PROPOSED
GUIDELINES FOR EARTHQUAKE-RESISTANT UNREINFORCED MASONRY HERITAGE STRUCTURES

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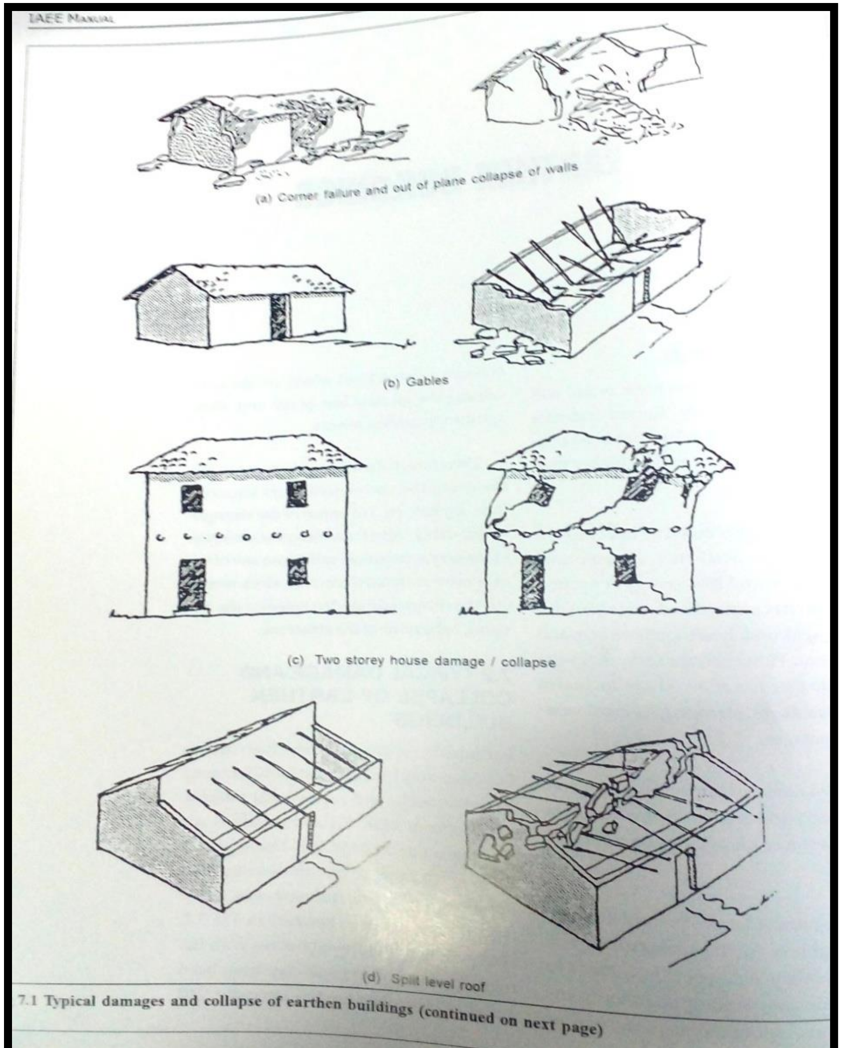
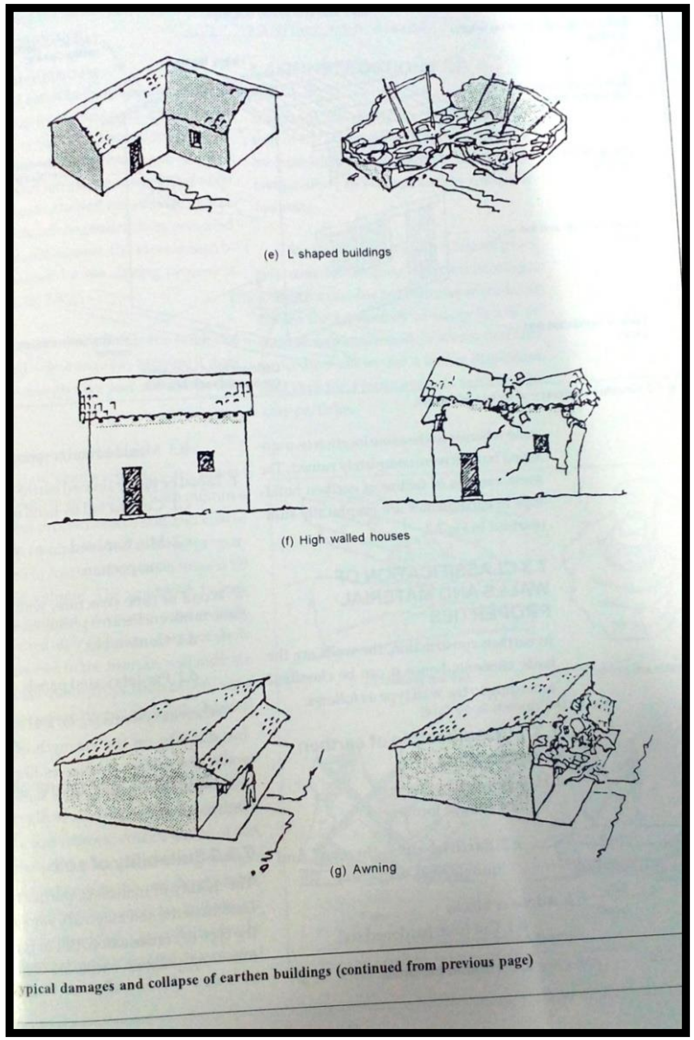
TYPICAL DAMAGE AND COLLAPSE SCENARIOS

TYPICAL DAMAGE AND COLLAPSE OF UNREINFORCED MASONRY



TYPICAL DAMAGE AND COLLAPSE OF UNREINFORCED MASONRY



GUIDELINES FOR EARTHQUAKE-RESISTANT UNREINFORCED MASONRY HERITAGE STRUCTURES

DESIGN PARAMETERS TO BE CONSIDERED

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- Type of material
- Age
- Reconstruction/Repair History
- Method of Reconstruction
- Location
- Type of Soil at Site

DESIGN PARAMETERS TO BE CONSIDERED

- Site Soil Bearing Capacity
- Site Geology
- Seismic Source Type
- Proximity to Fault Line
- Factor of Safety
- Use of Structure/Occupancy
- Additional Loads Imposed on the Structure

GUIDELINES FOR EARTHQUAKE-RESISTANT UNREINFORCED MASONRY HERITAGE STRUCTURES

STRUCTURAL SAFETY AND CAPABILITY ASSESSMENT

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- Cracks
- Vegetation
- Water Intrusion Marks
- Rot
- Voids within walls
- Loose blocks/coral stones

GUIDELINES FOR EARTHQUAKE-RESISTANT UNREINFORCED MASONRY HERITAGE STRUCTURES

TESTS TO BE CONDUCTED

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- Geotechnical Survey
- Seismic Survey
- Soil Suitability tests:
  - Dry Strength Test
  - Fissuring Control Test
- Material Strength tests
- Tests to Determine Material Composition
- Dynamic testing (Shaking Table, Vibrometer)
- Moisture content tests (for Timber)

PRACTICAL GEOTECHNICAL ENGINEERING

Subsurface Explorations & Sampling

Objective: to obtain sufficient data for selection of types, locations, and dimensions

1. Type and Spacing of Explorations
2. Depth of Explorations

Major Factors:

- magnitude and distribution of the load
- the nature of the subsurface conditions
- potential for liquefaction of the site

Bearing Capacity of Shallow Foundations

Foremost requirements :

adequate depth

tolerable settlements

safety against failure.

Influence of Groundwater Table

The position of the groundwater table may have a significant effect on bearing capacity of shallow foundations especially in soil liquefaction analysis.

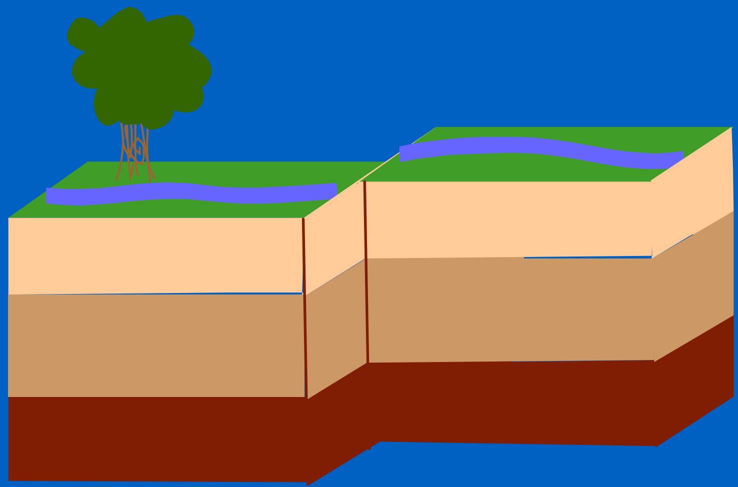
LIQUEFACTION

- The development of high pore water pressures due to ground shaking and upward flow of water turning the sand into a liquefied condition.
- It can result in ground surface settlement or a bearing capacity failure of the foundation.

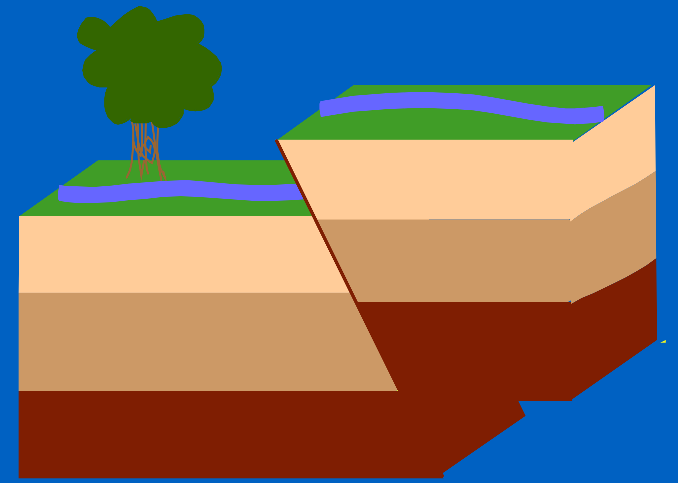
INVESTIGATION for ASSESSING SEISMIC HAZARDS

PURPOSE : **to demonstrate absence of seismic hazards or adequately define the seismic hazards so that suitable recommendations for mitigation can be developed.**

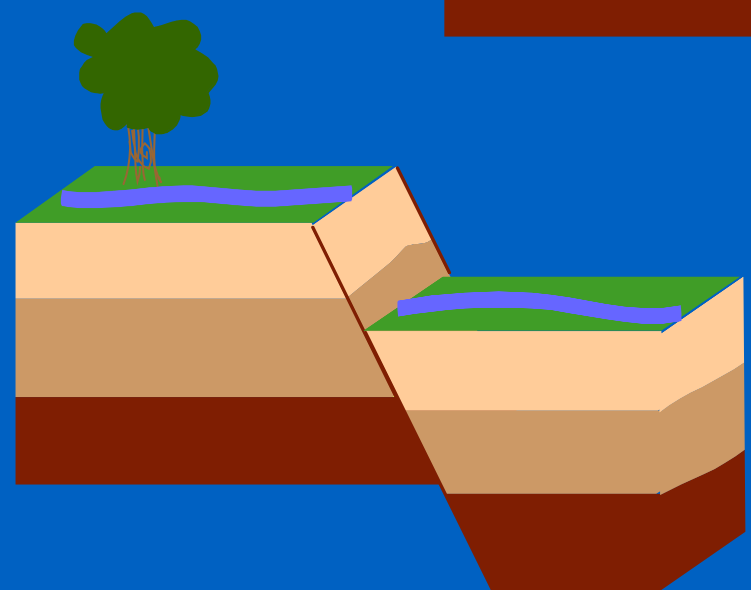
THREE TYPES OF FAULTS



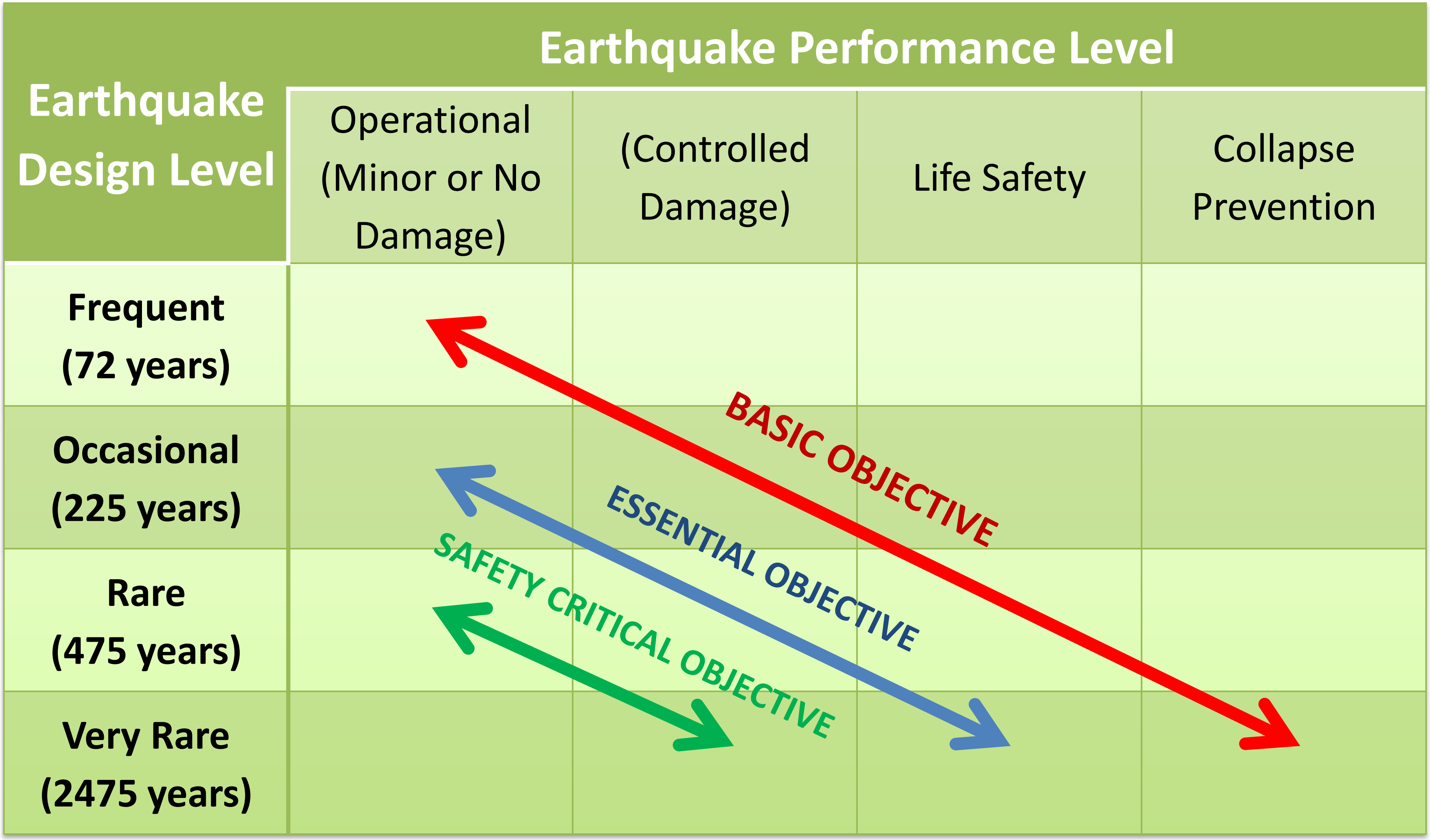
Strike-Slip



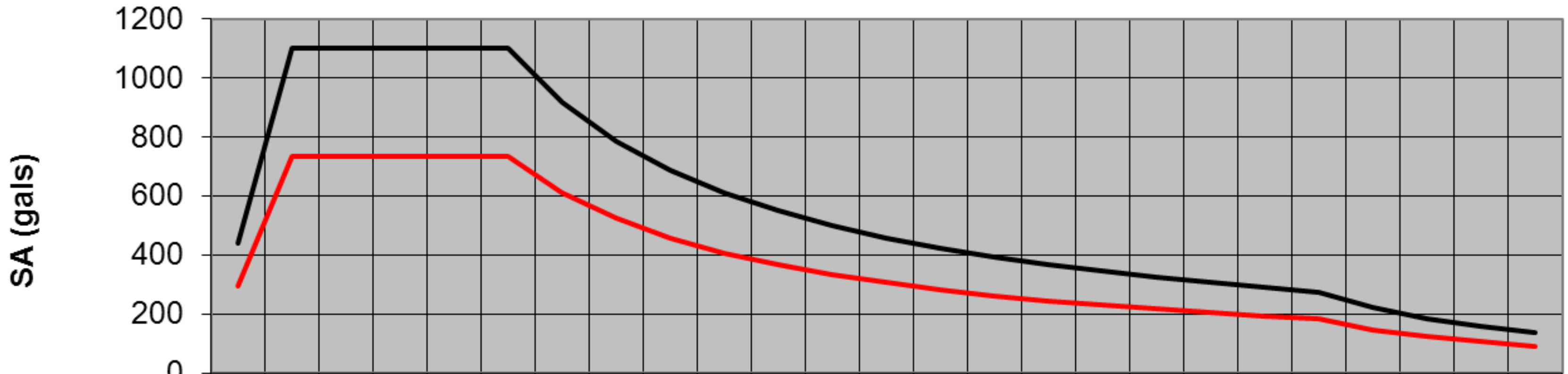
Thrust



Normal



PERFORMANCE MATRIX (after SEAOC 1995)

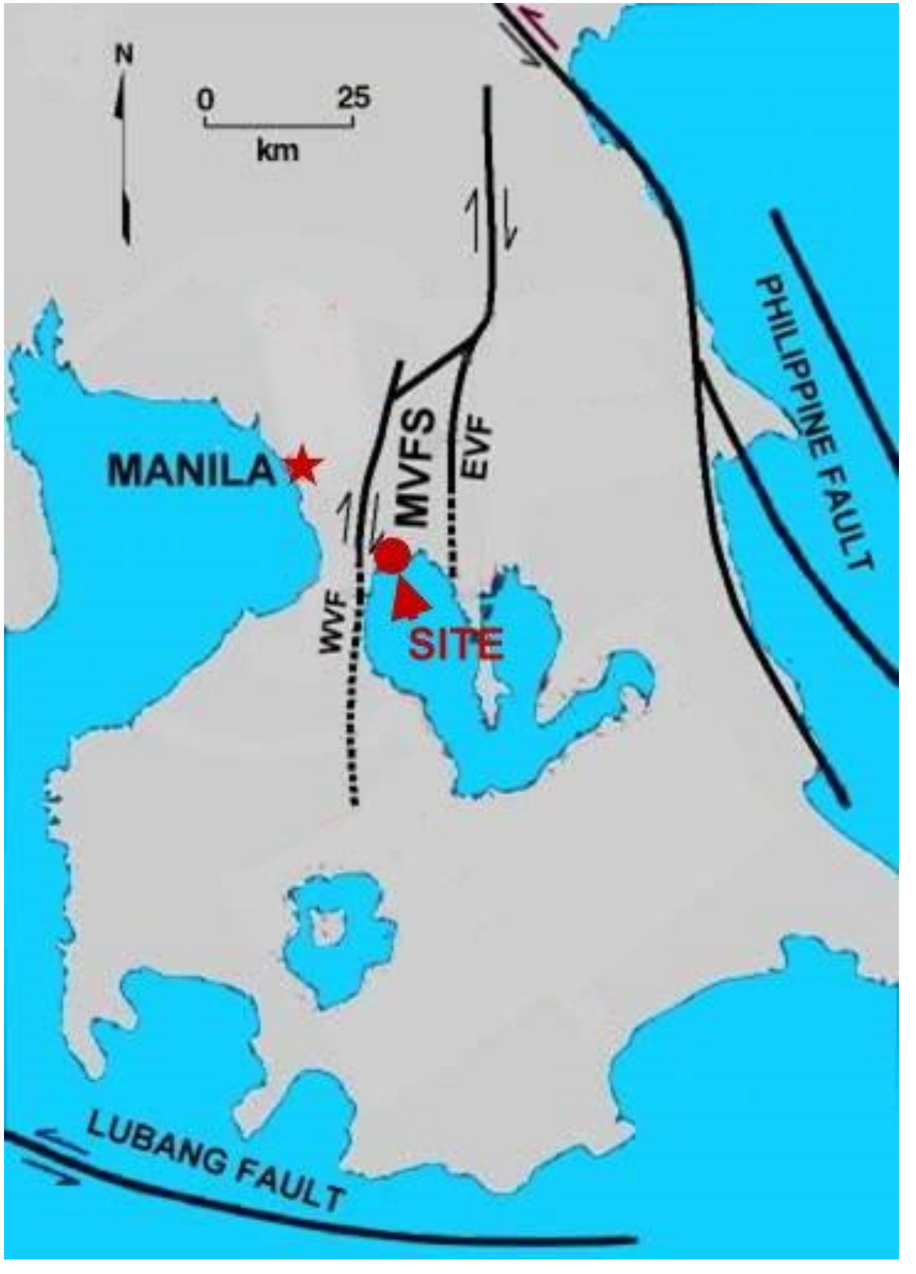


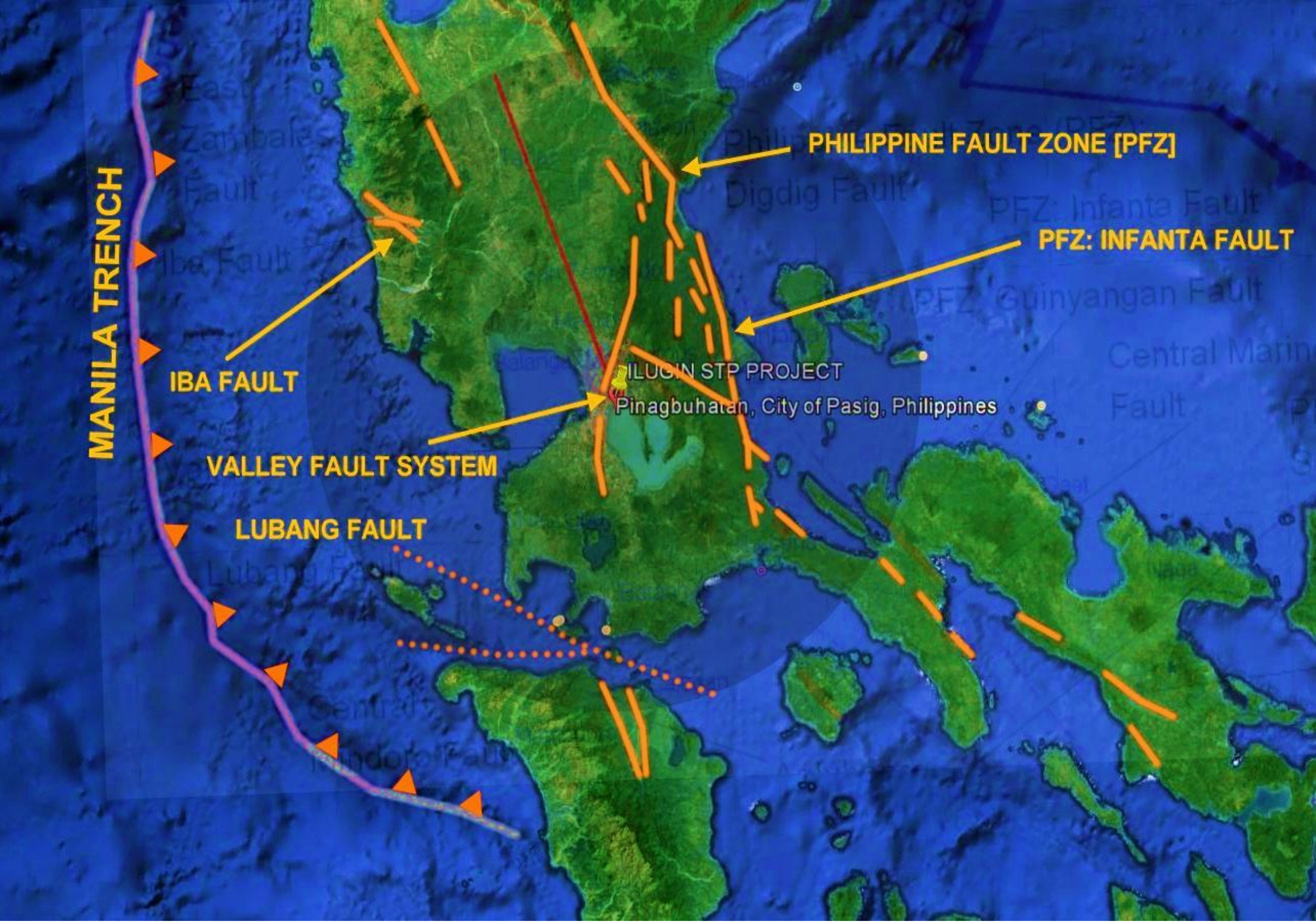
	0	0.2	0.4	0.6	0.8	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	5	6	7	8
RSA M7.2-D43	294	734	734	734	734	734	611	524	458	407	367	333	306	282	262	244	229	216	204	193	183	147	122	105	91.7
NSCP 2010	440	1100	1100	1100	1100	1100	917	786	688	611	550	500	458	423	393	367	344	324	306	289	275	220	183	157	138

475 YEAR RETURN PERIOD (5% damping)

Distance from Tagbilaran to epicenter: 43 km
Earthquake Magnitude: 7.2

EXAMPLE: SITE SPECIFIC SEISMICITY STUDY


N
0
25
km
MANILA
MVFS
EVF
WVF
SITE
PHILIPPINE FAULT
LUBANG FAULT



Fault lines within 150 km radius.

FAULT No.	Fault Name	Fault Type	Fault Length (km) 475YRP	Fault Length (km) 950YRP	Epicntrl Fault Distance (km)	Mw 450 YRP	Mw 2475 YRP
1	Fault #1	SS	67	100	3	6.8	7.4
2	Fault #2	SS	136	150	50	7.5	7.6
3	Fault #3	SS	125	150	60	7.5	7.6
4	Fault #4	SS	56	150	70	7.2	7.6
5	Fault #5	Subdctn	255	350	180	7.8	8.2

Mo	λm	t	$P[N \geq 1] = 1-e^{-\lambda mt}$	EXPOSURE TIME	PE
5.6	0.0140	72	0.503414	50	50%
6.0	0.0045	224	0.201484	50	20%
6.8	0.0022	475	0.095163	50	10%
7.4	0.0004	2475	0.024690	50	2%

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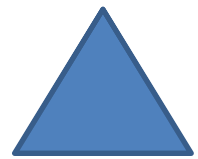
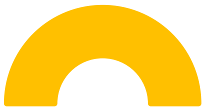
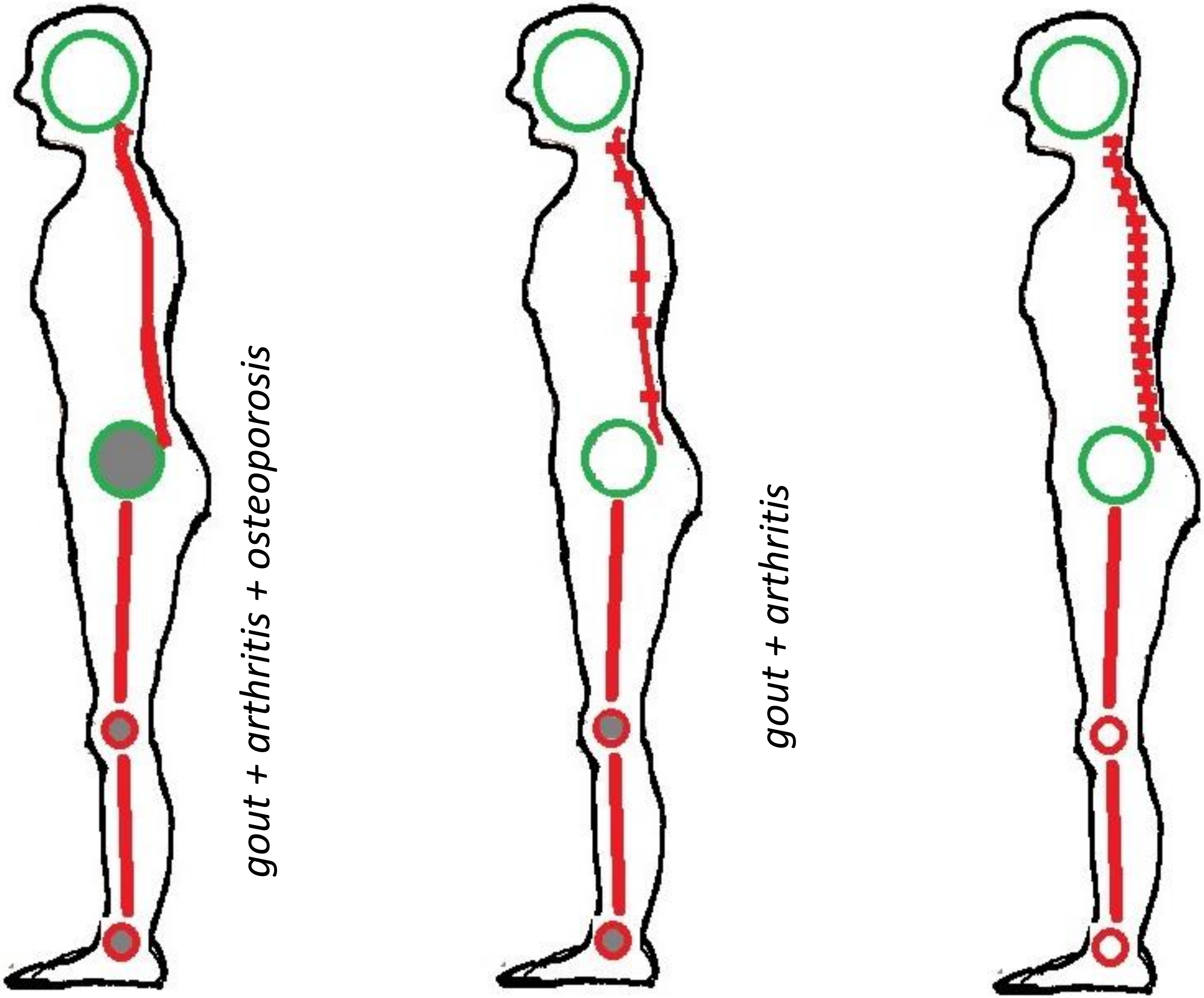
ANALYSIS APPROACH

BASIC PRINCIPLES OF ENGINEERING

Engineering retrofitting and restoration works require a good understanding of the basic principles of structural engineering on the behavior of:

- **the triangle**  $F = ma$
- **the lintel**  $F = ma + kd$
- **the arch**  $F = ma + cv + kd$



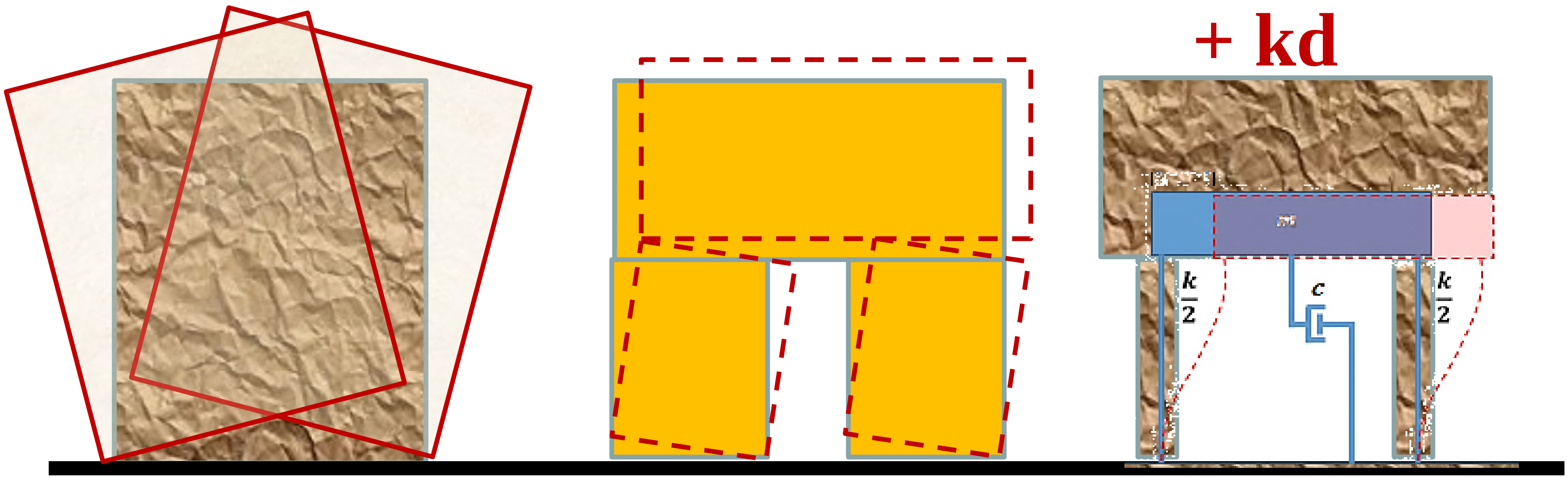
$$F = ma \qquad F = ma + kd \qquad F = ma + cv + kd$$

FLEXIBILITY OF HUMAN SKELETON

F = ma

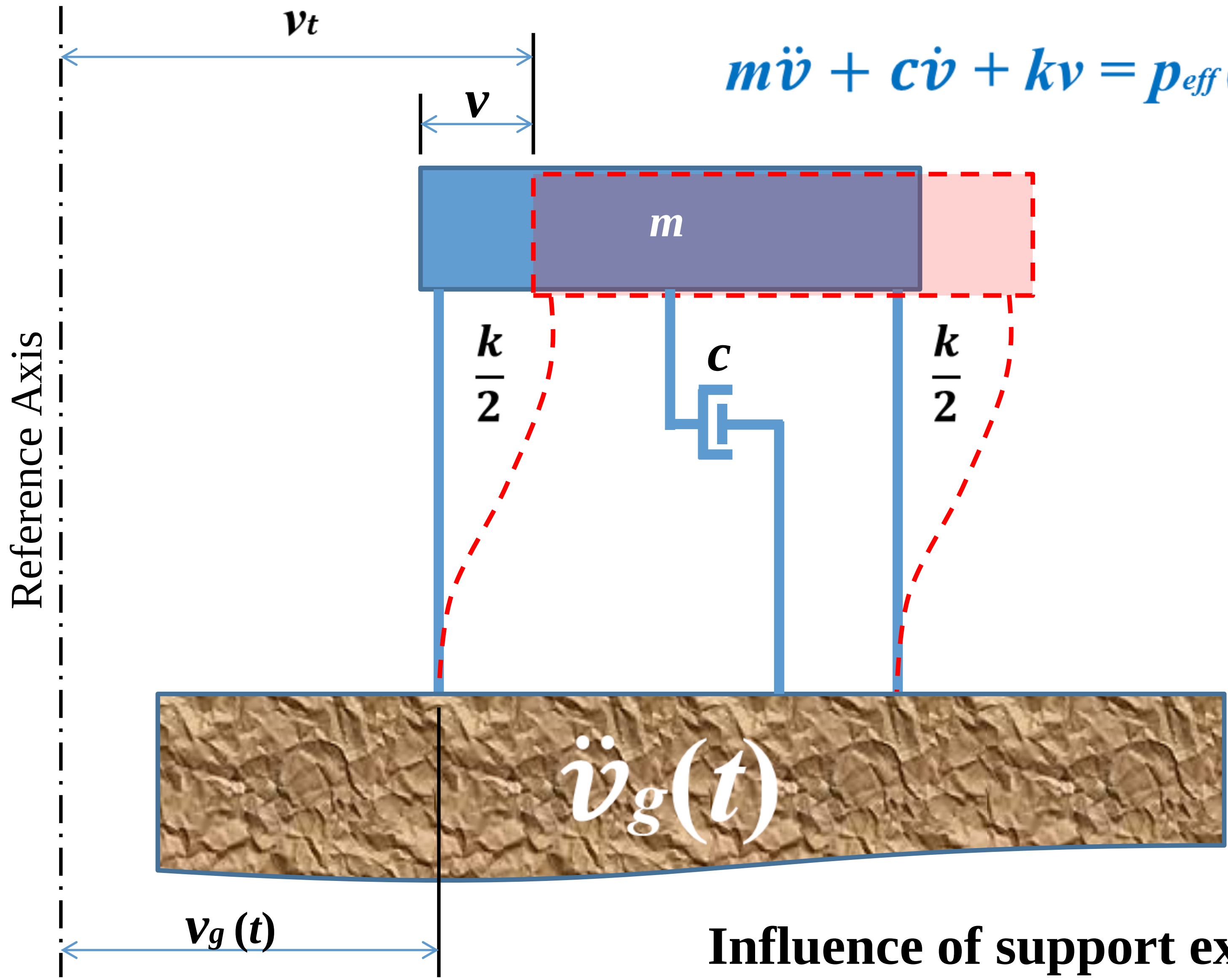
F = ma
+ kd

F = ma
+ cv
+ kd

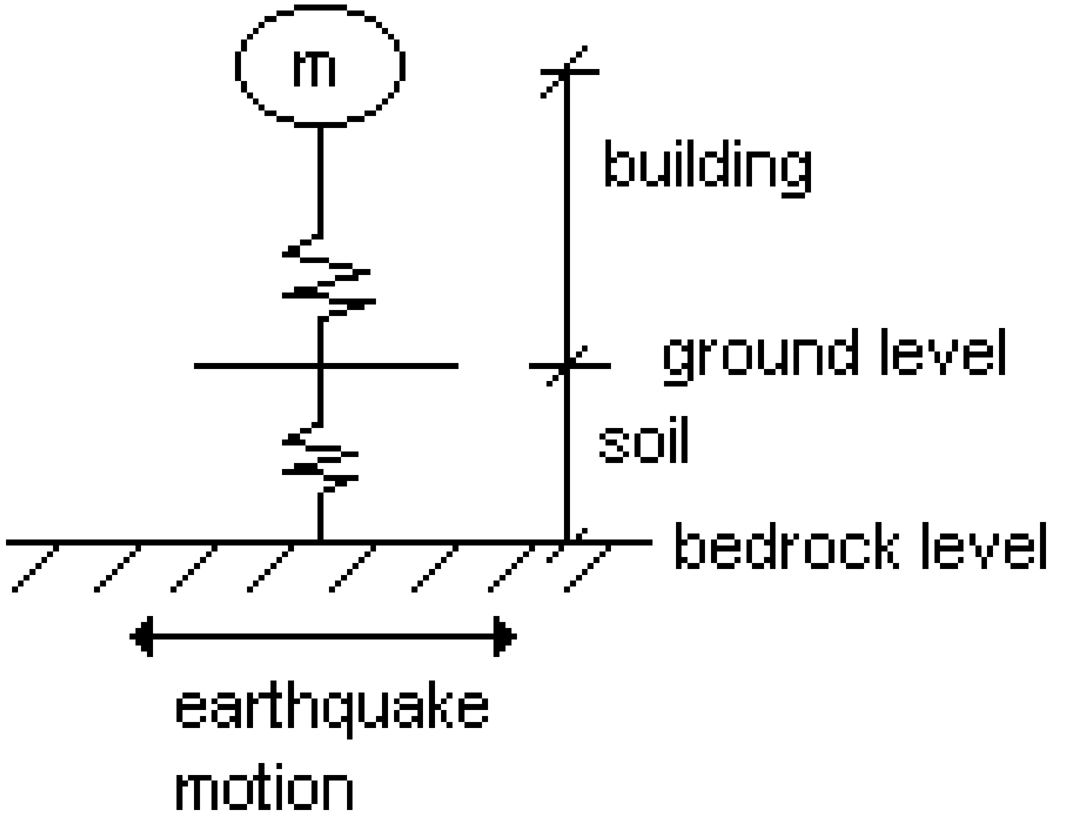


$$m\ddot{v} + c\dot{v} + kv = p(t)$$

$$m\ddot{v} + c\dot{v} + kv = p_{eff}(t)$$

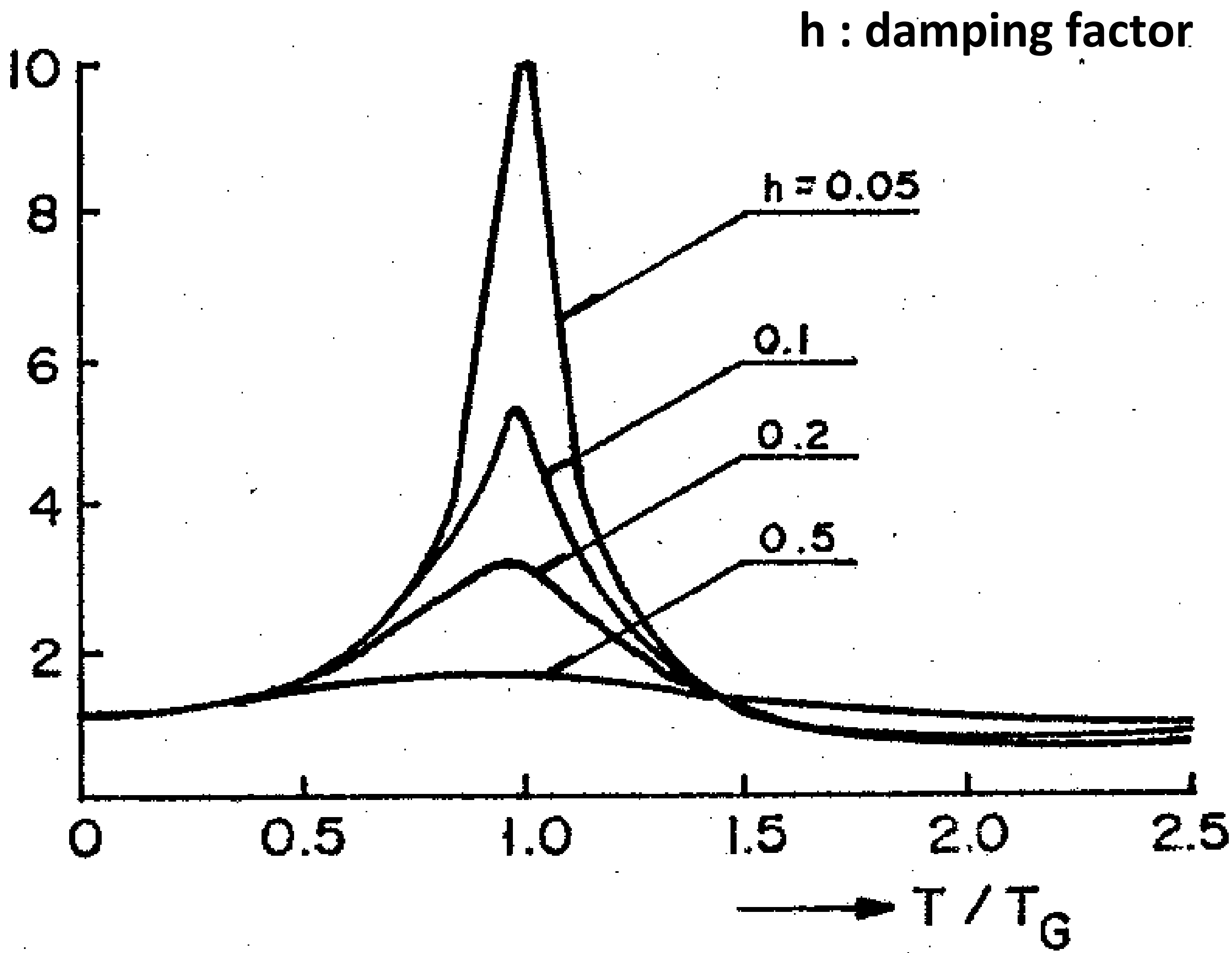


Influence of support excitation on SDOF equilibrium



Soil profile type:

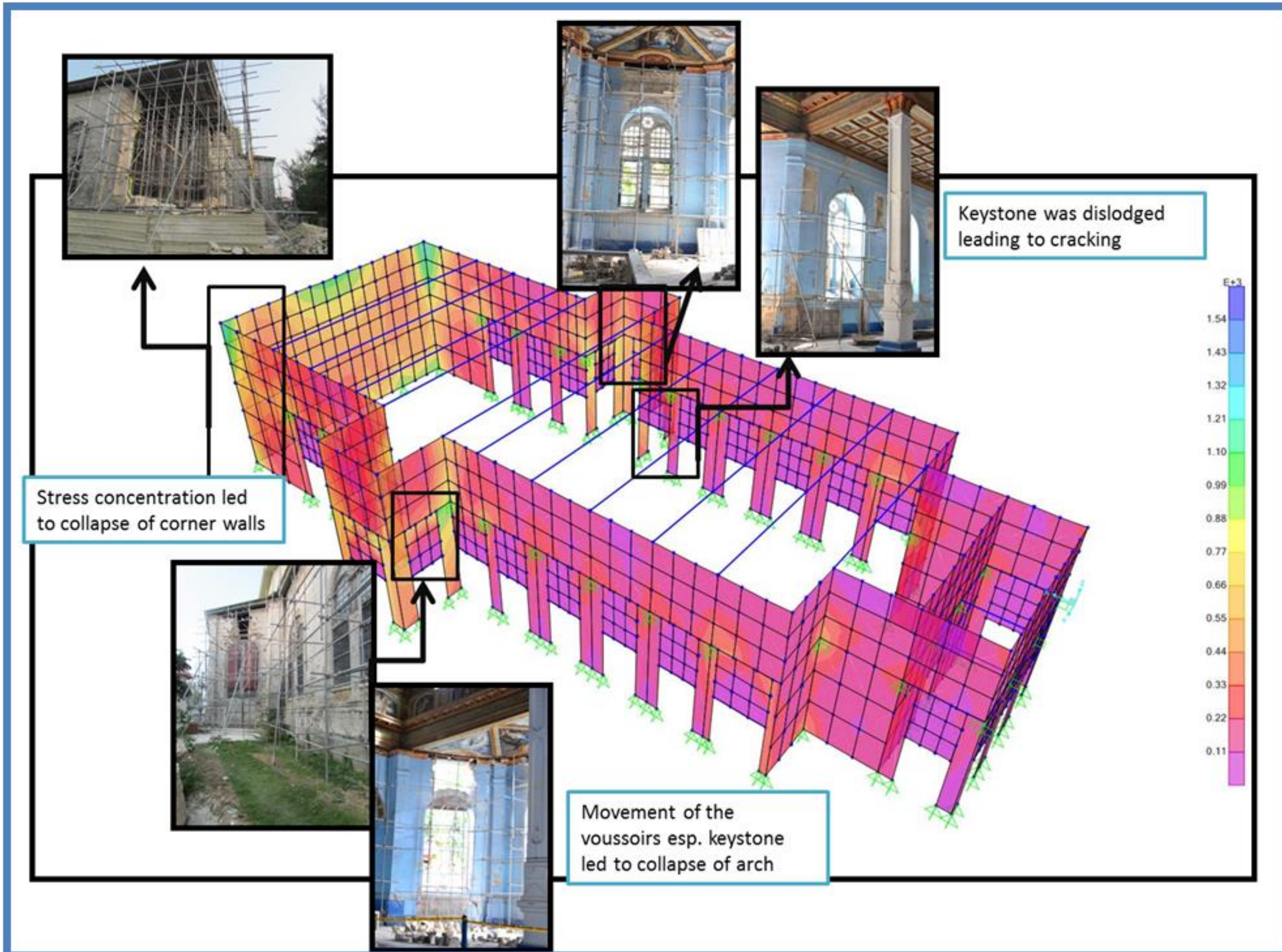
- The soil layers beneath a structure effects the way that structure responds to the earthquake motion.
- When period of vibration of the building is close to the period of vibration of the underlying soil, the bedrock motion is amplified.

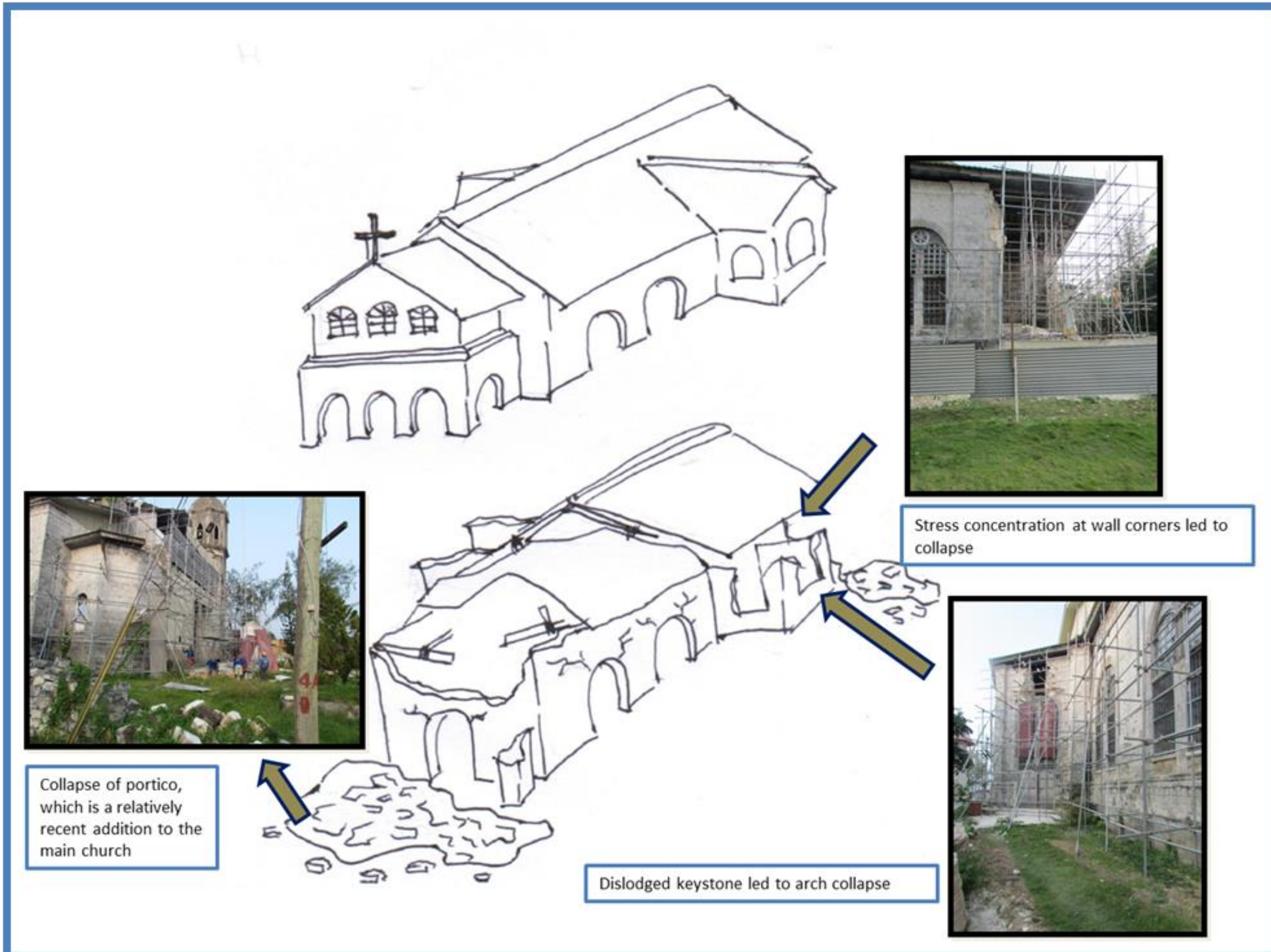


AMPLIFICATION OF GROUND ACCELERATION

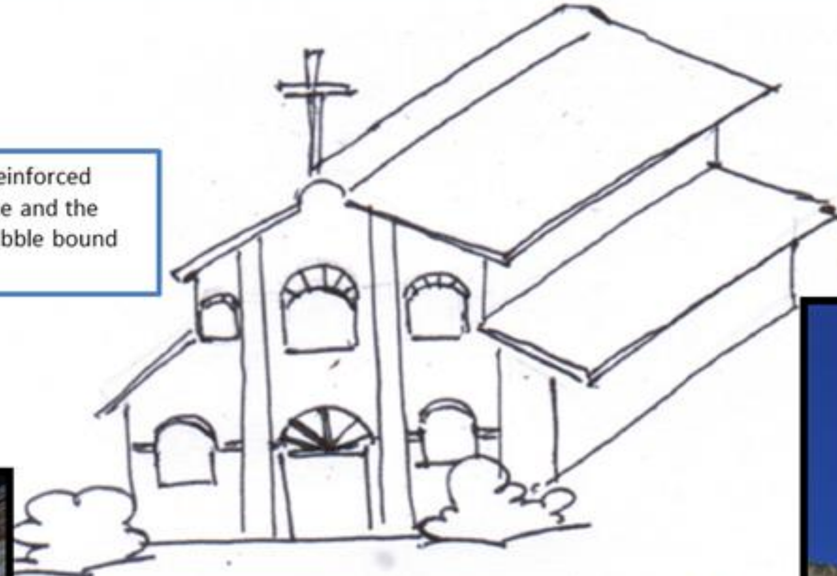

ANALYSIS APPROACH

- Complete data on material properties and interaction
- Damping properties
- Analysis is on a case-to-case basis.
- Design programs that may be used in structural modeling include, but are not limited to: SAP2000, ETABS, STAAD, etc. –provided that the model can adequately represent structural behavior

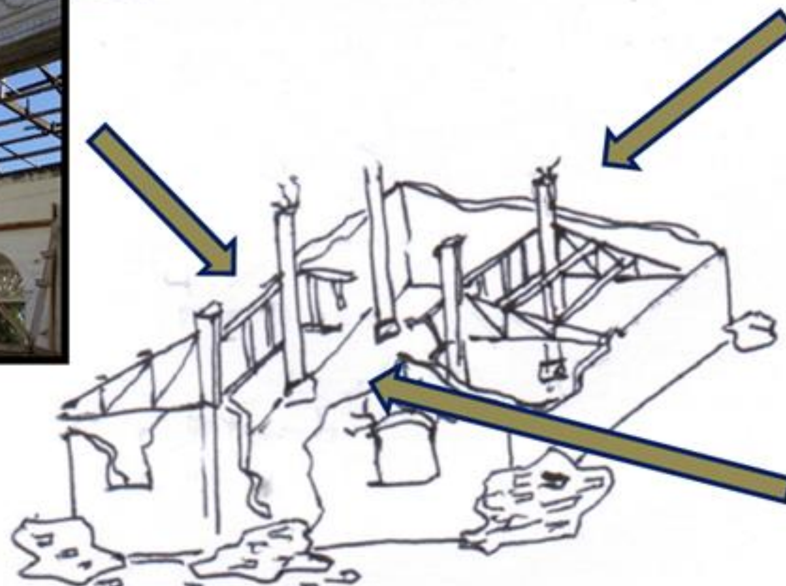

Keystone was dislodged leading to cracking
Stress concentration led to collapse of corner walls
Movement of the voussoirs esp. keystone led to collapse of arch
E+3
1.54
1.43
1.32
1.21
1.10
0.99
0.88
0.77
0.66
0.55
0.44
0.33
0.22
0.11


Stress concentration at wall corners led to collapse
Collapse of portico, which is a relatively recent addition to the main church
Dislodged keystone led to arch collapse

The church fabric consists of reinforced concrete for most of the façade and the upper levels resting on lime rubble bound by coral stone and mortar



Collapse of the upper level due to instability caused by material incompatibility without adequate connection



Only the reinforced concrete columns on the nave were left standing along with the attached wooden trusses on the wings

EVOLUTION OF SEISMIC BASE SHEAR

$V = 0.1\,W$	1920's
$V = ZKCW$	1966
$V = ZKCSW$	1976
$V = \dfrac{ZIC}{R_W}\,W$	1994
$V = \dfrac{C_v\,I}{RT}\,W$	2001 - 2010

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GENERAL RECOMMENDATIONS

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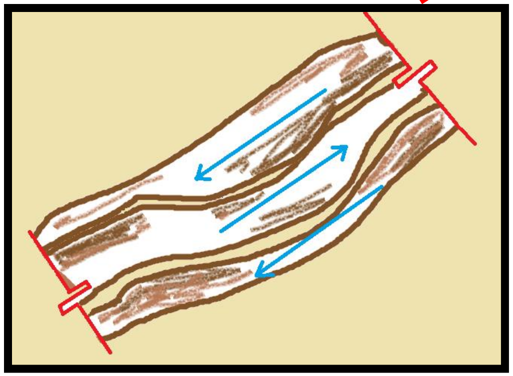
- FOOTINGS: Preferably built using stone or reinforced concrete.
- WALLS: Providing outside pilasters at wall junctions will increase seismic stability. Walls also must have vertical reinforcements.
- ROOFING: Roof structure must be light, well-connected and adequately-connected to the walls.
- PLASTERING: This gives protection and durability to the walls, in addition to its contribution to aesthetics.
- BLOCKS/STONES: Must be of good quality and be adequately-bonded.


Added in 1976
Bell Tower section
fell in 1788 EQ.
ST. JAMES THE GREAT CHURCH
Bolinao, Pangasinan


ATC Plus

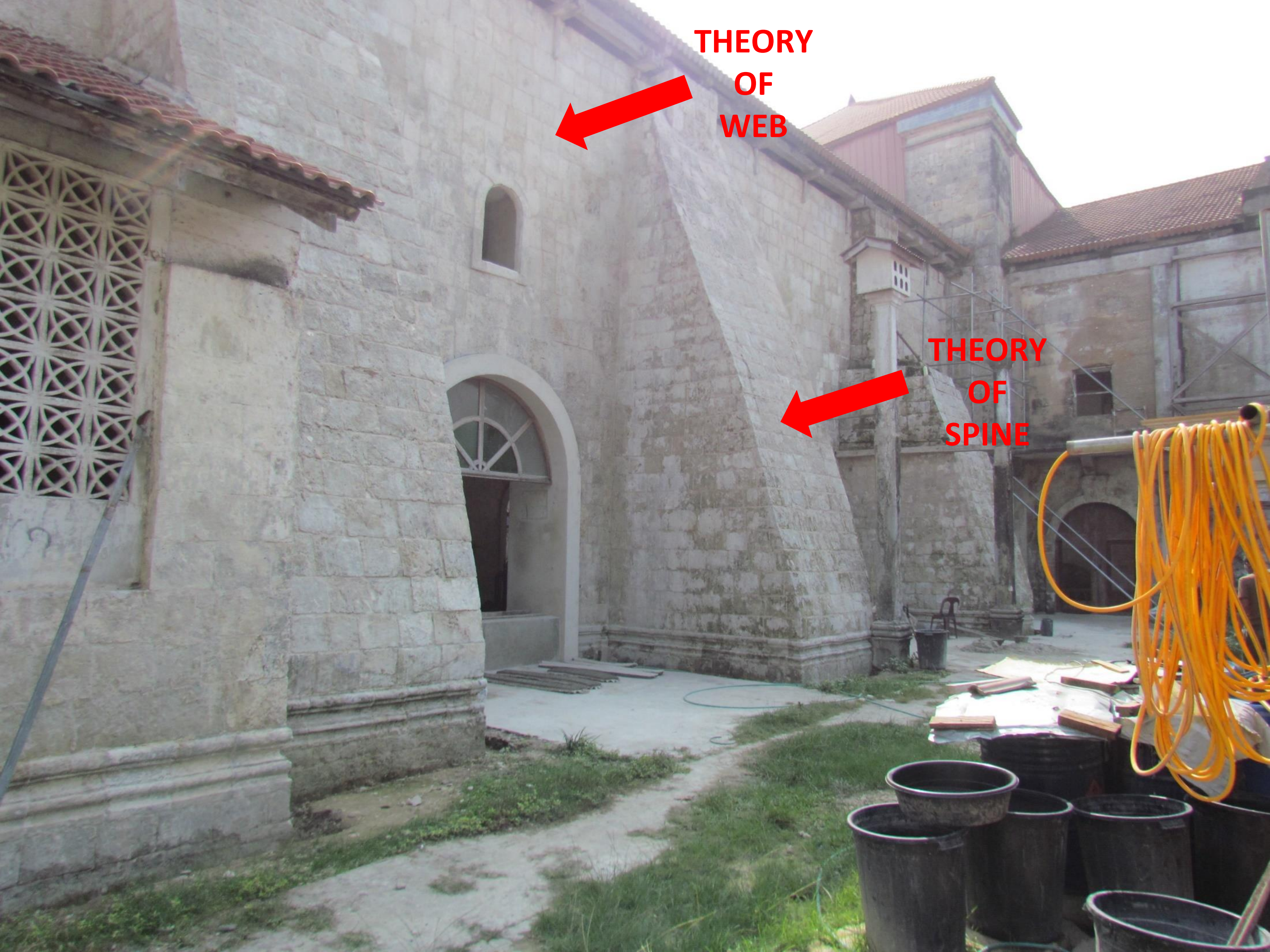
Acts as a damper.

Functions of Existing Elements



Wood trusses act as seismic dampers similar to a *muelle* or leaf springs found in *calesas* that dissipate energy by sliding together in opposite directions when force is applied. These are very effective damping mechanism that has contributed to the survival of old churches during earthquakes.


STITCHING
Notice to the Public
DANGER
CONSTRUCTION
AREA
KEEP OUT!


THEORY
OF
WEB
THEORY
OF
SPINE


WARNING
HARD HAT
AREA
SAFETY
FIRST

San Agustin Church after 1880 Earthquake

SALAMAT PO!