
(a) Original position
(b) Deformation
(c) Rupture and release of energy
(d) Rocks rebound to original undeformed shape


Fault
Fence
(a) Original position
(b) Deformation


EUROPE
ASIA
NORTH AMERICA
PACIFIC OCEAN

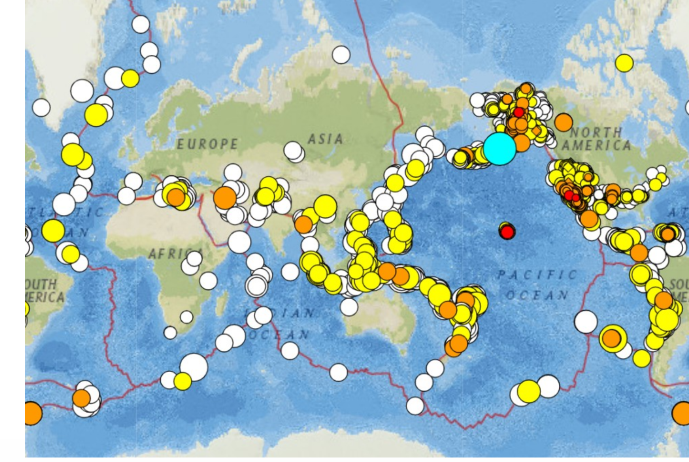
How do we measure an earthquake?

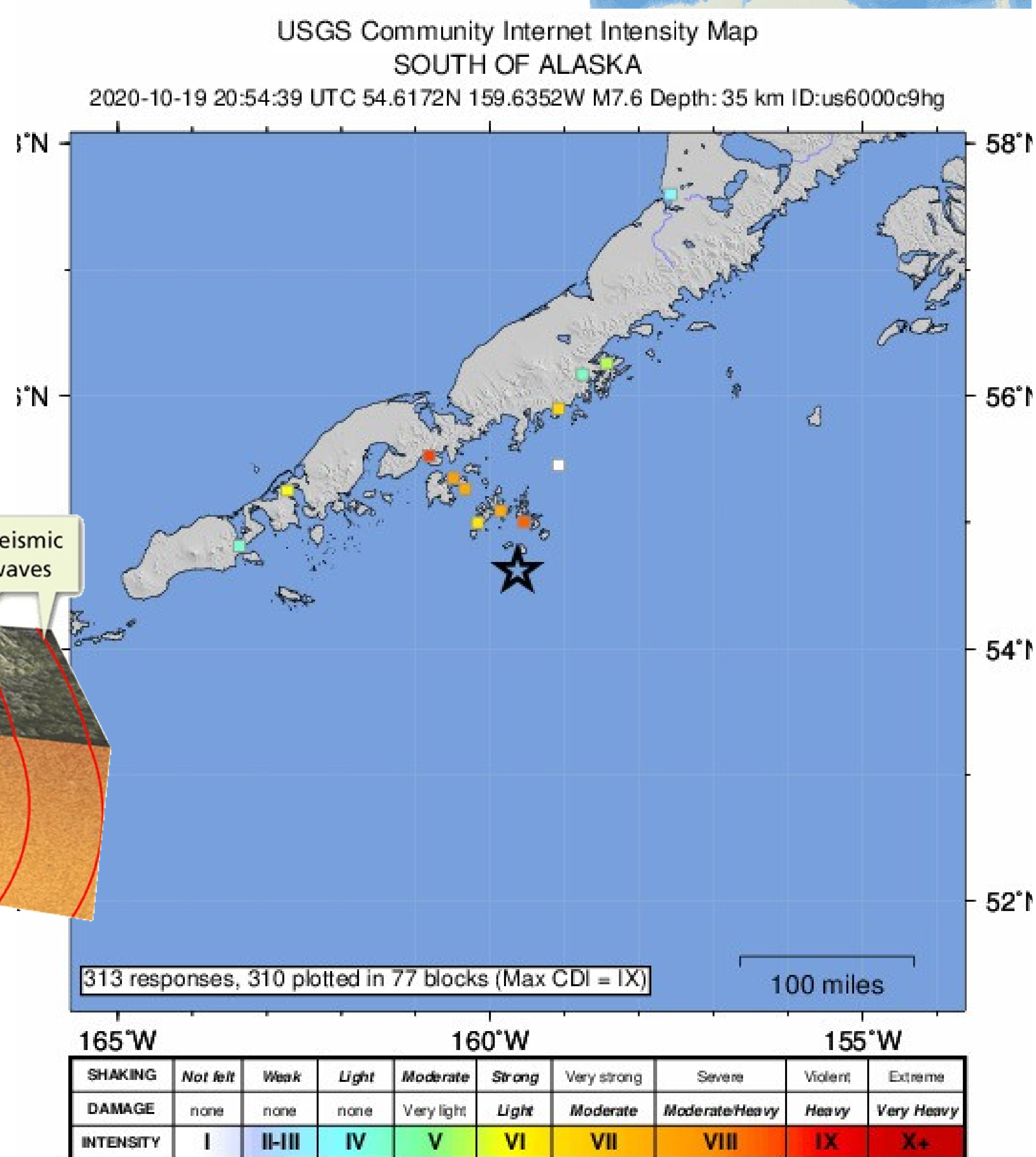
MAGNITUDE

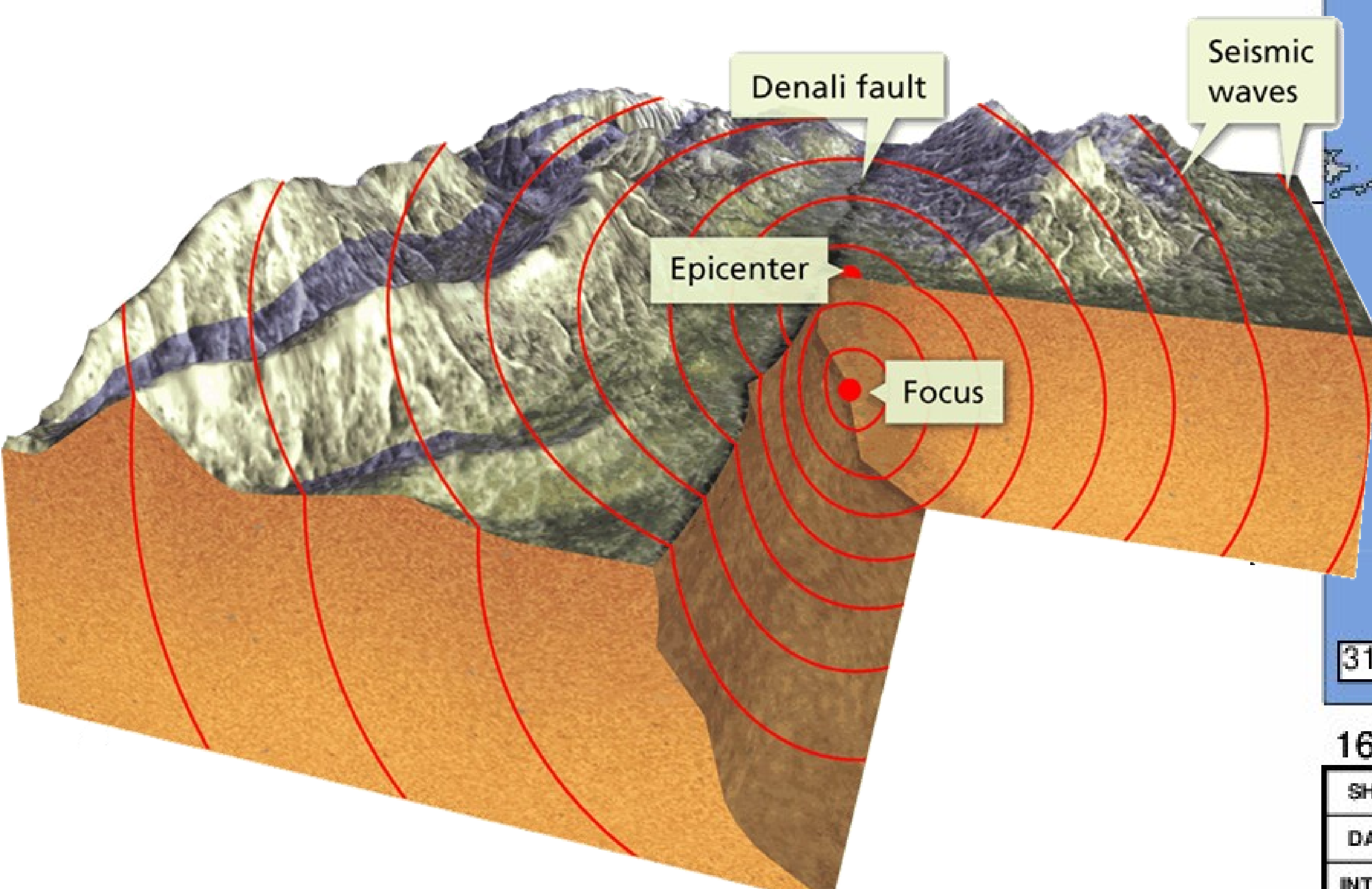
- Express in Richter Scale
- Cause
- Size of the event

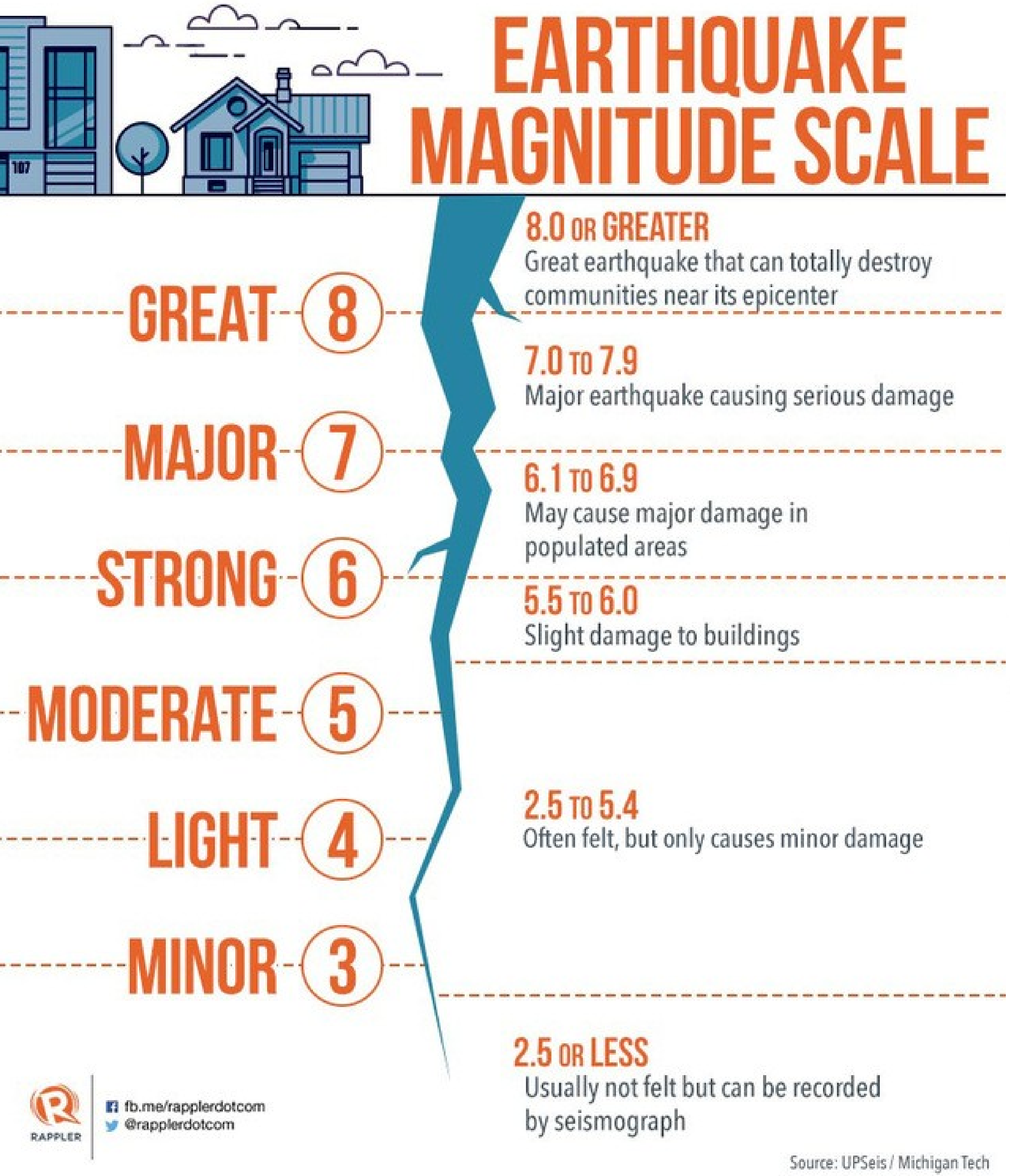
INTENSITY

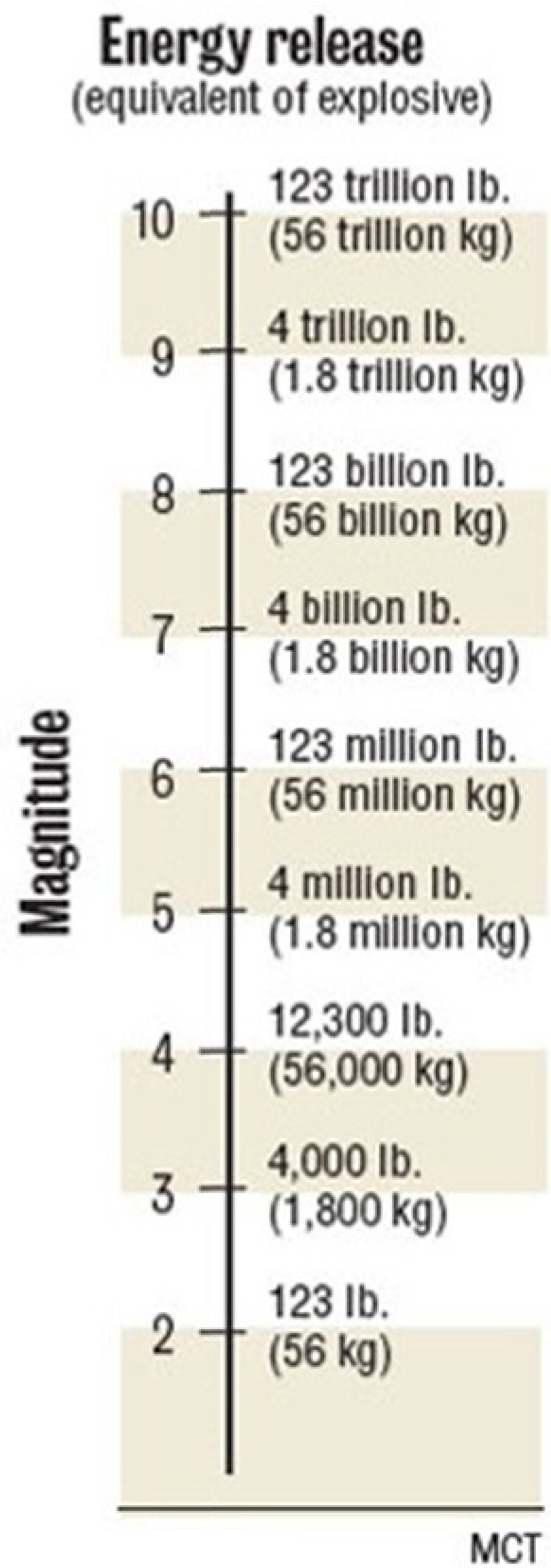
- Express in Modified Mercalli Scale
- Effect
- Damage potential of the event

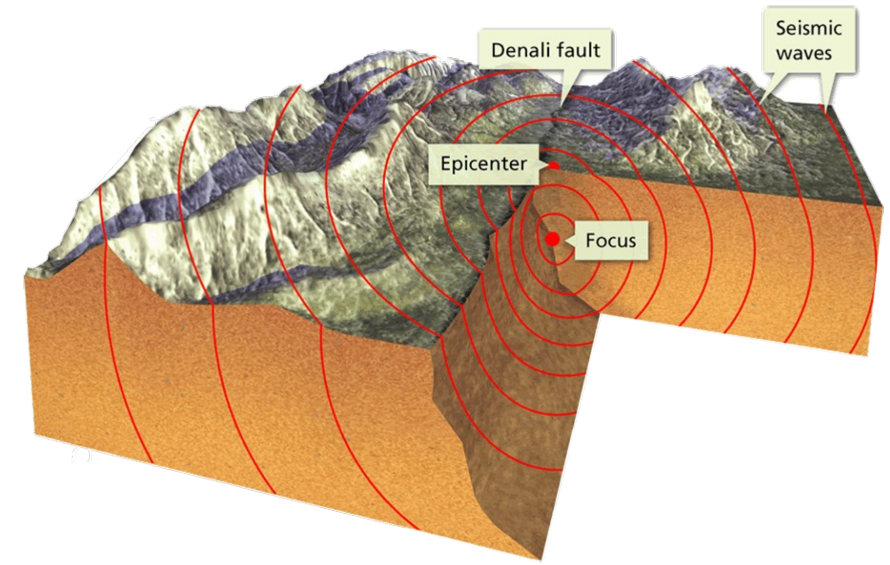






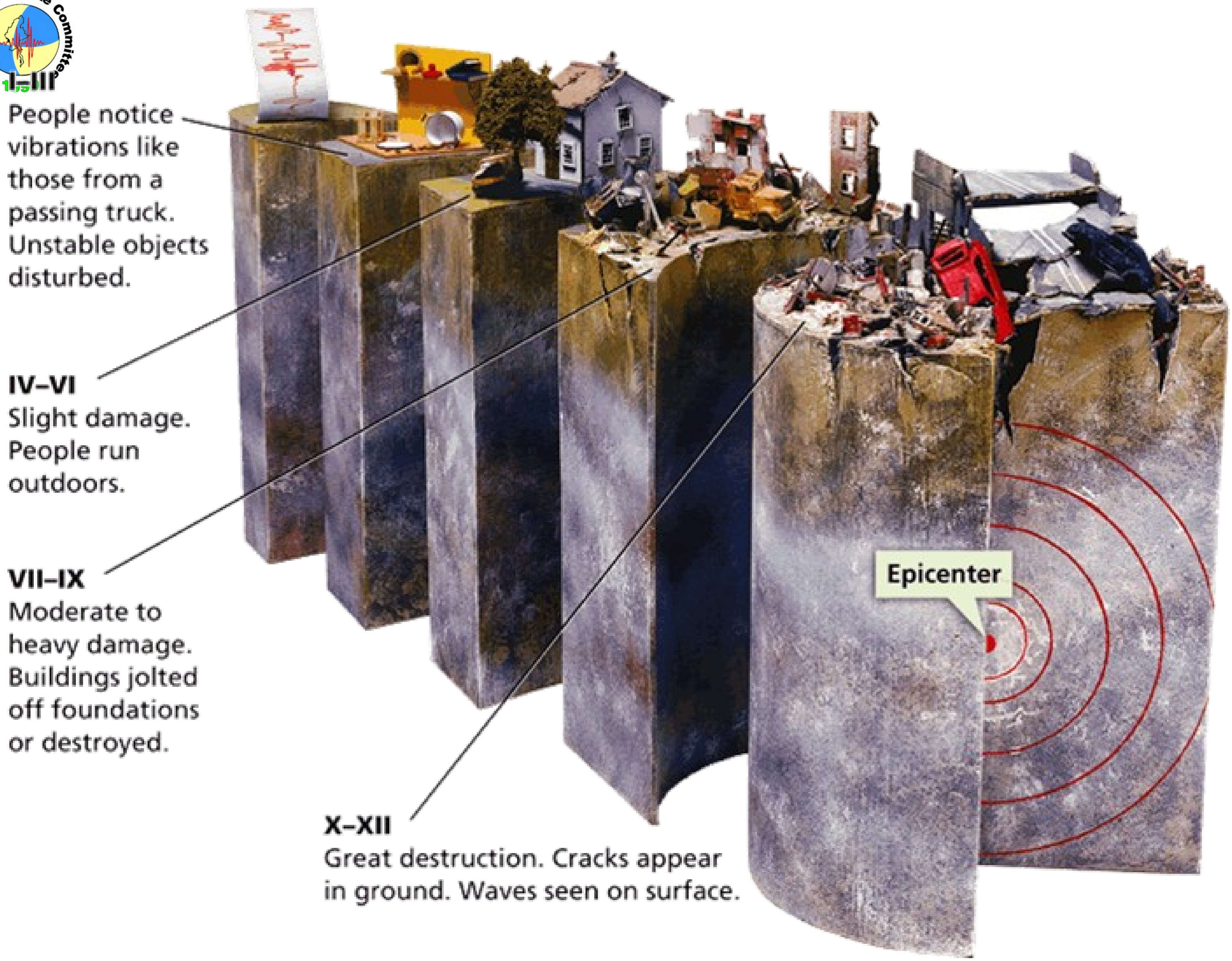


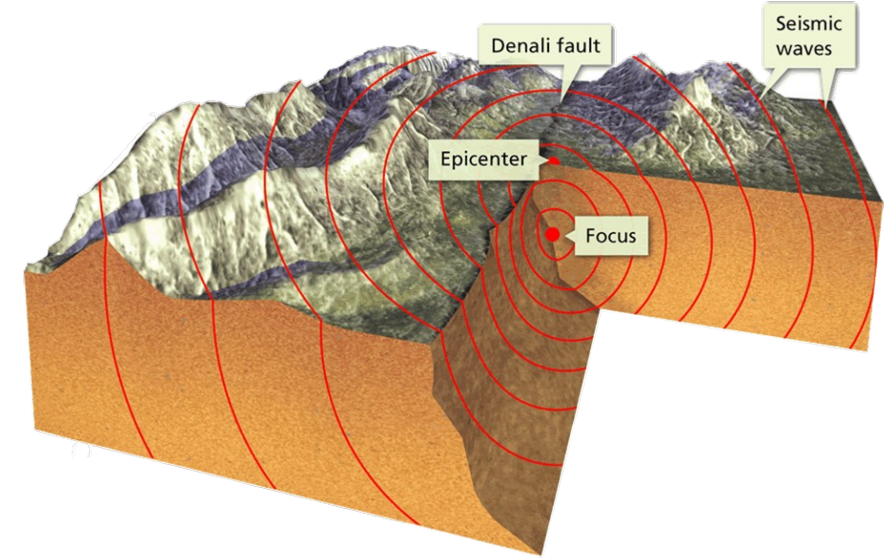




MAGNITUDE

- Express in Richter Scale
- Cause
- Size of the event
- Interest of the Scientists





INTENSITY

- Express in Modified Mercalli Scale
- Effect
- Damage potential of the event
- Interest of the Engineers

INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
Shaking	Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Damage	None	None	None	Very slight	Light	Moderate	Moderate/ heavy	Heavy	Very heavy
Peak Acc	<0.17	0.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Peak Vel	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16 - 31	31-60	60-116	>116

Peak Acc = Peak ground acceleration (g), Peak Vel = Peak ground velocity (cm/s)

Earthquakes in our world

Vesuvius AD62

These two prosperous Roman cities had not yet recovered from the quake of 62 when they were buried by the eruption of Mount Vesuvius in 79. When Vesuvius erupted in AD79 it obliterated two Roman cities, Pompeii and Herculaneum, killing most of the inhabitants and permanently altering the landscape around them.

Aleppo Earthquake 1138

Aleppo is situated northern portion of the Dead Sea and it separates the African plate from the Arabian Plate. The series of the earthquakes took place from October 1138 to the month of the June 1139. The area that was the hit the most was Harim. The earthquake caused deaths of around 230,000 people.

Shaanxi earthquake 1556

The Shaanxi earthquake that hit China in 1556, the deadliest earthquake on record, wiped out almost entire counties and killed around 830,000 people. Records describe how the landscape was completely changed, with new mountains and valleys appearing and rivers changing course.

Lisbon Earthquake 1755

The Lisbon earthquake and tsunami was one of the largest earthquakes the modern era has seen, with a possible magnitude of 9 on the moment magnitude scale. This would be equivalent to the Indian Ocean earthquake and tsunami of 2004.

The 1755 earthquake virtually destroyed Lisbon, with as many as 100,000 people killed. Massive fissures up to 5 meters (16 ft) wide opened in the city. Survivors hurried to the port area, which was relatively open and unscathed, only to be met with a 30-meter-high (100 ft) tsunami.

The Age of Enlightenment is directly linked to the events on November 1, 1755, which was the celebration of All Saints' Day, as the disaster destroyed nearly every religious building and church throughout Lisbon and, more importantly, Portugal.[10]

Immanuel Kant, Jean-Jacques Rousseau, and many others took inspiration from the earthquake and led us to our cultural, political, ideological, and industrial revolutions in Europe.

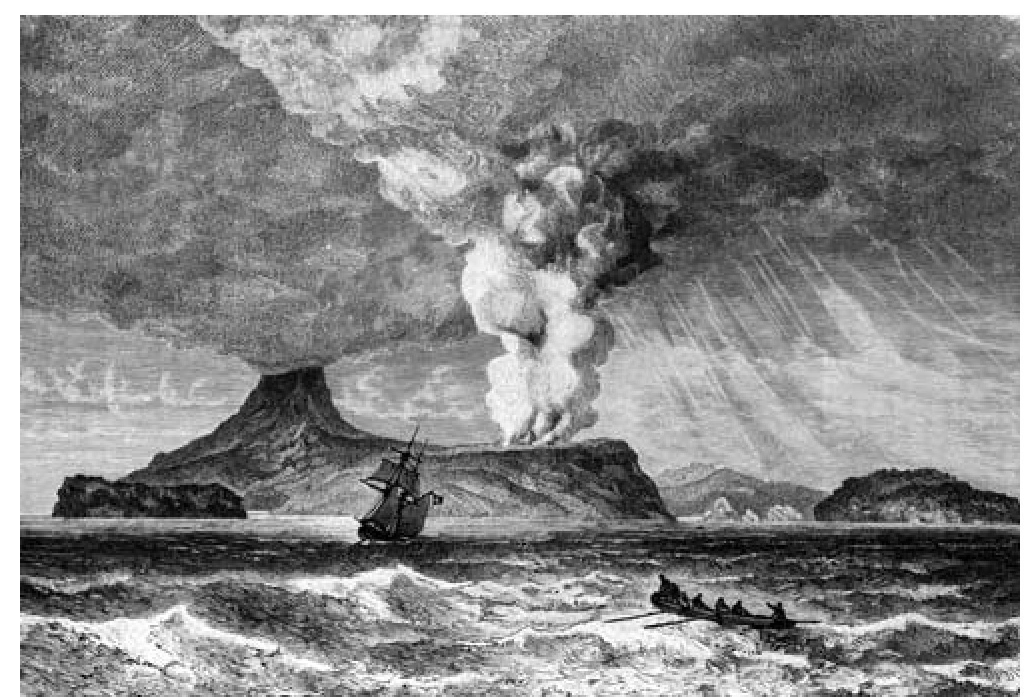
This reasoning became the primary source of authority and legitimacy. It came to advance ideals like liberty, progress, tolerance, fraternity, constitutional government, and the separation of church and state.

Krakatoa 1883

It is an island of Indonesia, located in the Sunda Straight.

A series of eruptions began on August 27th, proving to be some of the most damaging volcanic activity in recorded history.

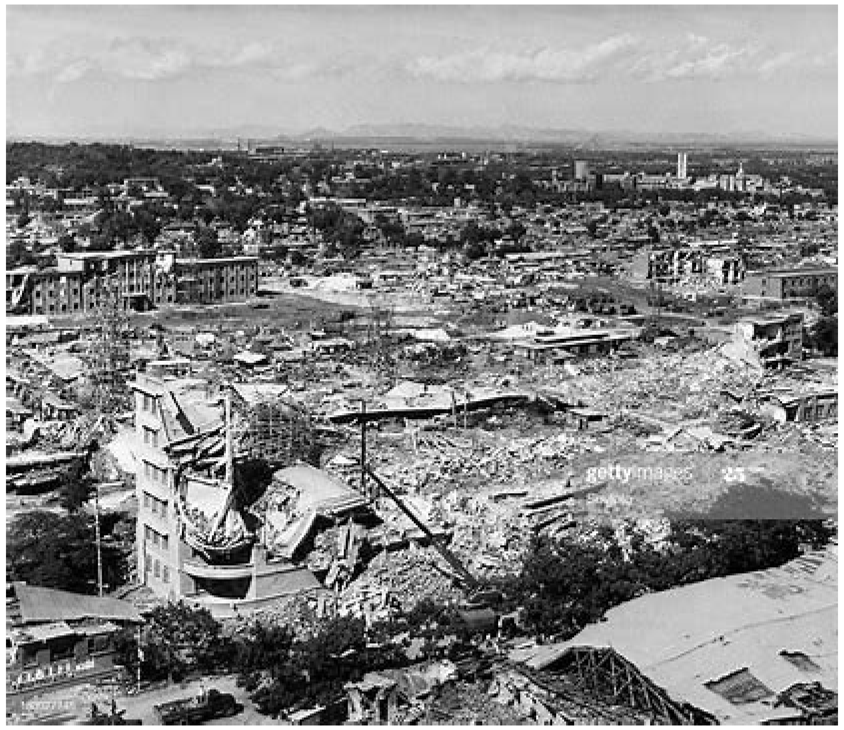
The death toll is estimated to be around the twelve-hundred thousand mark. Not only did lava flows and ash affect the death toll, but the eruptions also created a series of tsunamis around the island, making things a little more complicated for people trying to flee the scene.



Great Kanto Quake 1923

The Great Kanto Quake which struck Japan in 1923 killed hundreds of thousands of people and devastated Tokyo so much so that the government even considered moving the capital somewhere else.

Ultimately, the disaster sparked both soul-searching and nationalism in Japan. Just eight years later, the nation took its first steps toward World War II with the invasion and occupation of Manchuria.



Tangshan earthquake 1976

The Tangshan earthquake in 1976 was one of the deadliest earthquakes in China's history, causing around 242,000 people to lose their lives. The political repercussions of the disaster, however, went far beyond the death toll and damage.

The quake is seen as a key contributor to the end of the Cultural Revolution in China – one of the most violent eras in Chinese history, and the arrest of the 'Gang of Four', who were blamed for implementing the regime's harsh policies.

Indian Ocean Tsunami 2004
Aceh province, Sumatra, Indonesia 9.1 … 200,000 The deaths resulting from this offshore quake actually were caused by a tsunami originating in the Indian Ocean that, in addition to killing more than 150,000 in Indonesia, killed people as far away as Sri Lanka and Somalia.

TŌHOKU EARTHQUAKE AND TSUNAMI, FUKUSHIMA DAIICHI NUCLEAR DISASTER (2011)
A magnitude 9.0 earthquake off the coast of Japan triggered a tsunami wave that rose 133 feet at its highest and traveled as far as six miles inland – much larger and more powerful than expected.
That alone would have been cataclysmic enough, but the event also triggered a technological disaster on the scale of the infamous 1986 Chernobyl crisis: a series of nuclear meltdowns and a large-scale release of radioactive material from the Fukushima Daiichi power plant.
Although estimates of the death toll vary, as many as 20,000 people were killed.

Nepal 2015
Kathmandu, Nepal 7.8 IX 9,000 The Nepal earthquake of 2015 was accompanied by two aftershocks of magnitude 6.6 and 6.7 within the first hour after the quake. A magnitude-7.3 aftershock struck the region on May 12, killing more than 100 people.

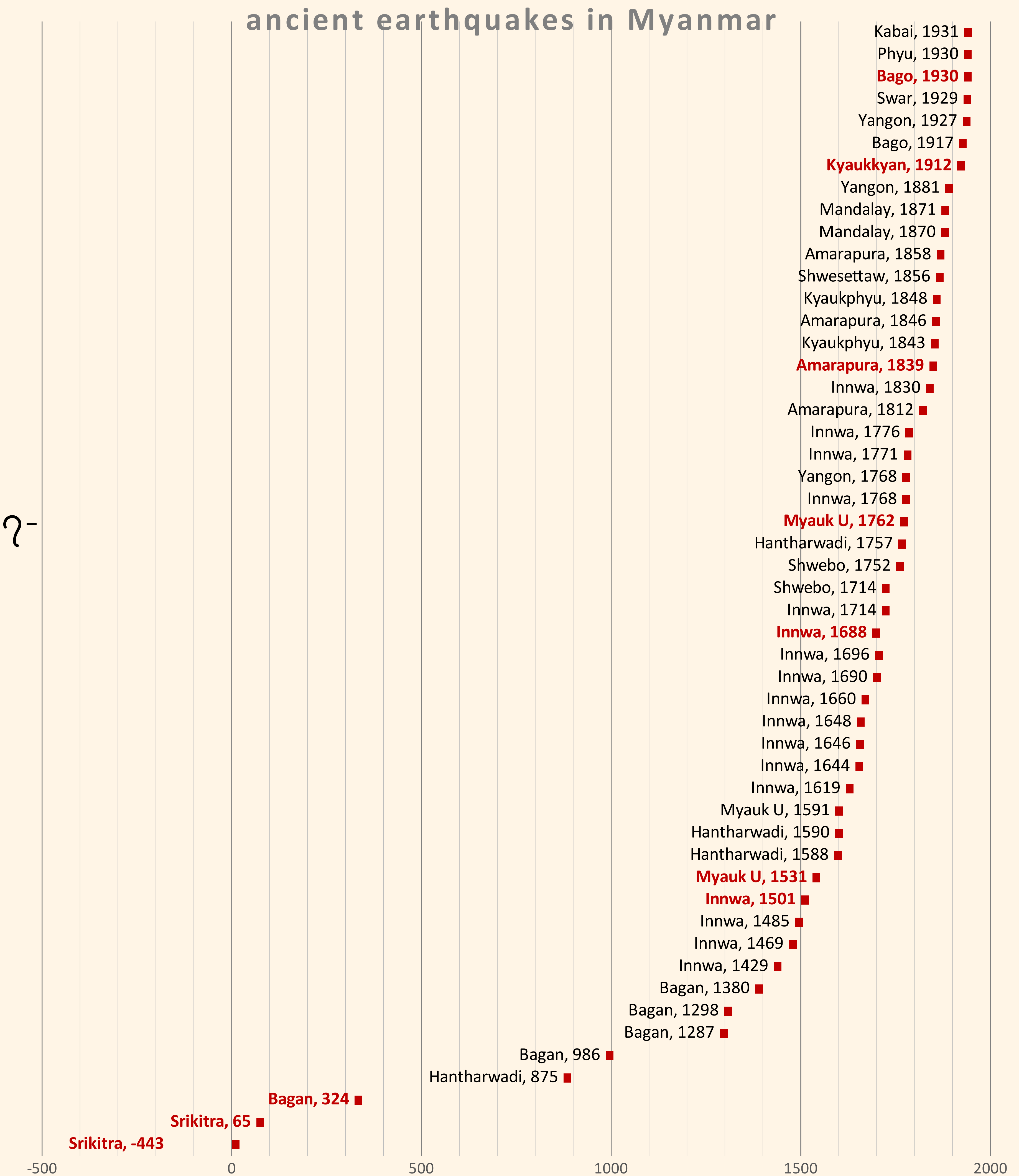
Earthquakes in Myanmar

ကိုးကားချက်။

သမိုင်းဝင် ငလျင်ကြီးများနဲ့ ပုဂံ

ရွှေကိုင်းသား

(စနေစာပေဝိုင်း၊ ဟံသာဝတီသတင်းစာ ပုံနှိပ်တိုက်၊ မေလ ၁ ရက် ၁၉၇၆၊ စာ ၂၆၇-၂၉၃)



အစောဆုံး ငလျင်မှတ်တမ်း

ဘီစီ ၄၄၃၊ သရေခေတ္တရာ မြို့

၁။ သာသနာ ၁၀၁ နှစ် ခရစ် မပေါ်မီ ဘီစီ ၄၄၃ ခုနှစ်။ သရေခေတ္တရာ မြို့တည် ဒွတ္တပေါင်မင်း လက်ထက် ဘုရားသခင် ထားခဲ့တဲ့ ဗျာဒိပ်တော်နဲ့အညီ သာသနာတော် ၁၀၁ ခုနှစ်မှာ...

က။ မြေကြီးငလျင် ပဲ့တင်ထပ်မျှ လှုပ်တယ်။

ခ။ ဘိုးဦးတောင်အရပ်မှာ အင်းကြီးပေါ်တယ်။

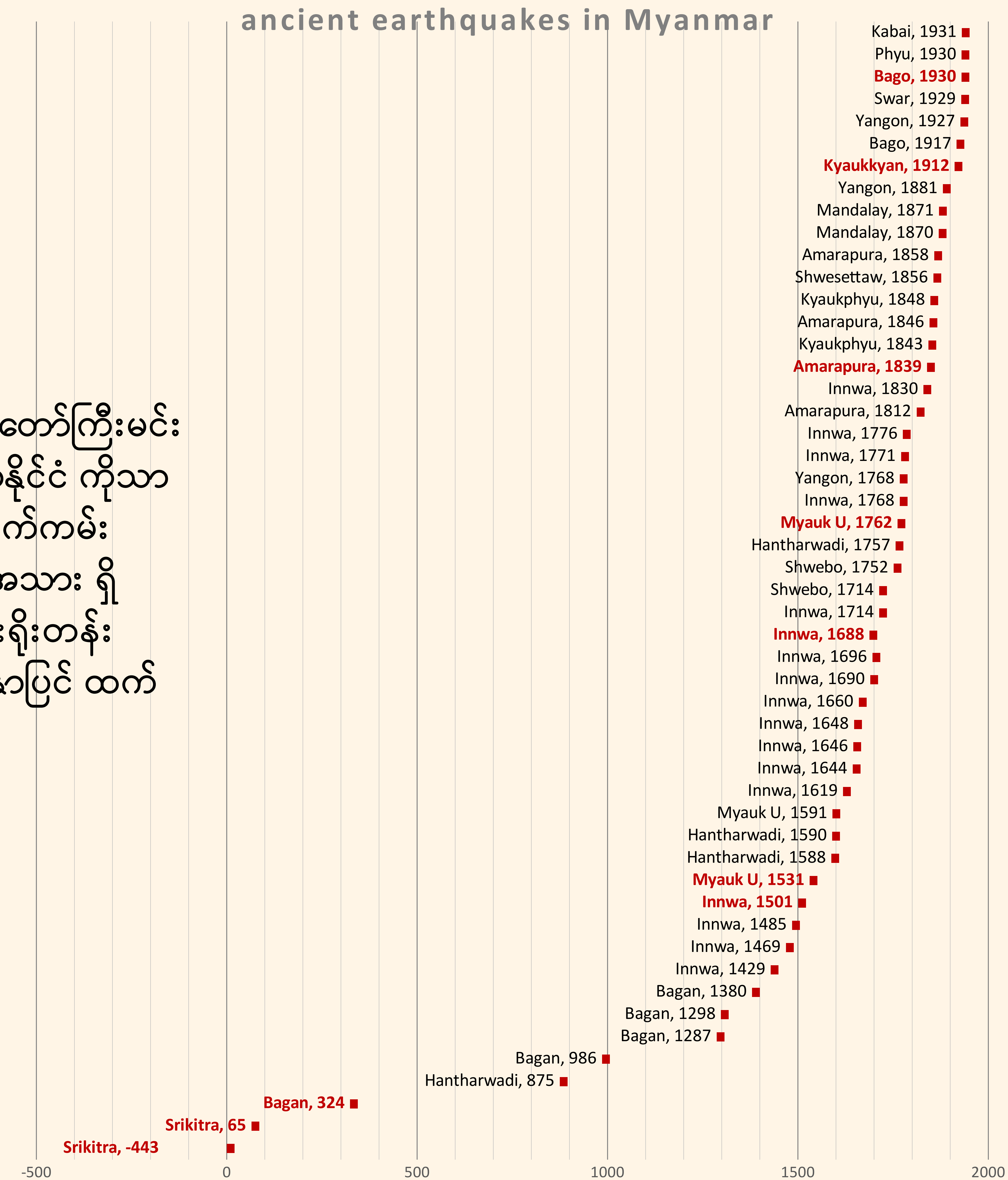
ဂ။ စမုန်ဆံမြိတ်မြစ် ဖြစ်ပေါ်လာတယ်။

ဃ။ ပုပ္ပါးတောင် မြေက စုန့်စုန့်တက်လာတယ်။

င။ သရေခေတ္တရာ ပြည်တည်ရာမှာ ပင်လယ်ရေ ခန်းခြောက်တယ် လို့ မှန်နန်းစတဲ့ မြန်မာရာဇဝင် ကျမ်းတွေမှာ တညီတညွတ်ထဲ ရေးသားဖေါ်ပြခဲ့ကြ တယ်။

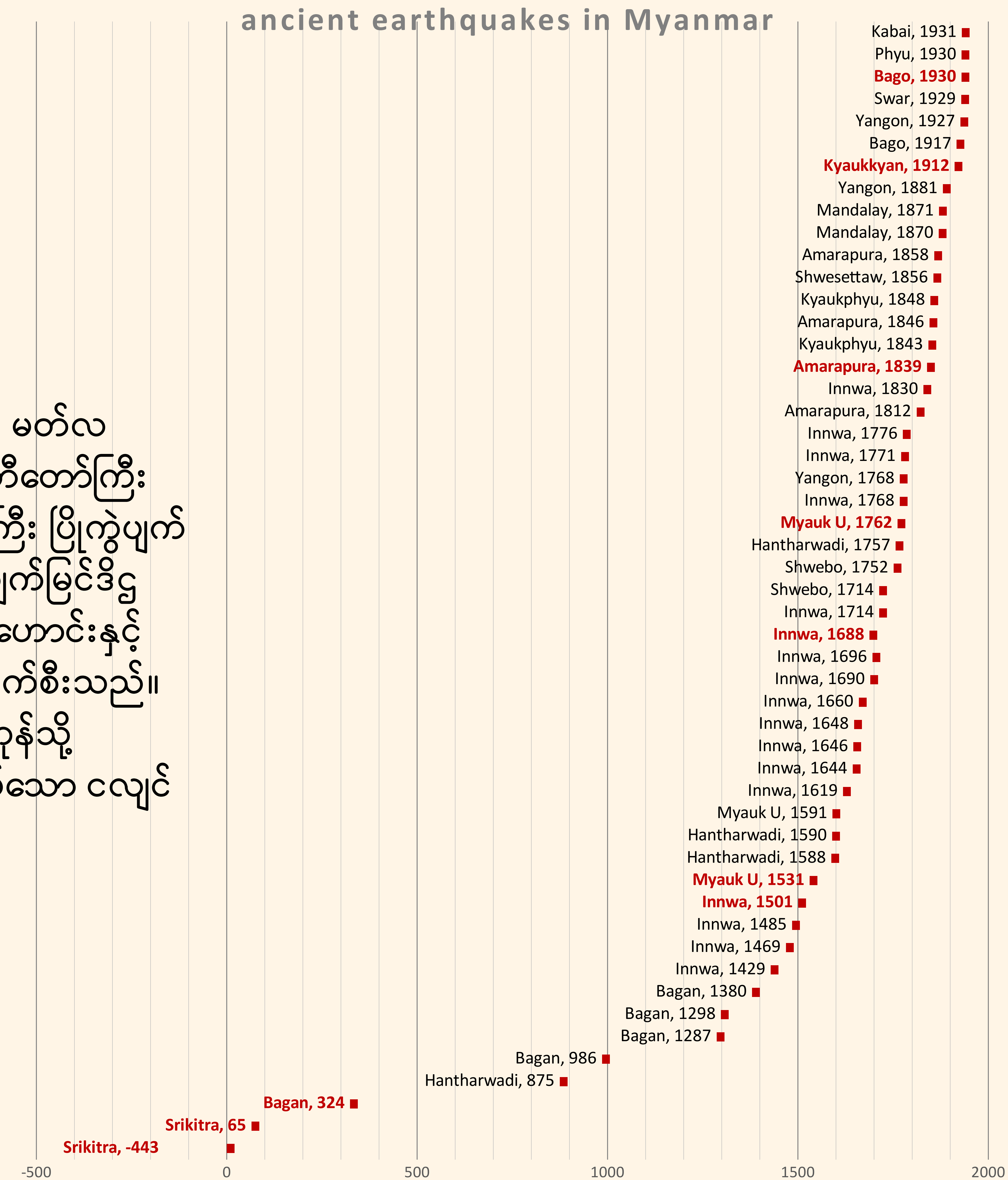
၁၇၆၂၊ ရခိုင်ငလျင်

"ခရစ် ၁၇၆၂ ခုနှစ် ဧပြီလအတွင်း နောင်တော်ကြီးမင်း လက်ထက်တွင် မြေငလျင်လှုပ်ရာ မြန်မာနိုင်ငံ ကိုသာမက ဘင်္ဂလားပင်လယ်အော်၏ အရှေ့ဘက်ကမ်း တလျှောက်လုံးပါ လှုပ်သည်ဟု အမှတ်အသား ရှိသည်။ ထိုငလျင်ကြောင့် ရခိုင်တိုင်း ကမ်းရိုးတန်း အချို့နေရာဒေသတို့သည် မူလ မြေမျက်နှာပြင် ထက် ပို၍ တက်ကြွ လာခဲ့သည်။



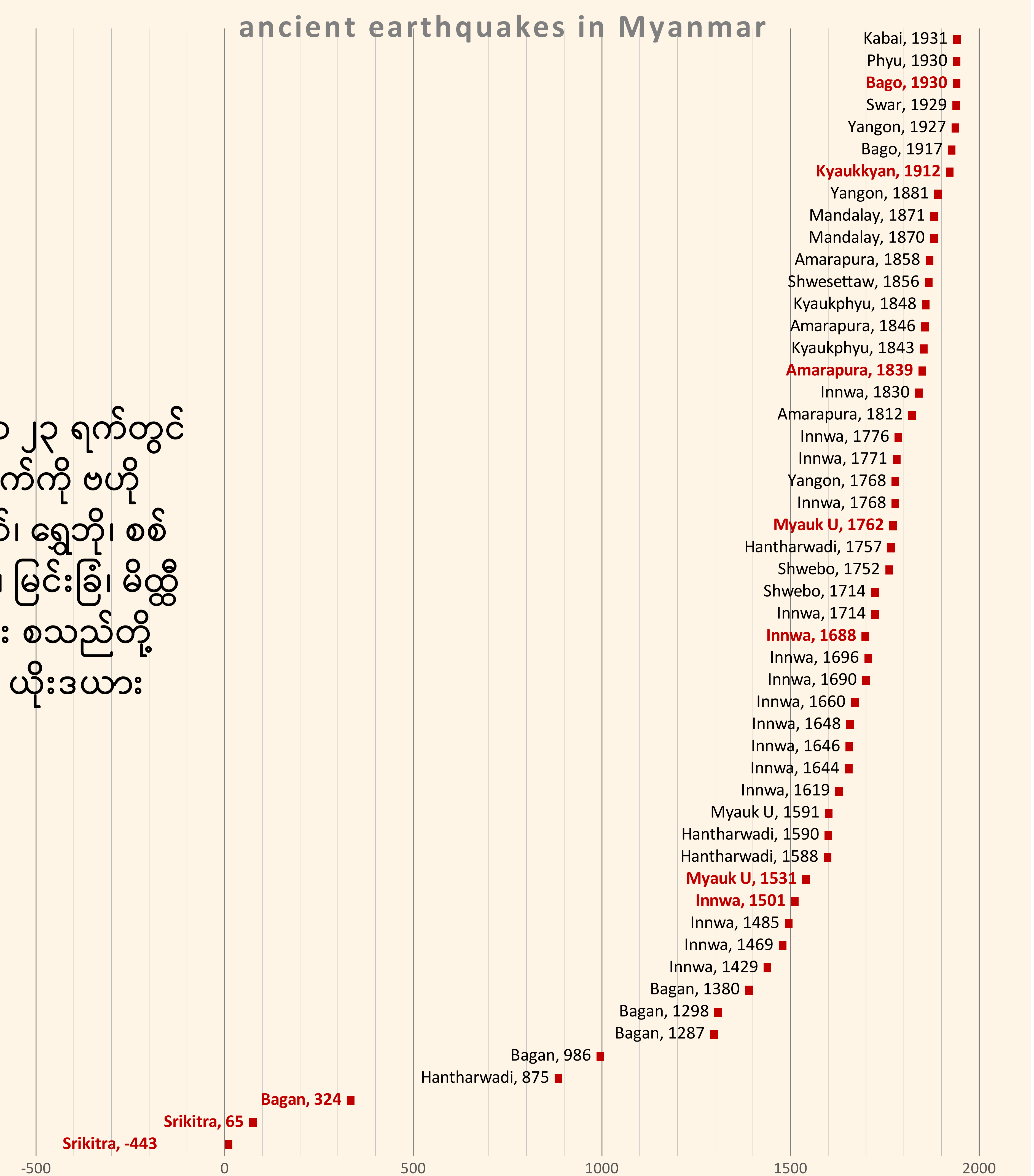
၁၈၃၉၊ အင်းဝငလျင်

''သာယာဝတီမင်လက်ထက် ၁၈၃၉ ခုနှစ် မတ်လ အတွင်း မြေငလျင်လှုပ်ရာ မင်းကွန်းစေတီတော်ကြီး နှင့်အတူ မင်းကွန်း ခေါင်းလောင်းတော်ကြီး ပြိုကွဲပျက် စီးခဲ့ရသည်မှာ ယနေ့တိုင်ပင် ကျွန်ုပ်တို့ မျက်မြင်ဒိဋ္ဌ ဖြစ်သည်။ ထိုစဉ်က အင်းဝရွှေနန်းတော်ဟောင်းနှင့် အမရပူရ ရွှေနန်းတော် တို့သည်လည်း ပျက်စီးသည်။ ထိုငလျင်မှာ ဗန်းမော် ဒေသမှသည် ရန်ကုန်သို့ တိုင်အောင် လေးငါးရက် ဆက်တိုက်လှုပ်သော ငလျင် ဖြစ်သည်။



၁၉၁၂၊ မေမြို့ငလျင်

"ထို့နောက် ဗြိတိသျှခေတ် ၁၉၁၂ ခု မေလ ၂၃ ရက်တွင် ရှမ်းပြည်နယ်ရှိ ကျောက်ကြမ်းဒေသတဝိုက်ကို ဗဟို ပြု၍ မြေငလျင်လှုပ်ရာ မန္တလေး၊ မိုးကုတ်၊ ရွှေဘို၊ စစ်ကိုင်း၊ အောက်ချင်းတွင်း၊ ကျောက်ဆည်၊ မြင်းခြံ၊ မိတ္ထီလာ၊ မကွေး၊ ရမည်းသင်း၊ တောင်ငူ၊ ပဲခူး စသည်တို့ အပြင်းအထန် ခံရ၍ ၎င်းမြေထုငလျင်သည် ယိုးဒယားနိုင်ငံ သို့ပင်လျှင် ပြန့်နှံ့သွားသည်။



၁၉၂၉-၃၀၊ ပဲခူးငလျင်

"၁၉၂၉ ခုနှစ်ဩဂုတ်လ ၈ရက်တွင် တောင်ငူအပိုင် ဆွာမြို့တွင် ငလျင်လှုပ်ရာ လူတို့အတော်ပင် အထိတ်တလန့် ဖြစ်ခဲ့ရသည်။

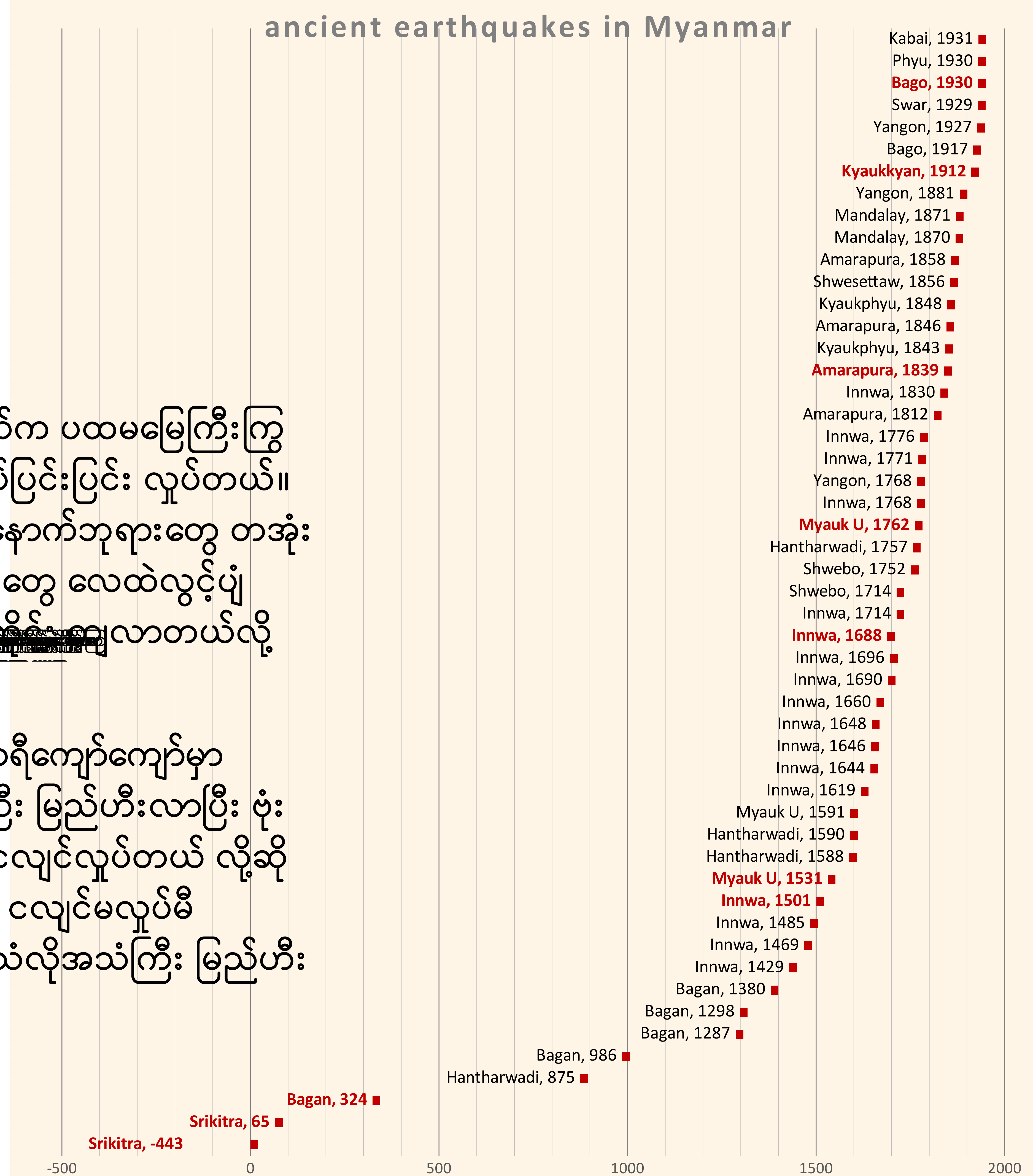
"သို့သော် မြန်မာနိုင်ငံတွင် အပြင်းထန်ဆုံး၊ အပျက်စီးဆုံး၊ အသေအပျောက် အများဆုံး ငလျင်မှာ ၁၉၃၀ပြည့်နှစ် မေလ ၅ ရက်တွင် လှုပ်သော ပဲခူးမြေငလျင်ပင် ဖြစ်သည်။ ရွှေမော်ဓော စေတီကြီး ပြိုကျပျက်စီးသည်။ ပဲခူး၌ လူပေါင်း ၅၀၀ ကျော်ခန့် သေကြေပျက်စီး၍ ရန်ကုန်မြို့၌ပင်လျှင် အချို့တိုက်များပြို၍ လူအနည်းငယ် သေကြေ ပျက်စီးသည်။ ထိုငလျင်များမှာ မြန်မာနိုင်ငံ အောက်ပိုင်းဒေသကို ပို၍ အထိအခိုက် များစေခဲ့သည်။ အထူးသဖြင့် ပဲခူးနယ်တဝိုက် ကျောက်ဖြူ၊ မြိတ် စသည့်နေရာတို့တွင် ပြင်းထန်၍ မြောက်ပိုင်း ရှမ်းပြည် မိုးမိတ်နှင့် တောင်ပိုင်း ရှမ်းပြည်တို့တွင်လည်း အနည်းငယ် လှုပ်ခဲ့သည်။

"ထို့နောက် ခြောက်လကျော်ခန့် ကြာသောအခါ ဖြူးမြို့တွင် ၁၉၃၀ ပြည့်နှစ် ဒီဇင်ဘာလ ၃ ရက်၌ မြေငလျင် ကြီးစွာလှုပ်ရာ လူပေါင်း ၃၀ ကျော် သေကြေပျက်စီးခဲ့သည်။

၁၉၇၅၊ ပုဂံငလျင်

ပုဂံမြို့က ကိုယ်တွေ့တဦးရဲ့ ပြောပြချက်က ပထမမြေကြီးကြွတက်လာပြီး ဘယ်ညာ သုံးကြိမ်ခန့် ခပ်ပြင်းပြင်း လှုပ်တယ်။ နောက် တော်လဲသံကြီး ကြားရတယ်။နောက်ဘုရားတွေ တအုံးအုံးနဲ့ ပြိုကျပြီး အုတ်မှုန့် သဲမှုန့် မြေမှုန့် တွေ လေထဲလွင့်ပျံတက်ကုန်တယ်။ ဒါကိုတချို့က သဲမုန်[illegible]ကျလာတယ်လို့ ထင်ကြတယ်။

သတင်းတပုဒ်ကတော့ ညနေခြောက်နာရီကျော်ကျော်မှာ အနောက်တောင်ဒေါင့်က တော်လဲသံကြီး မြည်ဟီးလာပြီး ဗုံးပေါက်ကွဲသံလို ကြားရတယ်။ နောက် ငလျင်လှုပ်တယ် လို့ဆိုတယ်။ ပဲခူးတိုင်း မင်းလှမြို့နယ် မှာလဲ ငလျင်မလှုပ်မီ အနောက်တောင်ထောင့်ဆီက မိုးချုန်းသံလိုအသံကြီး မြည်ဟီးလာပြီးမှ ငလျင်လှုပ်တယ် လို့ဆိုတယ်။



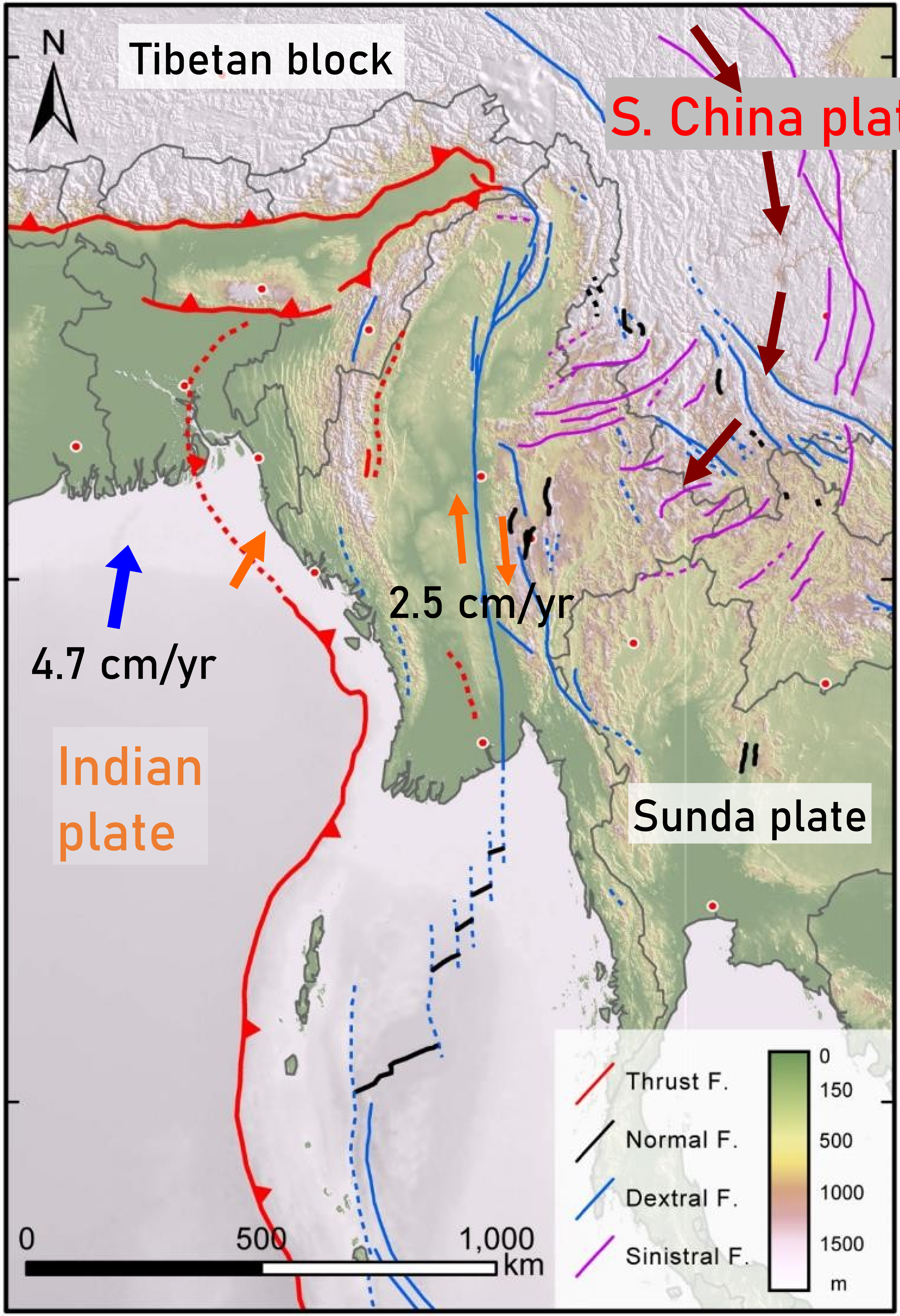
Earthquakes in Myanmar

Earthquakes sources in Myanmar

- Sagaing Fault
- Subduction Zone
- Shear Zone in Shan Platau

Tectonics of Myanmar

Wang Yu et al., 2013

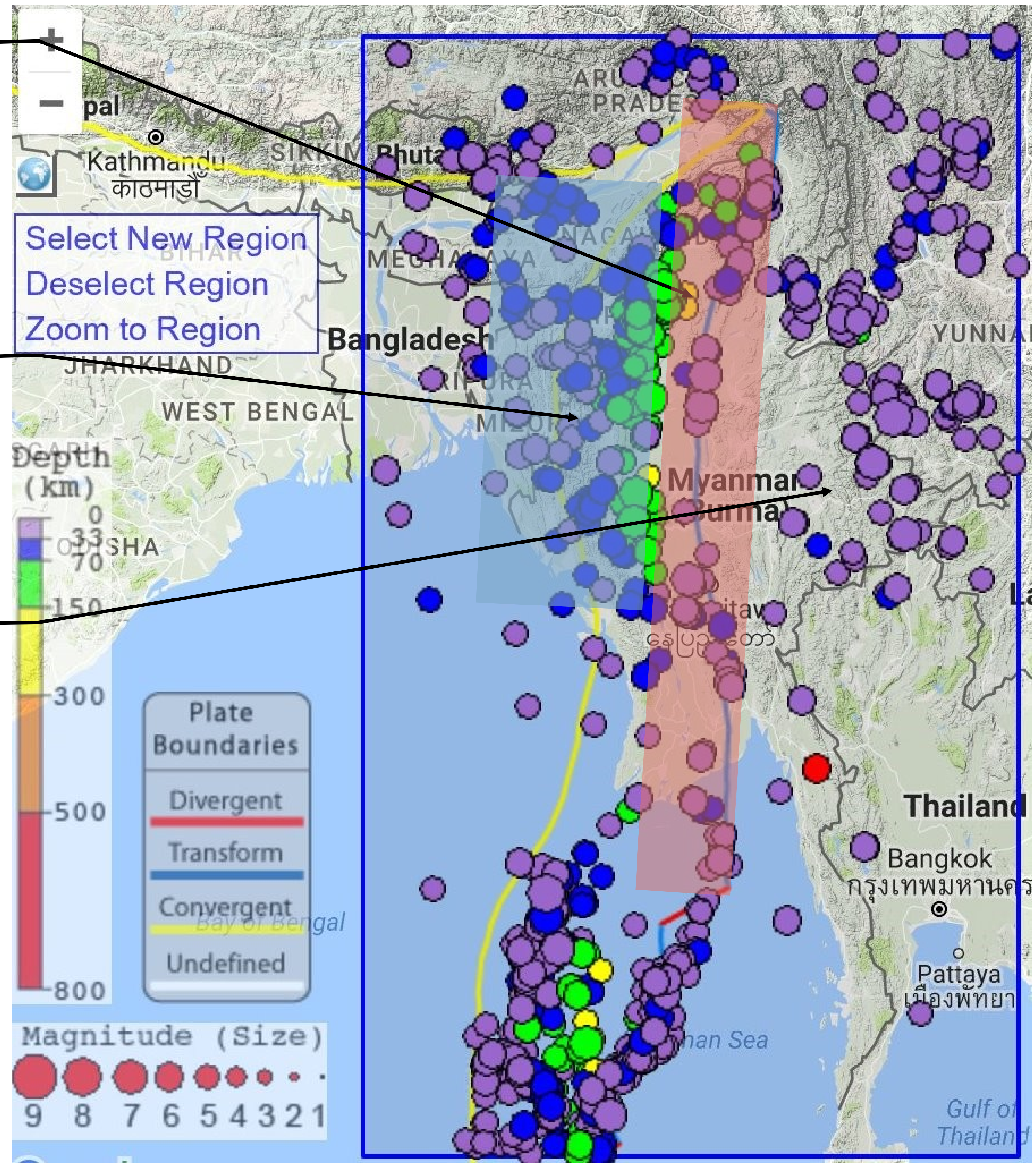


Seismicity of Myanmar (Mag 5 and above)

Sagaing Fault
Strike Slip
Right Lateral
Shallow Earthquakes
2.5 cm/yr

Subduction Zone
Trust Reverse Fault
Deep Earthquakes
4.7 cm/yr

Secondary Faults
Shallow Earthquakes

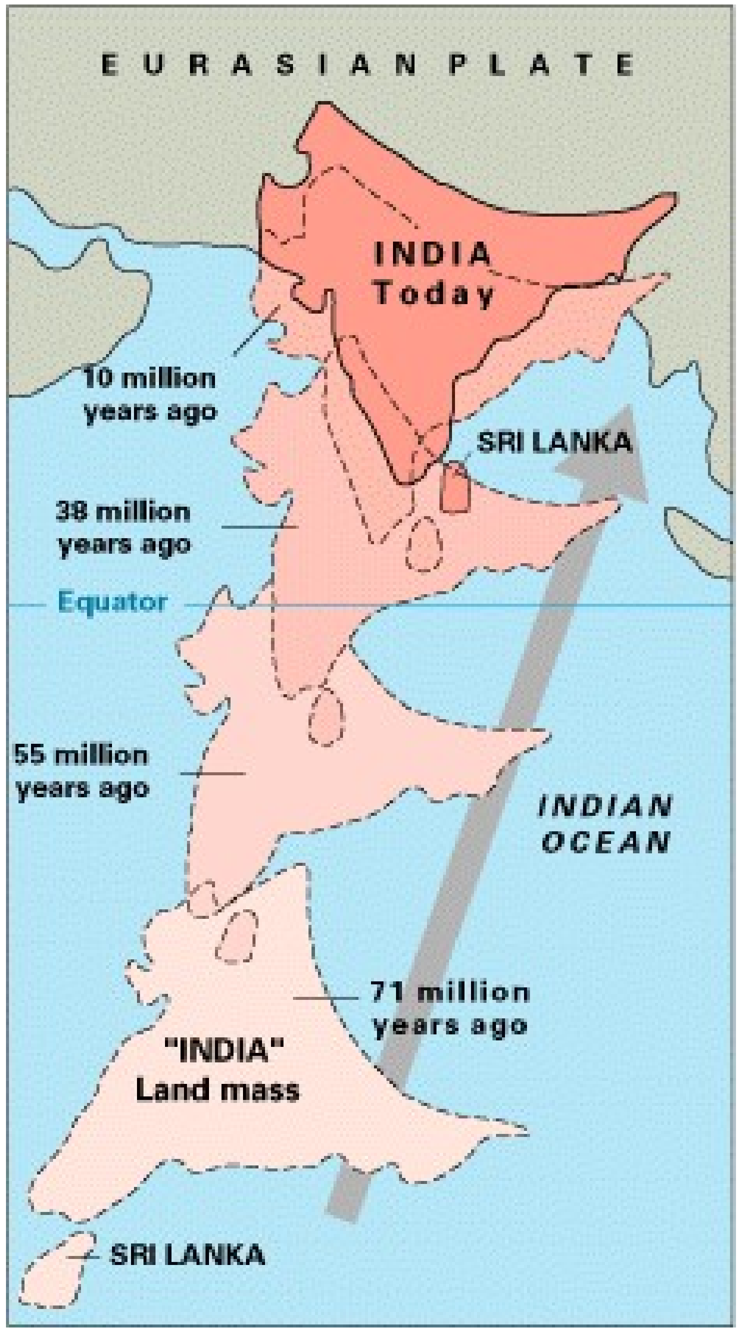


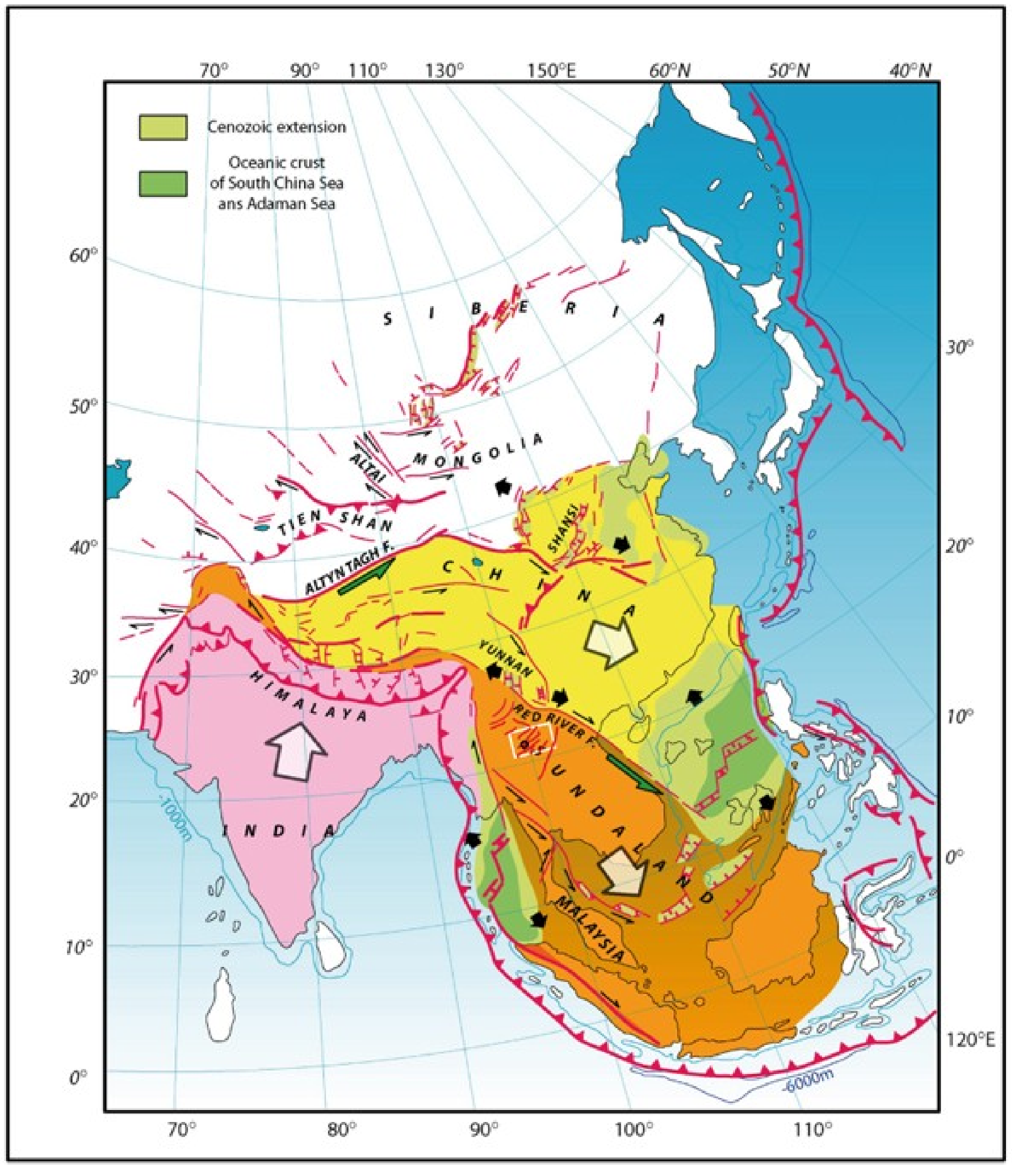
Earthquake Engineering Concept

Earthquake Engineering

- Earthquake Hazard
- Capacity of a structure
- Demand vs. Capacity

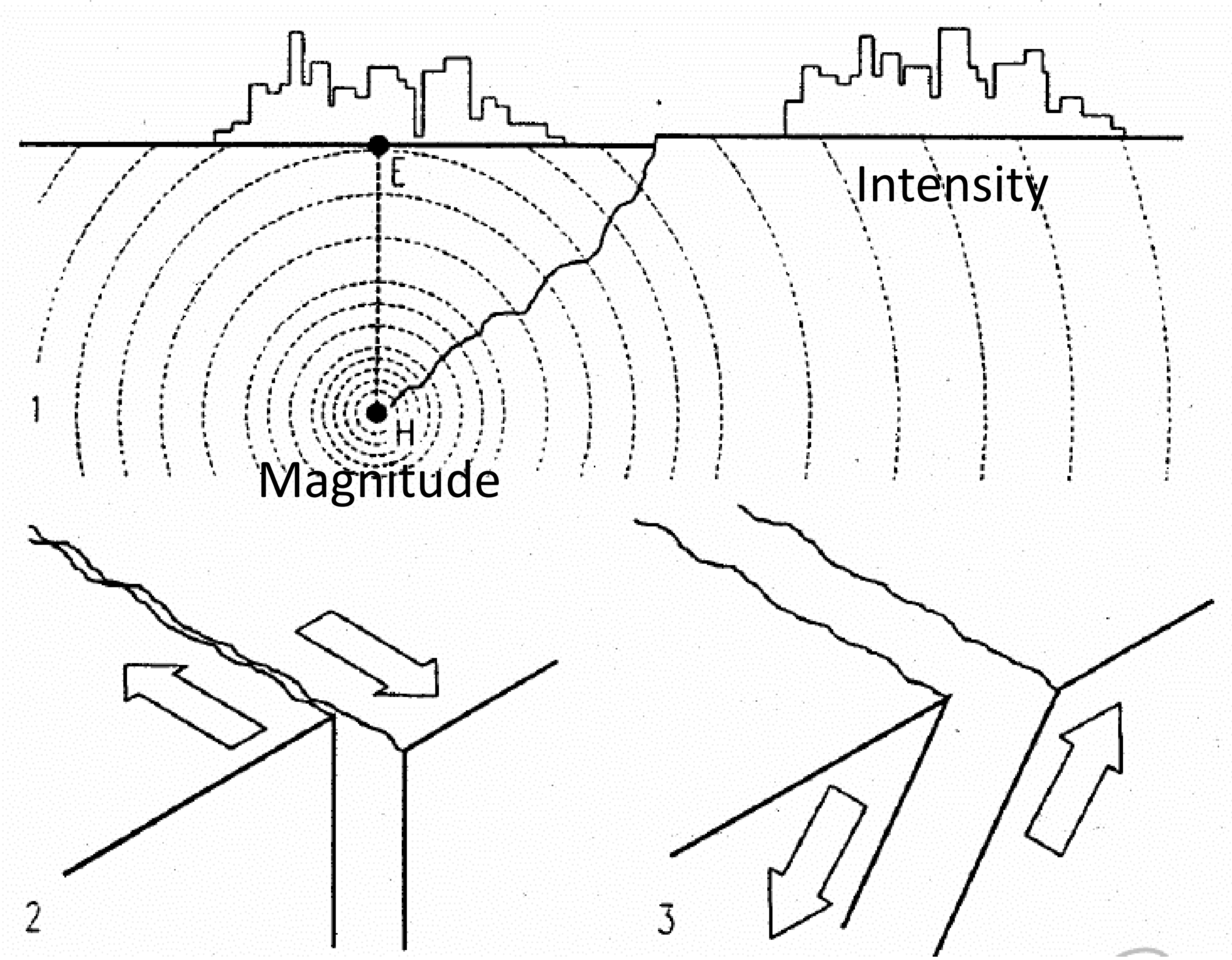
Earthquake Hazard- Demand Side

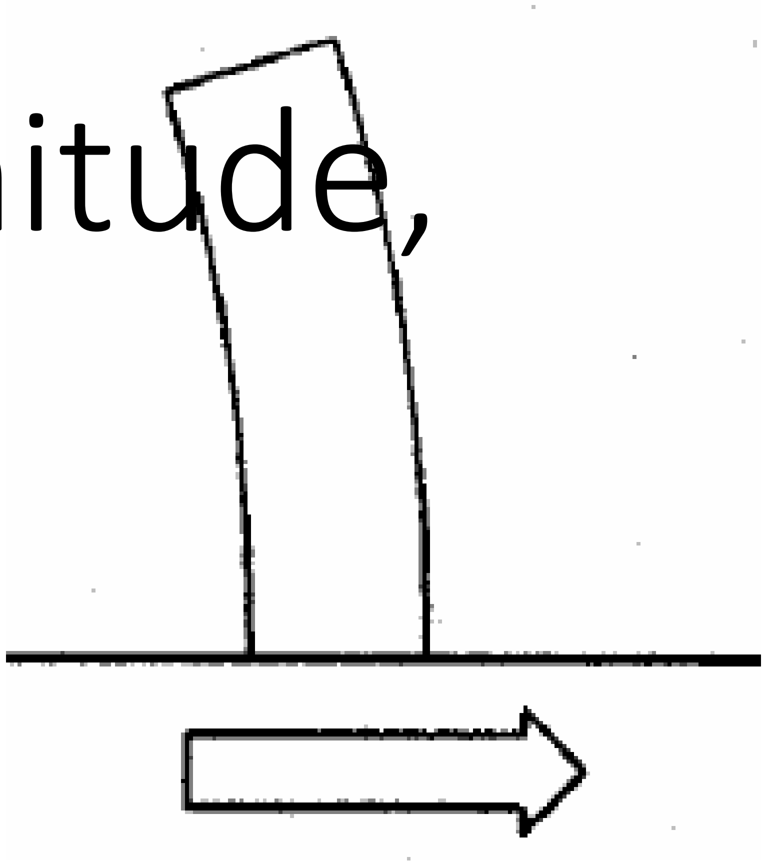




- Earth mass is moving and striking one another.
- Create earthquake

Ground Shaking, Magnitude, Intensity

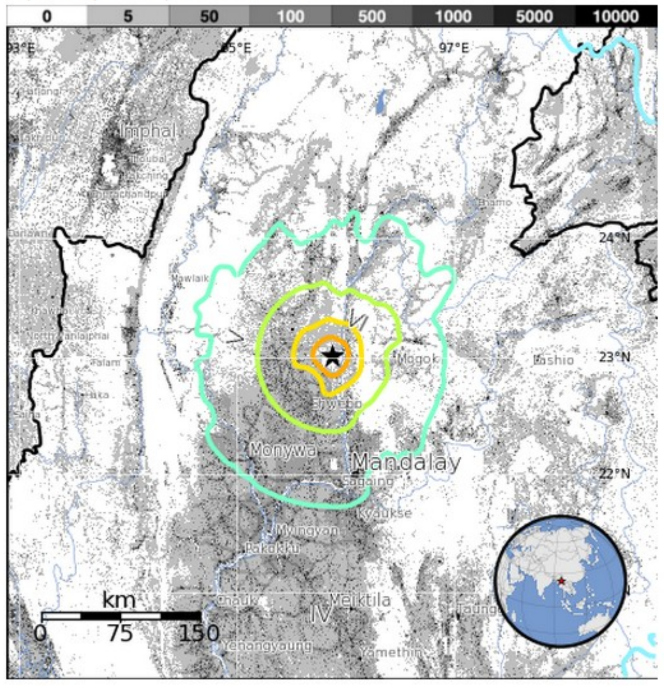




- Sudden earth shaking applies at the base of the buildings

Population Exposure

Population per ~1 sq. km. from LandScan



Structure Information Summary

Overall, the population in this region resides in structures that are highly vulnerable to earthquake shaking, though some resistant structures exist.

Secondary Effects

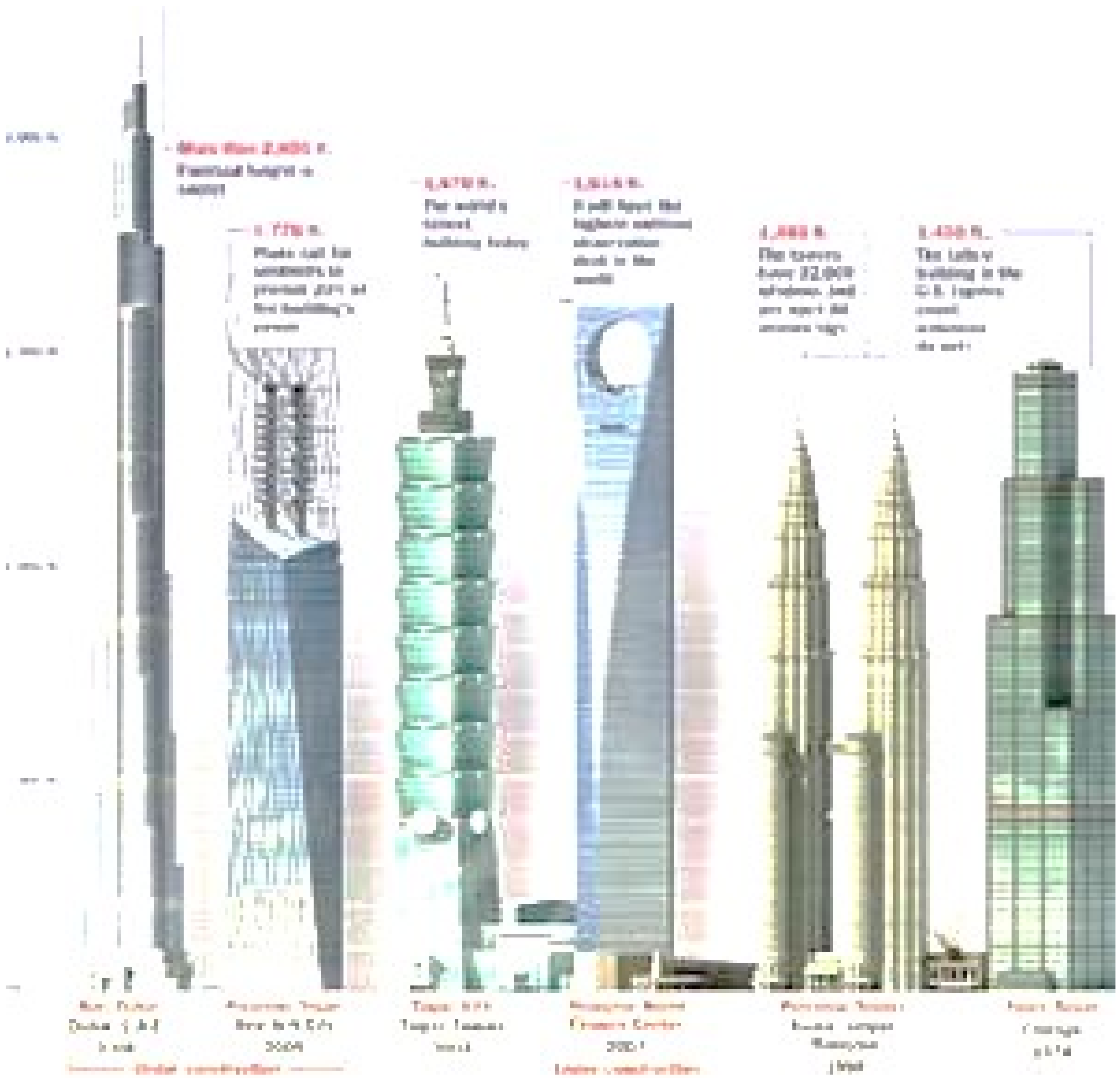
Recent earthquakes in this area have caused secondary hazards such as landslides that might have contributed to losses.

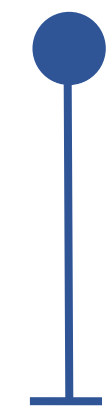
Selected Cities Exposed

from GeoNames Database of Cities with 1,000 or more residents.

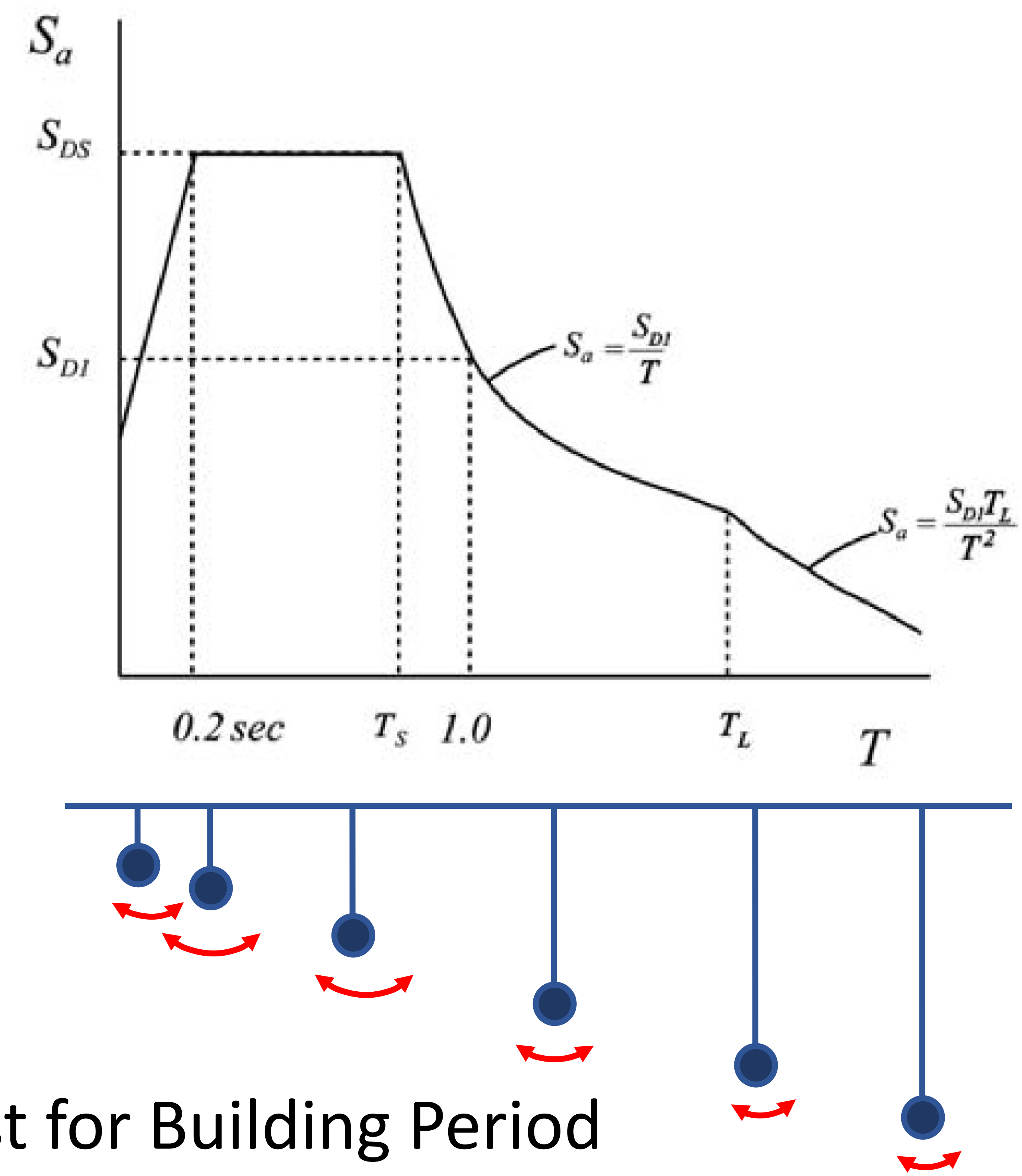
MMI	City	Population
VI	Shwebo	88k
V	Mogok	90k
V	Mandalay	1,208k
V	Maymyo	117k
V	Monywa	182k
V	Sagaing	78k
IV	Imphal	223k
IV	Myitkyina	90k
IV	Haka	0
IV	Taunggyi	160k
IV	Kohima	92k

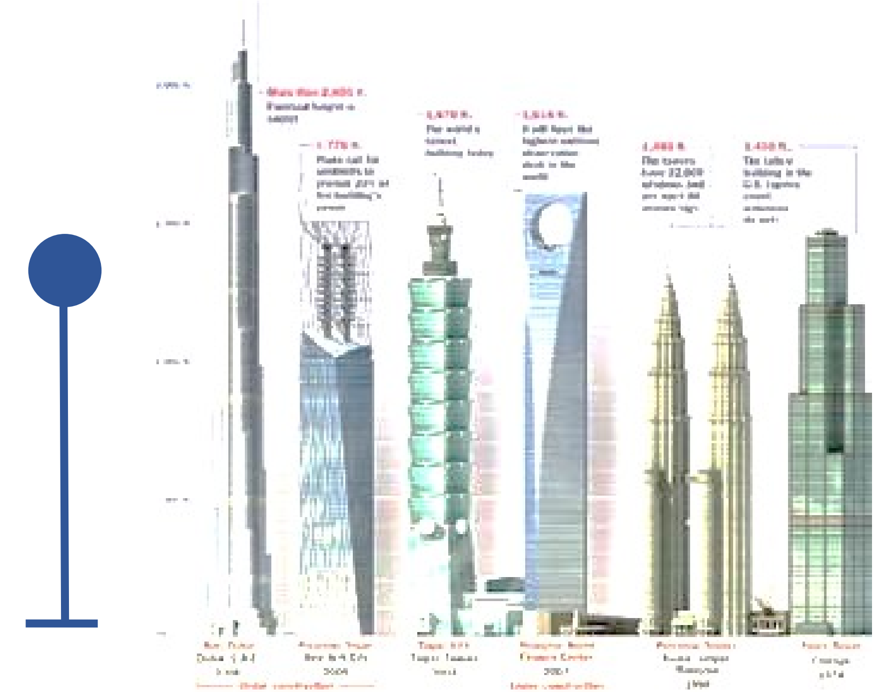
Seismic Response





Response Spectrum

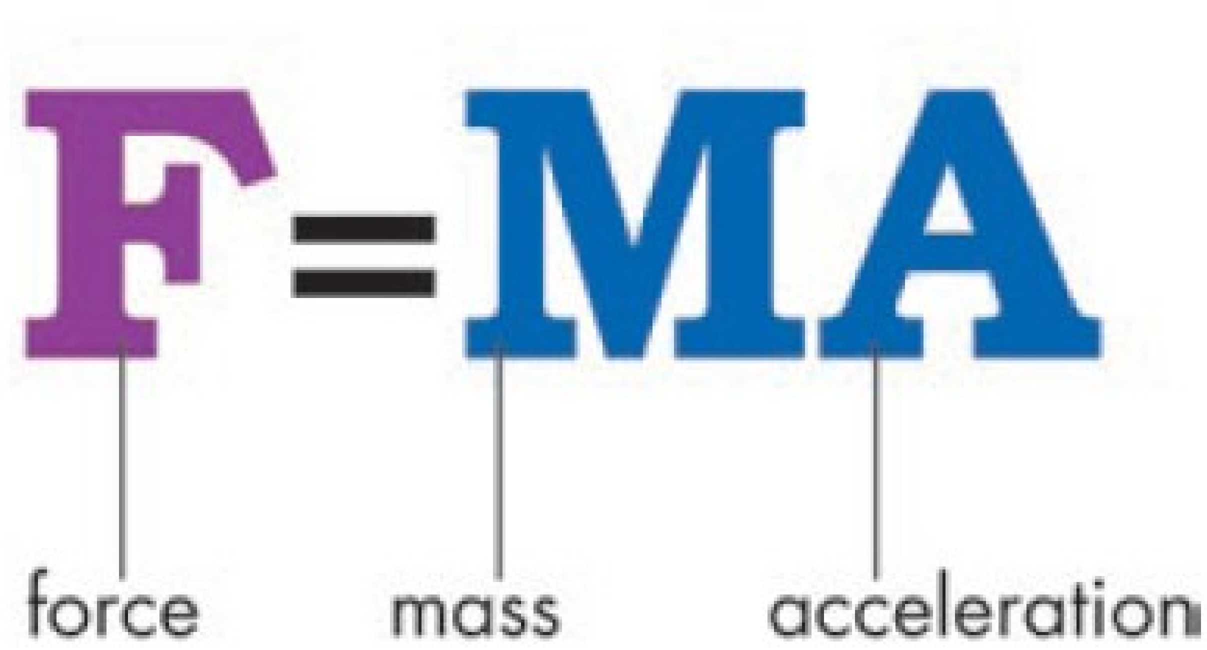


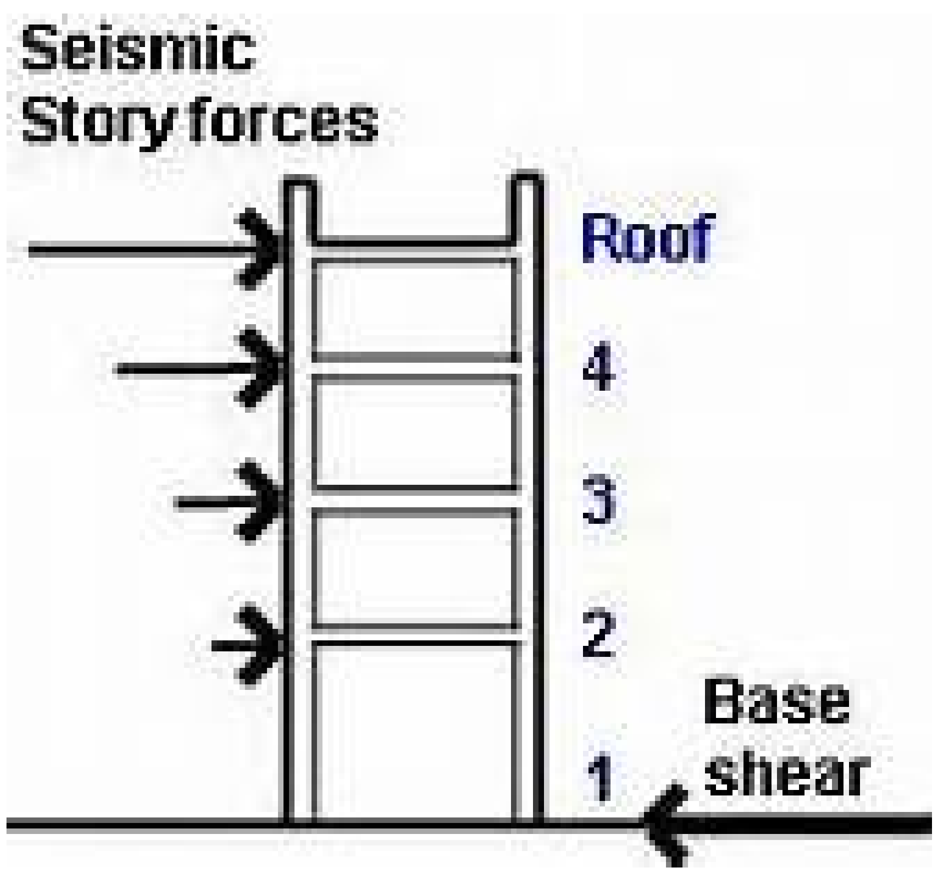


Adjust for Building Period

- Approximately T = Number of Story / 10

Seismic Forces





- Apply to each level with respect of its story mass.
- Total story forces = Base Shear

Building Response- Capacity Side

1. IN MINOR EARTHQUAKES WITHOUT SERIOUS DAMAGE

   DBE

   (Design Basis Earthquake)

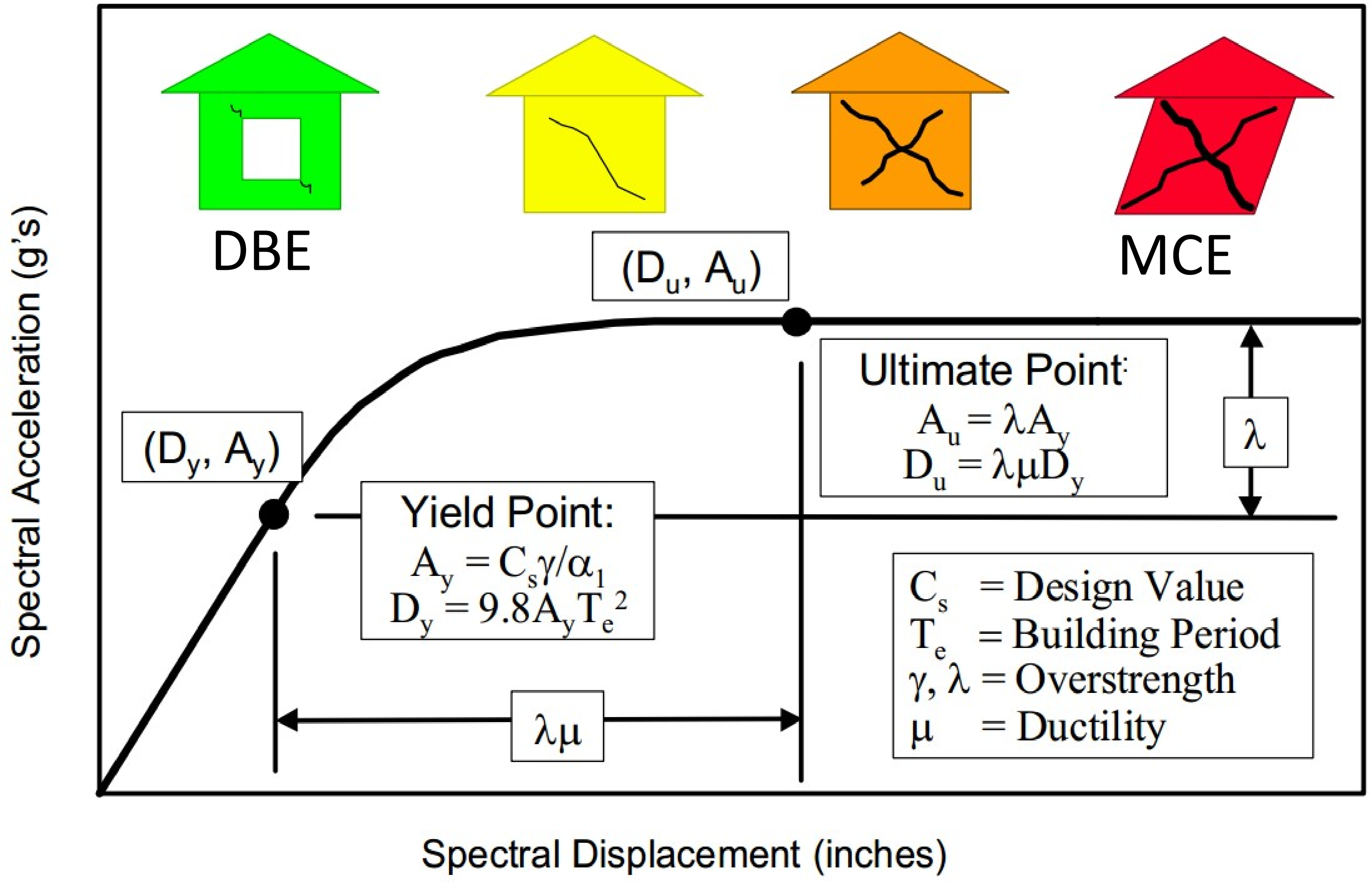
   5% in 50 years

2. IN MAJOR EARTHQUAKES WITHOUT STRUCTURAL DAMAGE BUT POSSIBLY EXPERIENCE SOME NON-STRUCTURAL DAMAGE

   MCE

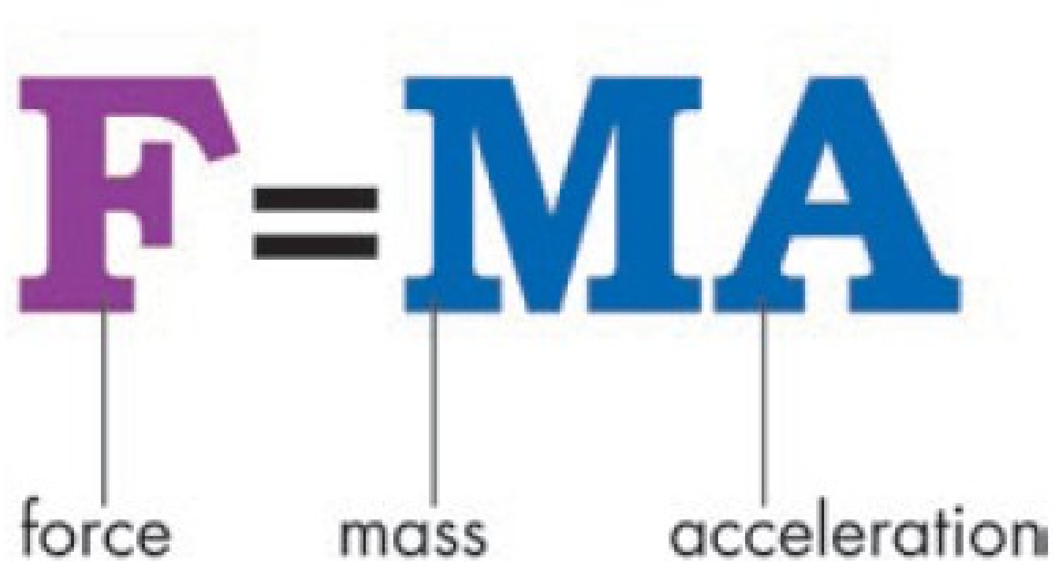
   (Maximum Credible Earthquake)

   2% IN 50 YEARS



Demand and Capacity

- Safety Equation
  - Capacity > Demand
  - Capacity = Safety Factor x Demand



Capacity > Demand

Capacity > **Demand**

Reducing Demand by Mass

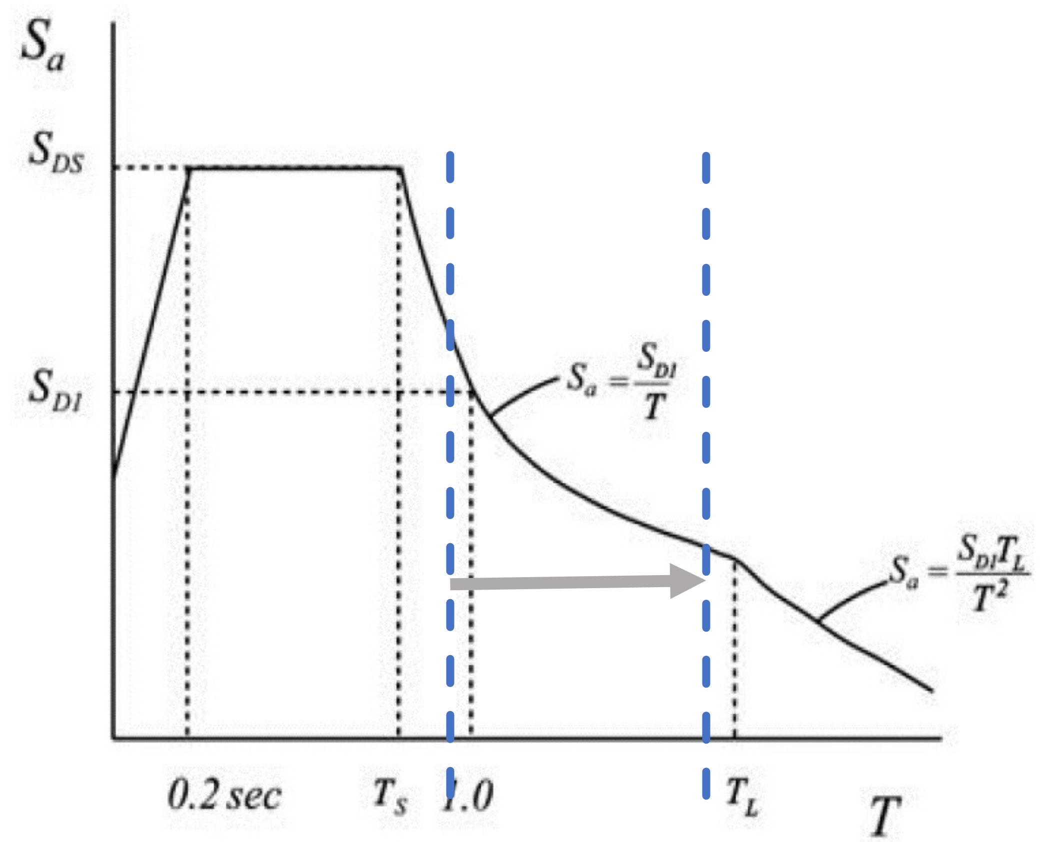
F = m.a

- Reducing Mass
  - Use lighter materials

Reducing Demand by Acceleration

F = m.a

- Reducing Acceleration
  - Make more flexible and ductile
  - Use damper (spectrum scale down)
  - Use base Isolation (frequency shift)



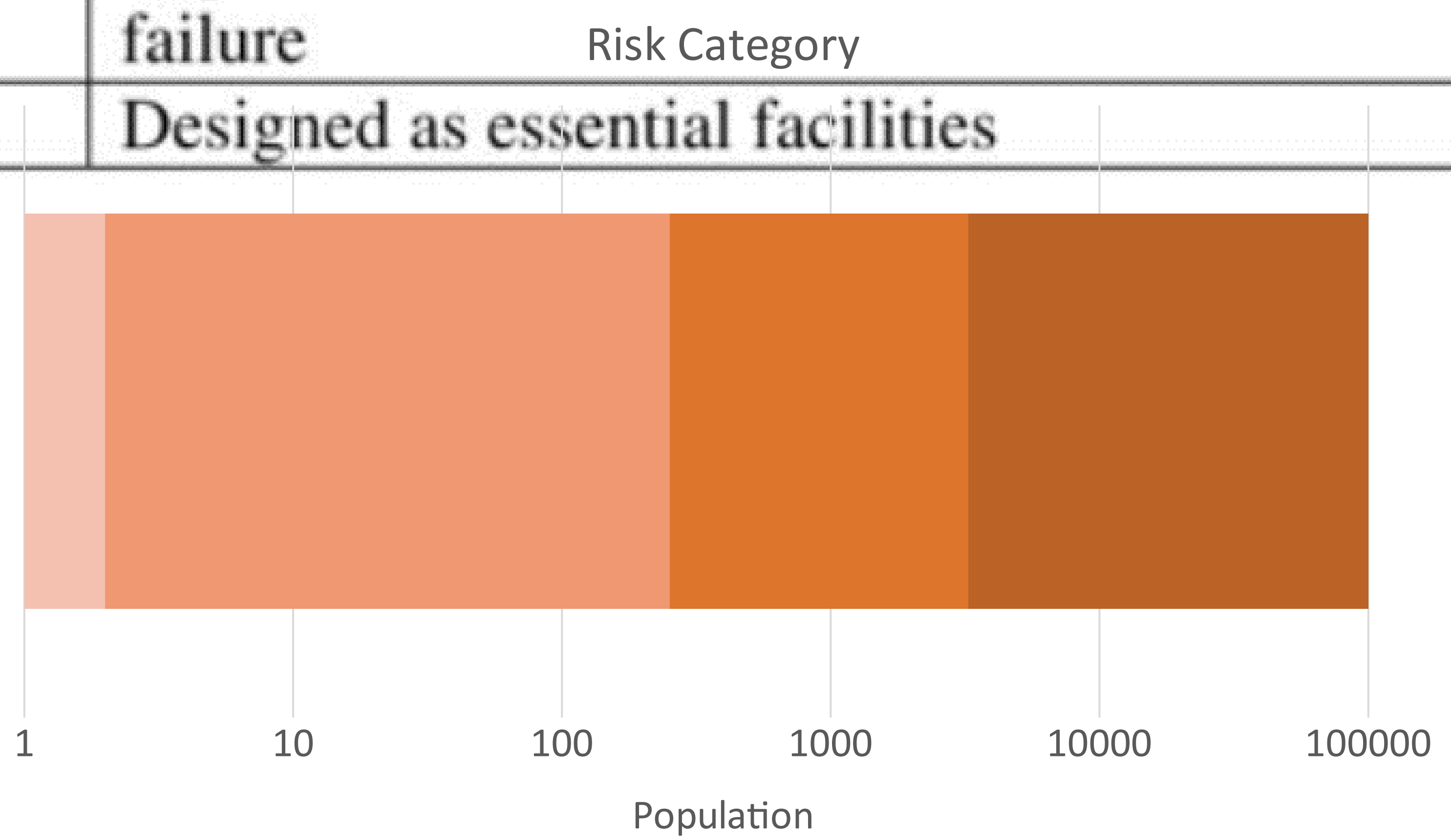
Earthquake Design Concept in MNBC

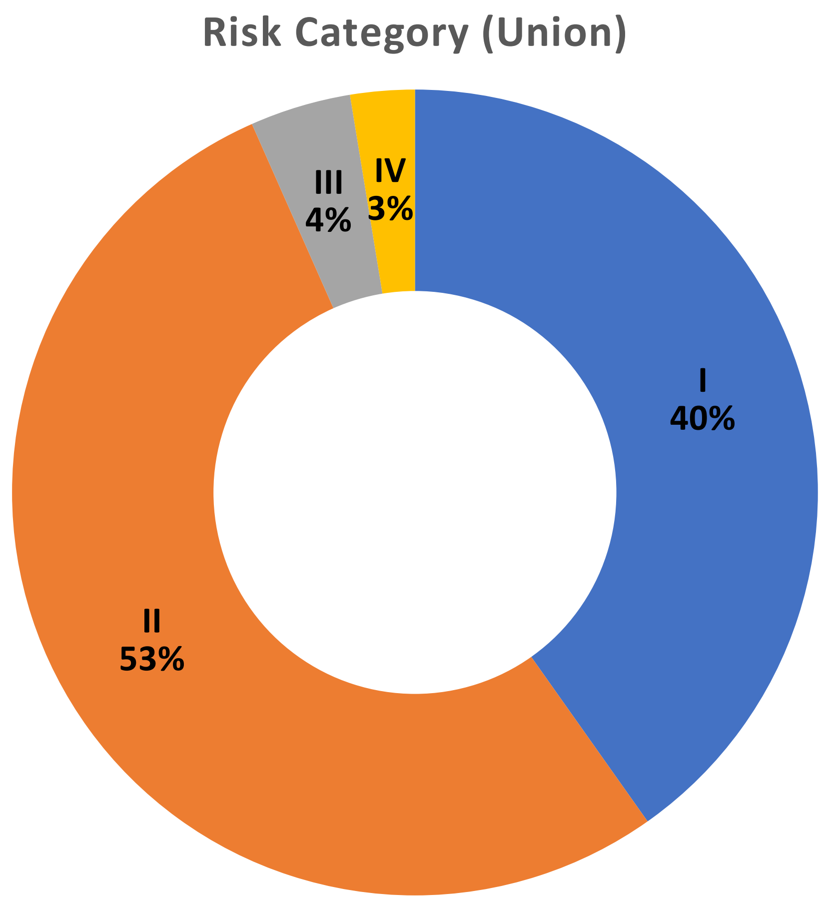
Myanmar National Building Code

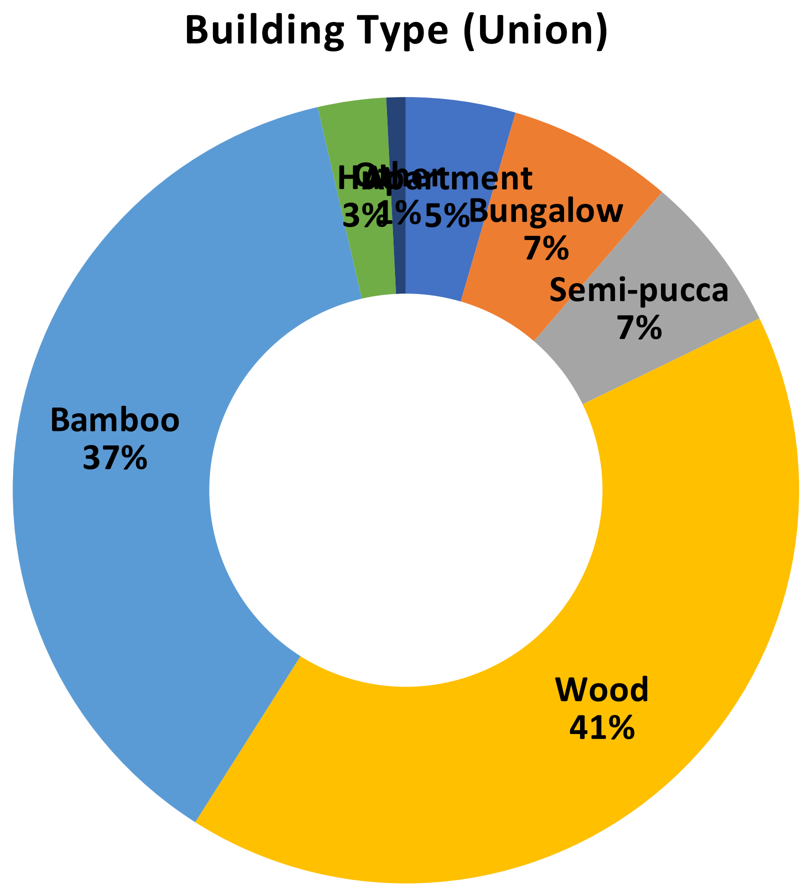
- MNBC Structural Design- IBC-2006 and ASCE7-05 codes.
  - Occupancy Category
  - Load Combinations
  - Earthquake Design Flow Chart

Occupancy Category

Risk Category	Nature of Occupancy
I	Representing a low hazard to human life in the event of failure
II	Except those listed in other categories
III	Represent a substantial hazard to human life in the event of failure
IV	Designed as essential facilities







Category	Risk Category	Apartment	Bungalow	Semi-pucca	Wood	Bamboo	Hut	Other	All Buildings
I	Temporary					37.40%	2.80%		40.20%
II	Medium		6.12%	5.85%	41.20%				53.17%
III	High	4.05%							4.05%
IV	Ess/Haz	0.45%	0.68%	0.65%				0.80%	2.58%
	Union	4.50%	6.80%	6.50%	41.20%	37.40%	2.80%	0.80%	100.00%

Combinations for Factored Loads

3.2.1.2.2 Basic load combinations

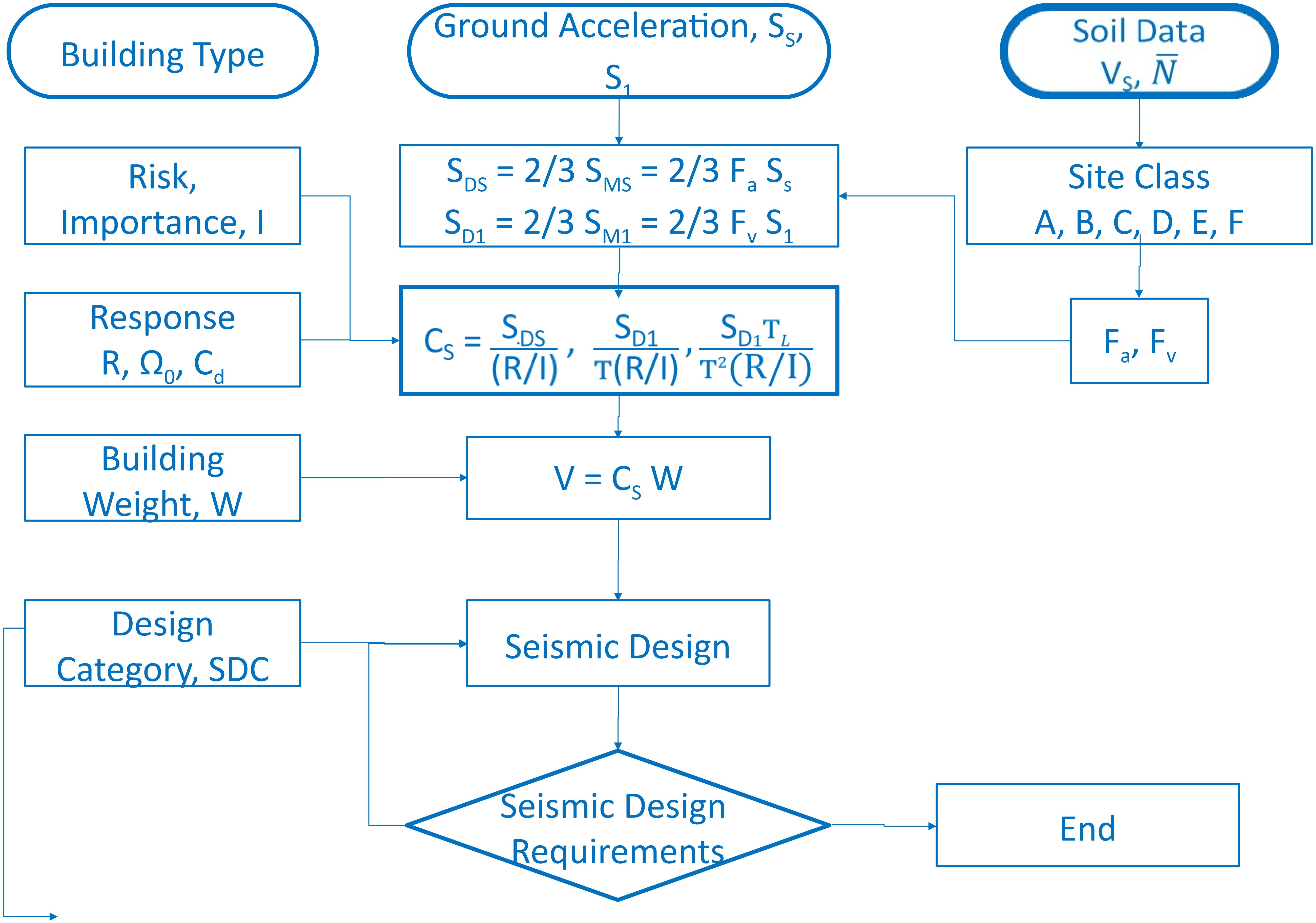
1.	$1.4\ (D + F)$	Eq. (3.2.1)
2.	$1.2(D+F + T) + 1.6(L + H) + 0.5\ (L_r \text{ or } R)$	Eq. (3.2.2)
3.	$1.2D + 1.6(L_r \text{ or } R) + (L \text{ or } 0.8W)$	Eq. (3.2.3)
4.	$1.2D + 1.6W + L + 0.5(L_r \text{ or } R)$	Eq. (3.2.4)
5.	$1.2D + 1.0E + L$	Eq. (3.2.5)
6.	$0.9D + 1.6W + 1.6H$	Eq. (3.2.6)
7.	$0.9D + 1.0E + 1.6H$	Eq. (3.2.7)

Combinations for Unfactored Loads

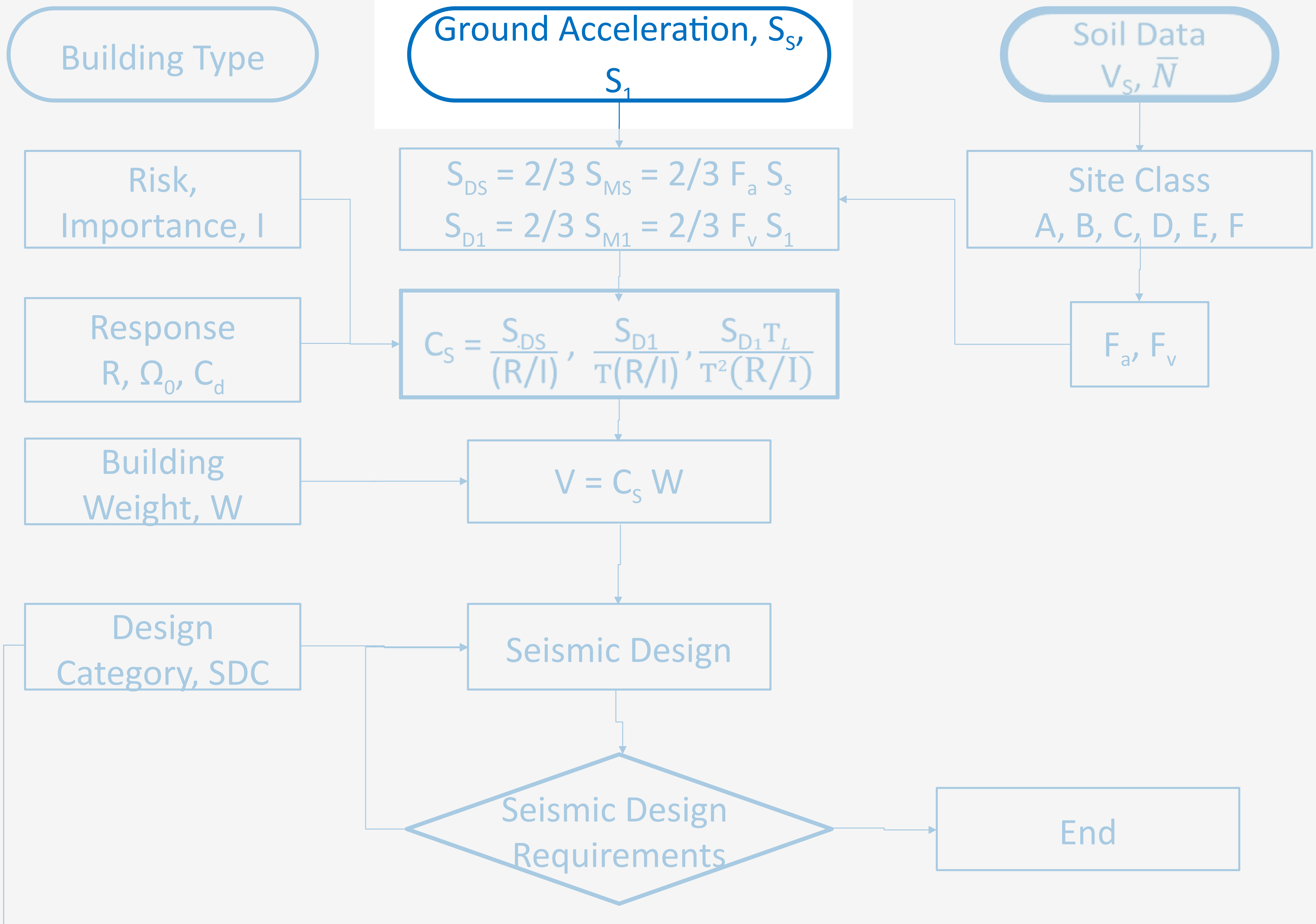
3.2.1.3.1 Basic load combinations

1.	$D + F$	Eq. (3.2.8)
2.	$D + H + F + L + T$	Eq. (3.2.9)
3.	$D + H + F + (L_r \text{ or } R)$	Eq. (3.2.10)
4.	$D + H + F + 0.75(L + T) + 0.75\ (L_r \text{ or } R)$	Eq. (3.2.11)
5.	$D + H + F + (W \text{ or } 0.7E)$	Eq. (3.2.12)
6.	$D + H + F + 0.75(W \text{ or } 0.7E) + 0.75L + 0.75\ (L_r \text{ or } R)$	Eq. (3.2.13)
7.	$0.6D + W + H$	Eq. (3.2.14)
8.	$0.6D + 0.7E + H$	Eq. (3.2.15)

Earthquake Design Flow Chart

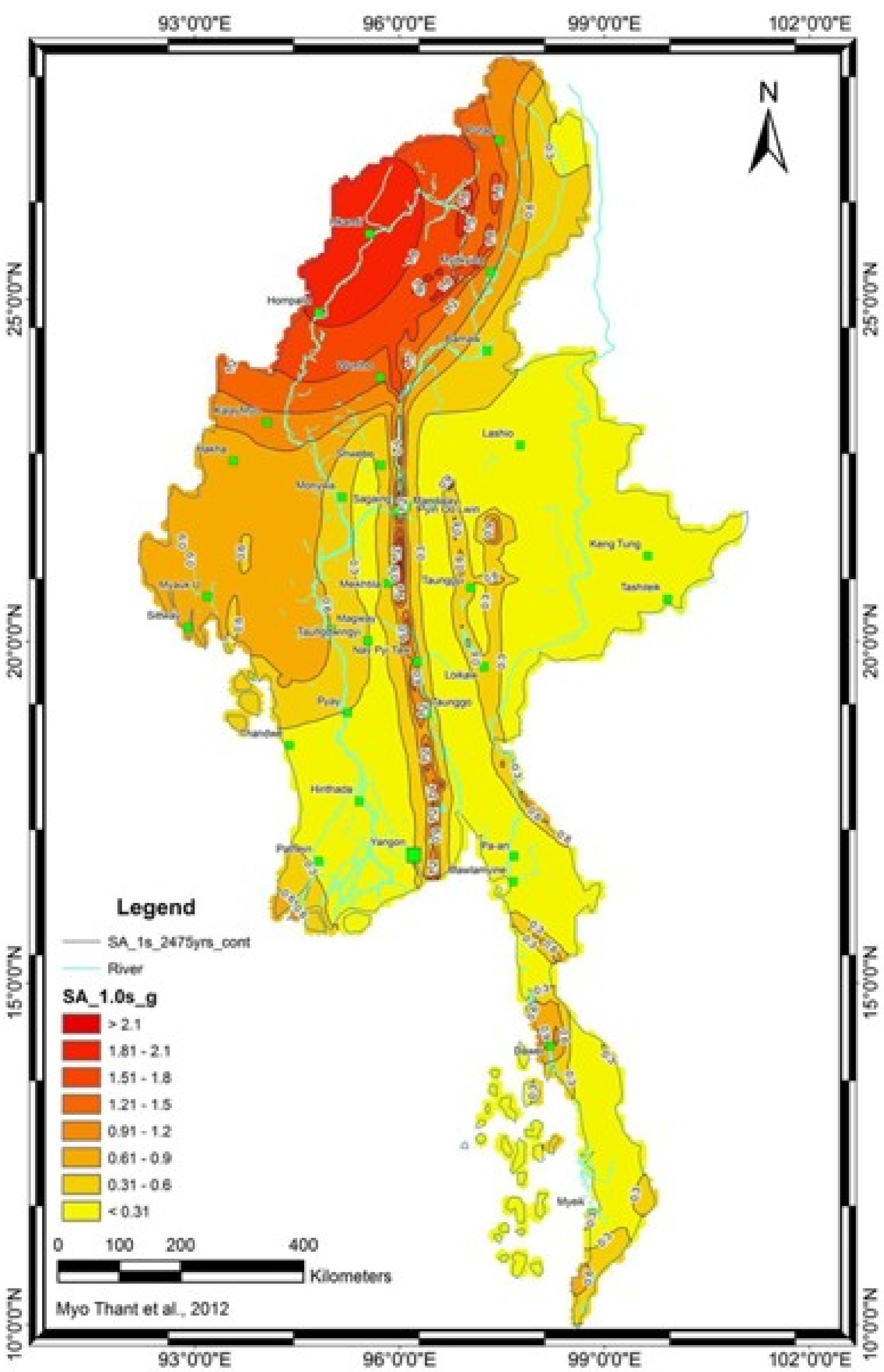


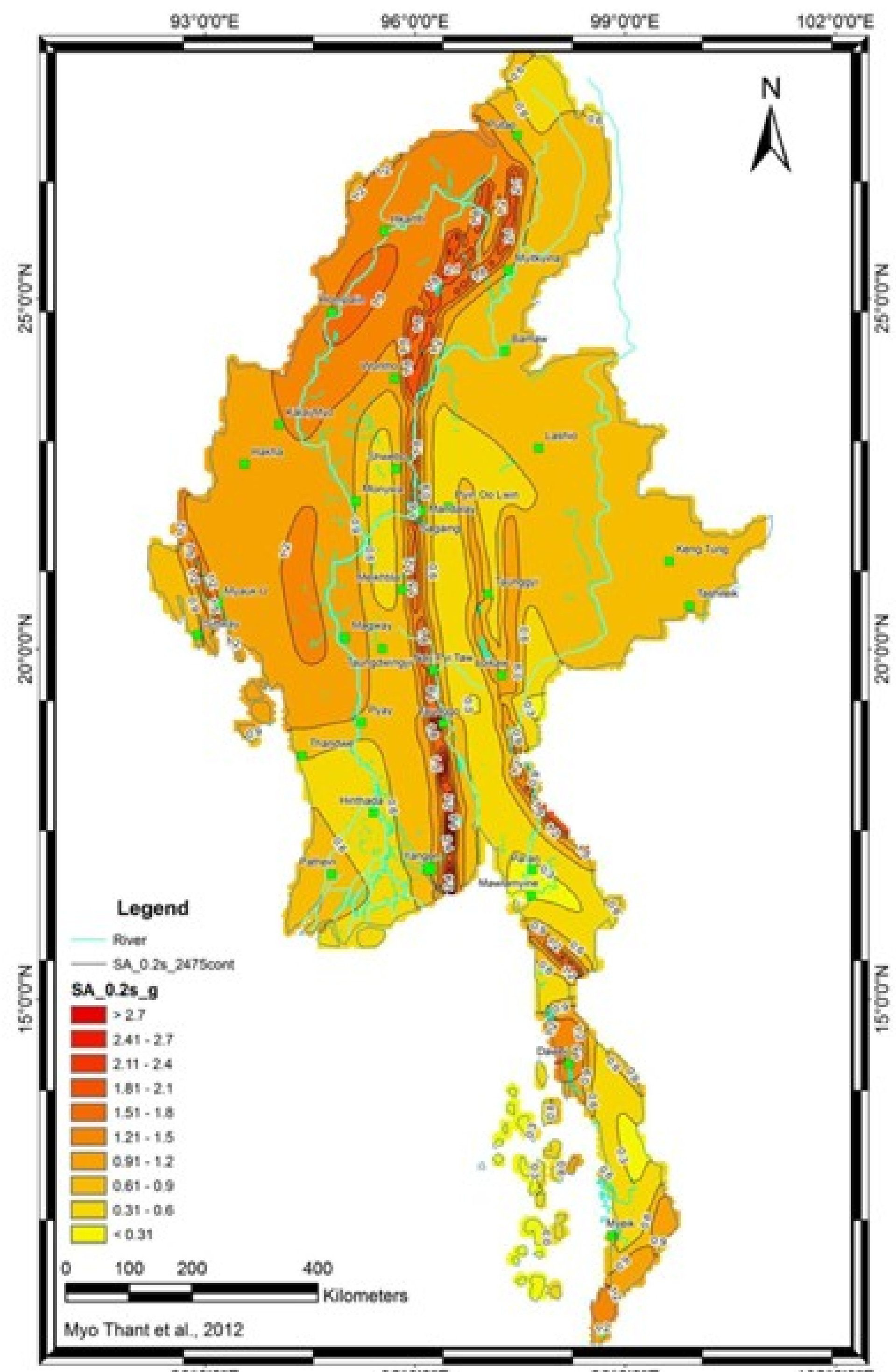
Earthquake Load



- **Ground Acceleration, S_S, S_1**

- **Spectral Response Acceleration at 2% Probability in 50 Years with 5% Critical Damping, Site Class B**





S_s for 0.2 second

Short Period Acceleration

for Short Buildings

S_1 for 1 second

Long Period Acceleration

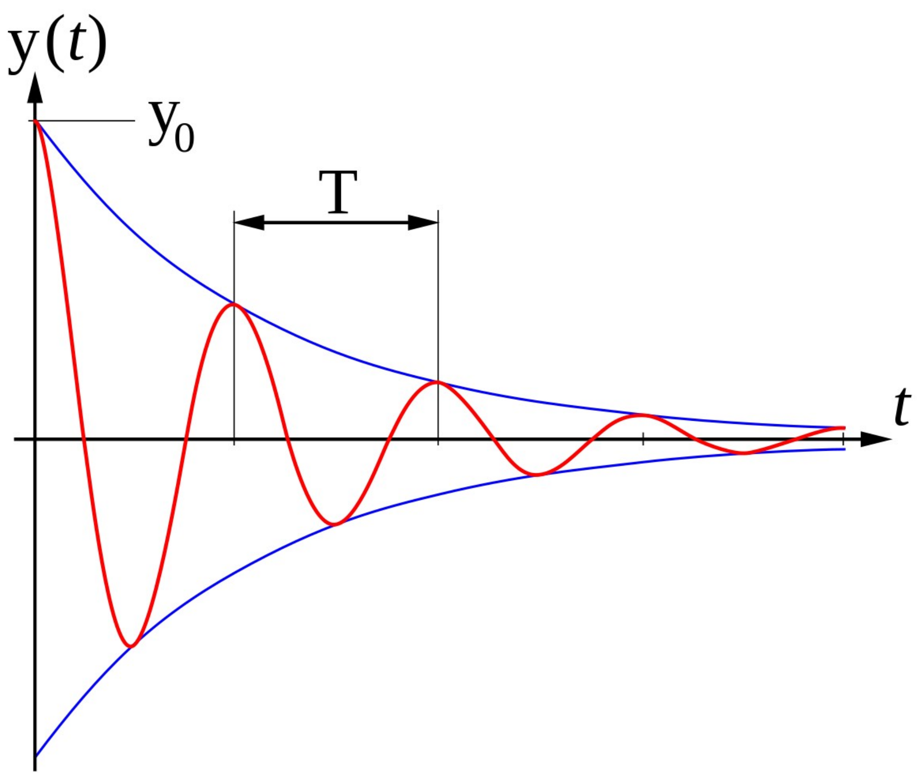
for Tall Buildings

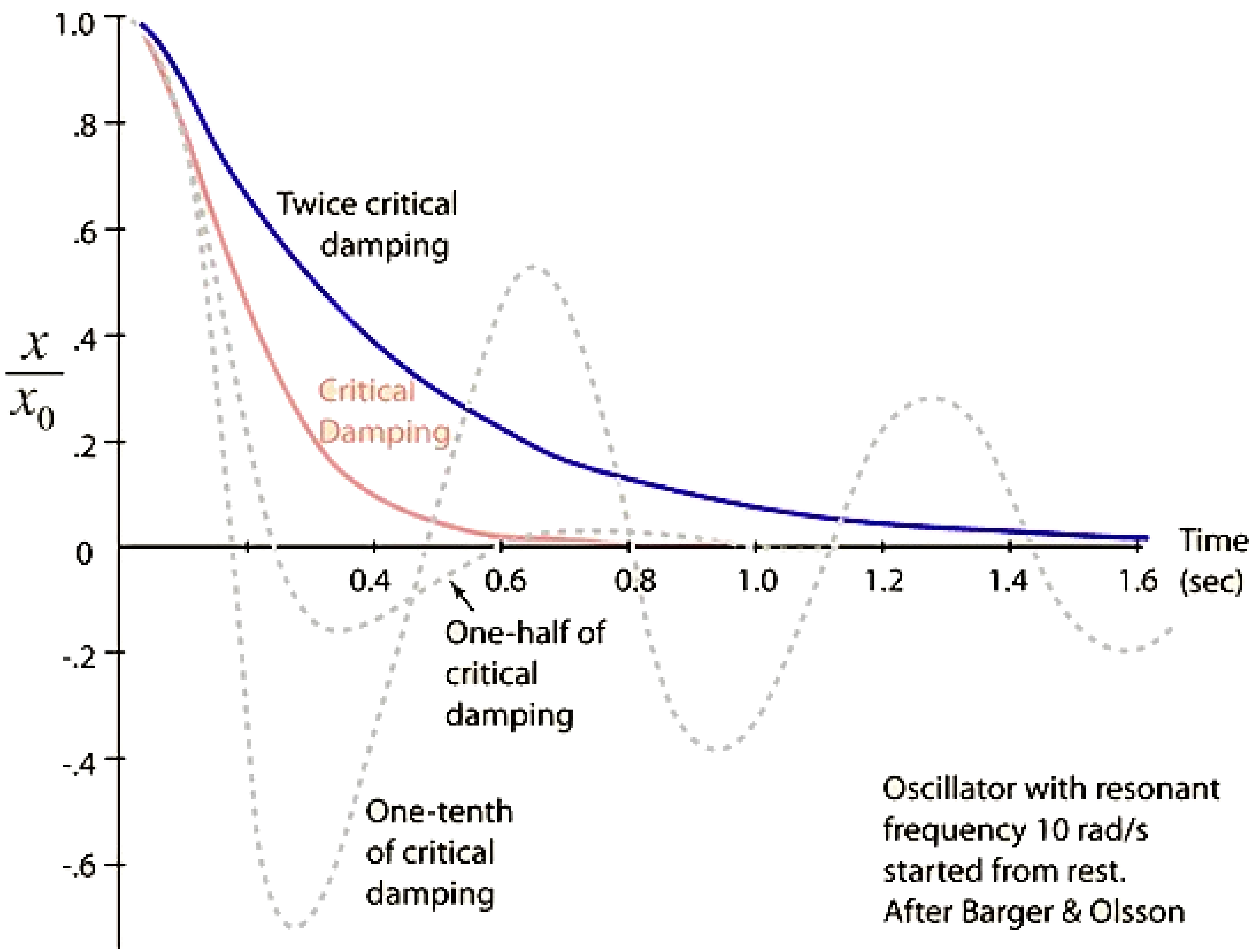
- **Ground Acceleration, S_S, S_1**
- Spectral Response Acceleration at **2% Probability in 50 Years** with 5% Critical Damping, Site Class B
- Under the assumption of a Poisson distribution, seismic risk, expressed in terms of a probability of earthquakes exceeding a specified magnitude (M) in a given exposure time (t) with the average recurrence interval (R) can be expressed as:
- $p = 1 - e^{-\frac{t}{R}}$
- For 50 years design life, 2% probability gives **R = 2475 years**

- **Ground Acceleration, S_S, S_1**
- Spectral Response Acceleration at **2% Probability in 50 Years** with 5% Critical Damping, Site Class B
- Under the assumption of a Poisson distribution, seismic risk, expressed in terms of a probability of earthquakes exceeding a specified magnitude (M) in a given exposure time (t) with the average recurrence interval (R) can be expressed as:
- For 50 years design life, 2% probability gives **R = 2475 years**

Ground Acceleration, S_S, S_1

Spectral Response Acceleration at 2% Probability in 50 Years with **5% Critical Damping**, Site Class B





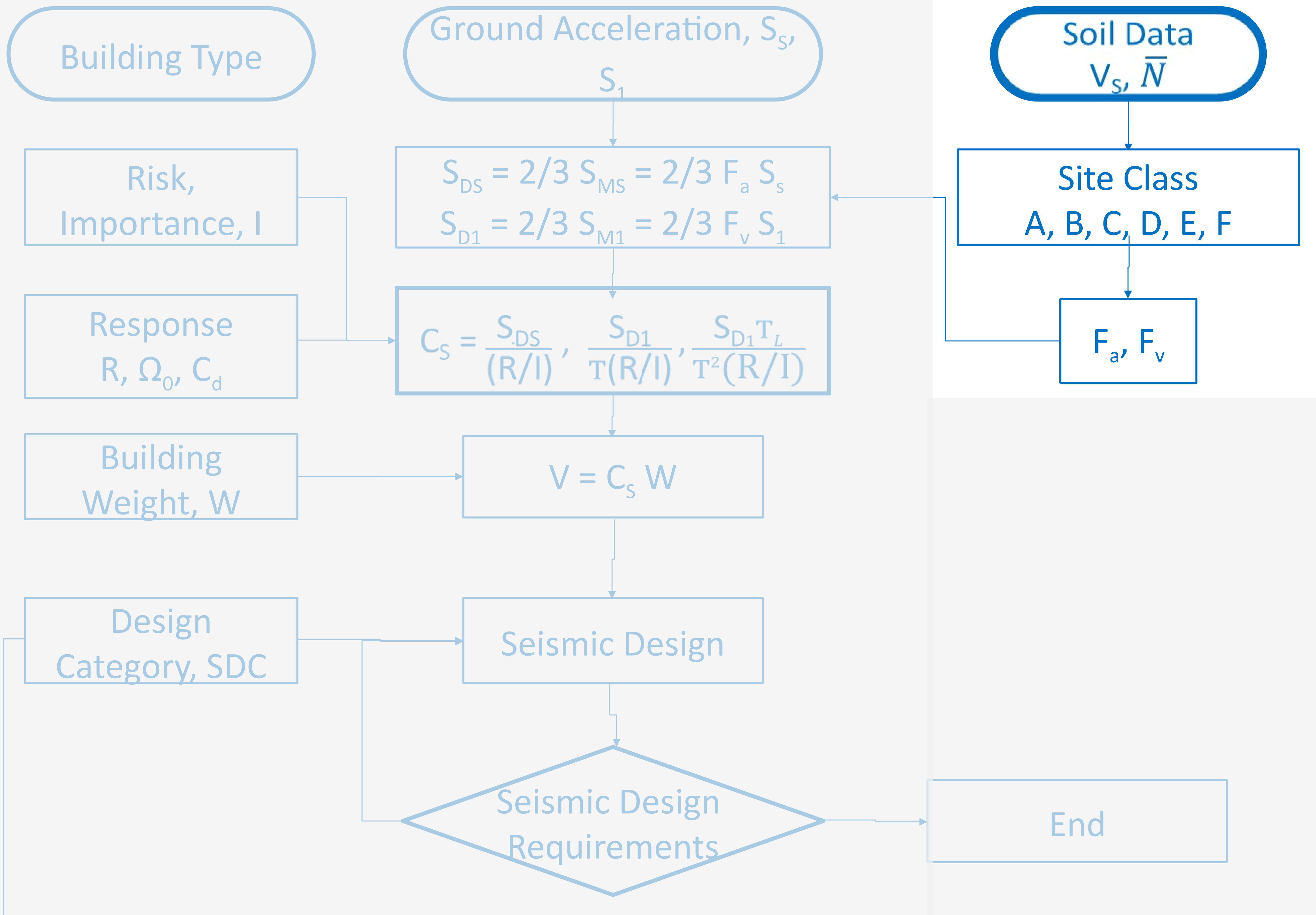
- For buildings,
- oscillation decays at
- 5% critical damping.

- **Site Class**

- Spectral Response Acceleration at 2% Probability in 50 Years with 5% Critical Damping, **Site Class B**

SITE CLASS	SOIL PROFILE NAME	AVERAGE PROPERTIES IN TOP 100 feet		
		Shear wave velocity, v_S , (ft/s)	SPT, N	Undrained shear, s_u , (psf)
A	Hard rock	v s > 5,000	N/A	N/A
B	**Rock**	**2,500 > v_s > 5,000**	**N/A**	**N/A**
C	Very dense soil and soft rock	1,200 ≤ v_s ≤ 2,500	N > 50	s_u ≤ 2,000
D	Stiff soil profile	600 ≤ v_s ≤ 1,200	15 ≤ N ≤ 50	1,000 ≤ s_u ≤ 2,000
E	Soft soil profile	v s < 600	N < 15	s_u < 1,000
F	Very soft / Unknown	Need further investigation.		

Earthquake Load



Site Coefficients F_a, F_v

Fa: Site modification factor

for short period,

Short Buildings

TABLE 3.4.3 SITE COEFFICIENT, F_a

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.3.4.7				

NOTE: Use straight-line interpolation for intermediate values of S_s .

Fv: Site modification factor

for long period,

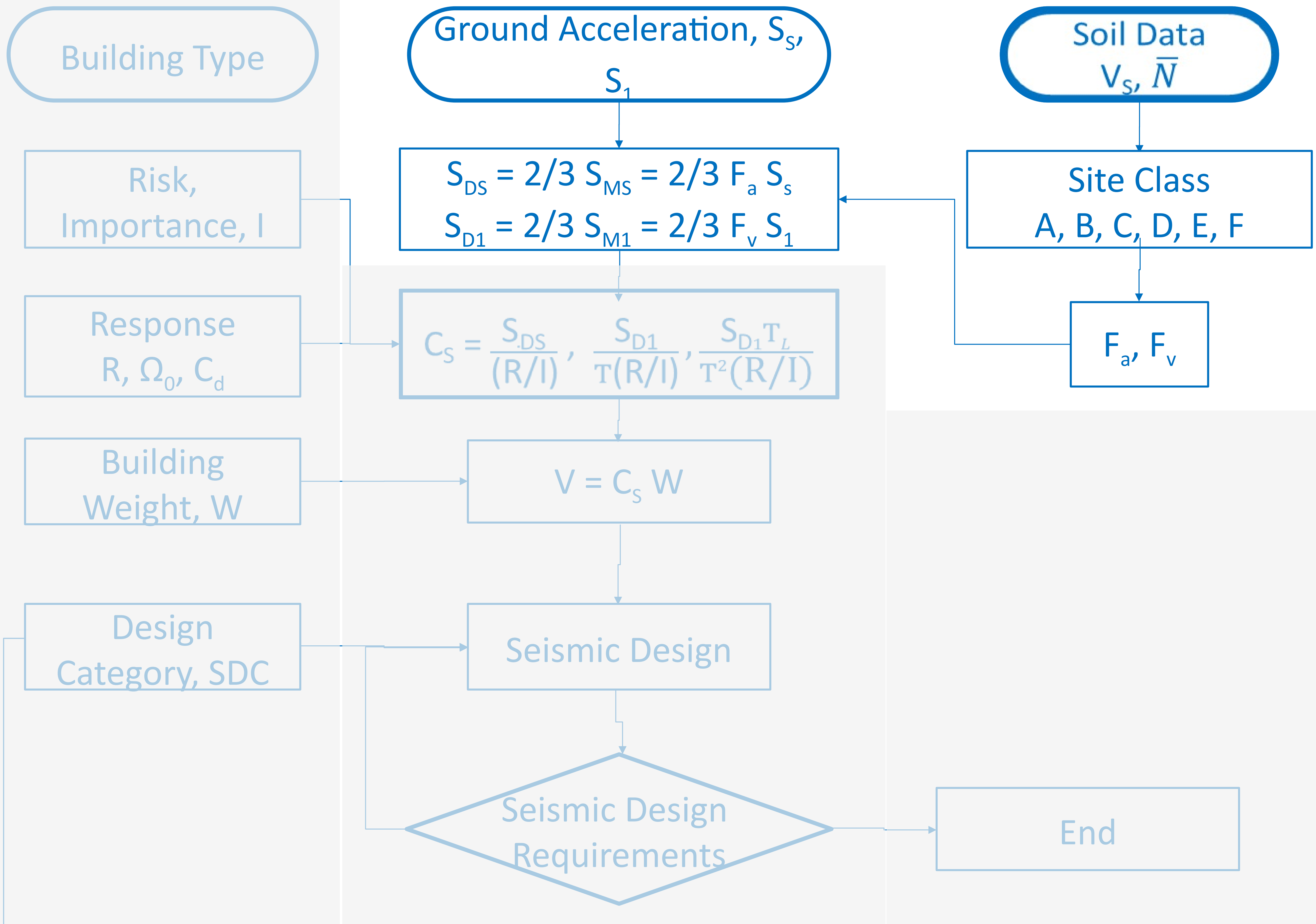
Tall Buildings

TABLE 3.4.4 SITE COEFFICIENT, F_v

Site Class	Mapped Maximum Considered Earthquake Spectral Response Acceleration Parameter at 1-s Period				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.3.4.7				

NOTE : *Use straight-line interpolation for intermediate values of S_1.*

Earthquake Load



• Design Spectral Acceleration, S_{DS}, S_{D1}

- $SDS = 2/3\ Fa\ Ss$
- $S_{D1} = 2/3\ F_v\ S_1$

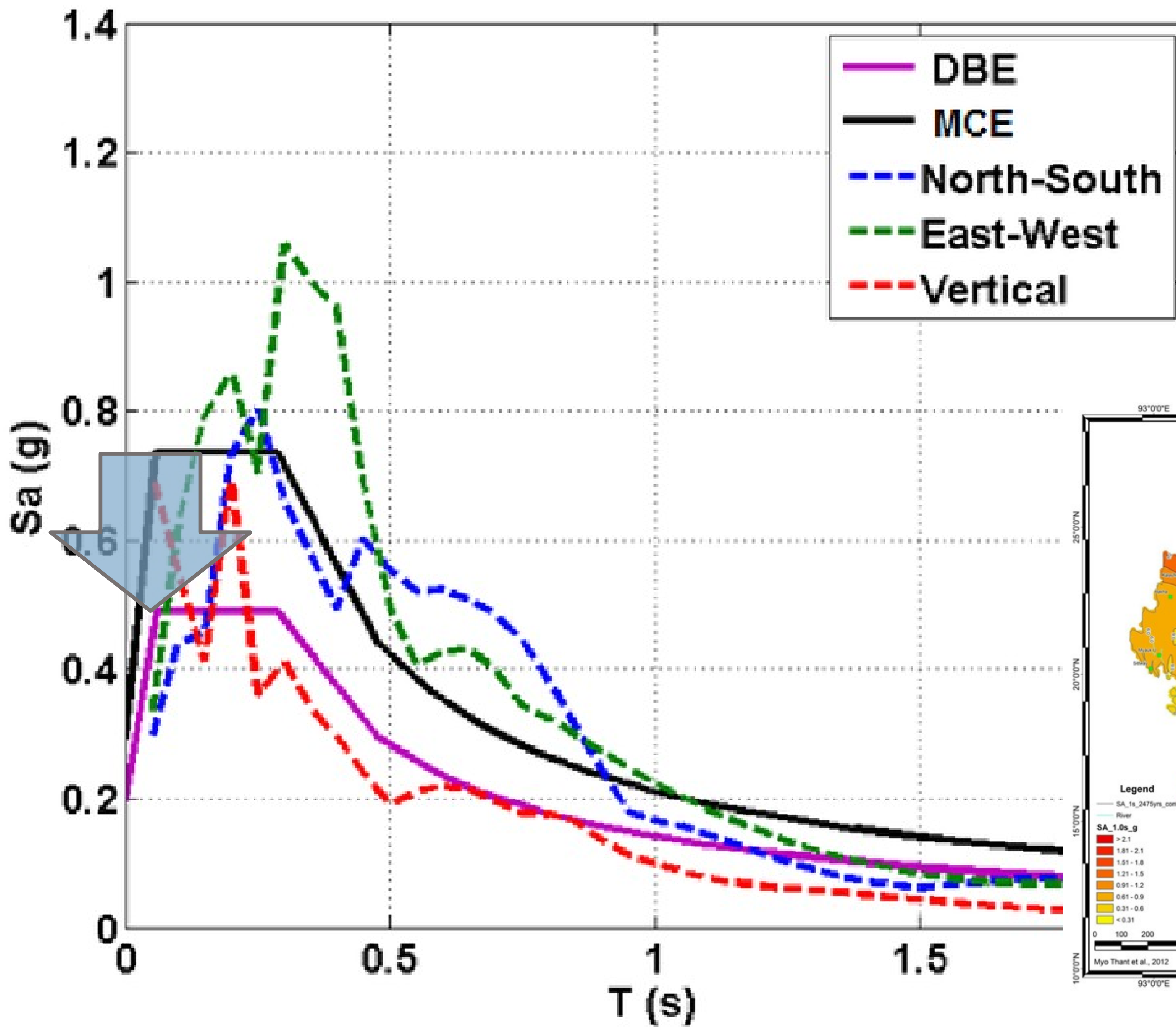
MCE: Maximum Considered Earthquake

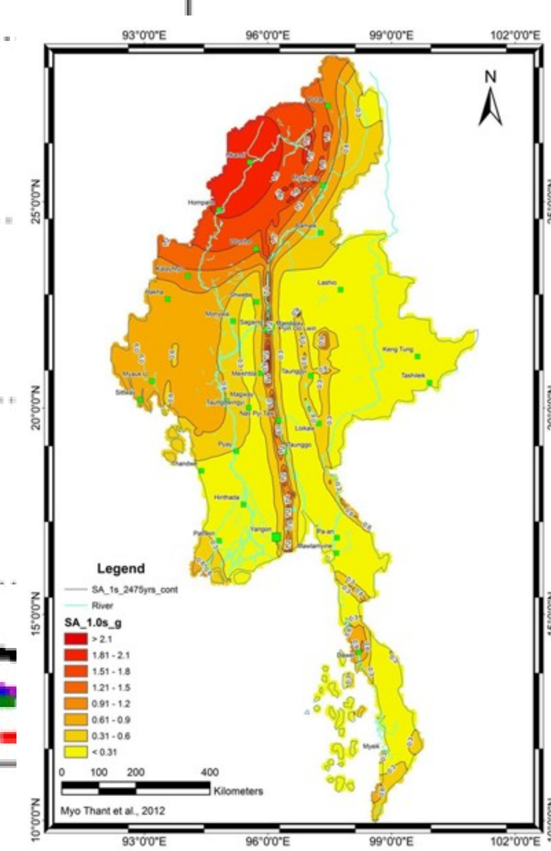
(2% probability in 50 years)

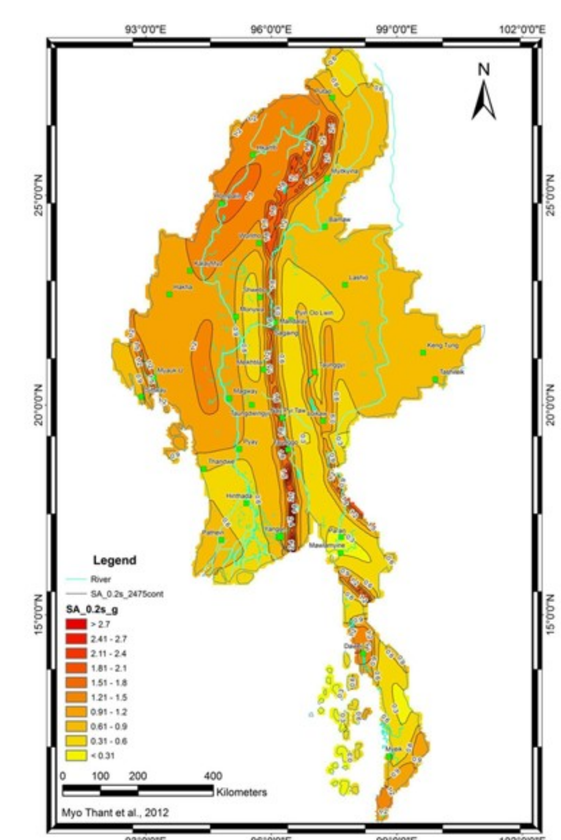
DBE: Design Basis Earthquake

(10% probability in 50 years)

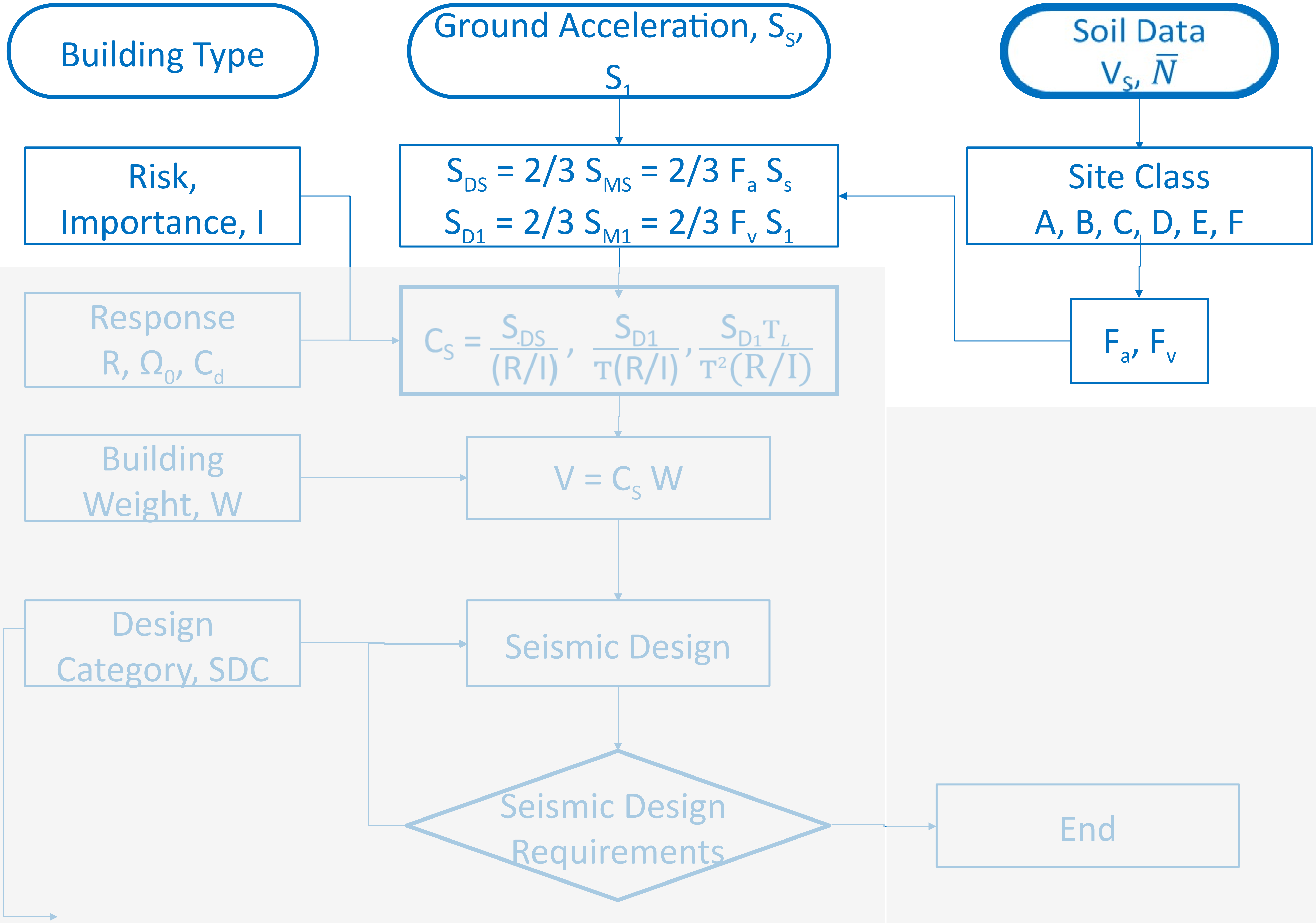
Reduce MCE to DBE by 2/3







Earthquake Load



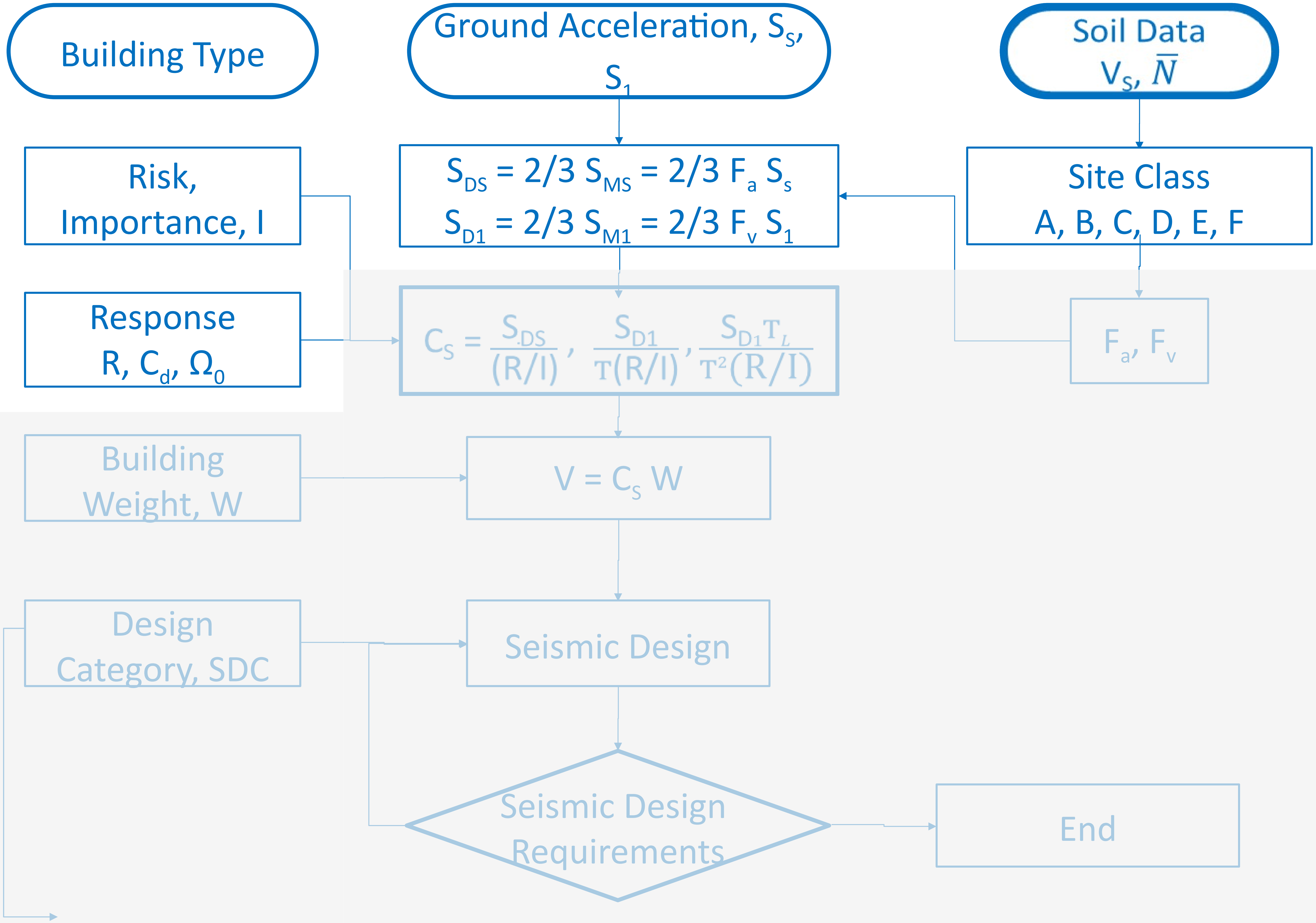
- Importance Factor, I

Risk Category	Nature of Occupancy
I	Representing a low hazard to human life in the event of failure
II	Except those listed in other categories
III	Represent a substantial hazard to human life in the event of failure
IV	Designed as essential facilities

TABLE 3.4.6 IMPORTANCE FACTORS

Occupancy Category	*I*
I or II	1.0
III	1.25
IV	1.5

Earthquake Load

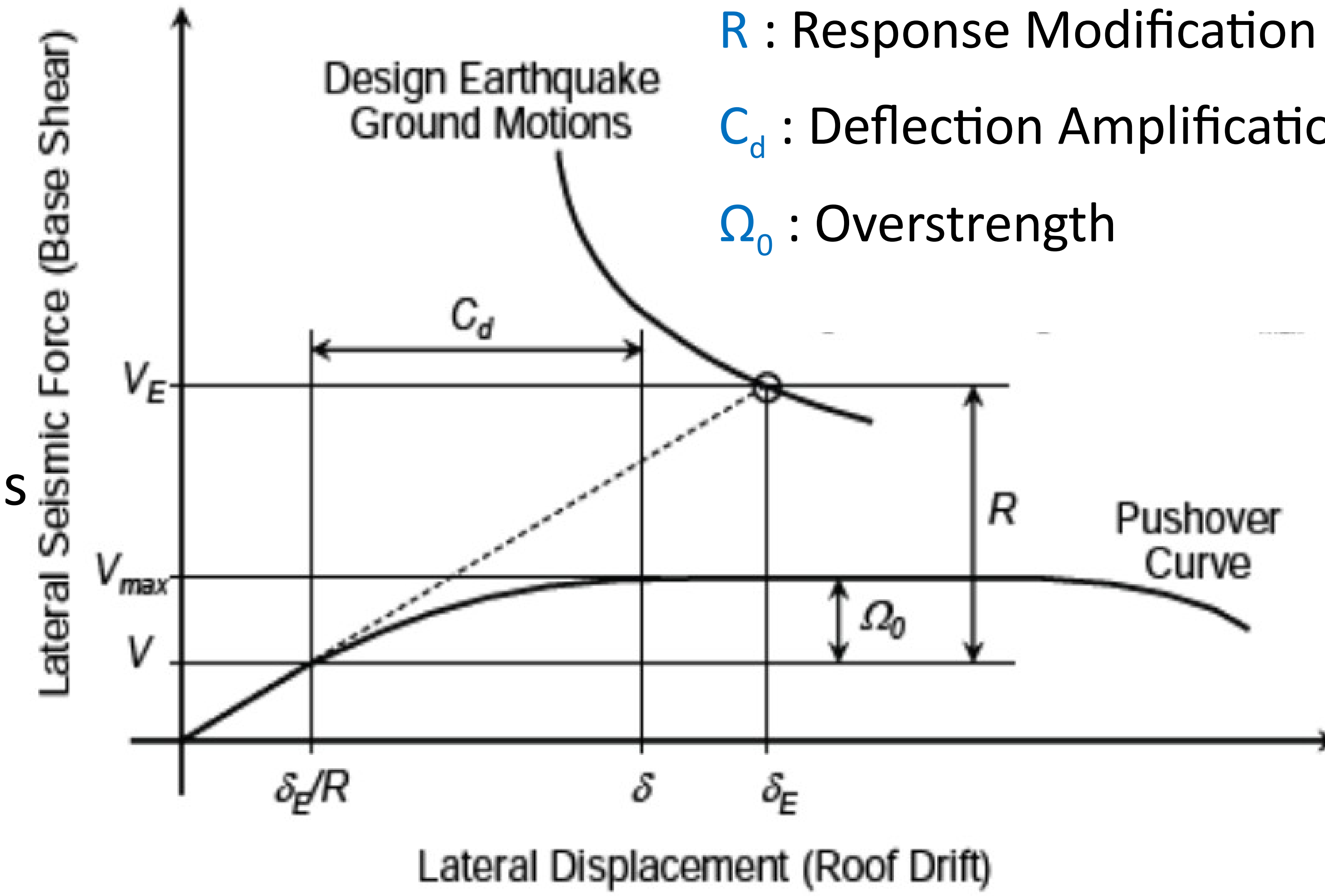


Response Factors: R, C_d, Ω_0

R : Response Modification

C_d : Deflection Amplification

Ω_0 : Overstrength

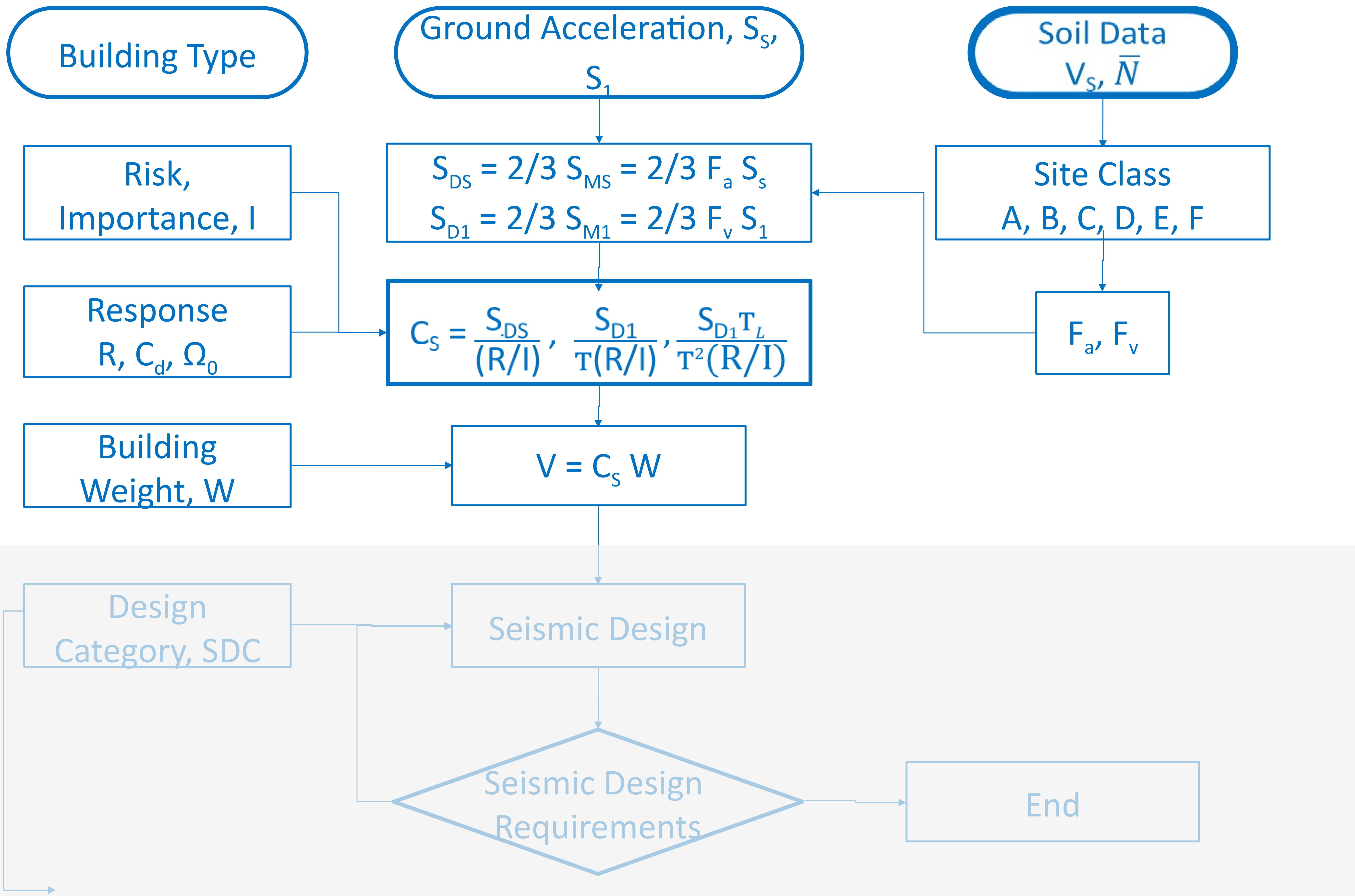


Seismic Force Resisting Systems

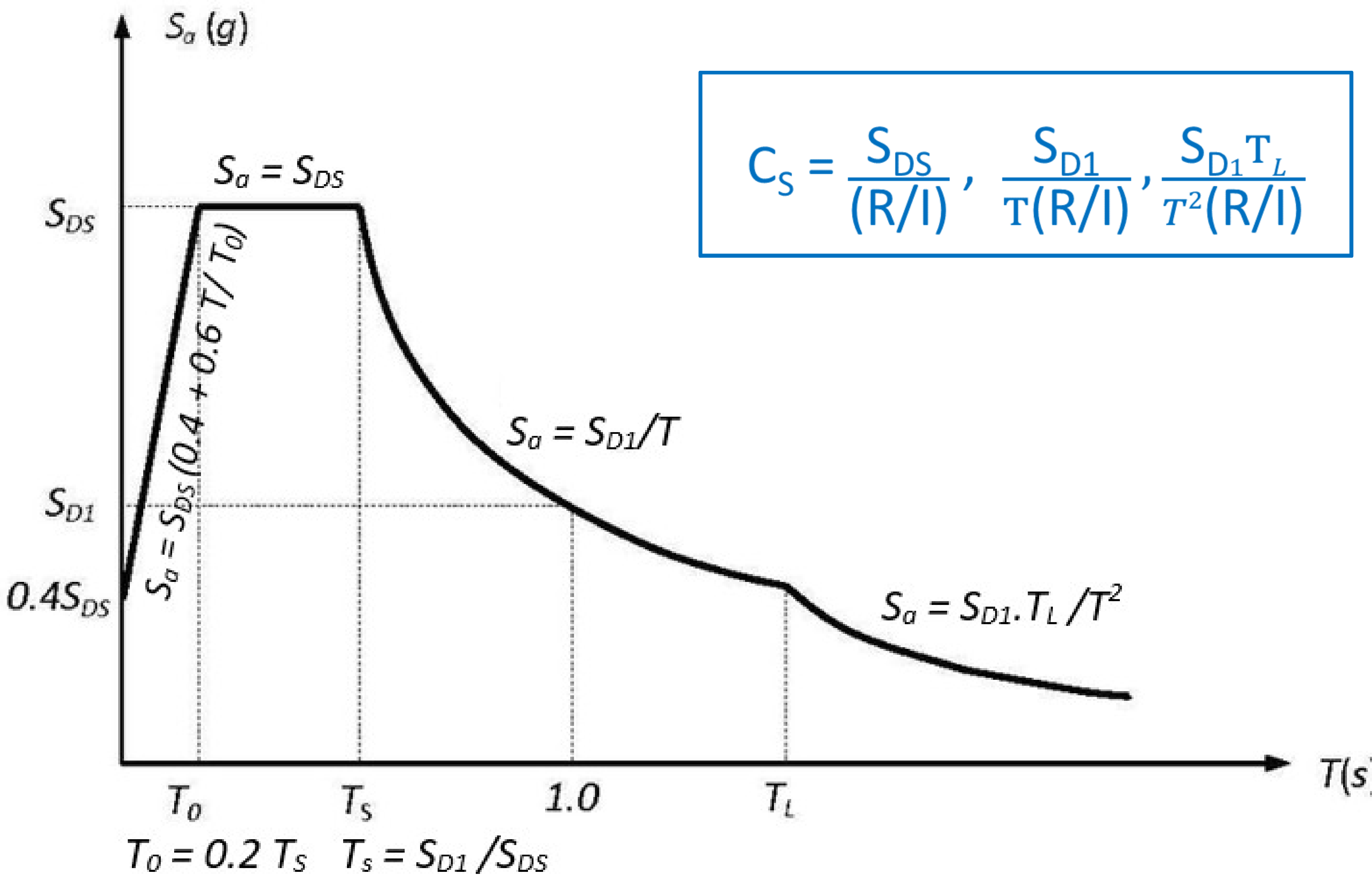
- A Bearing Wall Systems
- B Building Frame Systems
- C Moment Resisting Frame Systems
- D Dual Systems with SMRS
- E Dual Systems with IMRS
- F Shear Wall – Frame Interactive Systems
- G Cantilever Column Systems
- H Steel Systems

Seismic Force-Resisting System	ASCE 7-05, Required Detailing	Response Modification Factor, R^a	System Over strength Factor, Ω_0^g	Deflection Amplification Factor, C_d^b	Structural System Limitations and Building Height (ft) Limit[c]				
					Seismic Design Category				
					B	C	D[d]	E[d]	F[e]
A. BEARING WALL SYSTEMS									
1.Special reinforced concrete shear walls	14.2	5	2½	5	NL	NL	160	160	100
2.Ordinary reinforced concrete shear walls	14.2	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls	14.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls	14.2	1½	2½	1½	NL	NP	NP	NP	NP
5.Intermediate precast shear walls	14.2	4	2½	4	NL	NL	40[k]	40[k]	40[k]
6. Ordinary precast shear walls	14.2	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4	3½	2½	2¼	NL	NL	NP	NP	NP

Earthquake Load

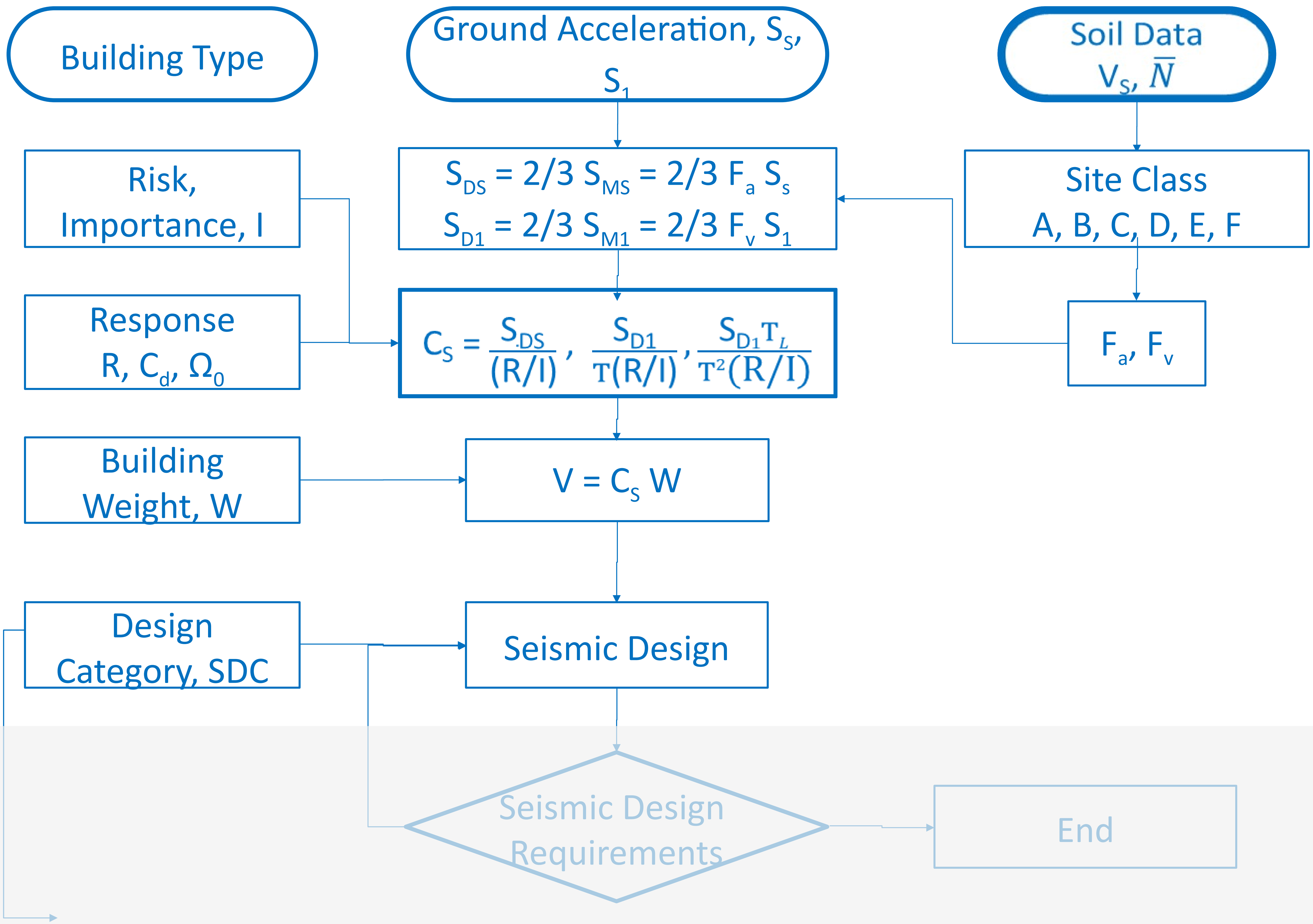


- Seismic Base Shear: V
- $V = C_S\ W$
- C_S : Response Coefficient



$$C_S = \frac{S_{DS}}{(R/I)},\ \frac{S_{D1}}{T(R/I)},\ \frac{S_{D1}T_L}{T^2(R/I)}$$

Earthquake Load



- Seismic Design Category, SDC

- Larger Seismicity needs Higher SDC

SEISMIC DESIGN CATEGORY (SDC)

There are various correlations of the qualitative Modified Mercalli Intensity (MMI) with quantitative characterizations of ground-shaking limits for the various SDCs.

MMI V	No real damage	SDC A
MMI VI	Light nonstructural damage	SDC B
MMI VII	Hazardous nonstructural damage	SDC C
MMI VIII	Hazardous damage to susceptible structures	SDC D
MMI IX	Hazardous damage to robust structures	SDC E

- Seismic Design Category, SDC
- More Important (Higher Occupancy Risk) needs Higher SDC

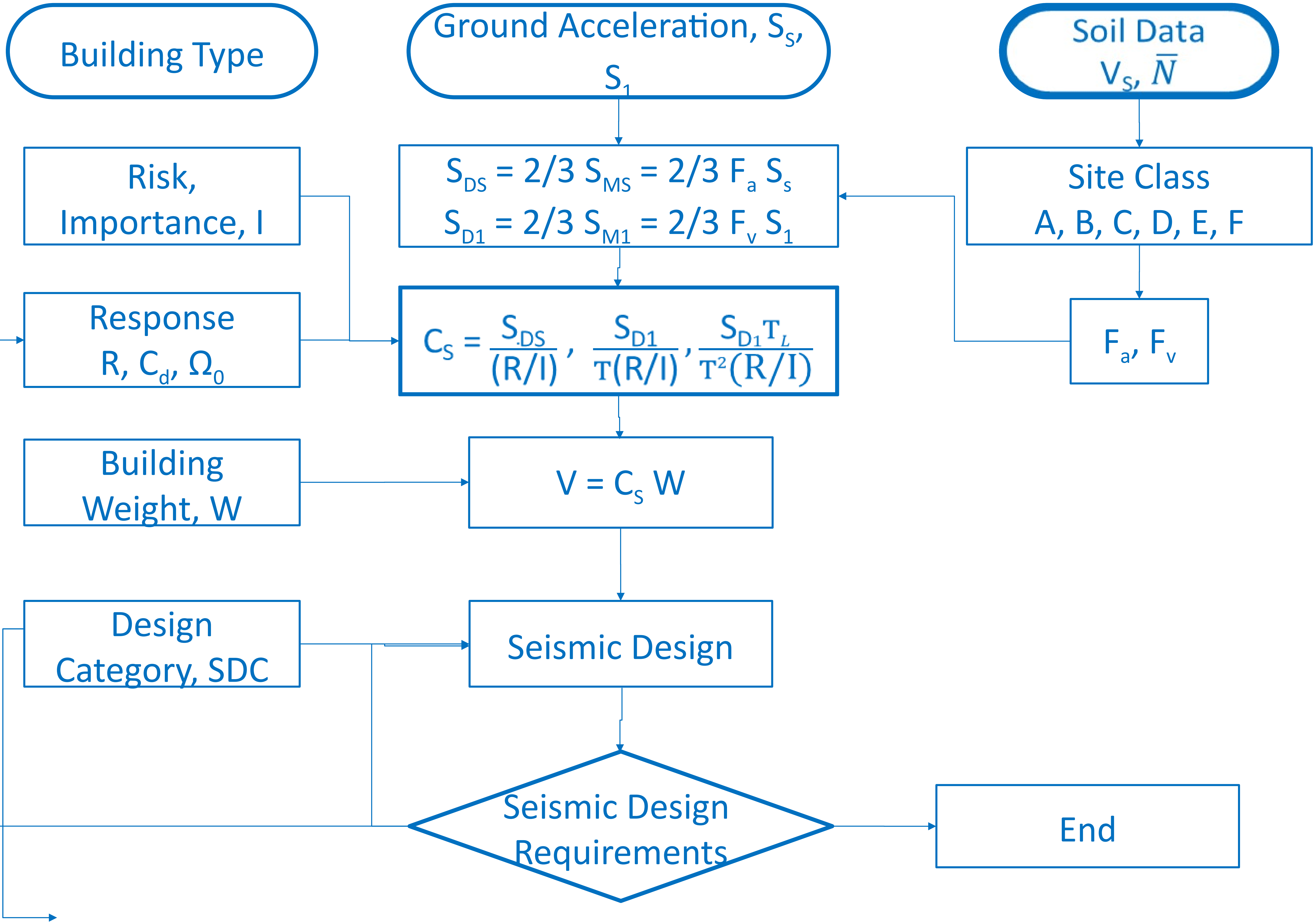
Risk Category	Nature of Occupancy
I	Representing a low hazard to human life in the event of failure
II	Except those listed in other categories
III	Represent a substantial hazard to human life in the event of failure
IV	Designed as essential facilities

Seismic Design Category, SDC

SDC with Seismicity .vs. Occupancy Risk

S_{DS}	S_{D1}	Level of Seismicity	I & II	III	IV
<0.167 g	<0.067 g	Very Low	**A**	**A**	**A**
0.167 to 0.33 g	0.067 to 0.133 g	Low	**A**	**B**	**C**
0.33 to 0.5 g	0.133 to 0.2 g	Moderate	**B**	**C**	**D**
>0.5 g	>0.2 g	High	**C**	**D**	**D**
	>0.75 g	Severe	**D**	**E**	**F**

Earthquake Load



Seismic Design Requirements according to SDC

SDC	Building Type and Expected MMI	Seismic Criteria
A	Buildings located in regions having a very small probability of experiencing damaging earthquake effects	No specific seismic design requirements but structures are required to have complete lateral-force-resisting systems and to meet basic structural integrity criteria.
B	Structures of ordinary occupancy that could experience moderate (MMI VI) intensity shaking	Structures must be designed to resist seismic forces.
C	Structures of ordinary occupancy that could experience strong (MMI VII) and important structures that could experience moderate (MMI VI) shaking	Structures must be designed to resist seismic forces. Critical nonstructural components must be provided with seismic restraint.
D	Structures of ordinary occupancy that could experience very strong shaking (MMI VIII) and important structures that could experience MMI VII shaking	Structures must be designed to resist seismic forces. Only structural systems capable of providing good performance are permitted. Nonstructural components that could cause injury must be provided with seismic restraint. Nonstructural systems required for life safety protection must be demonstrated to be capable of post-earthquake functionality. Special construction quality assurance measures are required.

Seismic Design Requirements according to SDC

SDC	Building Type and Expected MMI	Seismic Criteria
E	Structures of ordinary occupancy located within a few kilometers of major active faults capable of producing MMI IX or more intense shaking	Structures must be designed to resist seismic forces. Only structural systems that are capable of providing superior performance permitted. Many types of irregularities are prohibited. Nonstructural components that could cause injury must be provided with seismic restraint. Nonstructural systems required for life safety protection must be demonstrated to be capable of post-earthquake functionality. Special construction quality assurance measures are required.
F	Critically important structures located within a few kilometers of major active faults capable of producing MMI IX or more intense shaking	Structures must be designed to resist seismic forces. Only structural systems capable of providing superior performance permitted are permitted. Many types of irregularities are prohibited. Nonstructural components that could cause injury must be provided with seismic restraint. Nonstructural systems required for facility function must be demonstrated to be capable of post-earthquake functionality. Special construction quality assurance measures are required.

Seismic Design Requirements for Cracked Sections

Table 6.6.3.1.1(a)—Moment of inertia and cross-sectional area permitted for elastic analysis at factored load level

Member and condition		Moment of Inertia	Cross-sectional area
Columns		$0.70I_g$	$1.0A_g$
Walls	Uncracked	$0.70I_g$	
	Cracked	$0.35I_g$	
Beams		$0.35I_g$	
Flat plates and flat slabs		$0.25I_g$	

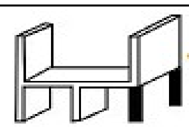
Seismic Design Requirements

Permitted Analysis Procedures

TABLE 12.6-1 PERMITTED ANALYTICAL PROCEDURES

Seismic Design Category	Structural Characteristics	Equivalent Lateral Force Analysis Section 12.8	Modal Response Spectrum Analysis Section 12.9	Seismic Response History Procedures Chapter 16
B, C	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	All other structures	P	P	P
D, E, F	Occupancy Category I or II buildings of light-framed construction not exceeding 3 stories in height	P	P	P
	Other Occupancy Category I or II buildings not exceeding 2 stories in height	P	P	P
	Regular structures with $T < 3.5T_s$ and all structures of light frame construction	P	P	P
	Irregular structures with $T < 3.5T_s$ and having only horizontal irregularities Type 2, 3, 4, or 5 of Table 12.2-1 or vertical irregularities Type 4, 5a, or 5b of Table 12.3-1	P	P	P
	All other structures	NP	P	P

Seismic Design Requirements for Horizontal Irregularity

Cat.	Sr.	Type		A	B	C	D	E	F	1	2	3	4	5	6	7	8	9
				SDC						**Remedial**								
Horizontal	1	Torsional	1a. Moderate: Δ1 > 1.2 Δavg		O			X	X			O			X			
			1b. Extreme: Δ1 > 1.4 Δavg			O		X	X		O	O	O		X			
			Δavg = (Δ1 + Δ2)/2				O	X	X	O	O	O	O	O	X			
	2	Reentrant Corner	B > 15% A D > 15% C E > 15% C				O	O	O	O				O				
	3	Diaphragm Discontinuity	Area XY > 50% AB				O	O	O	O				O				
	4	Out of Plane Offsets 	Out of Plane Offset		O	O						O				O		
							O	O	O		O	O		O		O		
	5	Nonparallel	Nonparallel System		O							O						
						O						O					O	
							O	O	O			O		O			O	
Vertical	1	Stiffness	1a. Moderate: A <70% B or A < 80% (B+C+D)/3 1b. Extreme: A <60% B or A < 70% (B+C+D)/3				O	X	X					O	X			
	2	Weight	Mass B > 150% Mass A				O	O	O					O				
	3	Vertical Geometry	X > 130% Y				O	O	O					O				
	4	Inplane Discontinuity	L1 > L		O	O										O		
							O	O	O	O				O		O		
	5	Weak Story	5a. Moderate: A < 80% B 5b. Extreme: A < 65% B		9	9	O	X	X					O	X			9

Remedial Measures

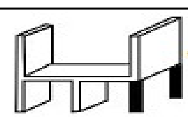
Source: ASCE 7-05, Table 12.3.1 and 12.3.2.

1. Increase design forces determined by static procedure by 25% for connection of diaphragms to vertical elements and to collectors, and for connections of collectors to the vertical elements. Collectors and their connections also shall be designed for these increased forces unless they are designed for load combinations with overstrength factor Ωo (ASCE 7-05, Section 12.3.3.4).
2. Multiply, M_{ta}, the torsional moment due to accidental torsion by a torsional amplification A_x (ASCE 7-05, Section 12.8.4.3).
$A_x = (\Delta_{max}/1.2\Delta_{avg})^2 \leq 3$
3. Perform a 3D dynamic analysis with due consideration for diaphragm stiffness. Use cracked section properties for concrete elements. Include PΔ effects (ASCE 7-05, Section 12.7.3).
4. Compute story drift, Δ, as the largest difference of the deflections along any of the edges of the structure at the top and bottom of the story under consideration (ASCE 7-05, Section 12.12.1).
5. Use model analysis or more rigorous procedure (ASCE 7-05, Table 12.6.1).
6. Not permitted (NP) (ASCE 7-05, Section 12.3.3.1).
7. Design columns, beams, trusses, or stabs supporting discontinuous walls or frames to resist maximum axial forces determined by using the following load combinations with the overstrength factor Ω_o:
$(1.2 + 0.2S_{DS})D + \Omega_o Q_E + L + 0.2S$
$(0.9 - 0.2S_{DS})D + \Omega_o Q_E + 1.6H$ (ASCE 7-05, Section 12.3.3.3).
8. Use 100% x + 30% y, if you are using ELF or modal analysis. Use simultaneous application of load, if you are analyzing the structure using a linear or nonlinear response history procedure (ASCE 7-05, Section 12.5.3).
9. Maximum height limit 30 ft or two stories, unless the weak story is capable of resisting a seismic force = Ωo times the design force (ASCE 7-05, Section 12.3.3.2).

Ref: 1. ASCE 7-05- Table 12.3.1./ 2. Reinforced Concrete Design of Tall Buildings, Taranath, Table 5.23, 5.24

- 1. Increase 25%
- 2. Torsion
- 3. Dynamic
- 4. Drift
- 5. Detail Analysis
- 6. Not Permitted
- 7. Overstrength
- 8. Directional
- 9. Height Limit

Seismic Design Requirements for Vertical Irregularity

Cat.	Sr.	Type		A	B	C	D	E	F	1	2	3	4	5	6	7	8	9
				SDC						Remedial								
Horizontal	1	Torsional	1a. Moderate: $\Delta 1 > 1.2\ \Delta avg$		O			X	X			O			X			
			1b. Extreme: $\Delta 1 > 1.4\ \Delta avg$			O		X	X		O	O	O		X			
			$\Delta avg = (\Delta 1 + \Delta 2)/2$				O	X	X	O	O	O	O	O	X			
	2	Reentrant Corner	B > 15% A D > 15% C E > 15% C				O	O	O	O				O				
	3	Diaphragm Discontinuity	Area XY > 50% AB				O	O	O	O				O				
	4	Out of Plane Offsets 	Out of Plane Offset		O	O						O				O		
							O	O	O		O	O		O		O		
	5	Nonparallel	Nonparallel System		O							O						
						O						O					O	
							O	O	O			O		O			O	
Vertical	1	Stiffness	1a. Moderate: A <70% B or A < 80% (B+C+D)/3 1b. Extreme: A <60% B or A < 70% (B+C+D)/3				O	X	X					O	X			
	2	Weight	Mass B > 150% Mass A				O	O	O					O				
	3	Vertical Geometry	X > 130% Y				O	O	O					O				
	4	Inplane Discontinuity	L1 > L		O	O										O		
							O	O	O	O				O		O		
	5	Weak Story	5a. Moderate: A < 80% B 5b. Extreme: A < 65% B		9	9	O	X	X					O	X			9

Remedial Measures

Source: ASCE 7-05, Table 12.3.1 and 12.3.2.

1. Increase design forces determined by static procedure by 25% for connection of diaphragms to vertical elements and to collectors, and for connections of collectors to the vertical elements. Collectors and their connections also shall be designed for these increased forces unless they are designed for load combinations with overstrength factor Ωo (ASCE 7-05, Section 12.3.3.4).
2. Multiply, M_{ta}, the torsional moment due to accidental torsion by a torsional amplification A_x (ASCE 7-05, Section 12.8.4.3).
$A_x = (\Delta_{max}/1.2\Delta_{avg})^2 \leq 3$
3. Perform a 3D dynamic analysis with due consideration for diaphragm stiffness. Use cracked section properties for concrete elements. Include PΔ effects (ASCE 7-05, Section 12.7.3).
4. Compute story drift, Δ, as the largest difference of the deflections along any of the edges of the structure at the top and bottom of the story under consideration (ASCE 7-05, Section 12.12.1).
5. Use model analysis or more rigorous procedure (ASCE 7-05, Table 12.6.1).
6. Not permitted (NP) (ASCE 7-05, Section 12.3.3.1).
7. Design columns, beams, trusses, or stabs supporting discontinuous walls or frames to resist maximum axial forces determined by using the following load combinations with the overstrength factor Ω_o:
$(1.2 + 0.2S_{DS})D + \Omega_o Q_E + L + 0.2S$
$(0.9 - 0.2S_{DS})D + \Omega_o Q_E + 1.6H$ (ASCE 7-05, Section 12.3.3.3).
8. Use 100% x + 30% y, if you are using ELF or modal analysis. Use simultaneous application of load, if you are analyzing the structure using a linear or nonlinear response history procedure (ASCE 7-05, Section 12.5.3).
9. Maximum height limit 30 ft or two stories, unless the weak story is capable of resisting a seismic force = Ωo times the design force (ASCE 7-05, Section 12.3.3.2).

Ref: 1. ASCE 7-05- Table 12.3.1./ 2. Reinforced Concrete Design of Tall Buildings, Taranath, Table 5.23, 5.24

- 1. Increase 25%
- 2. Torsion
- 3. Dynamic
- 4. Drift
- 5. Detail Analysis
- 6. Not Permitted
- 7. Overstrength
- 8. Directional
- 9. Height Limit

Living with earthquake

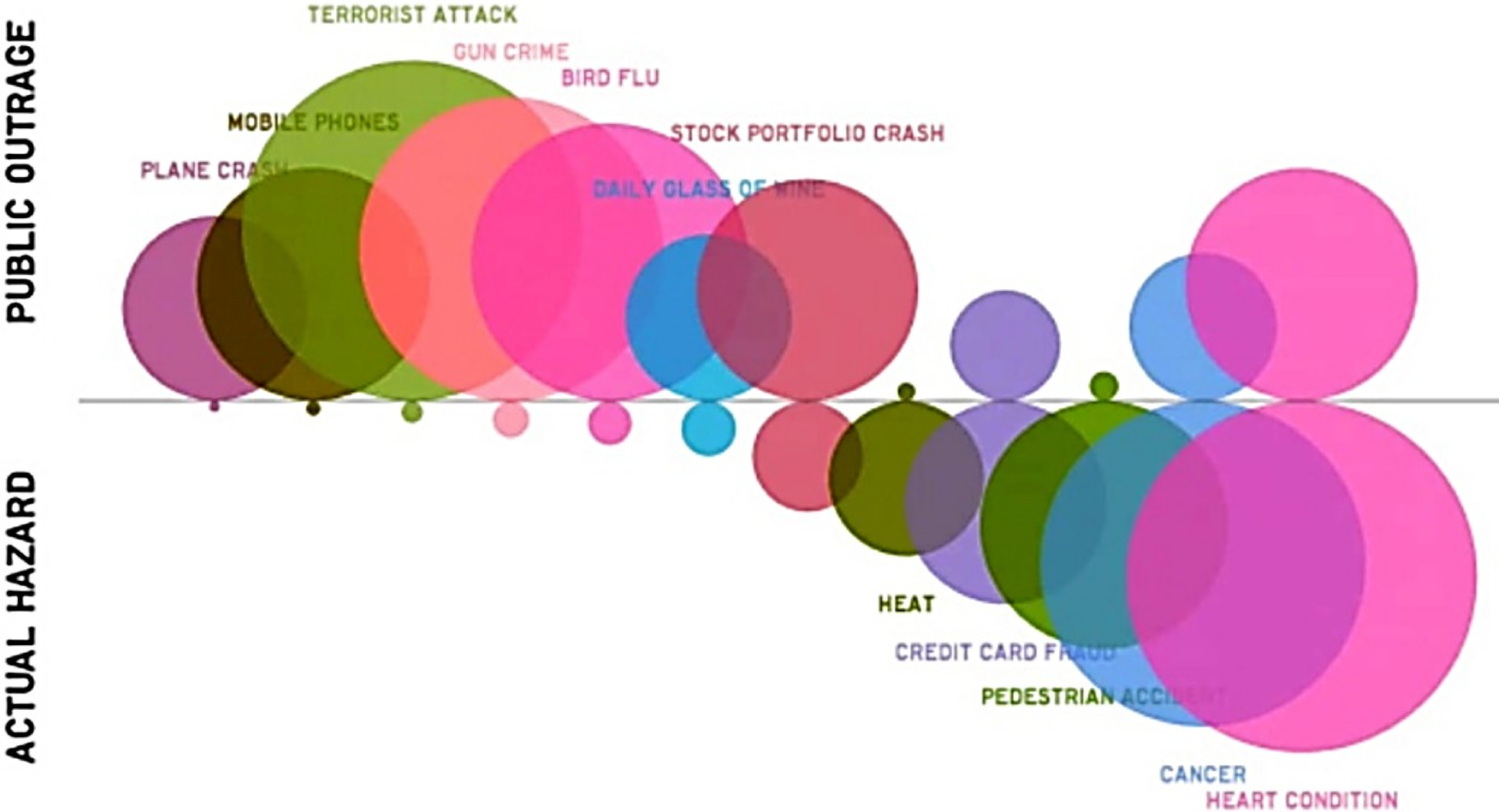
Earthquakes and the world

- Earth is 4.6 billion years old
- Oldest human identified 100,000 years ago
- Human civilization started 10,000 years ago

Risk


RELATED
REDUCE
ALSO
CAPACITY
PUBLIC
GEOLOGICAL
EFFECTS
DISRUPTION
DEGRADATION
INJURY

Risk Perception

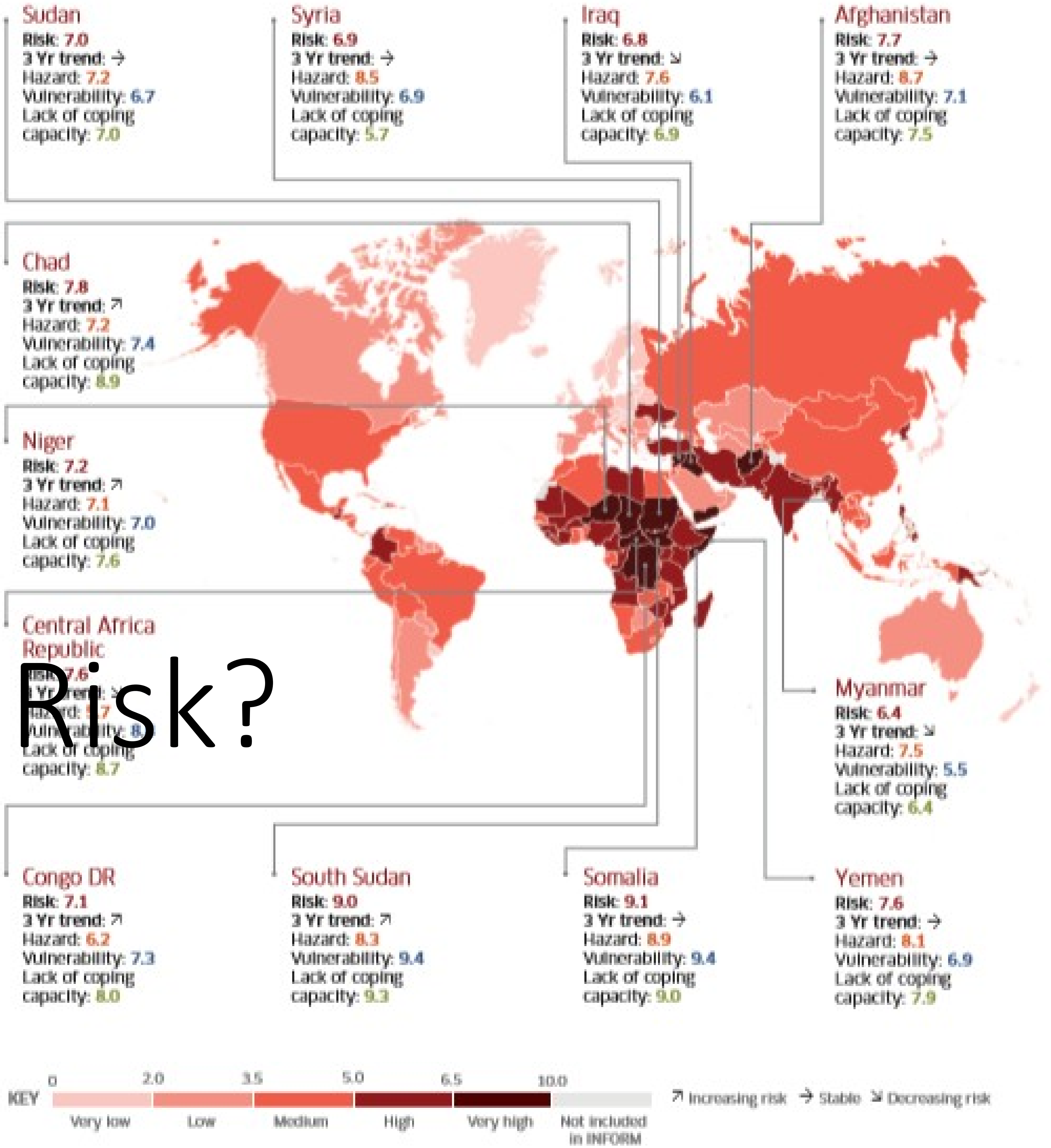


Risk

Probability of Dying in any One Year		
Cause	Risk	Consequences
Motor vehicle accident	1 in 100	Low
Smoking 10 cigarettes a day	1 in 200	Low
All natural causes, age 40	1 in 850	Low
Any kind of violence or poisoning	1 in 3300	Low
Influenza	1 in 5000	Medium
Leukemia	1 in 12,500	Low
Asteroid or comet impact	1 in 20,000	Very High
Playing field sports	1 in 25,000	Low
Accident at home	1 in 26,000	Low
Accident at work	1 in 43,500	Low
Nuclear War	1 in 50,000	Very High
Tornado	1 in 60,000	Medium
Floods	1 in 100,000	High
Earthquake	1 in 2,000,000	High
Hit by lightning	1 in 10,000,000	Low

Low Probability – High Consequences

What is Risk?



Sudan
Risk: 7.0
3 Yr trend: →
Hazard: 7.2
Vulnerability: 6.7
Lack of coping capacity: 7.0
Syria
Risk: 6.9
3 Yr trend: →
Hazard: 8.5
Vulnerability: 6.9
Lack of coping capacity: 5.7
Iraq
Risk: 6.8
3 Yr trend: ↘
Hazard: 7.6
Vulnerability: 6.1
Lack of coping capacity: 6.9
Afghanistan
Risk: 7.7
3 Yr trend: →
Hazard: 8.7
Vulnerability: 7.1
Lack of coping capacity: 7.5
Chad
Risk: 7.8
3 Yr trend: ↗
Hazard: 7.2
Vulnerability: 7.4
Lack of coping capacity: 8.9
Niger
Risk: 7.2
3 Yr trend: ↗
Hazard: 7.1
Vulnerability: 7.0
Lack of coping capacity: 7.6
Central Africa Republic
Lack of coping capacity: 8.7
Myanmar
Risk: 6.4
3 Yr trend: ↘
Hazard: 7.5
Vulnerability: 5.5
Lack of coping capacity: 6.4
Congo DR
Risk: 7.1
3 Yr trend: ↗
Hazard: 6.2
Vulnerability: 7.3
Lack of coping capacity: 8.0
South Sudan
Risk: 9.0
3 Yr trend: ↗
Hazard: 8.3
Vulnerability: 9.4
Lack of coping capacity: 9.3
Somalia
Risk: 9.1
3 Yr trend: →
Hazard: 8.9
Vulnerability: 9.4
Lack of coping capacity: 9.0
Yemen
Risk: 7.6
3 Yr trend: →
Hazard: 8.1
Vulnerability: 6.9
Lack of coping capacity: 7.9
KEY
0
2.0
3.5
5.0
6.5
10.0
Very low
Low
Medium
High
Very high
Not included in INFORM
↗ Increasing risk
→ Stable
↘ Decreasing risk

Risk Terminology

Exposure

Exposure

Risk

Vulnerability

Hazard

Risk

Risk = Hazard x Exposure x Vulnerability

Vulnerability

Hazard

Risk

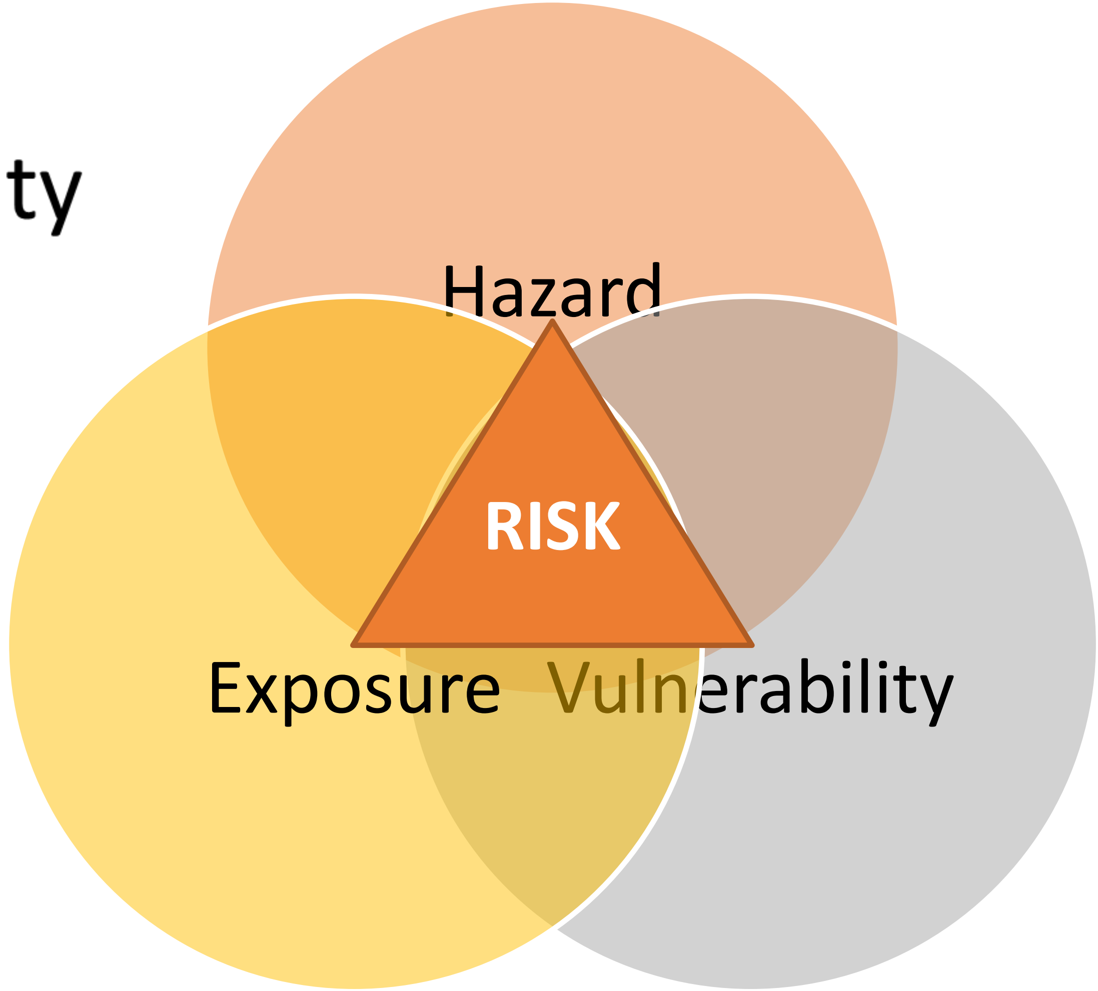
Hazard

Exposure

Vulnerability

Element of Risk

Risk = Hazard x Exposure x Vulnerability



Risk Terminology

Risk = **H**azard x **E**xposure x **V**ulnerability

Vulnerability

Hazard

No Exposure

No Risk

Risk Terminology

Risk = **H**azard x **E**xposure x **V**ulnerability

Vulnerability

Hazard

No Exposure

No Risk

H V

Medium Exposure

Medium Risk

E

H V

Risk Terminology

Risk = Hazard x Exposure x Vulnerability

Vulnerability

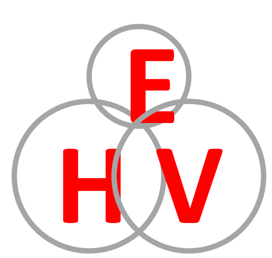
Hazard

No Exposure

No Risk

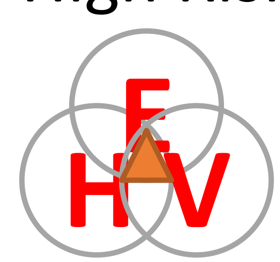
Medium Exposure

Medium Risk



High Exposure

High Risk



Risk Terminology

Risk = Hazard x Exposure x Vulnerability

Vulnerability

Hazard

No Exposure

No Risk

Medium Exposure

Medium Risk

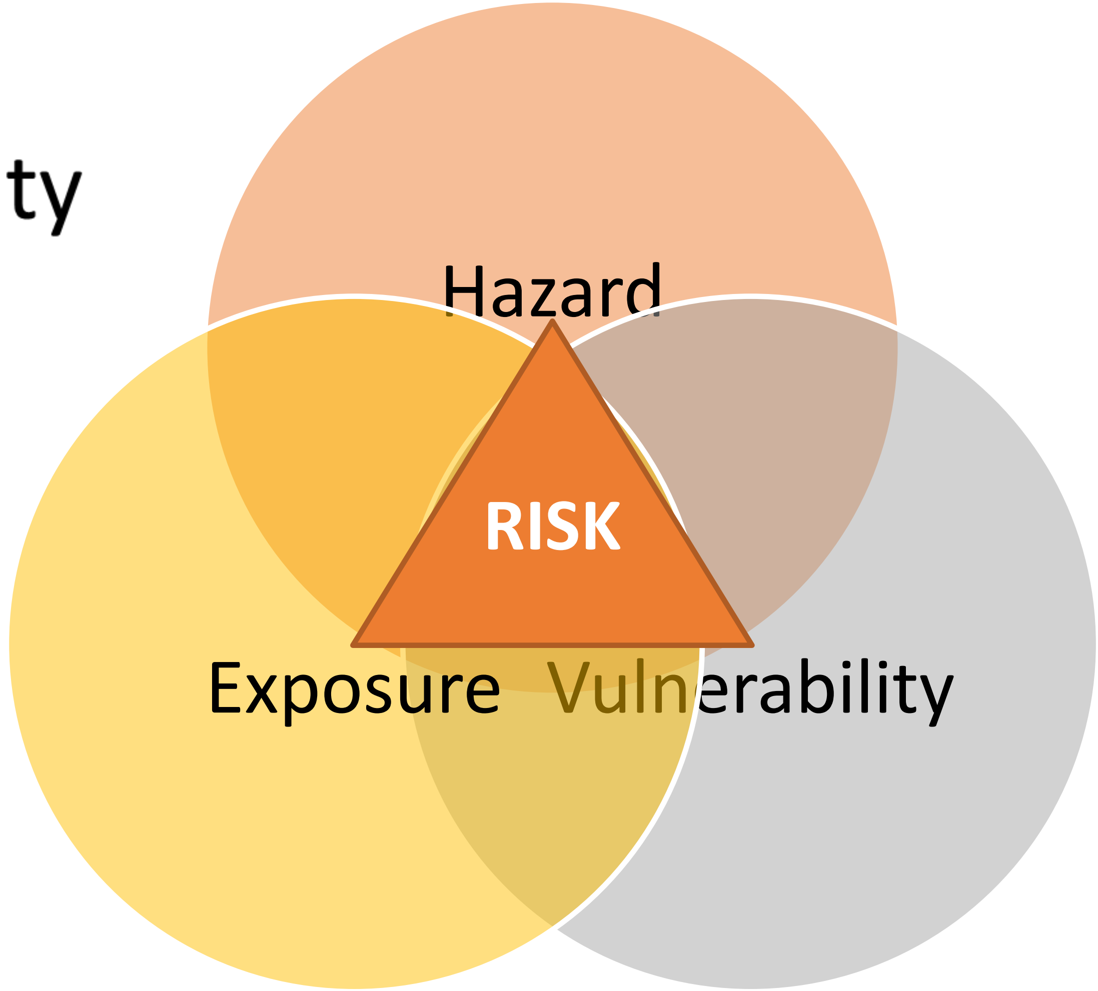
High Exposure

High Risk

Disaster

Element of Risk

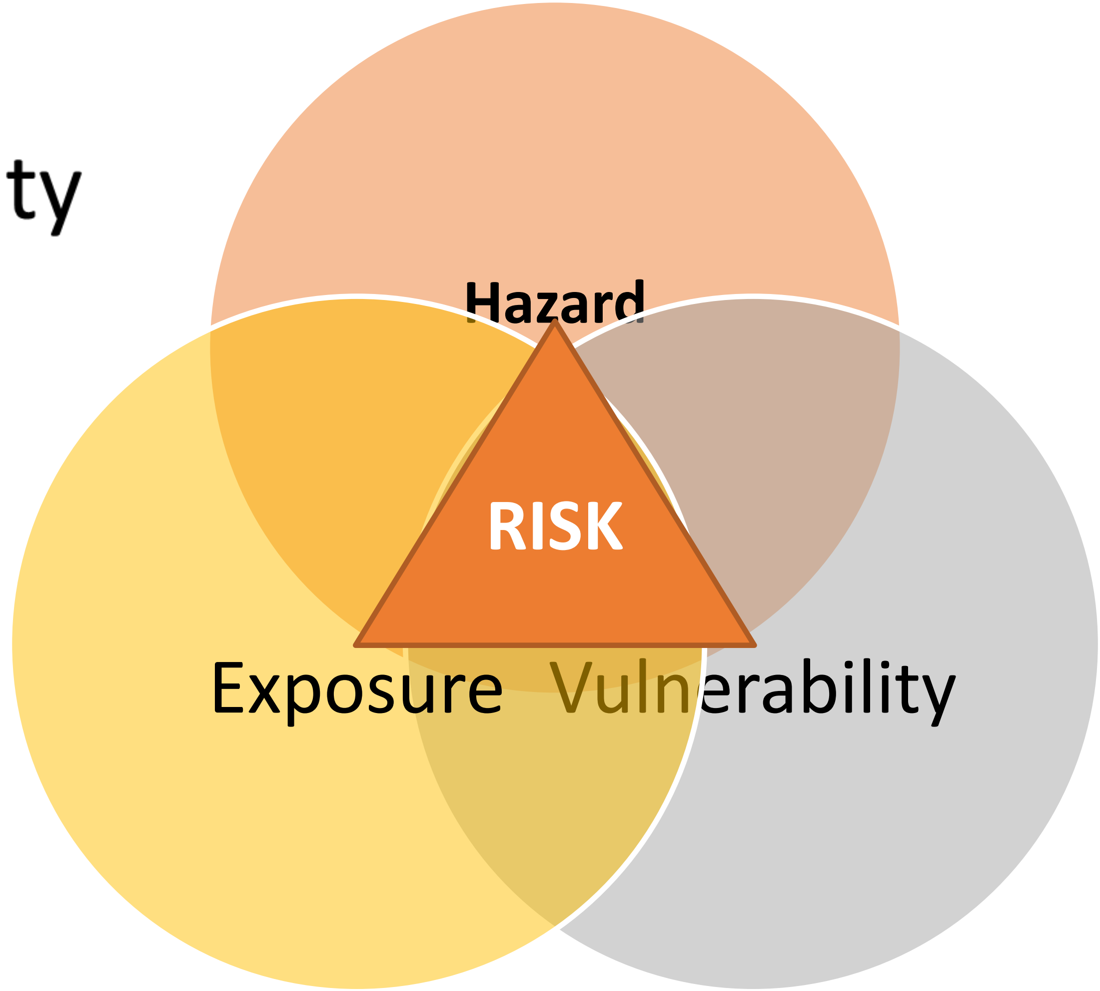
Risk = Hazard x Exposure x Vulnerability



Hazard

- Act of Nature
- Can not be controlled

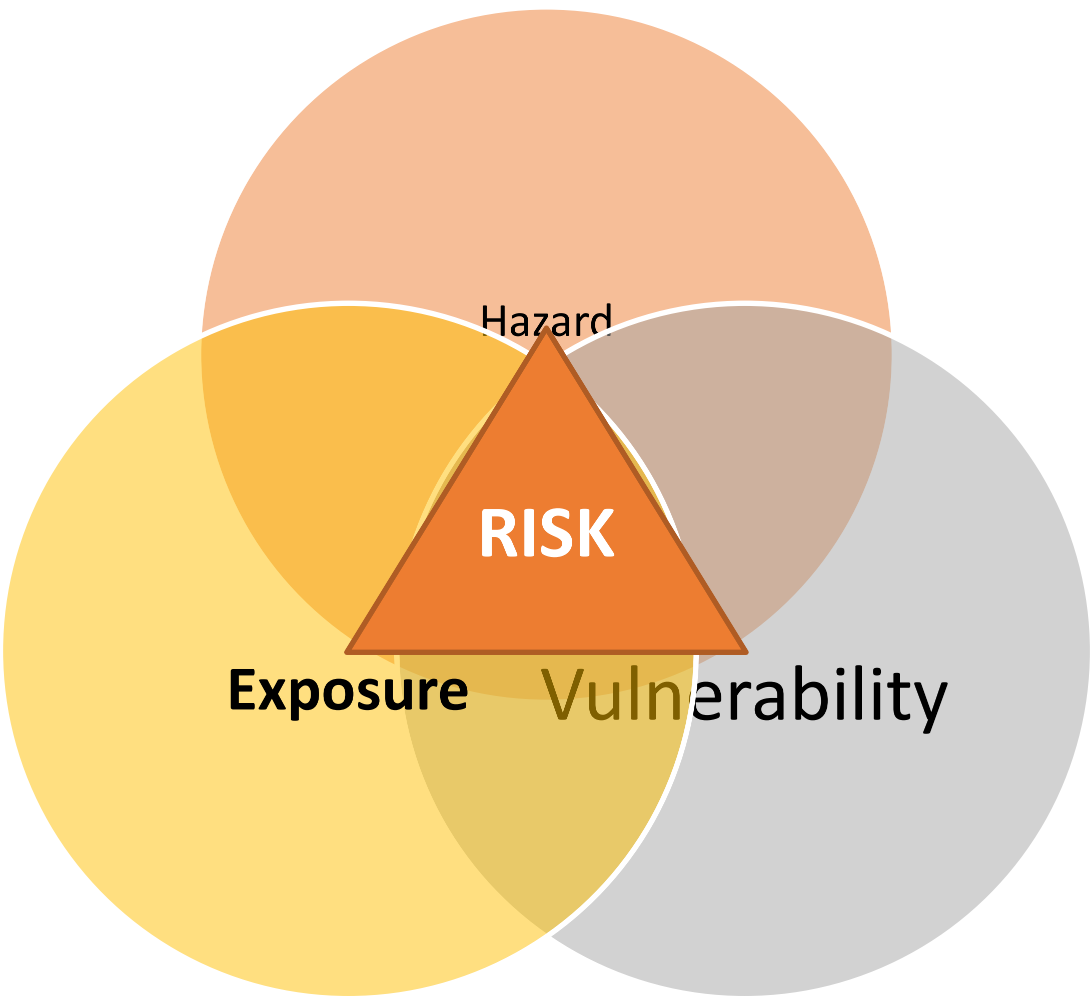
Risk = **Hazard** x Exposure x Vulnerability



Exposure

- Act of Human
- Urbanization: Global Trend

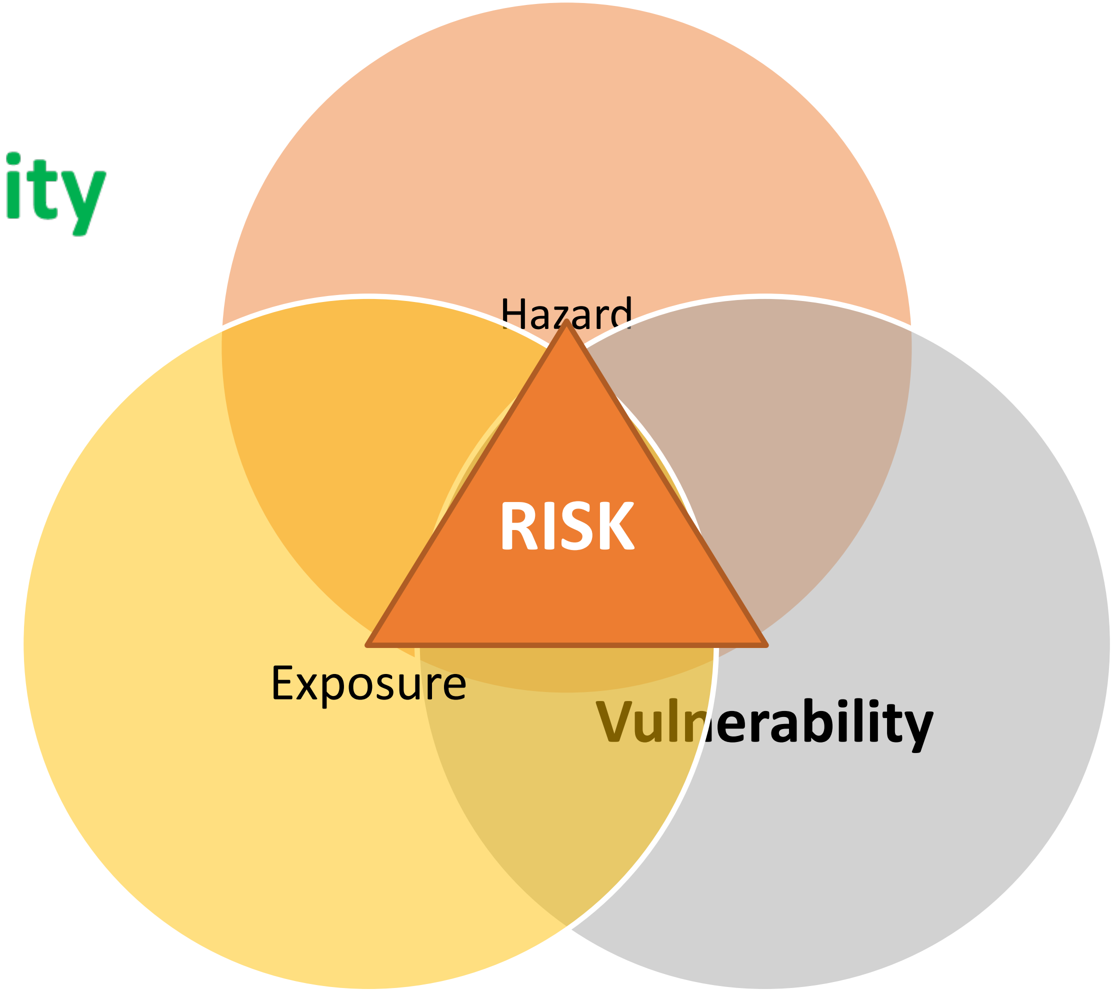
Risk = Hazard x **Exposure** x



Vulnerability

- Act of Human
- Reduce Vulnerability
- Increase Knowledge
- Enhance Resilience

Risk = Hazard x Exposure x **Vulnerability**



Risk Reduction

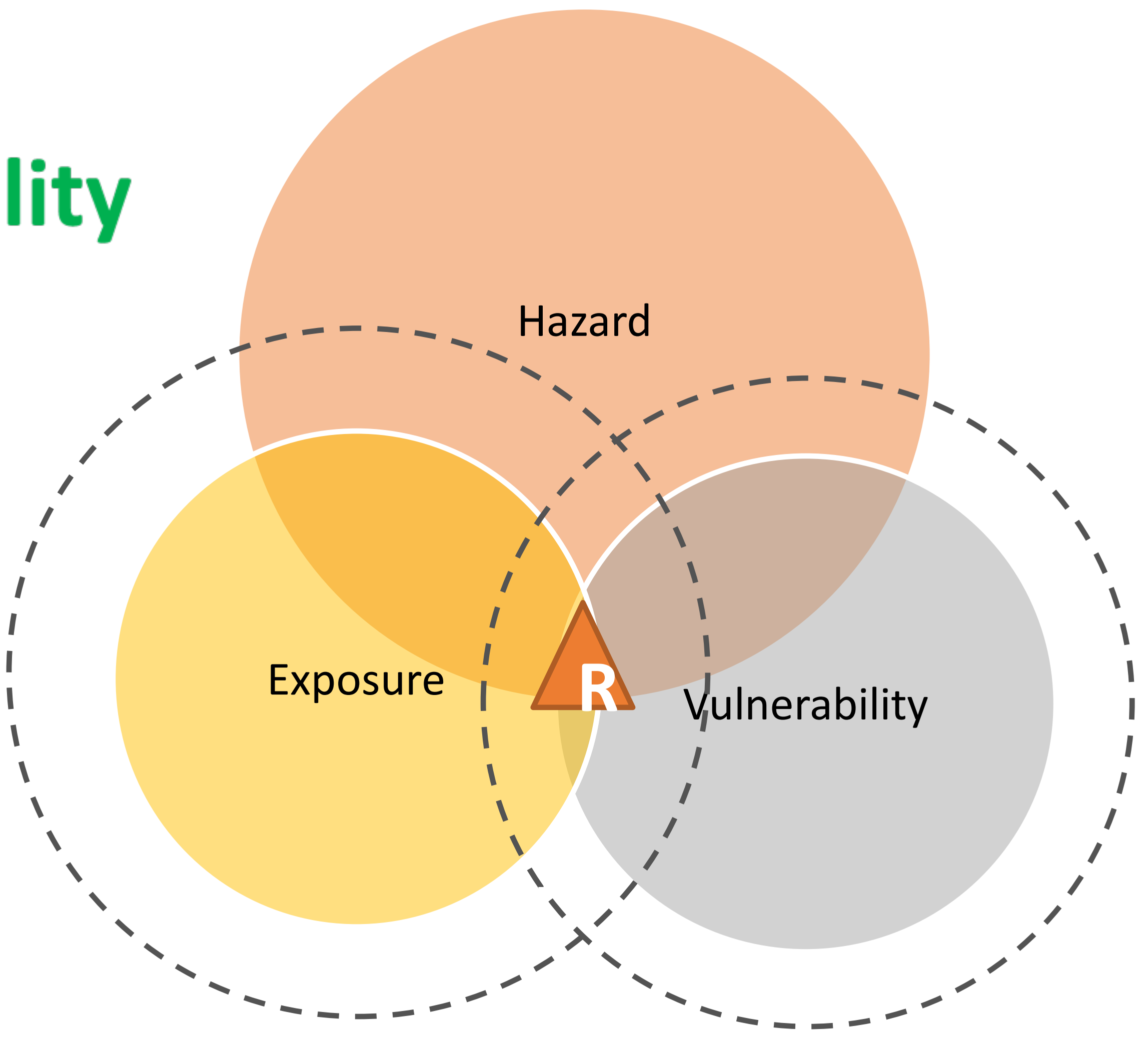
Reduce Vulnerability

- Increase Knowledge
- Enhance Resilience

Risk = Hazard x **Exposure** x **Vulnerability**

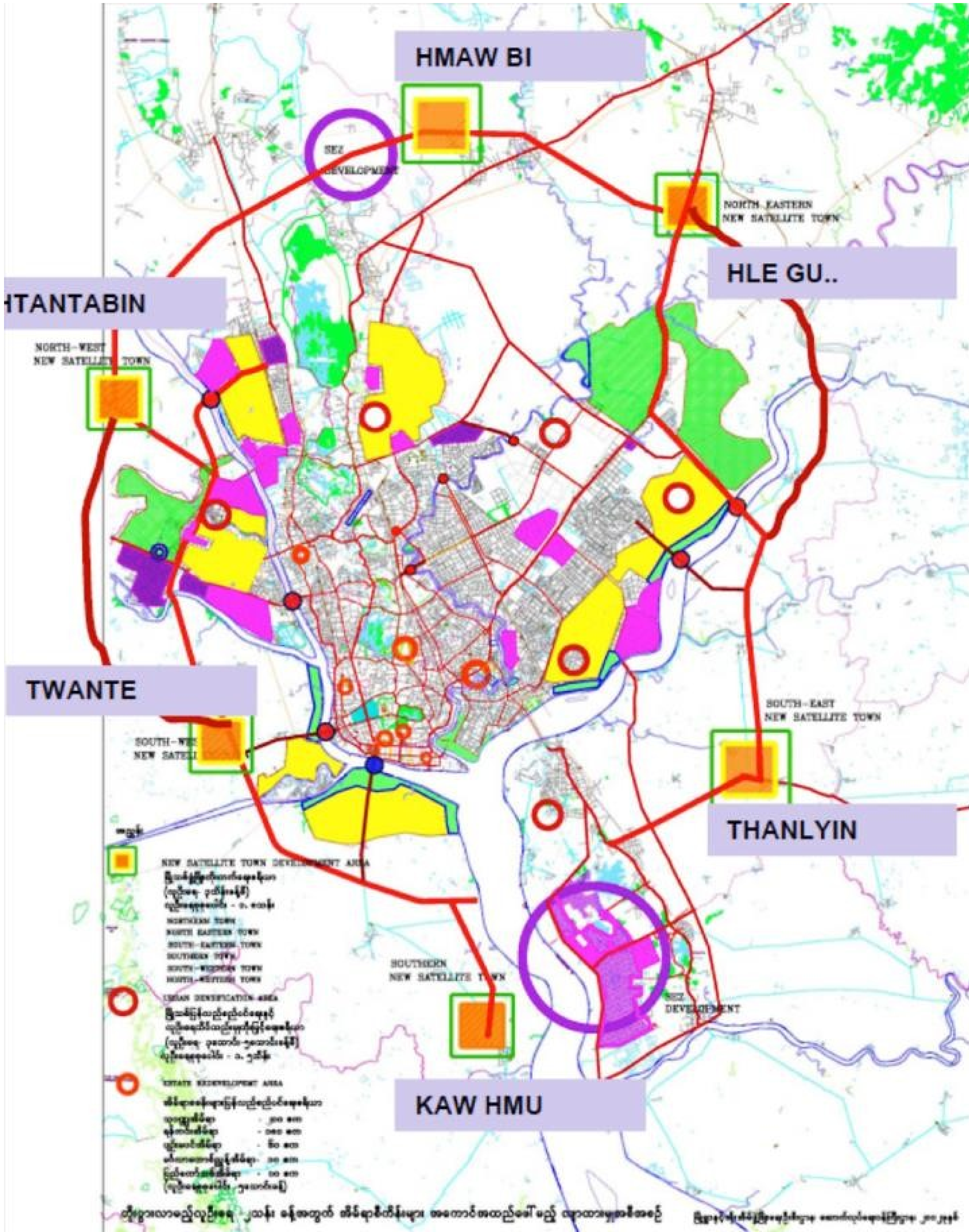
Reduce Exposure

- Control Urbanization
- Mitigate from High Risk Areas



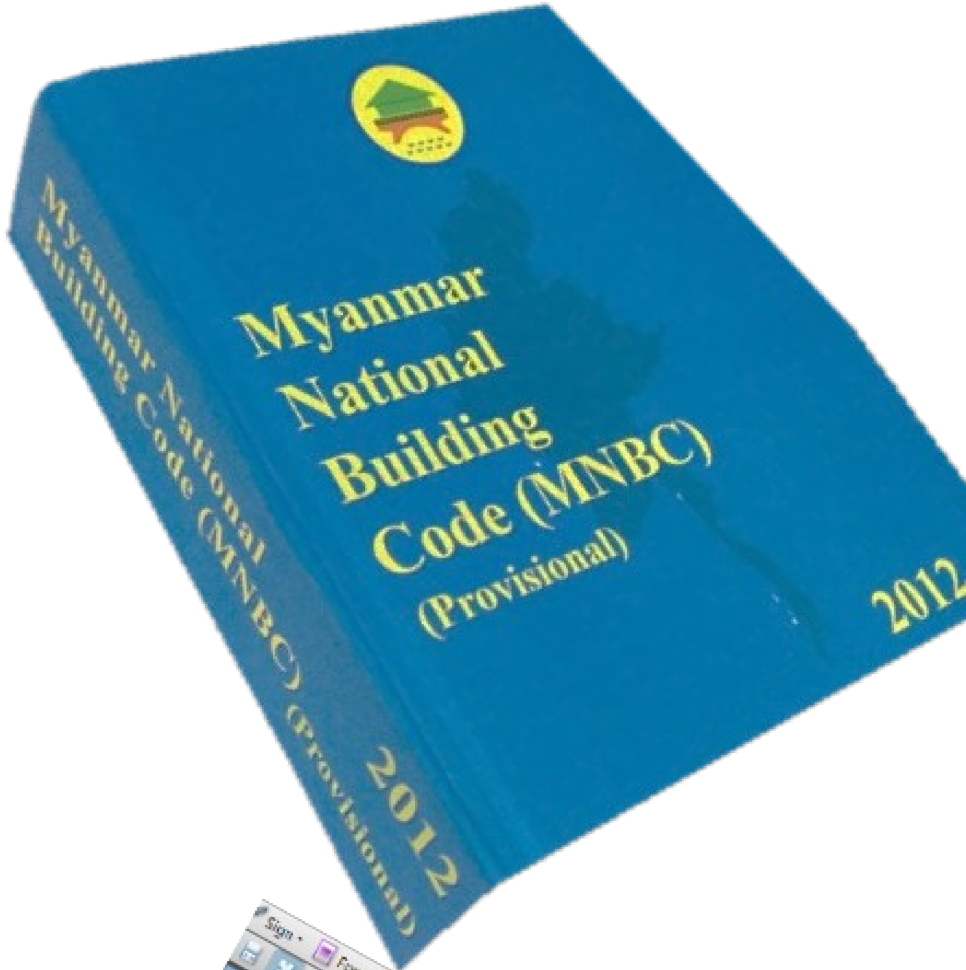
Reduce Exposure

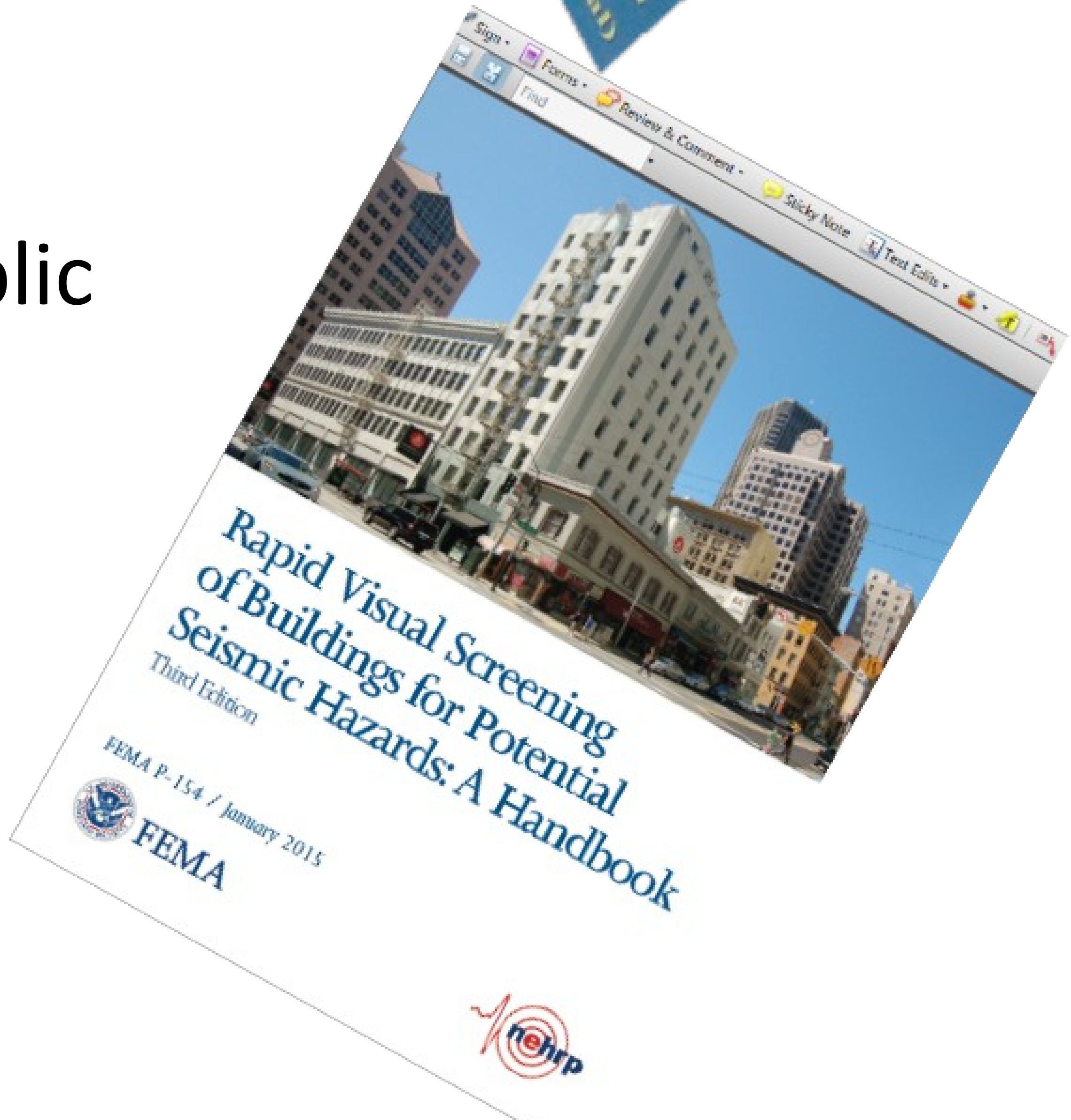
- City Planning
- Control Urbanization
- Mitigate from High Risk areas
- Invest more in Infrastructure and Life Lines



Reducing Vulnerability

- New Building
  - Engineered Building → Control by Building Code
  - None Engineered Building → Public Education





- Existing Building
  - Visual Inspection

Thanks