5. TOPOGRAPHY AGGRAVATION OF SEISMIC MOTIONS

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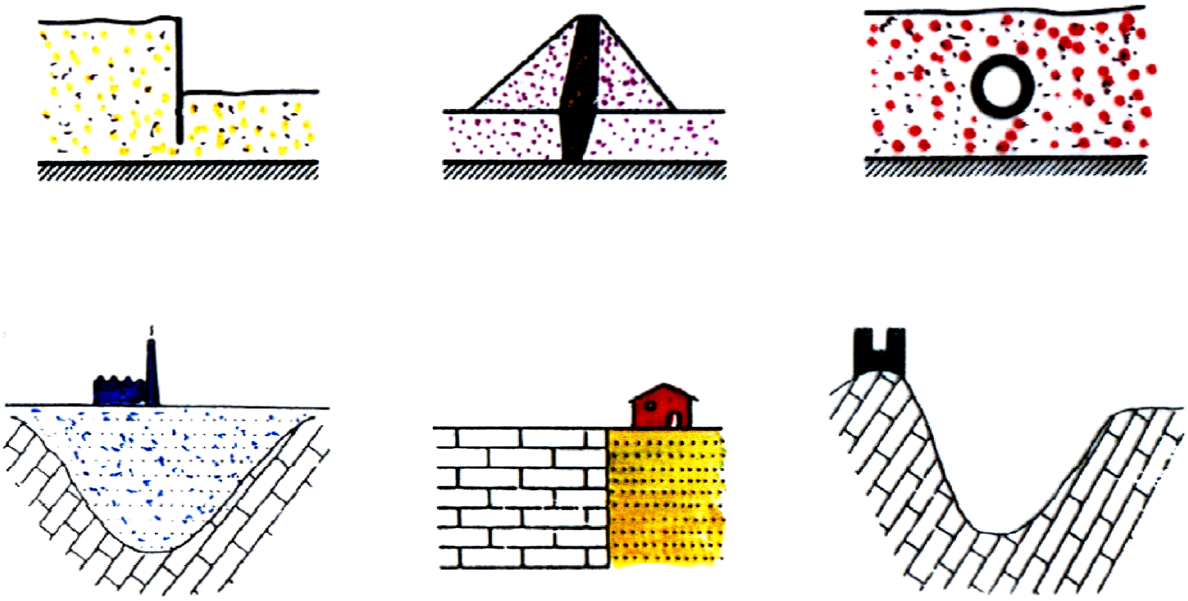
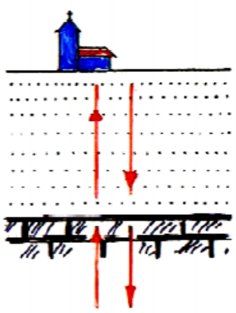
5.1 TYPICAL CASES & MECHANISMS

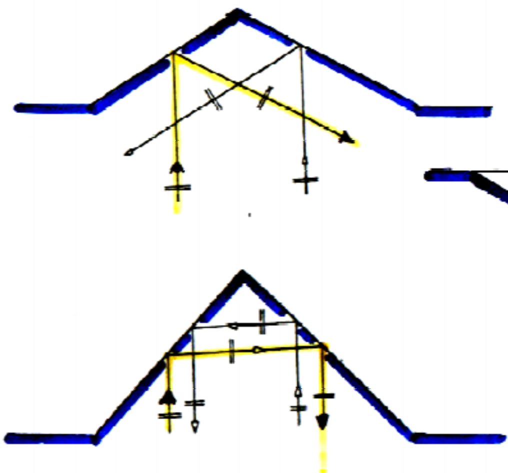


Basic Mechanisms

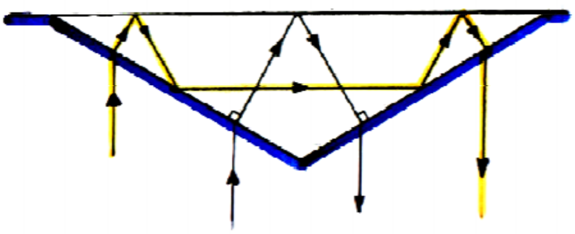
Refraction → focusing / deviation of seismic waves

1-D

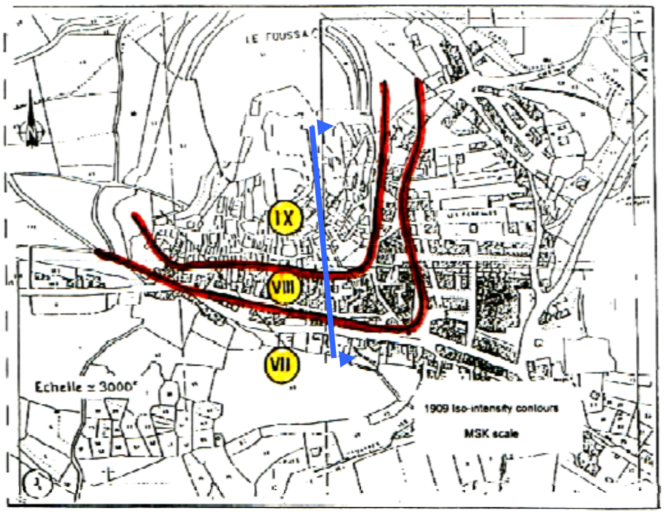




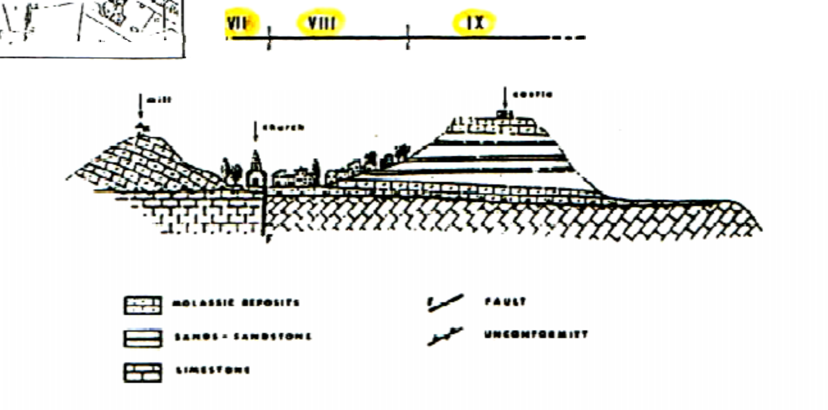
2-D

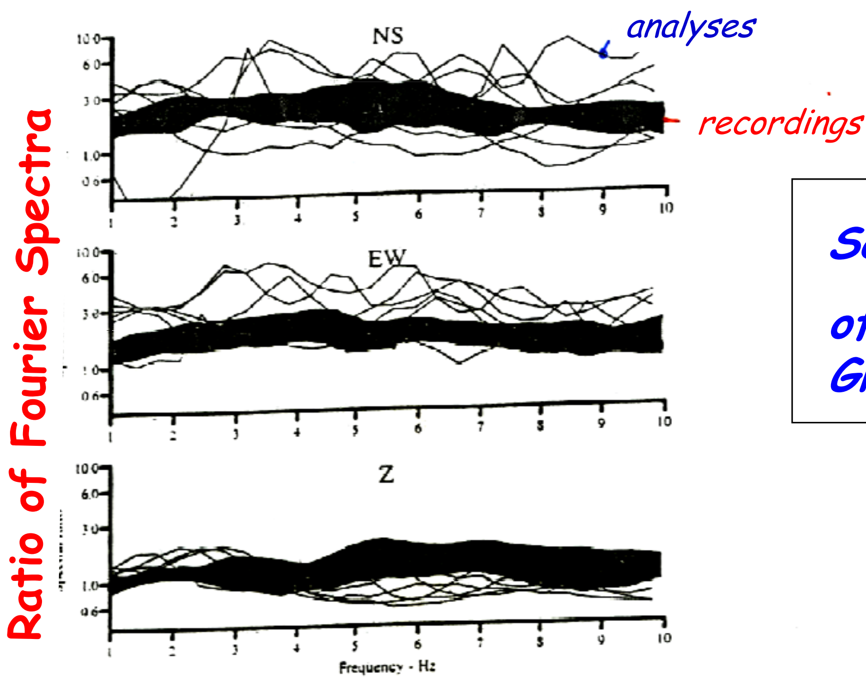


5.2 CASE HISTORIES

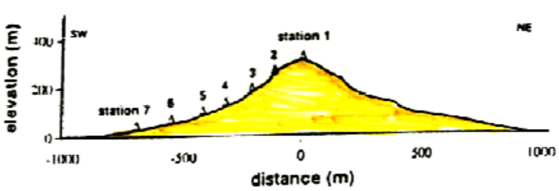


1909 Lambesc earthquake

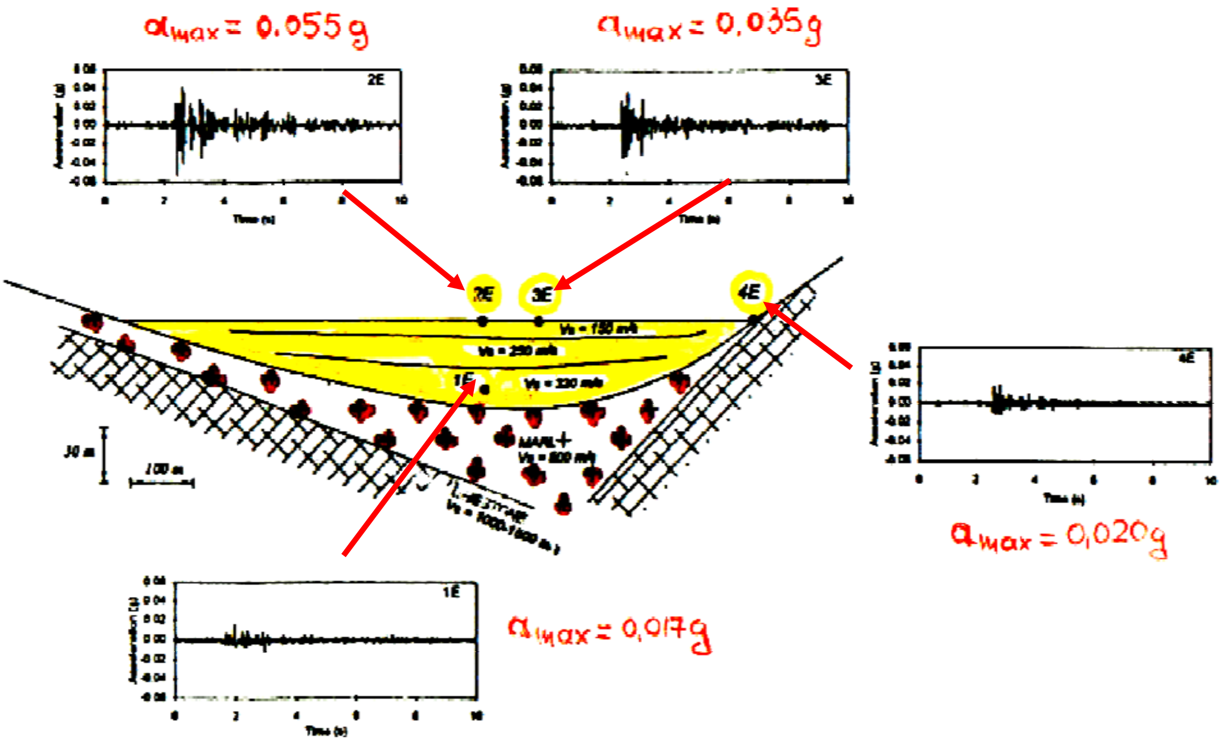




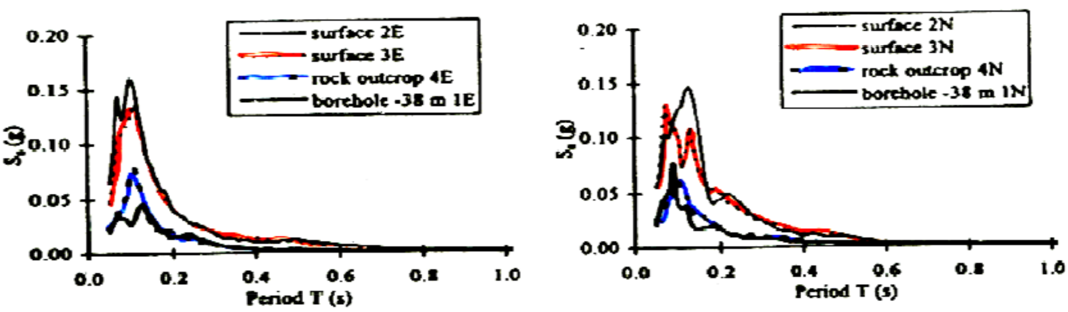
Seismic array of SOURPI, Greece

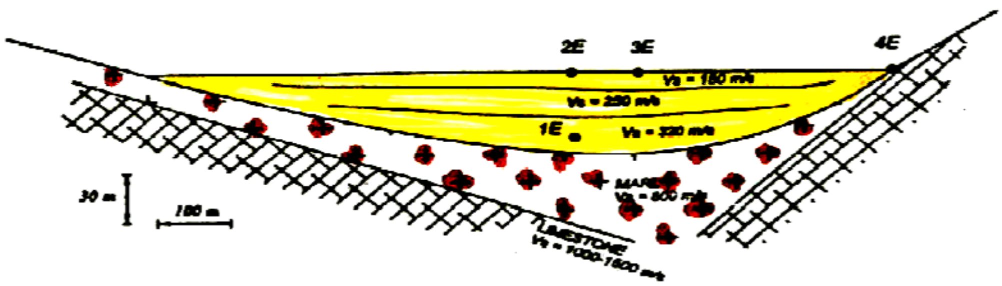


Seismic Array of CEFALONIA, Greece

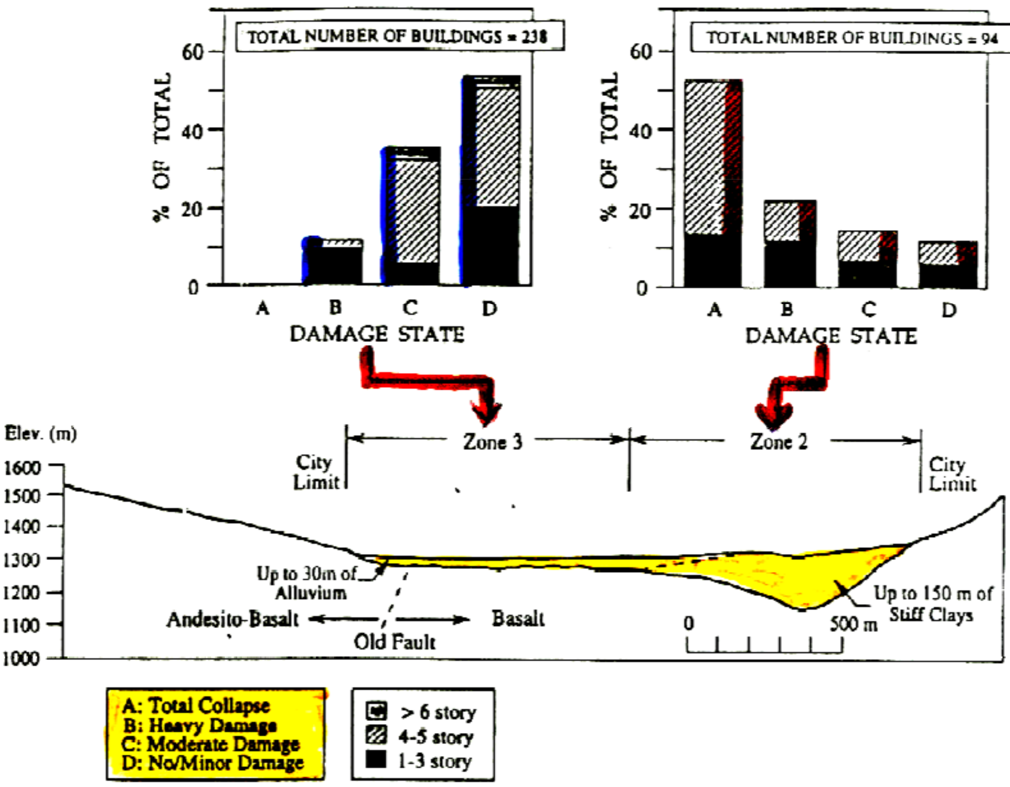


Seismic Array of CEFALONIA, Greece

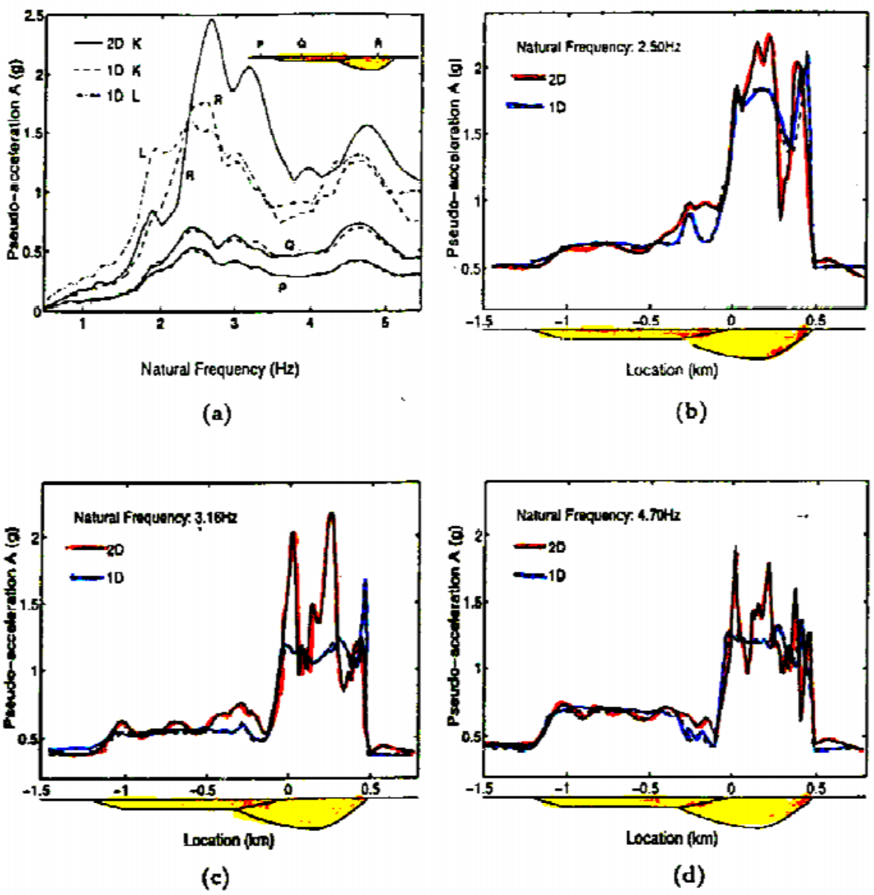




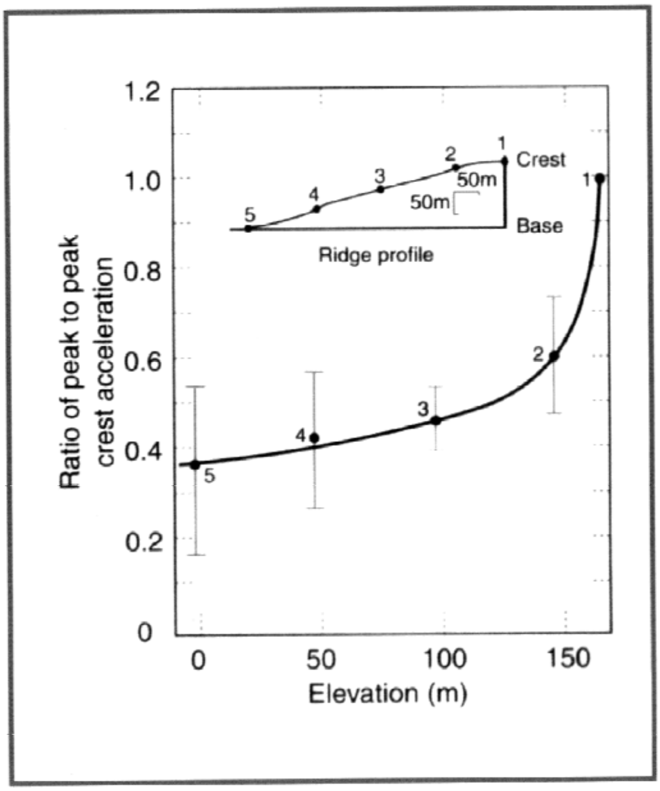
KIROVAKAN APMENIA (1988) earthquake



KIROVAKAN seismic response analyses

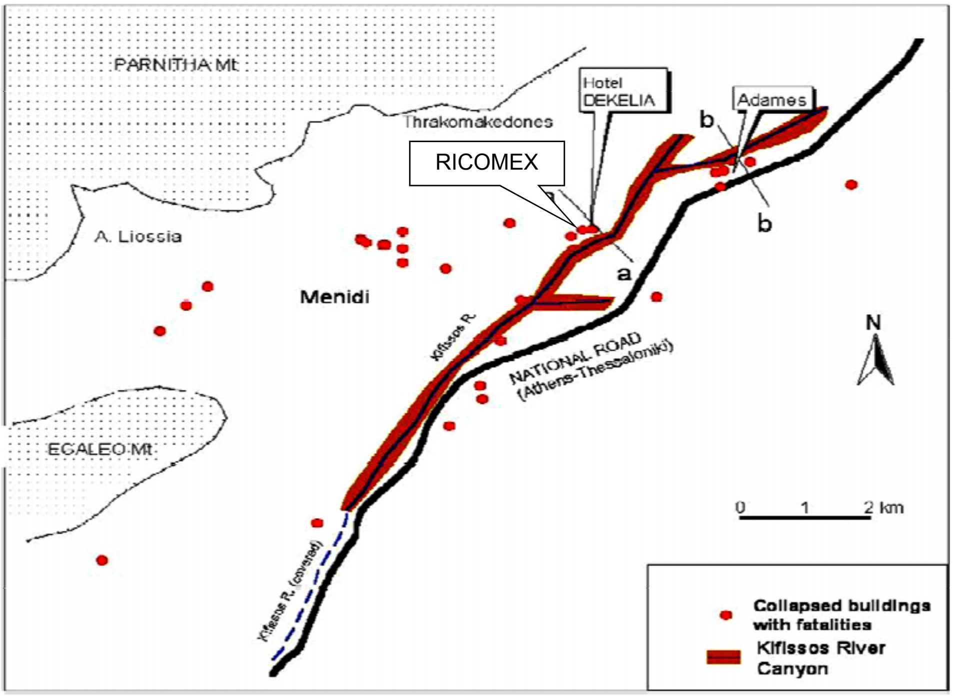


Seismic Array
Matsuzaki, JAPAN
(5 earthquakes)



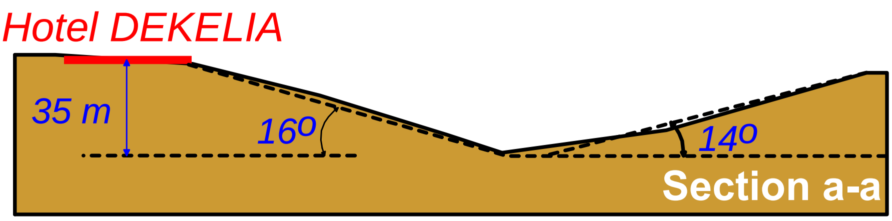
The peak seismic acceleration at the crest is …. 250% larger than that at the foot !

Athens (1999) earthquake



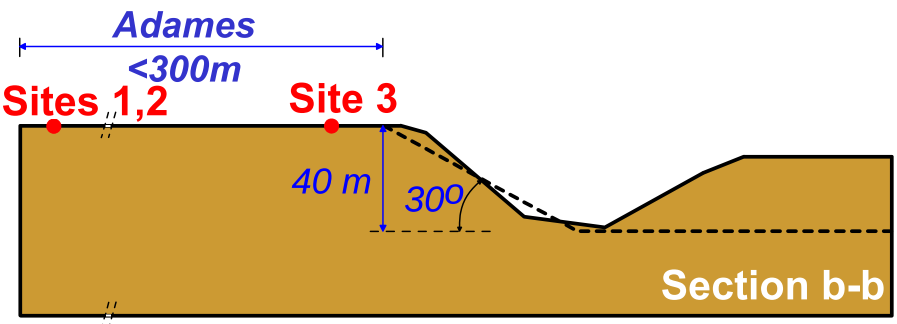
Concentration of damage buildings on both ridges of CHELIDONOU creek . . .

The case of RICOMEX factory . . .



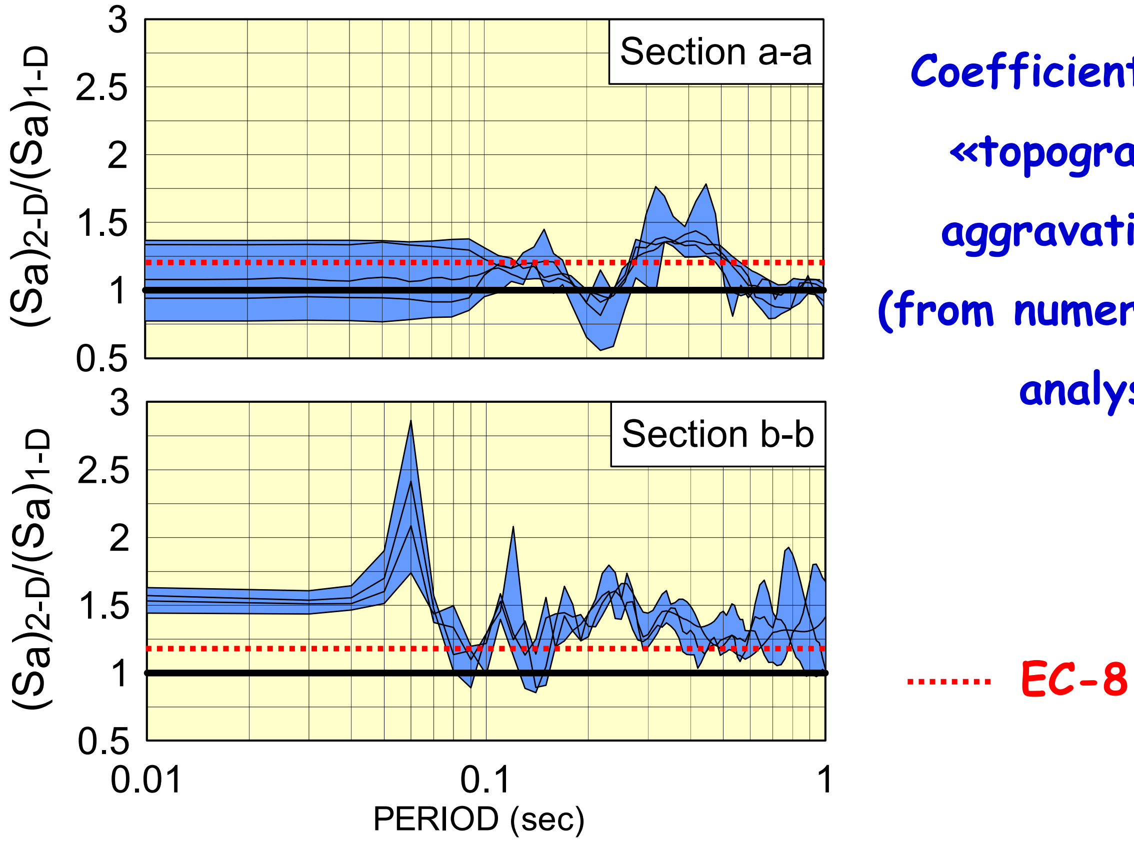
$\bar{V}_{s,30}$=380 m/sec
(NEHRP C)

Athanasopoulos et al. (2001)



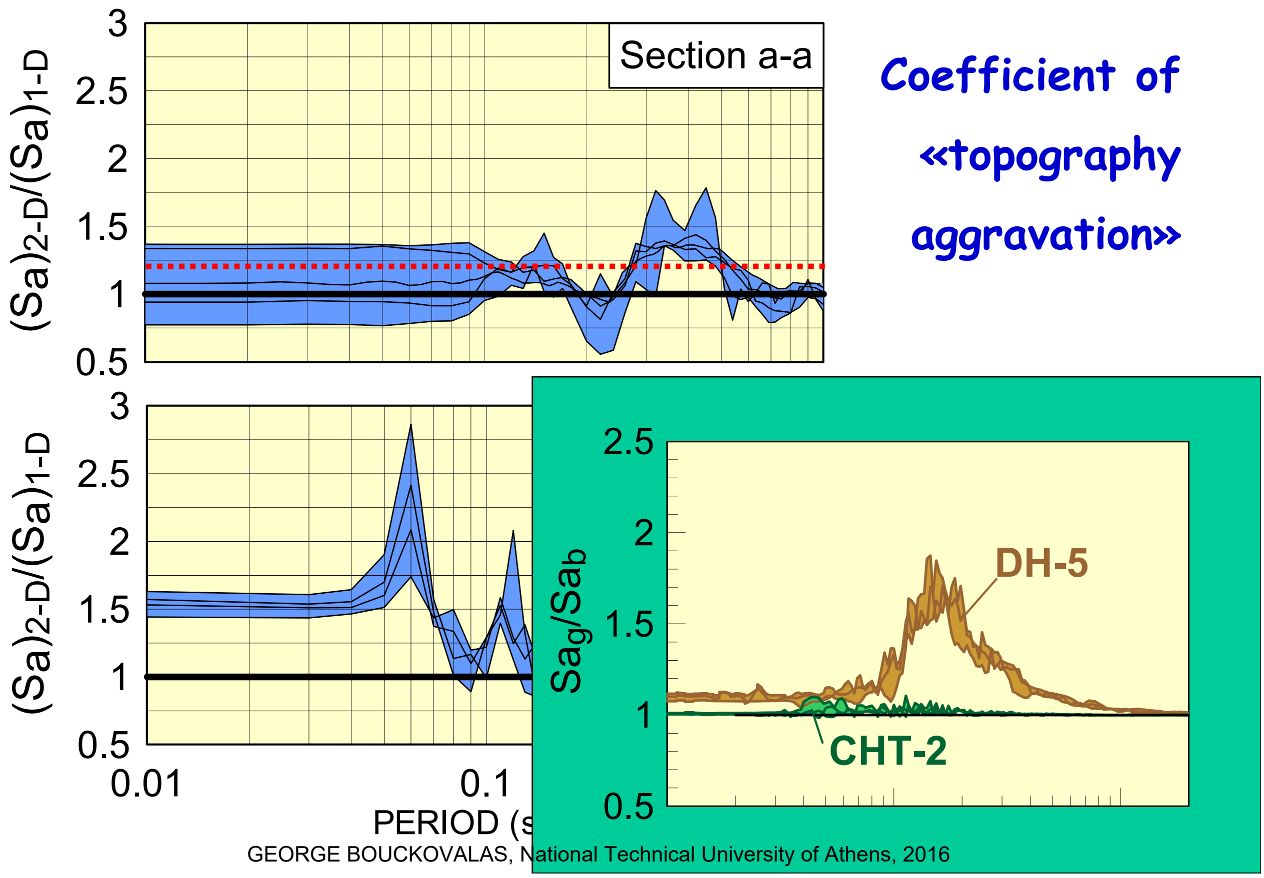
$\bar{V}_{s,30}$=370÷490 m/sec
(NEHRP C)

Kallou et al. (2001)



Coefficient of «topography aggravation» (from numerical analyses)

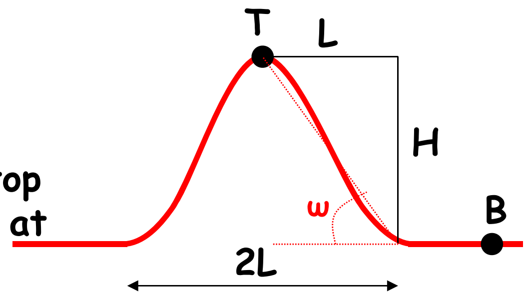
EC-8



Coefficient of «topography aggravation»

5.3 DESIGN GUIDELINES & SEISMIC CODES

(A) GELI et al. (1988) for hill-like topographies



- The seismic motion at the hilltop (point T) is more intense than at the hill-foot (point B)
- Topography aggravation is more significant for the horizontal component of motion, than for the vertical (which can be ignored)
- Topography aggravation increases with average slope inclination for i=H/L>0,25 (ω>14°)
- Topography aggravation is a function of excitation frequency. In general, the maximum aggravation is anticipated for λ≈2L

(B) French Seismic code (PS 92):

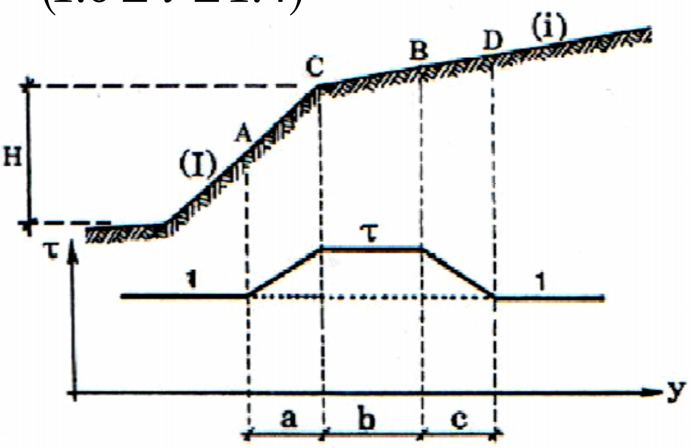
$$a_{max}(2D) = \tau \cdot a_{max}(1D)$$

$$\tau = 1 + 0.8(I - i - 0.4) \qquad (1.0 \le \tau \le 1.4)$$

$$a = H/3$$

$$c = H/4$$

$$b = \min\left\{\frac{H+10}{4}, 20I\right\}$$

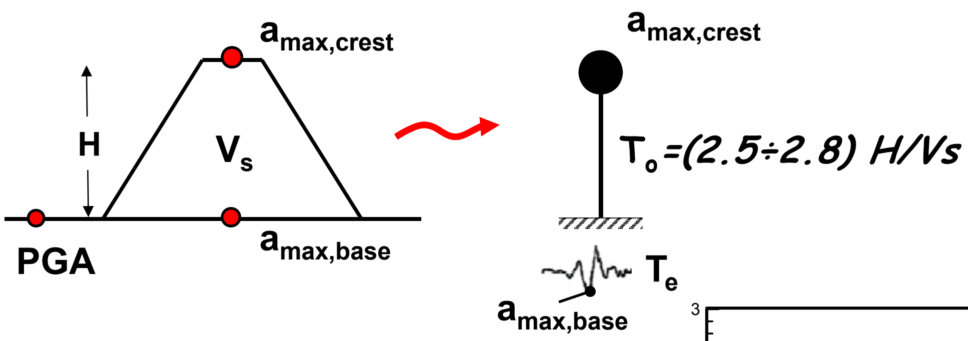


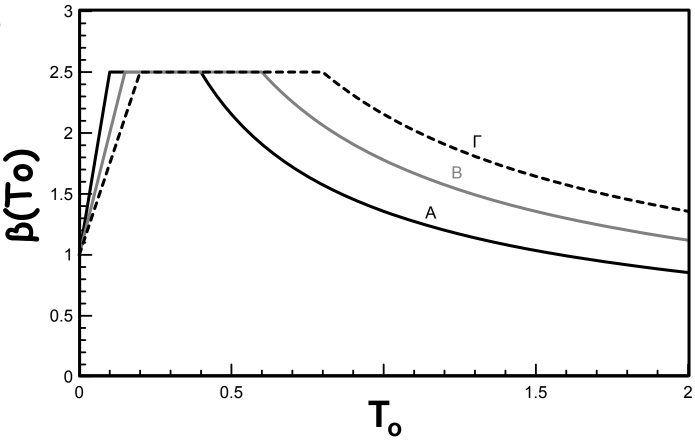
Example:

for I=1.5 (62.5°) and i=0, τ=1.40.

In addition, for H=50m, the distance to the free field behind the crest is b+c=15.0+12.5=27.5m or 0.55H

(C) Greek Seismic Code (EAK 2002)





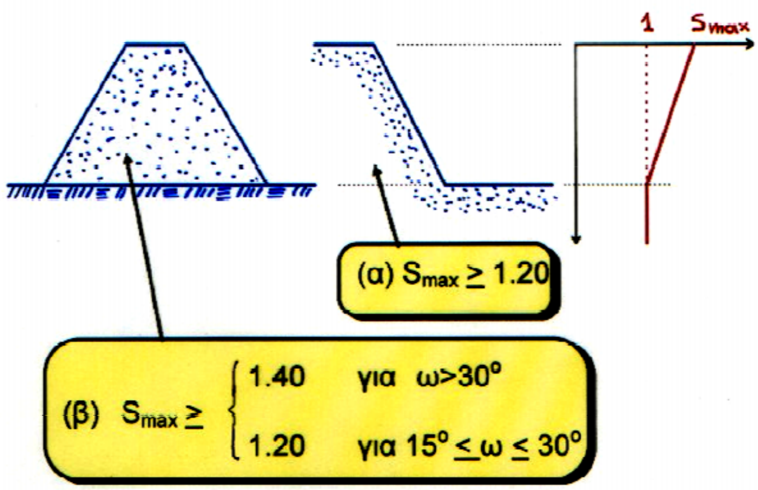
$a_{max,\ base}$= 0.50 PGA

$a_{max,\ crest}$= β(To) $a_{max,\ base}$

$a_{max,crest} \leq$ 1.25 PGA

(D) Eurocode (EC-8)

- Topography effects may be ignored for:
  H<30m ή/και i ≤ 27% (ω≤15°)
- In all other cases, the seismic acceleration increases linea … ment:



- For a soft soil cover, with thickness larger than 5.0m, the above values of S must be increased at least by 20%

5.4 COMPUTATIONAL METHODS

- Analytical solutions
  for simple geometries, uniform and linear elastic media

- Numerical solutions
  for complex geometries, non-uniform and non-linear hysteretic media (QUAD 4M, PLAXIS, ABAQUS, FLAC, etc.)

NUMERICAL METHODS

The numerical methods for the evaluation of topography effects constitute essentially generalization of the numerical methods which were presented in Chapter 4 for "Soil Amplification", since:

Soil Amplification = 1-D (vertical) propagation of seismic waves, while

Topography Aggravation = 2-D or 3-D seismic wave propagation.

However, it needs to be stressed that the "equivalent linear method" (or the "frequency domain analysis") cannot be applied now, for one main reason: there are no simple analytical solutions for 2-D or 3-D harmonic wave propagation problems, as in the case of 1-D soil amplification effects.

Thus, we will have to use non-linear time domain integration techniques, either in the form of the Finite Element (QUAD4M, TELEDYN, ABAQUS, PLAXIS…) or in the form of the Finite Difference (FLAC) method. In any case, we have to ensure that the available codes and the domain discretization that will be used satisfy the following basic requirements:

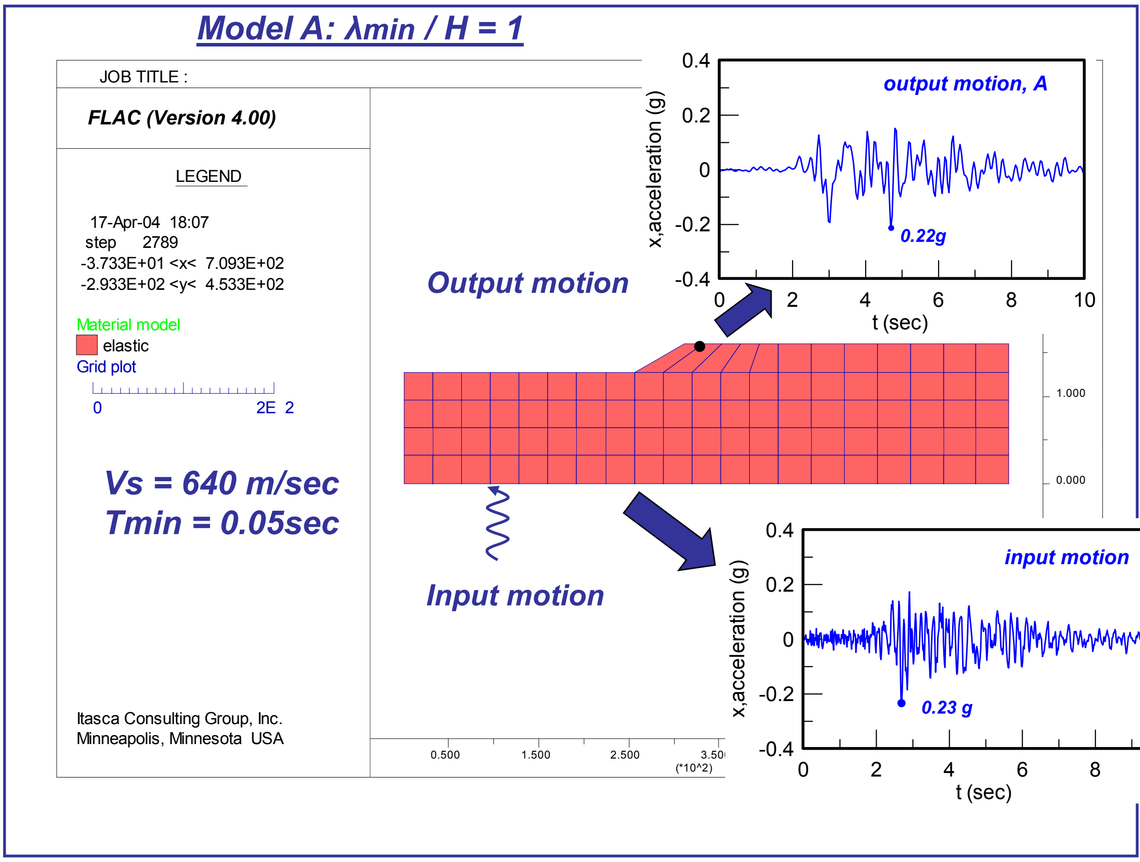
Basic requirements

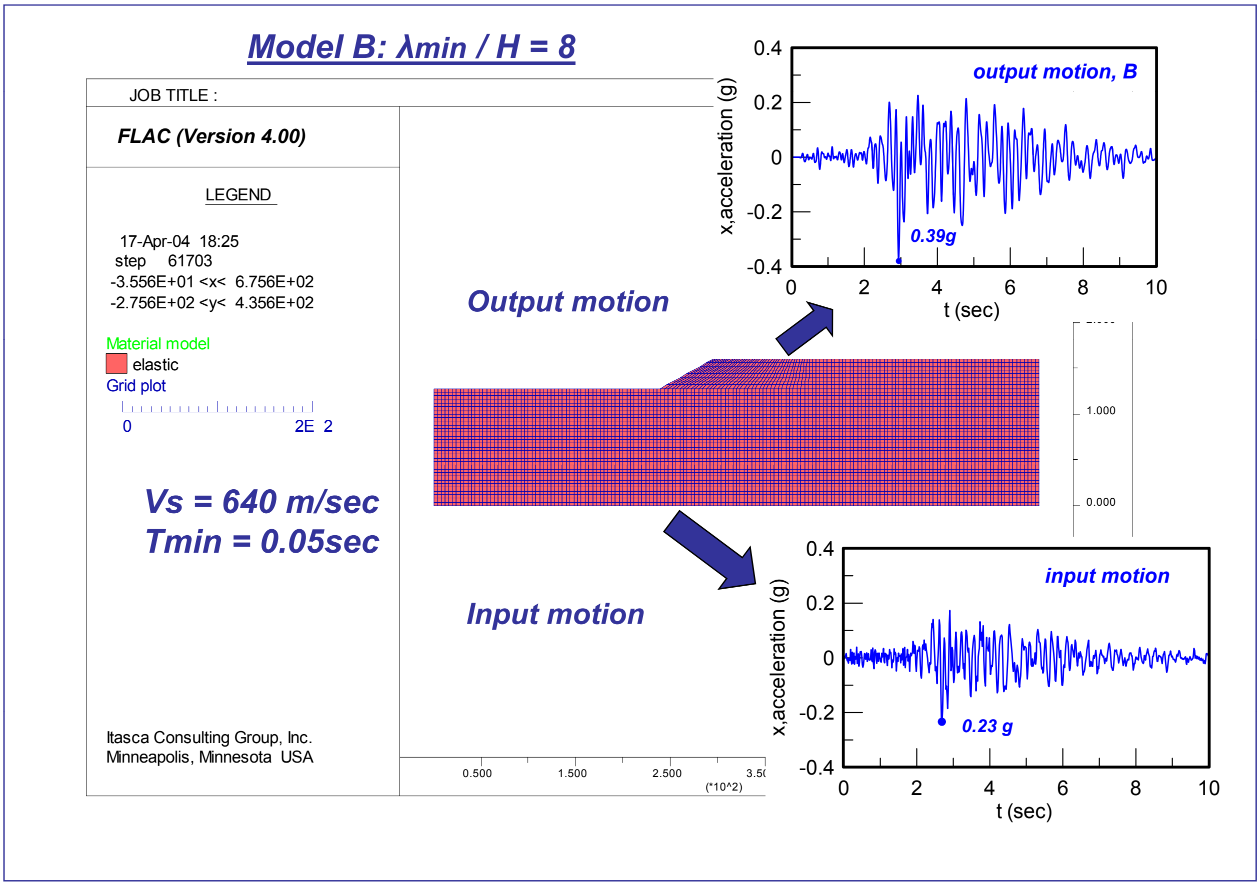
A. The constitutive model must simulate realistically, with quantitative accuracy, the cyclic soil element response, e.g. as it is described by the widely used G/G_{max} –γ and ξ-γ relationships.

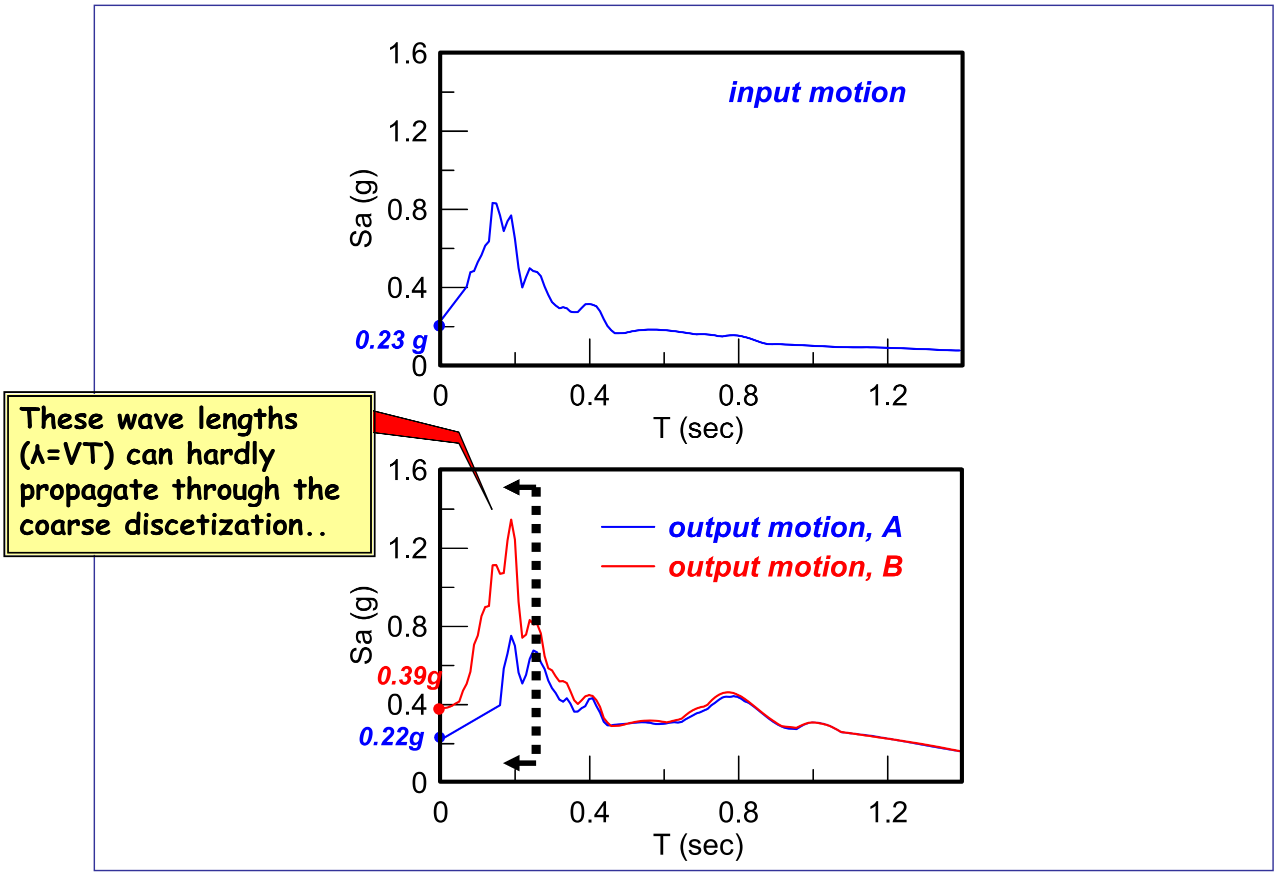
B. The boundary conditions for the sides and the base of the model cannot be simply hinges of rollers, as in static problems, but they must allow the transmition of seismic waves towards the free field. In the opposite case, we will have ……

C. The seismic excitation must be applied as time history of stresses at the base of the discretized model, and not as time histories of displacements (accelerations or velocities). This is necessary, if requirement (b) above is to be satisfied.

D. The discretization into finite elements (or zones) must be adequately fine so that the propagation of high frequency components of the seismic motion is not prevented. In gross terms, if the maximum frequency of interest is f_{max} and the wave propagation velocity is Cs, then the dimension of the soil elements (or zones) should not exceed $(0.10\text{-}0.15)\lambda_{min} = (0.10\text{-}0.15)Cs/f_{max}$ (why;)

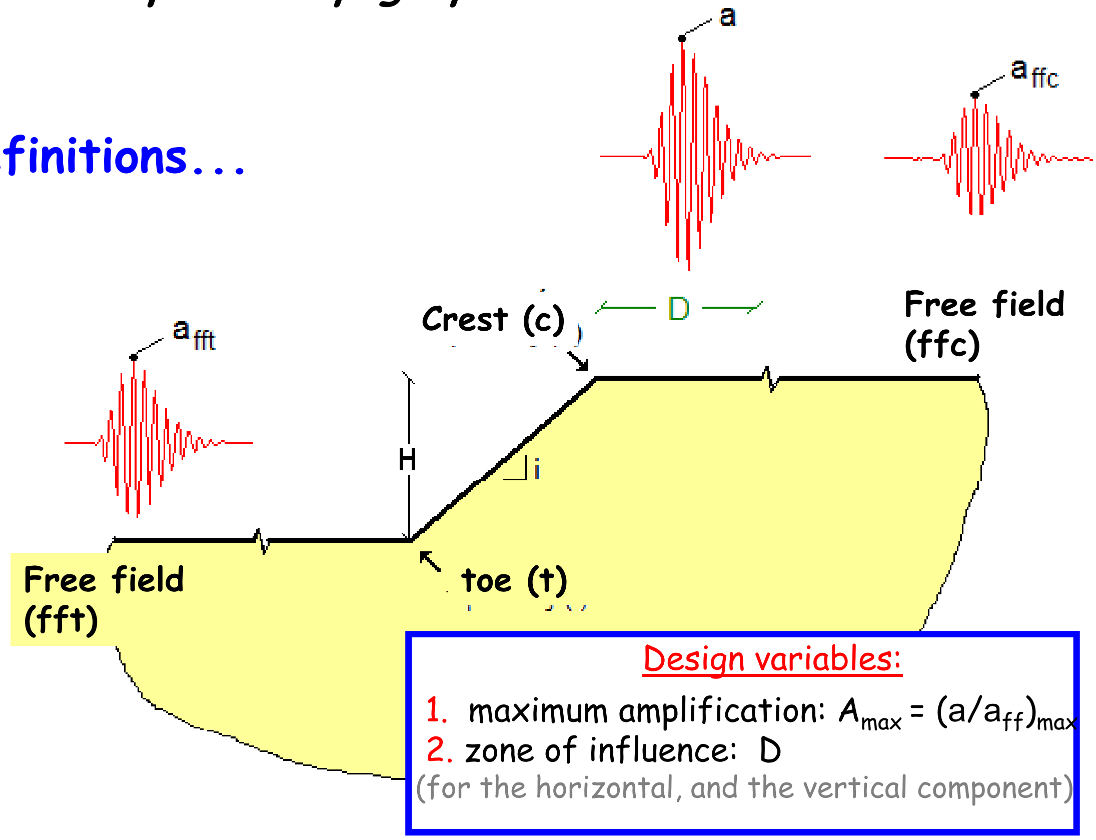



Model B: λmin / H = 8
JOB TITLE :
FLAC (Version 4.00)
LEGEND
17-Apr-04 18:25
step 61703
-3.556E+01 <x< 6.756E+02
-2.756E+02 <y< 4.356E+02
Material model
elastic
Grid plot
0 2E 2
Vs = 640 m/sec
Tmin = 0.05sec
Itasca Consulting Group, Inc.
Minneapolis, Minnesota USA
Output motion
Input motion
output motion, B
0.39g
input motion
0.23 g
x,acceleration (g)
t (sec)


input motion
Sa (g)
0.23 g
T (sec)
These wave lengths (λ=VT) can hardly propagate through the coarse discetization..
output motion, A
output motion, B
0.39g
0.22g

EXAMPLE: *Parametric analyses for the effect step-like topographies*

Definitions...



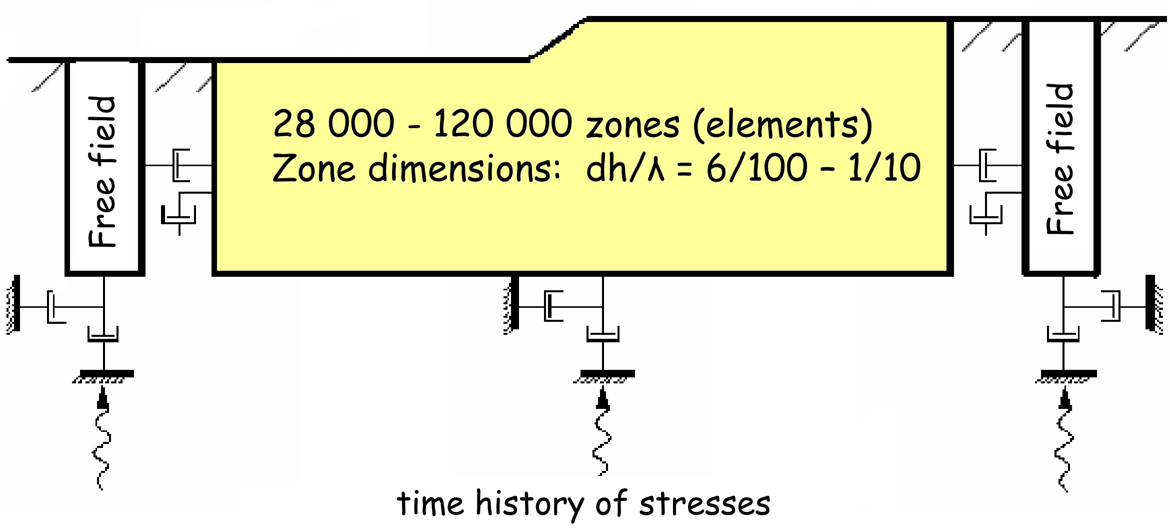
Design variables:

1. maximum amplification: $A_{max} = (a/a_{ff})_{max}$
2. zone of influence: D

(for the horizontal, and the vertical component)

Methodology . . .

- Finite Difference Code FLAC 2D
- Assumptions:
  - (2-D) homogeneous visco-elastic halfspace,
  - vertically incident SV waves

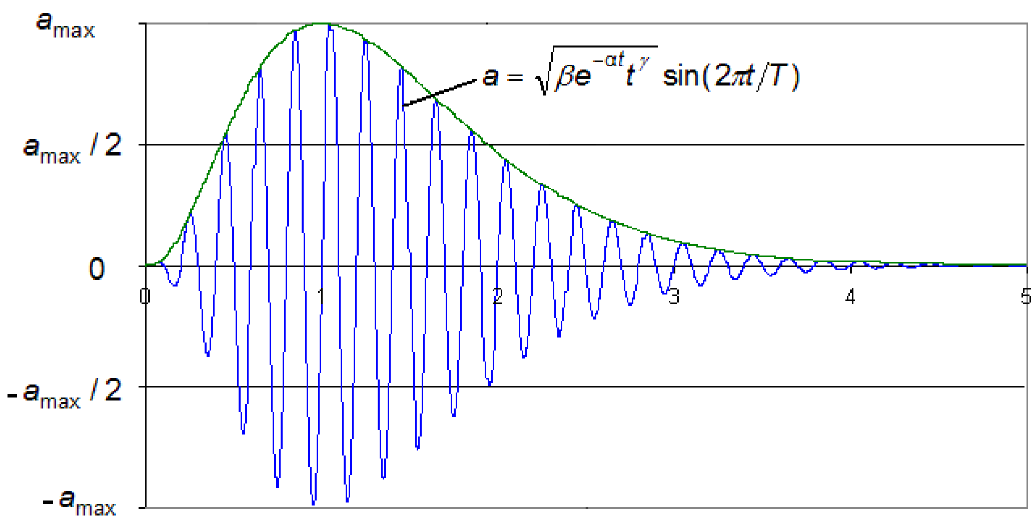


Excitation

Chang's Signal: It is essentially a harmonic excitation with variable amplitude, and the following basic characteristics

- Number of significant cycles N
- Maximum acceleration a_{max}
- Predominant period T

κατάλληλες σταθερές α, β, γ



Typical Results

for H/λ=2, i=30°, ξ=5% and N=6

Observe that, behind the crest:

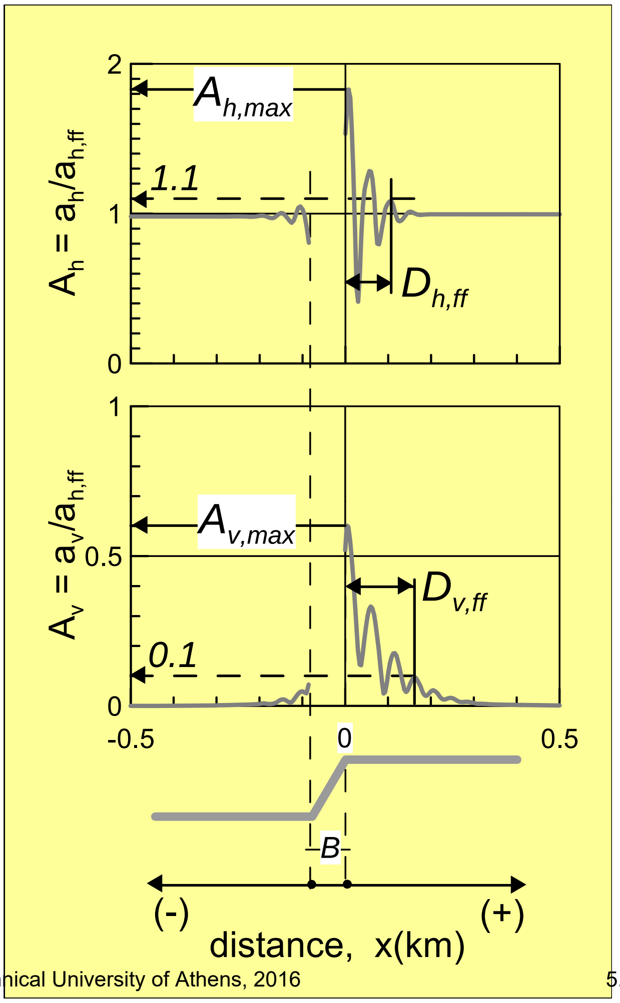
- The horizontal component of seismic motion is significantly amplified.

- A significant "parasitic" vertical component is created.

- There is intense fluctuation of topography aggravation within a small distance from the crest.

- The distance to the "free field" is quite significant.

Question: How easy is it to document topography aggravation based on actual seismic recordings ?

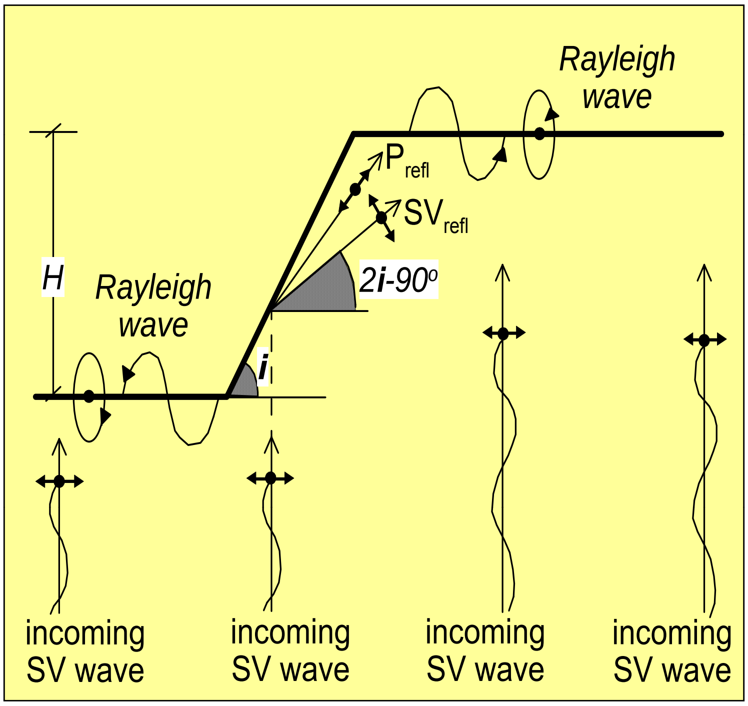


Mechanisms of observed topography aggravation:

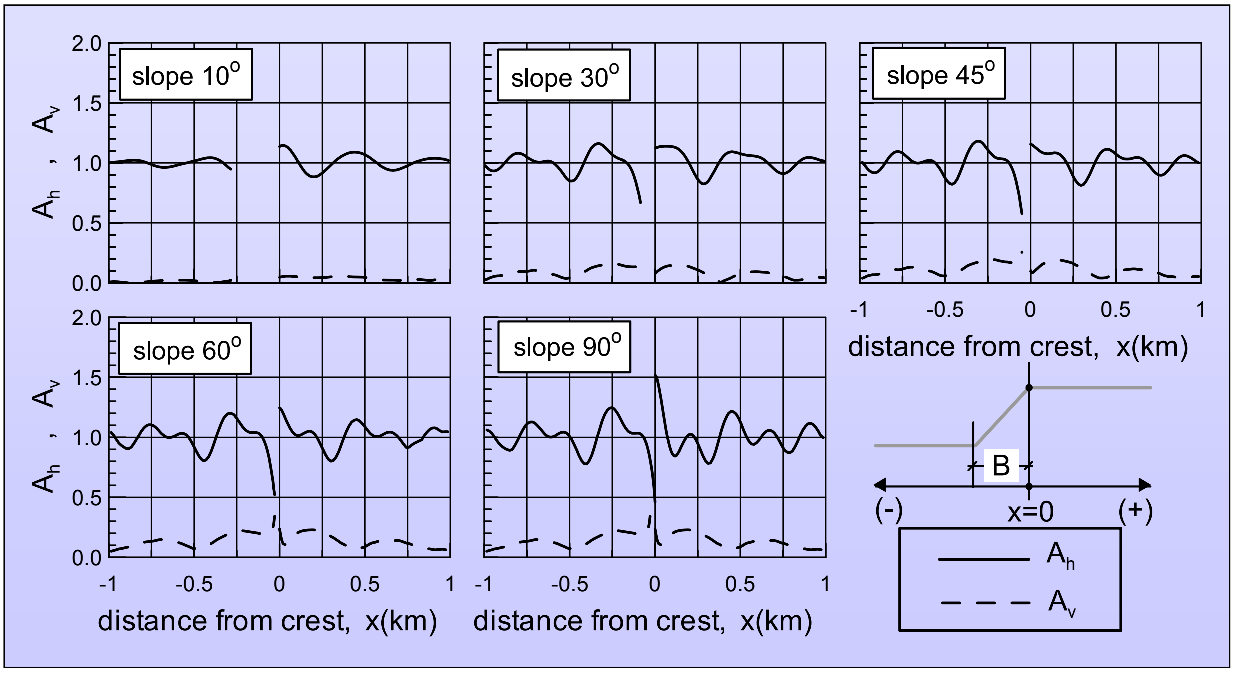
- There are four (4) different waves contributing to the motion of each point behind the crest: a vertically propagating SV, a reflected SV, a reflected P and a Rayleigh wave propagationg along the ground surface.

-These waves have different propagation velocities and propagation paths. As a result, their arrival is not synchronous, but with a phase difference and may lead either to amplification or de-amplification of the ground motion.

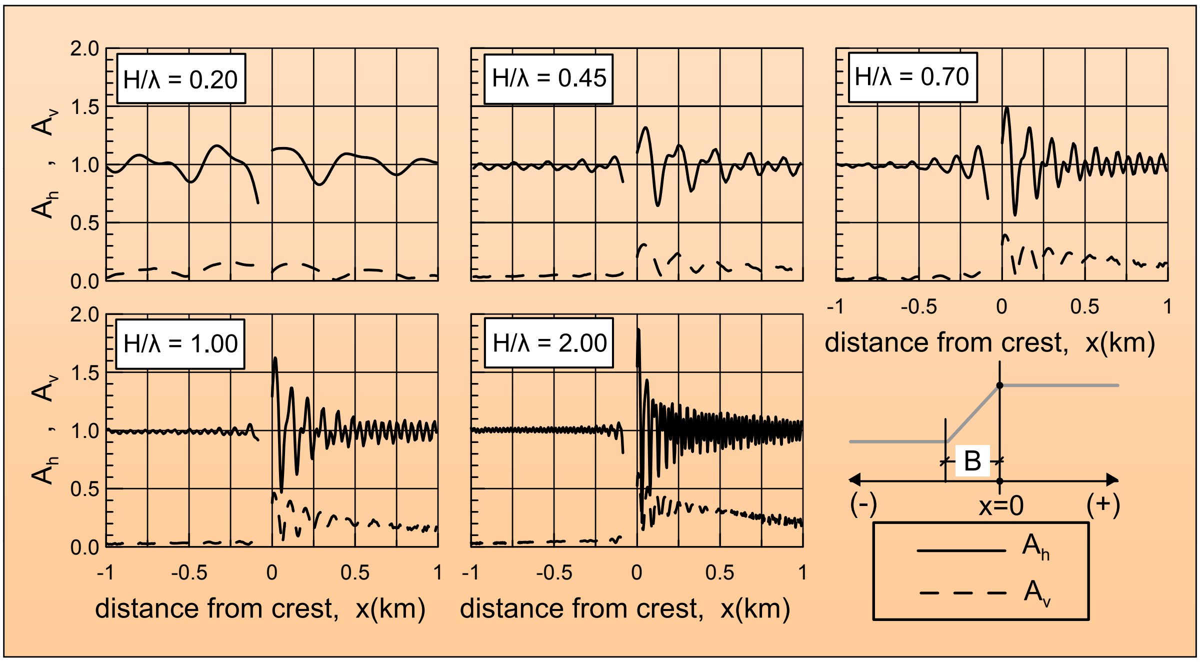
- In addition, the three latter waves have a vertical component of motion…….



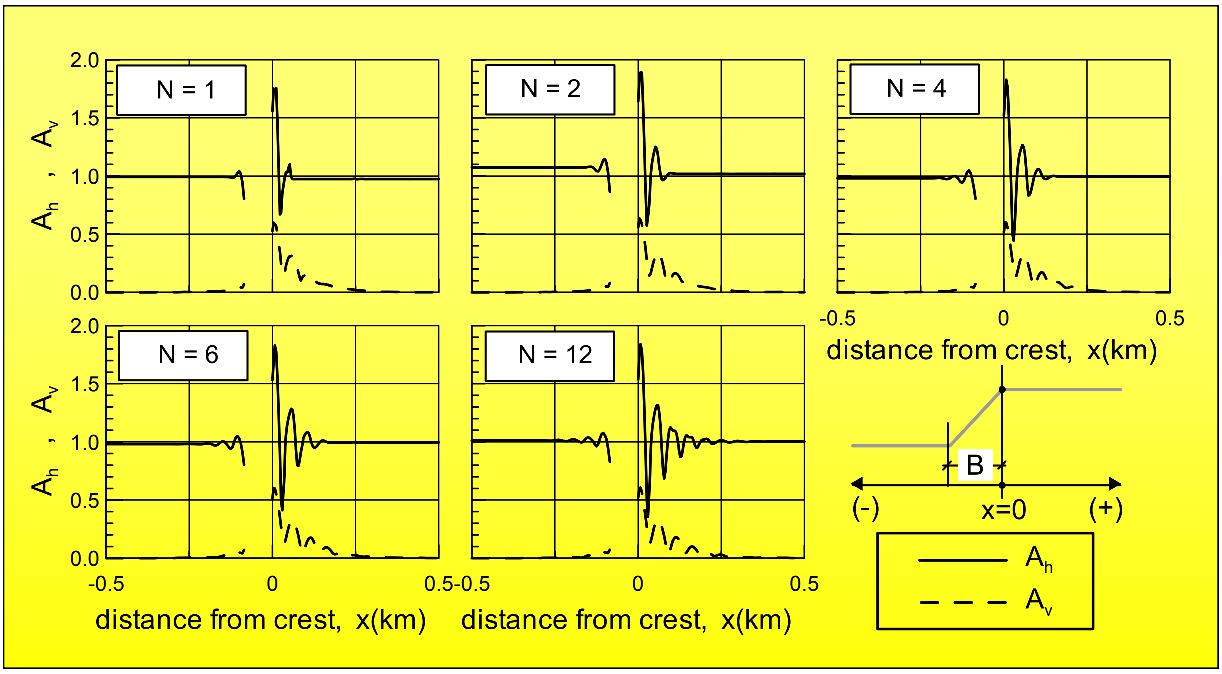
Slope inclination effect…..



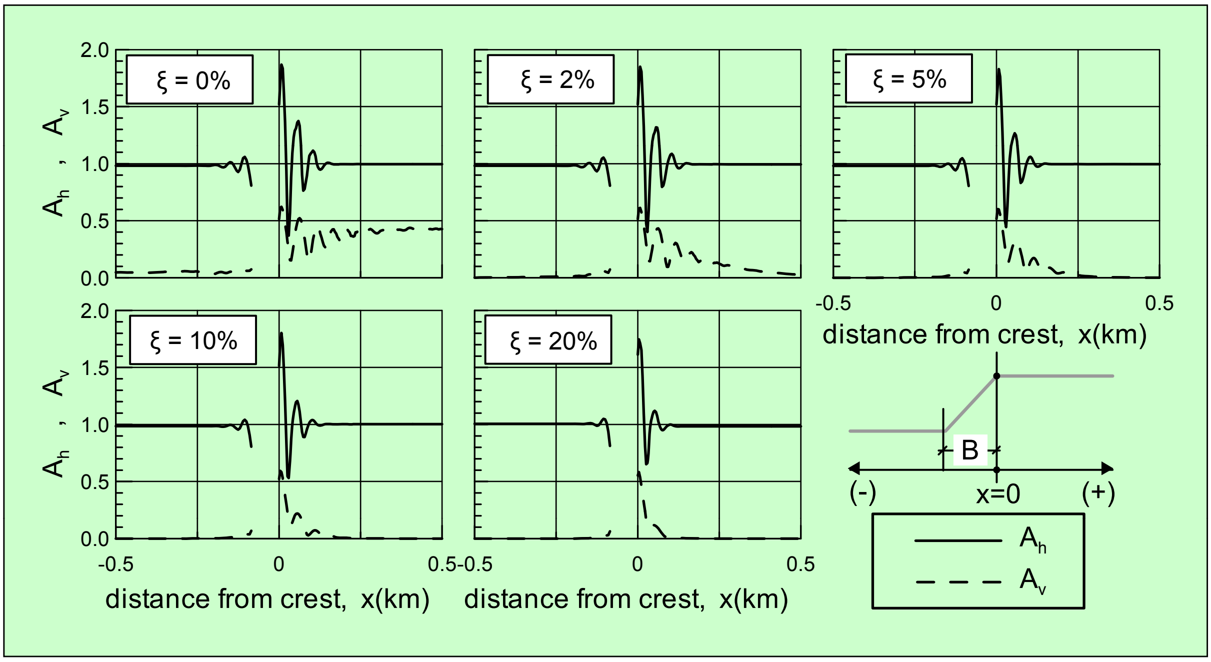
Effect of slope height …..



Effect of number of (significant) cycles …….



Effect of hysteretic damping ……..



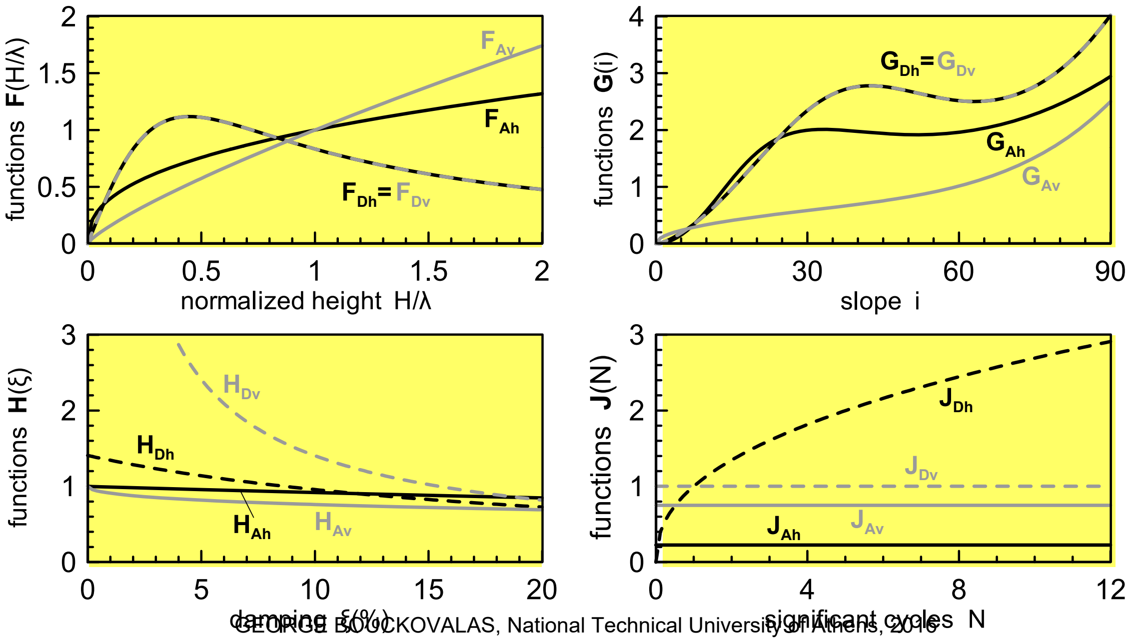
Approximate relations ……..

$$A_{h,max} = 1 + \mathbf{F_{Ah}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Ah}}(I)\mathbf{H_{Ah}}(\xi)\mathbf{J_{Ah}}(N)$$

$$A_{v,max} = \mathbf{F_{Av}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Av}}(I)\mathbf{H_{Av}}(\xi)\mathbf{J_{Av}}(N)$$

$$D_h / H = \mathbf{F_{Dh}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Dh}}(I)\mathbf{H_{Dh}}(\xi)\mathbf{J_{Dh}}(N)$$

$$D_v / H = \mathbf{F_{Dv}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Dv}}(I)\mathbf{H_{Dv}}(\xi)\mathbf{J_{Dv}}(N)$$



Approximate relations ……..

$$A_{h,max} = 1 + \mathbf{F_{Ah}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Ah}}(I)\mathbf{H_{Ah}}(\xi)\mathbf{J_{Ah}}(N)$$

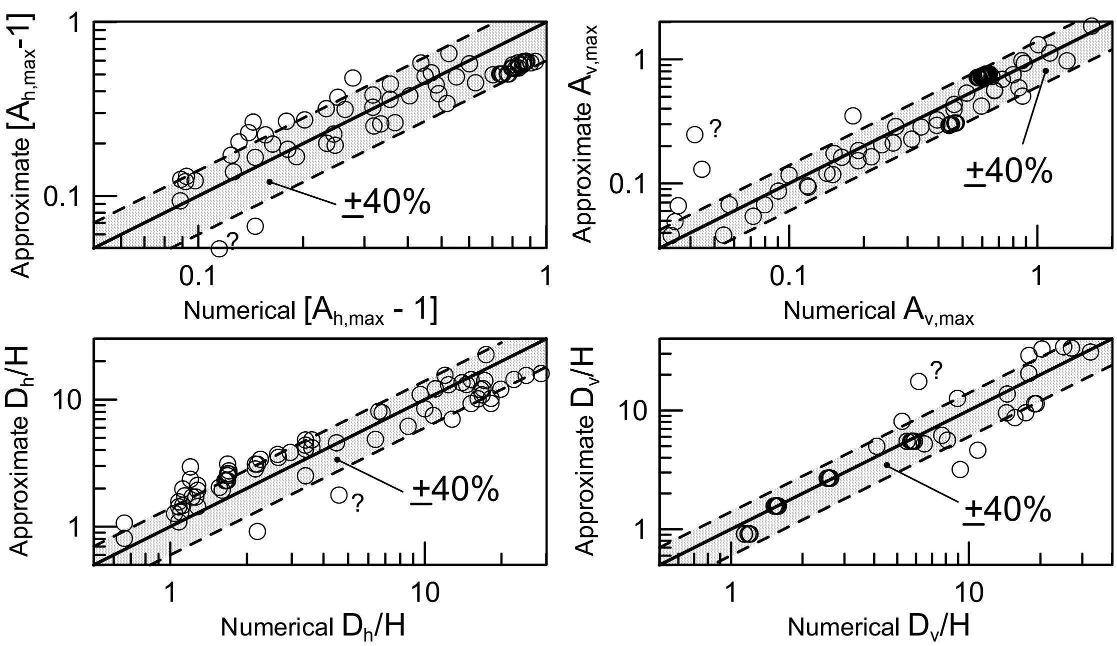
$$A_{v,max} = \mathbf{F_{Av}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Av}}(I)\mathbf{H_{Av}}(\xi)\mathbf{J_{Av}}(N)$$

$$D_h / H = \mathbf{F_{Dh}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Dh}}(I)\mathbf{H_{Dh}}(\xi)\mathbf{J_{Dh}}(N)$$

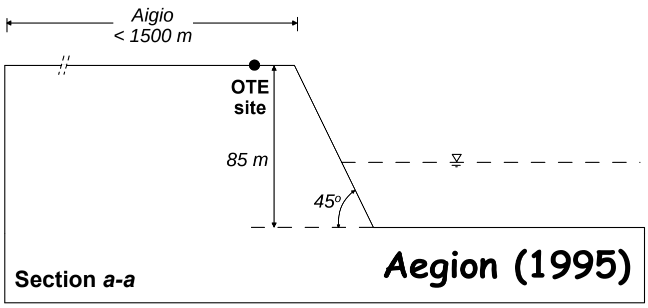
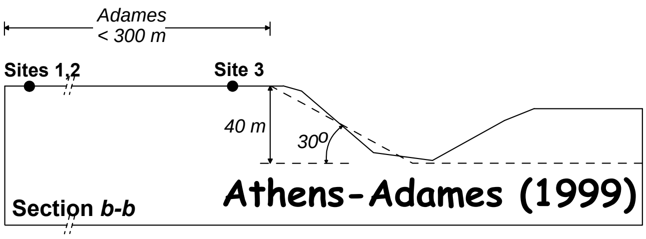
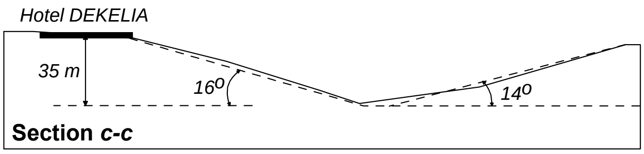
$$D_v / H = \mathbf{F_{Dv}}\left(\frac{H}{\lambda}\right)\mathbf{G_{Dv}}(I)\mathbf{H_{Dv}}(\xi)\mathbf{J_{Dv}}(N)$$

Parameter	F(H/λ)	G(I)	H(ξ)	J(N)
$A_{h,max}$	$(H/\lambda)^{0.4}$	$\frac{I^2 + 2I^6}{I^3 + 0.02}$	$\frac{1}{1 + 0.9\xi}$	0.225
$A_{v,max}$	$(H/\lambda)^{0.8}$	$I^{0.5} + 1.5I^5$	$\frac{1}{1 + 0.15\xi^{0.5}}$	0.75
D_h/H	$\frac{(H/\lambda)}{(H/\lambda)^2 + 0.2}$	$\frac{I^{1.5} + 3.3I^8}{I^4 + 0.07}$	$\frac{1}{0.71 + 3.33\xi}$	$N^{0.43}$
D_v/H	$\frac{(H/\lambda)}{(H/\lambda)^2 + 0.2}$	$\frac{I^{1.5} + 3.3I^8}{I^4 + 0.07}$	$\frac{0.233}{\xi^{0.78}}$	1.00

Accuracy of approximate relations ……..



Accuracy of approximate relations ……..

Numerical analyses		Approximate relations
A_h=1.40 D_h=6.2H		A_h=1.20-1.32 D_h=(3.5-5.6)H
A_h=1.30-1.50 A_V=0.24-0.26 D_h=(1.9-2.5)H		A_h=1.28-1.45 A_V=0.17-0.47 D_h=(2.7-4.6)H
A_h=0.75-1.35 D_h=(2-3)H		A_h=1.16-1.25 D_h=(1.5-2.0)H

Athens-Hotel Dekelia (1999)

HWK 5.1:

(a) Apply the approximate relations for "common" cases of natural slopes and seismic excitations and compute the expected range of variation of the main parameters of topography aggravation (A_h, A_v, D_h και D_v);

(b) Based on the results of (a) above, as well as on the following two figures, comment on the accuracy of the seismic code provisions and guidelines related to single slope topographies.