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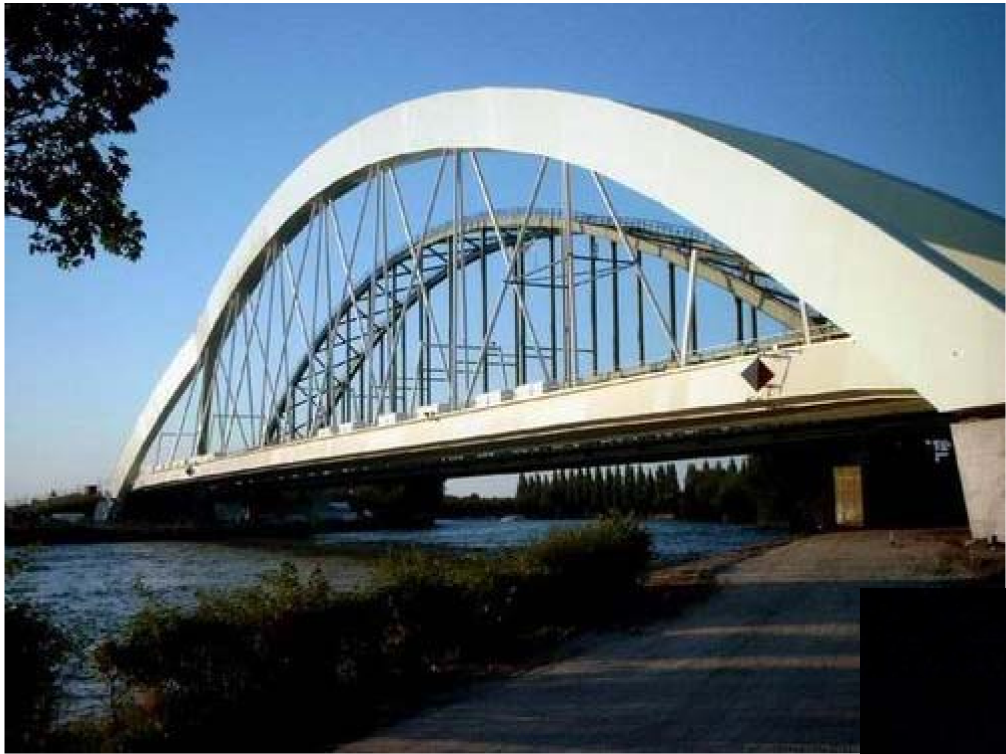
Structural designer and construction manager. Worked for Dutch department of public works before receiving his PhD in civil engineering from Delft Technical University in 1981. Worked for several engineering companies and mayor contractors as designer in the Netherlands and Indonesia. Worked as construction manager in Indonesia, Russian federation (Siberia) and Nigeria. Experienced in the field of bridges, utility buildings, industrial buildings and underground structures. His interest in material damping originates from encountered problems with wind induced vibration of bridge elements.

Energy transformation damping

See for explanation slide 19

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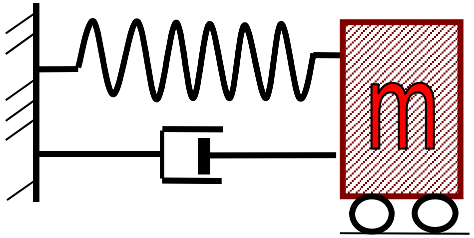
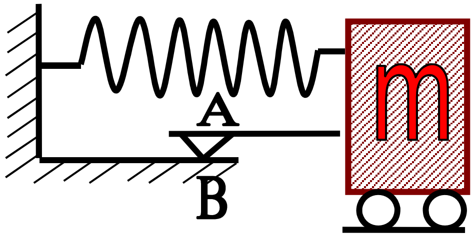
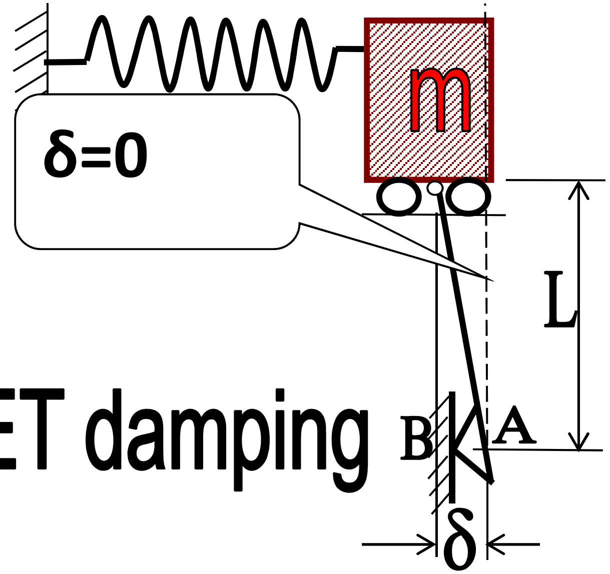
Fact:

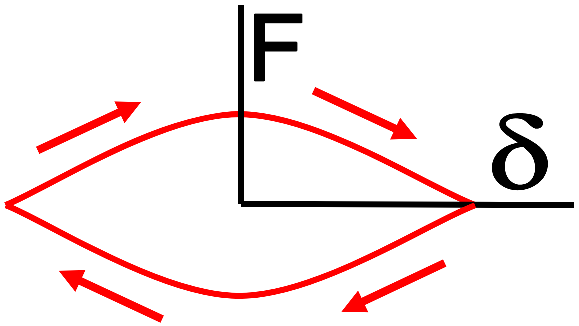
Energy loss per cycle is proportional to total energy (kinetic+elastic) regardless frequency and amplitude.

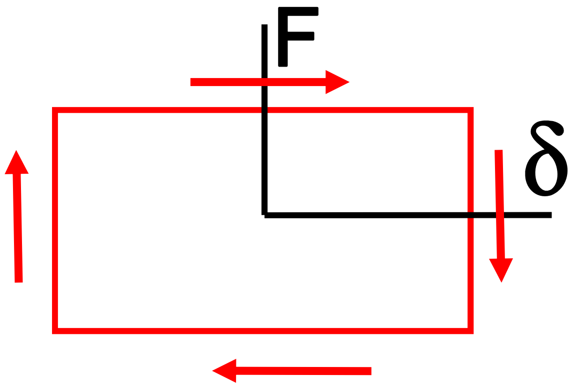


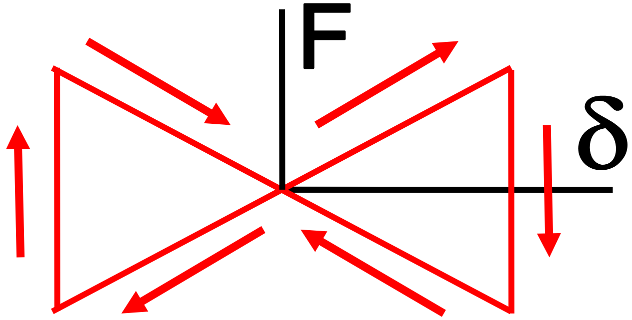




Viscous damping | Coulomb damping | ET damping

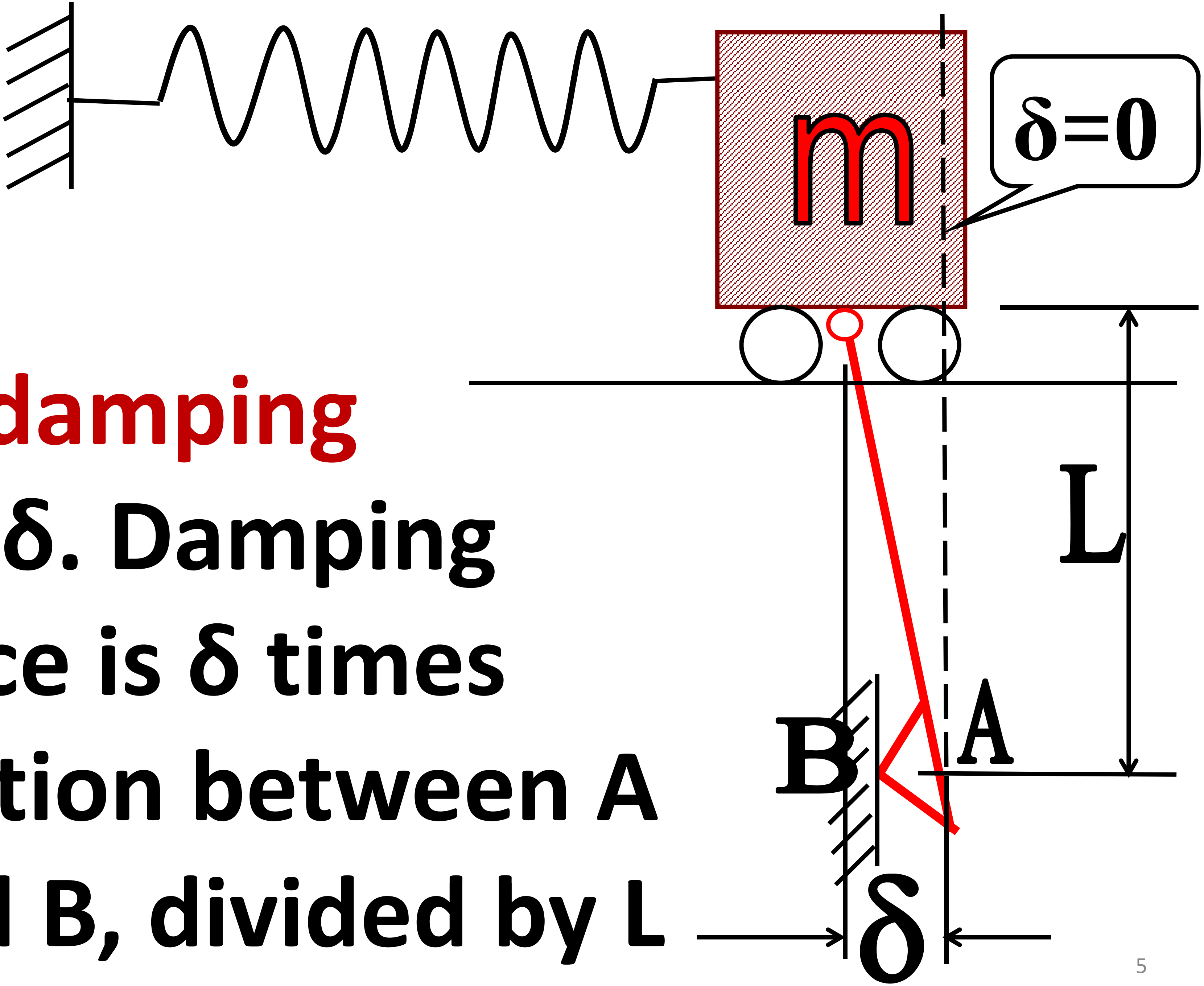






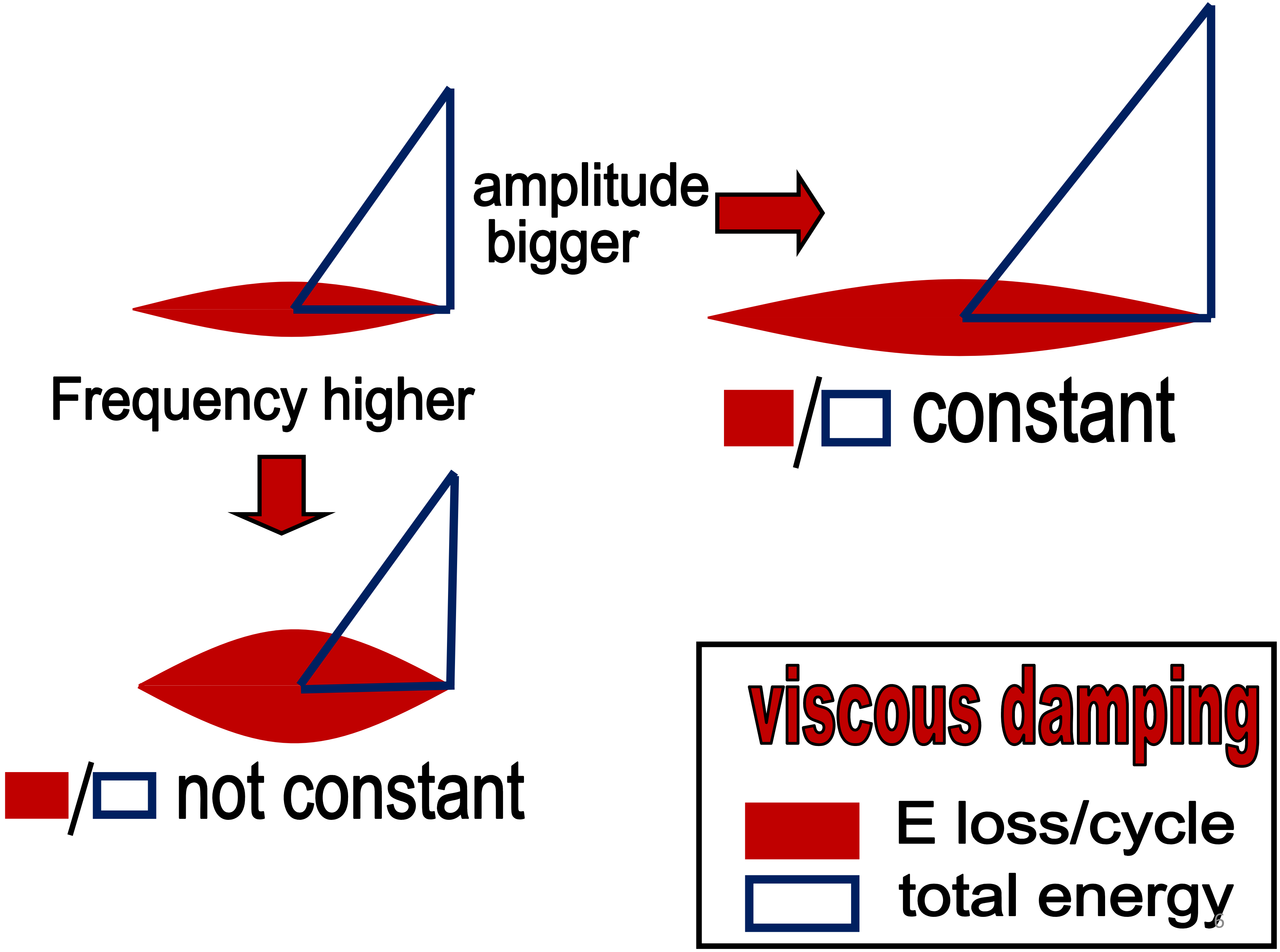
F~= δt | F=constant | F~= δ

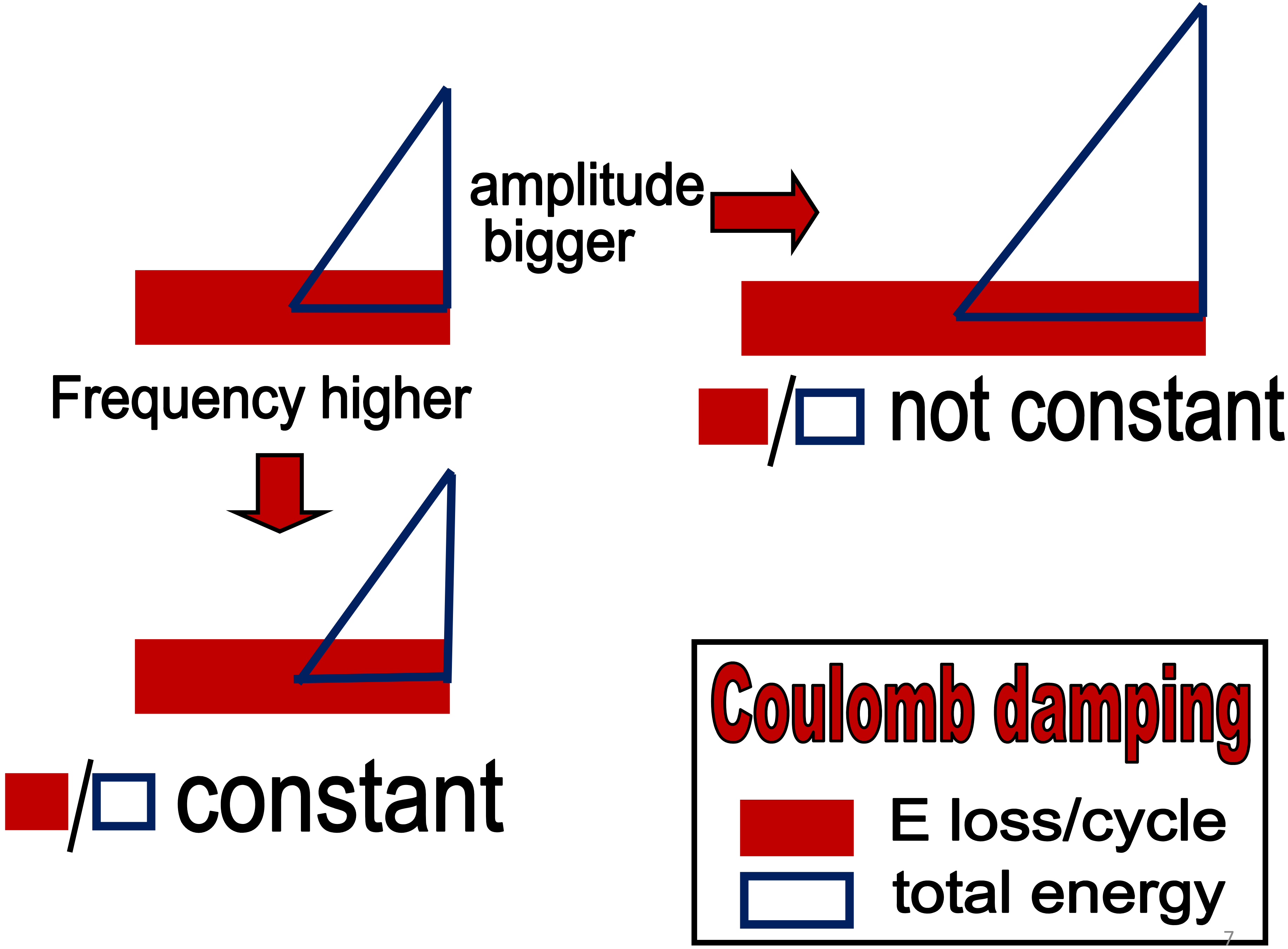
Damping models

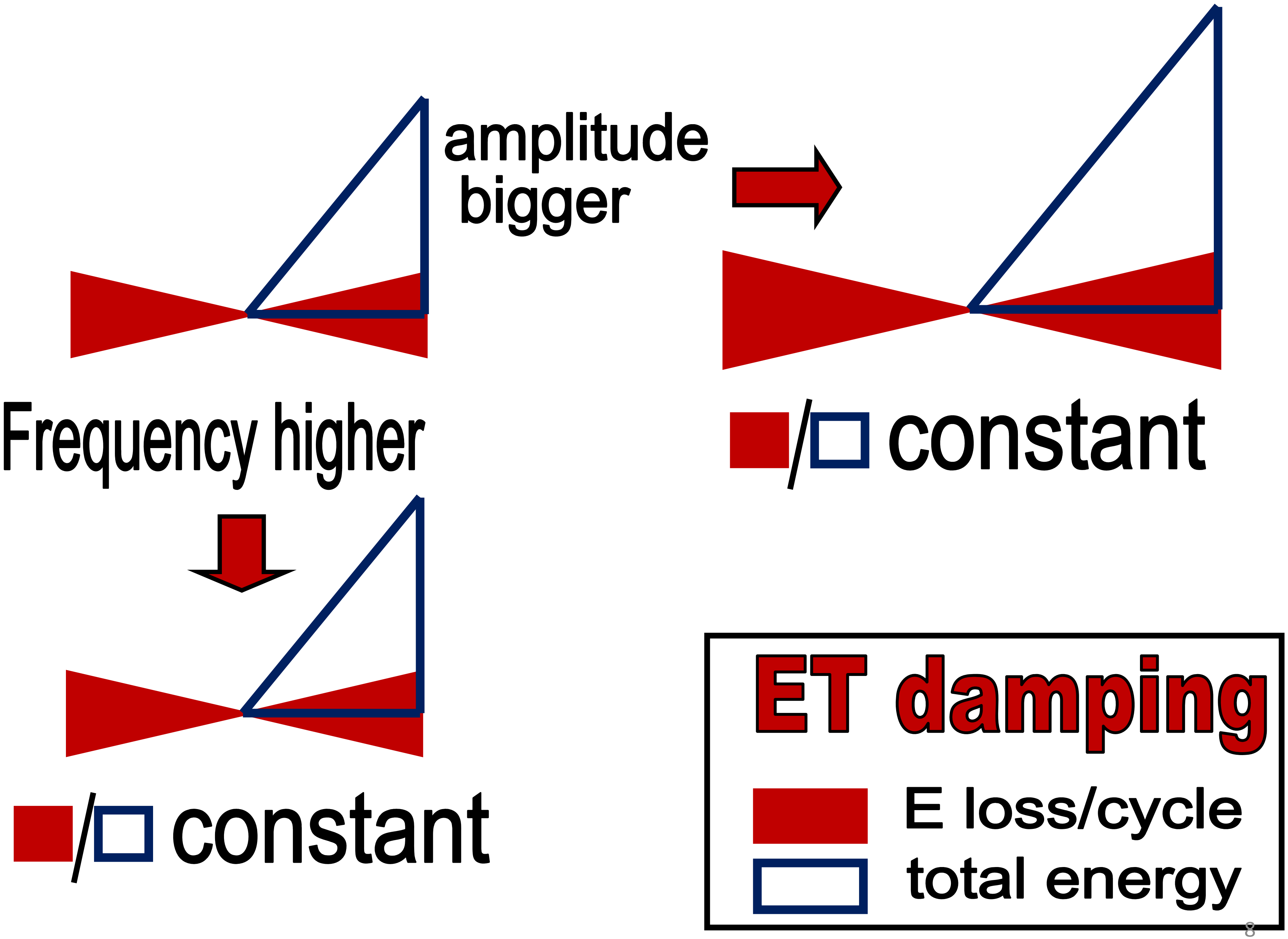


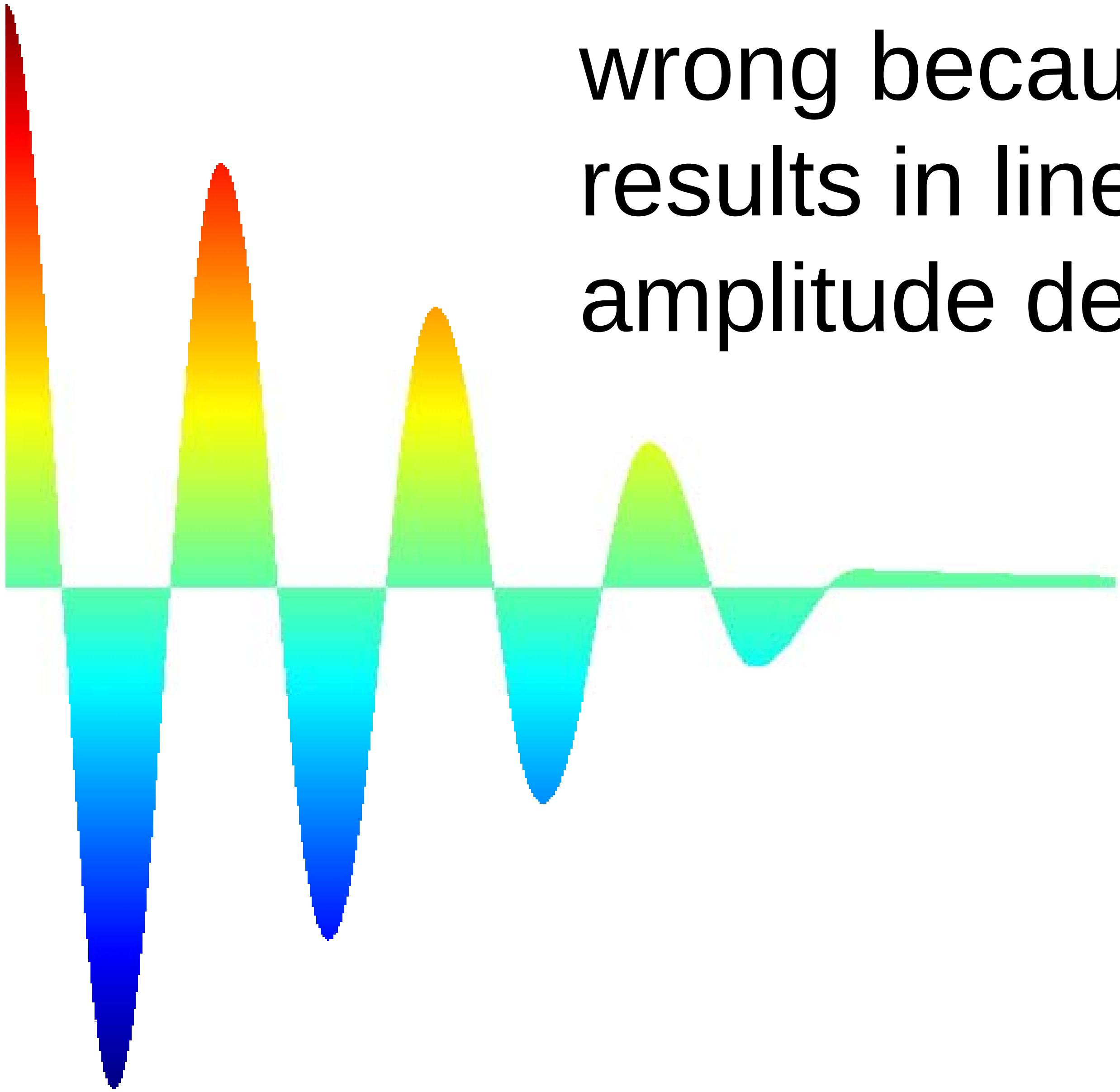
ET damping

L>>δ. Damping force is δ times friction between A and B, divided by L

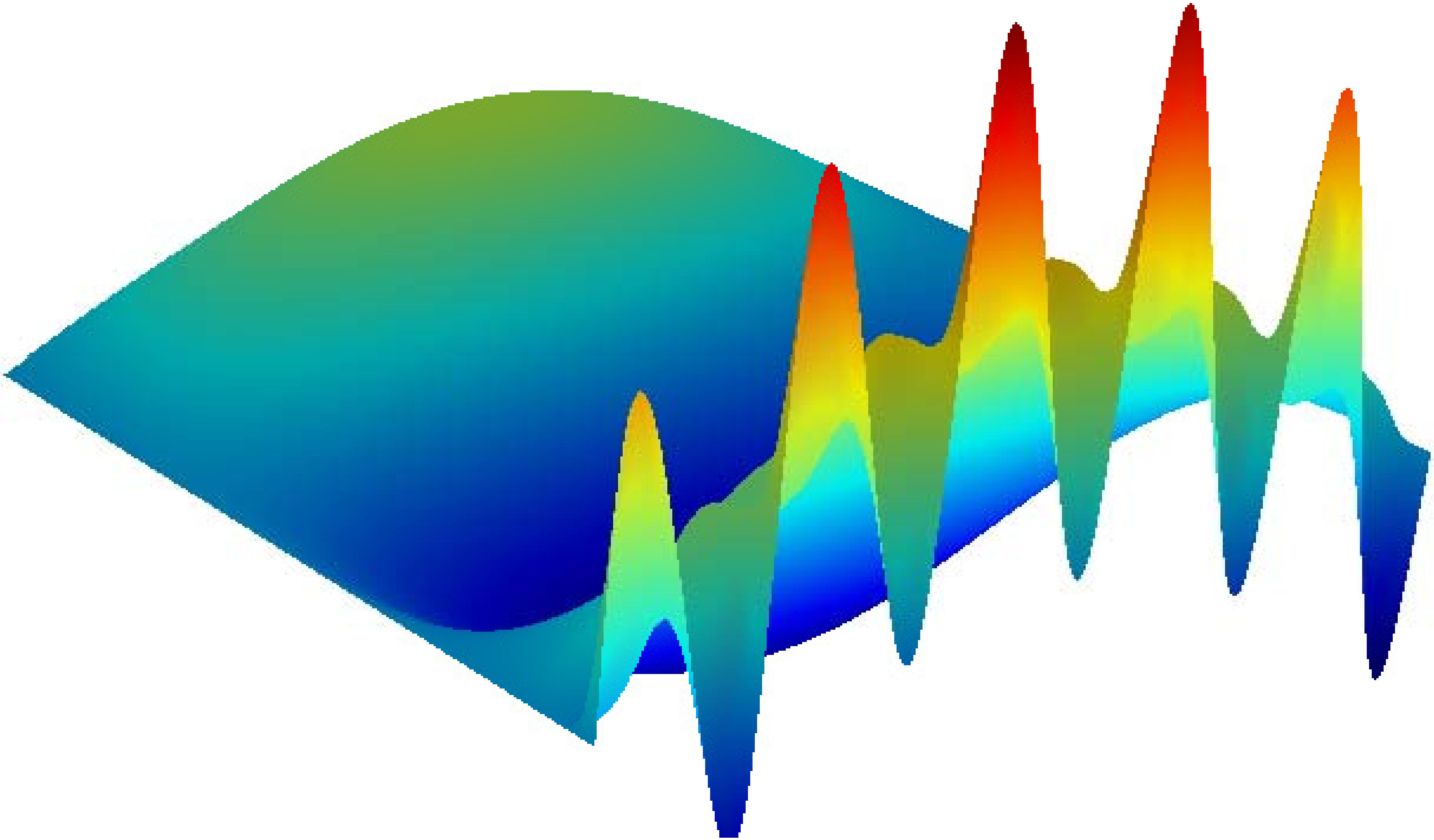

amplitude
bigger
Frequency higher
/ constant
/ not constant
viscous damping
E loss/cycle
total energy


amplitude
bigger
Frequency higher
/ not constant
/ constant
Coulomb damping
E loss/cycle
total energy

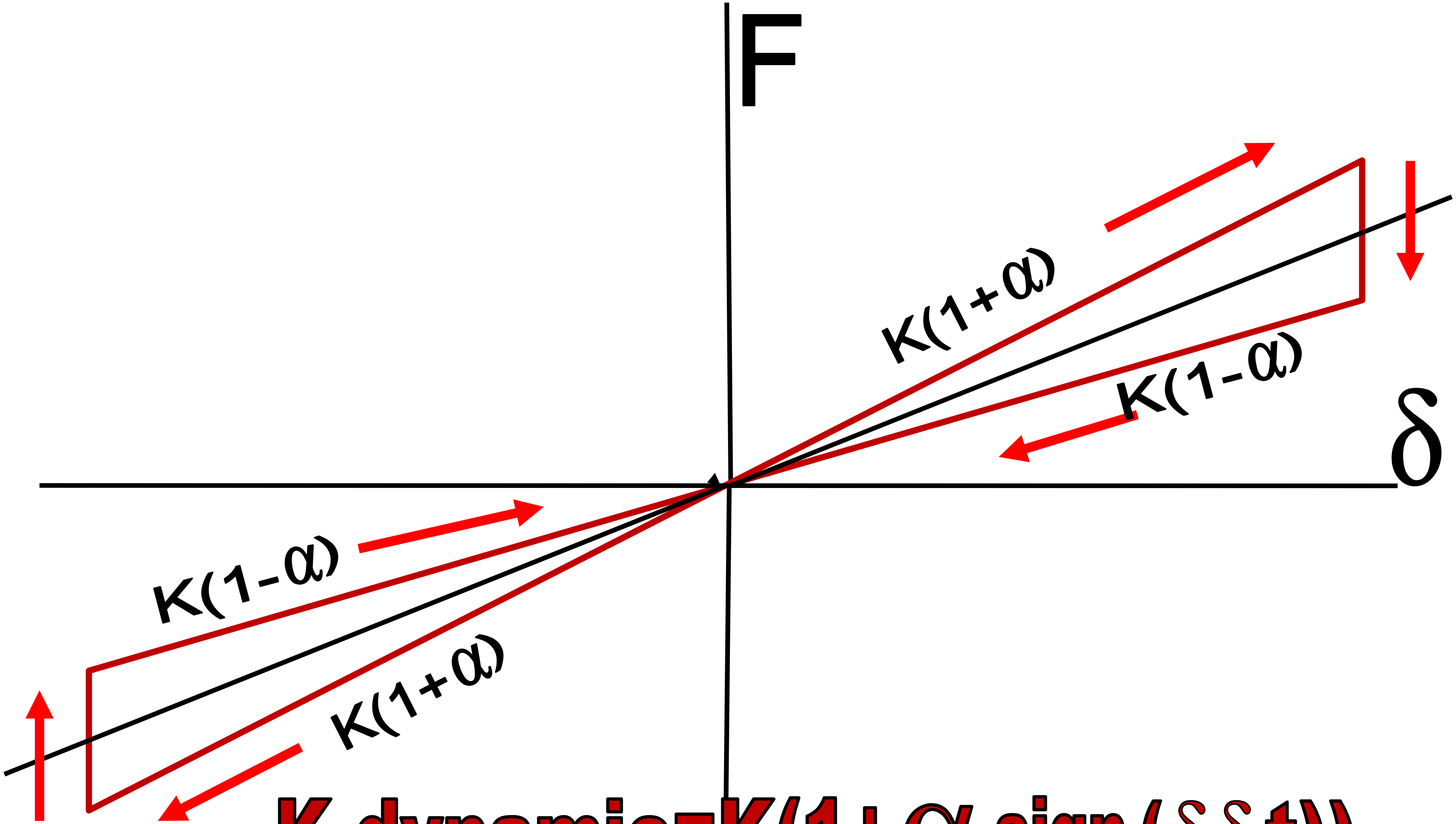

amplitude
bigger
Frequency higher
/ constant
/ constant
ET damping
E loss/cycle
total energy



Coulomb damping wrong because it results in linear amplitude decay



Viscous damping wrong because damping of high frequencies too big



$K\text{-dynamic}=K(1+\alpha\ \mathrm{sign}\ (\delta\ \delta t))$

Single mass–spring: $m\delta tt+k_{dyn}\delta=0$

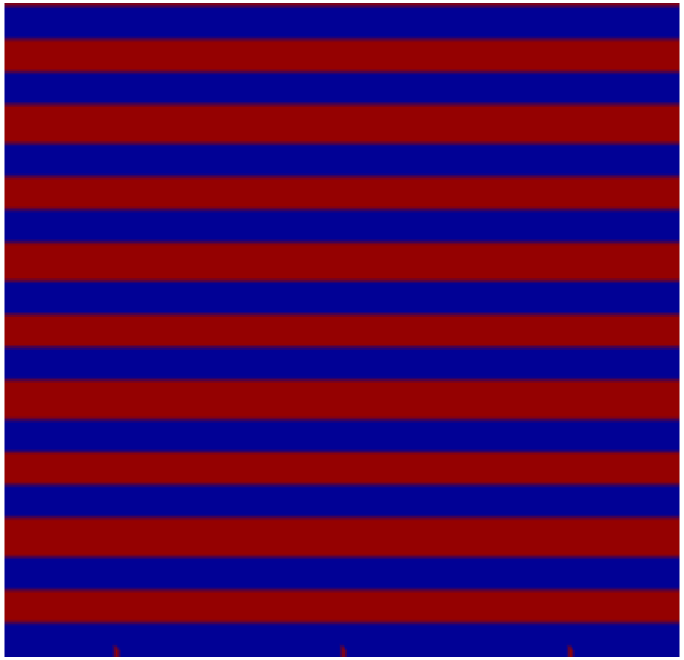
$$E_{dyn} = E(1+\alpha sign(\frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial x \partial t}))$$

$$SWI = sign(\frac{\partial u}{\partial x}\frac{\partial^2 u}{\partial x \partial t})$$

$$m\frac{\partial^2 u}{\partial t^2} - A\frac{\partial E}{\partial x}\frac{\partial u}{\partial x} - AE\frac{\partial^2 u}{\partial x^2} = 0$$

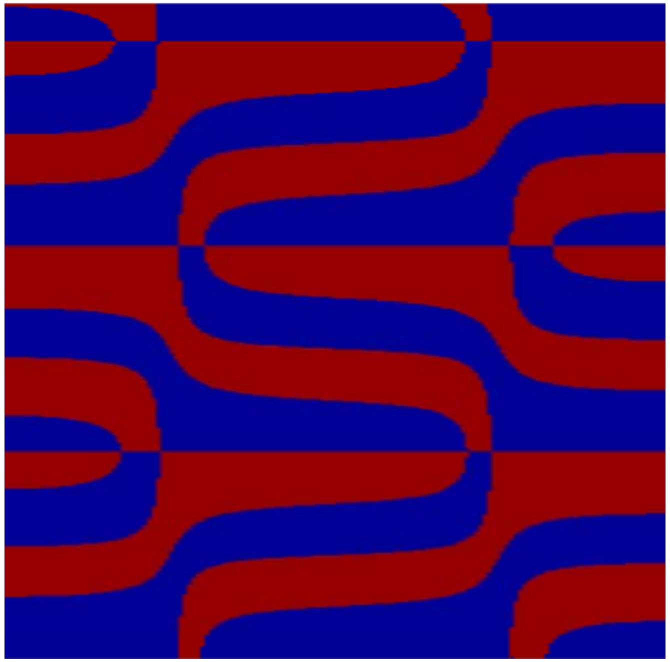
$$m\frac{\partial^2 u}{\partial t^2} - AE(\alpha\frac{\partial SWI}{\partial x}\frac{\partial u}{\partial x} + \alpha SWI\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial x^2}) = 0$$

sign(ux*uxt)



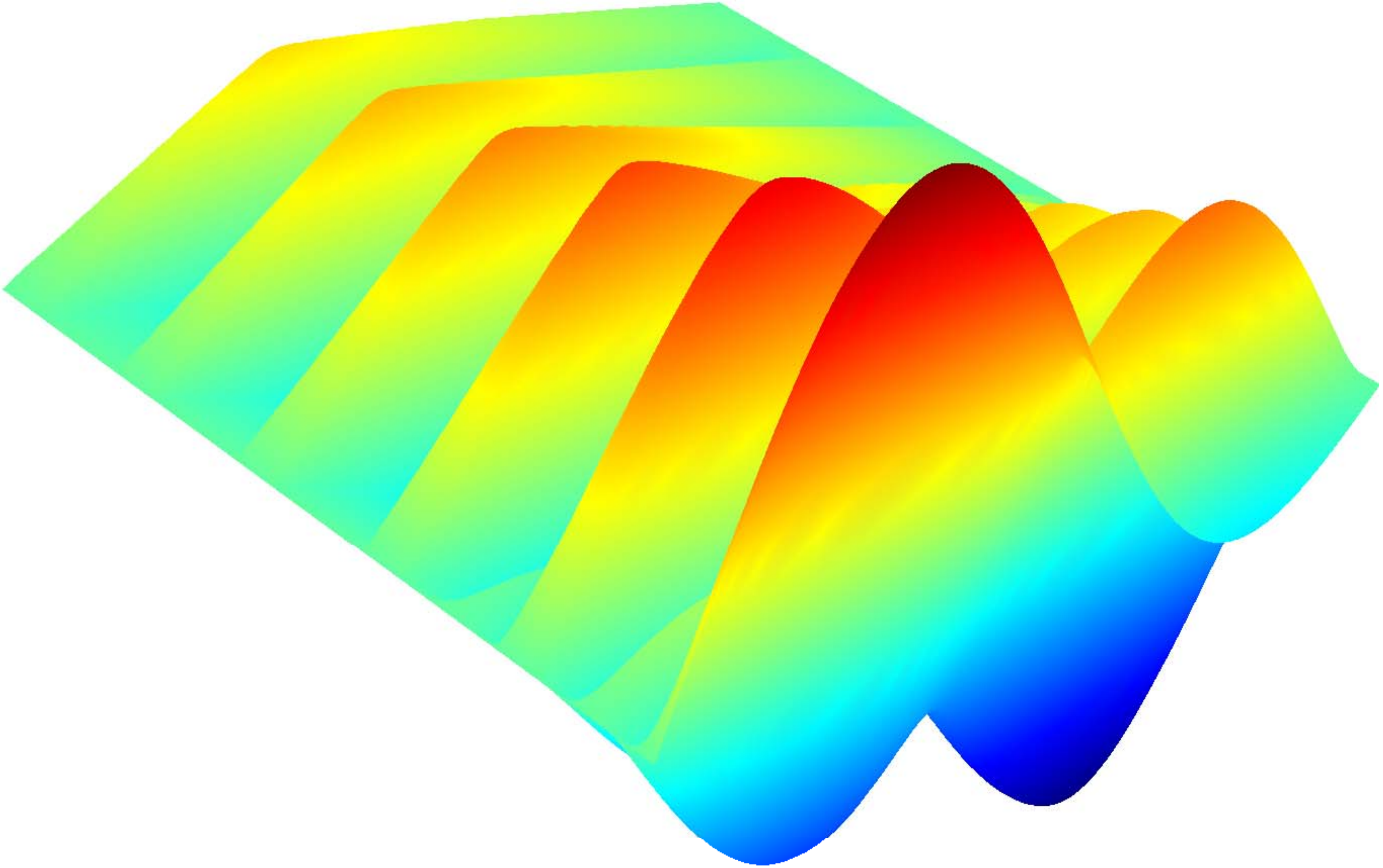
sin(3*x)

sign(ux*uxt)

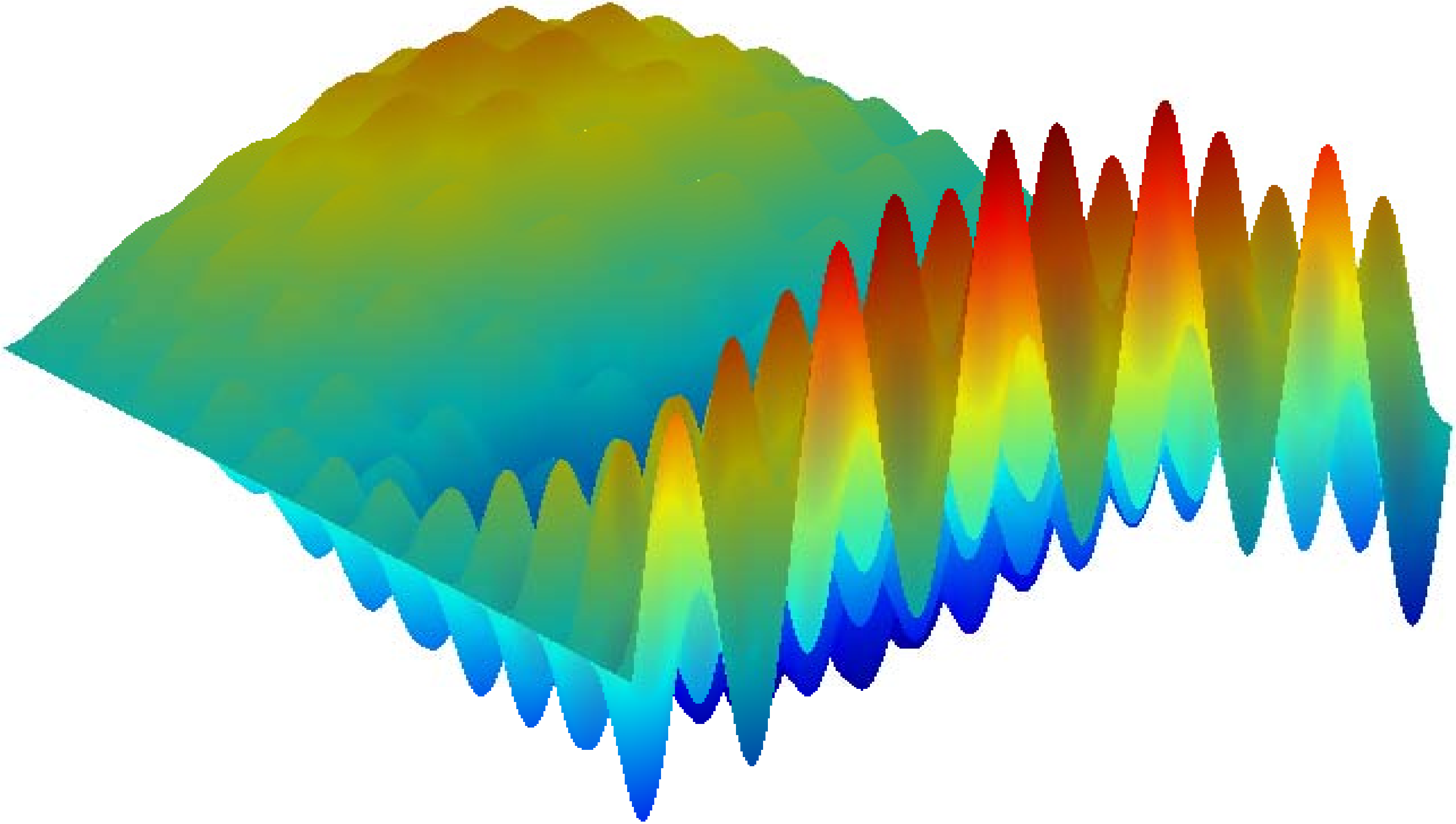


sin(x)+sin(2*x)

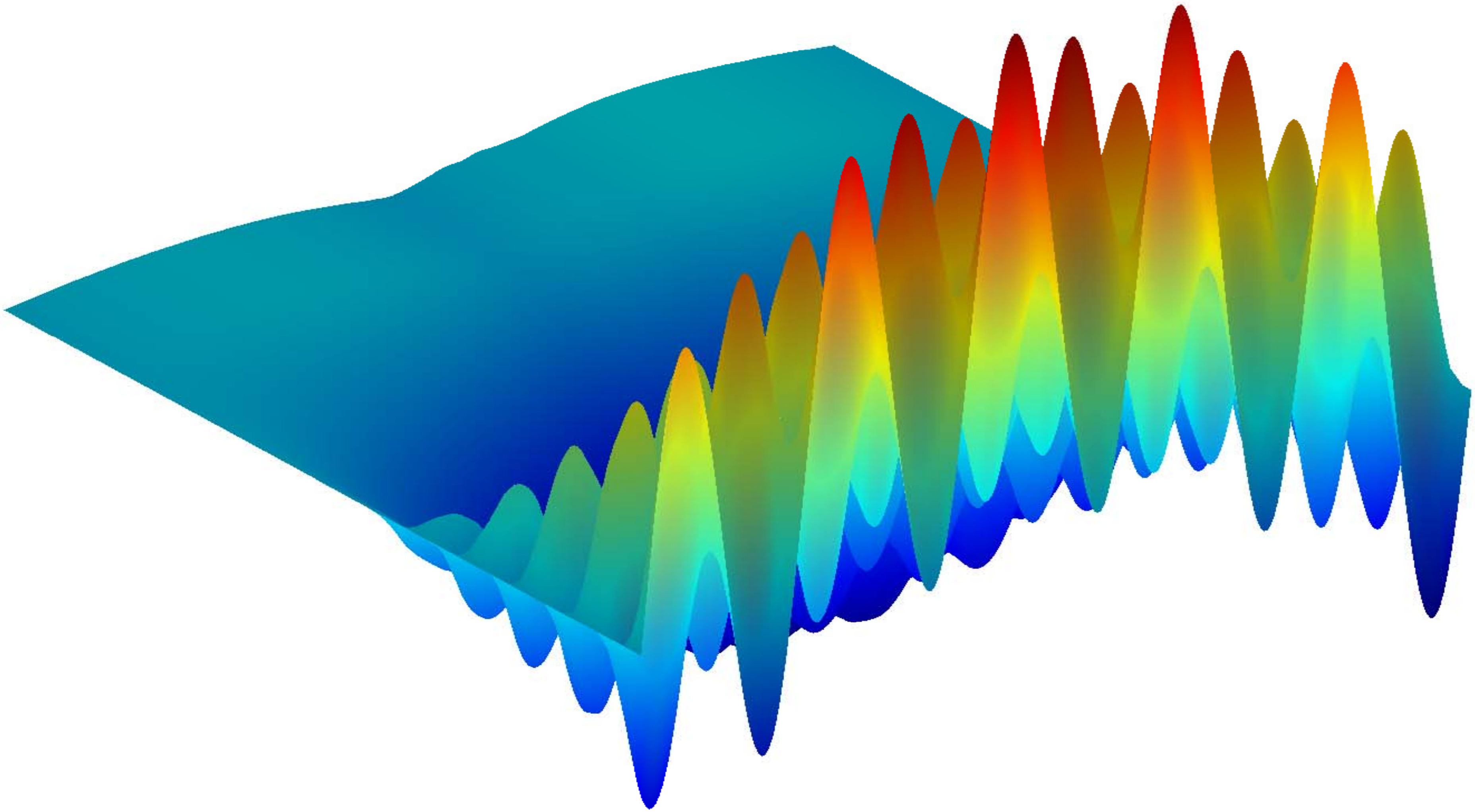
Single/multi mode



ET damping with init sin(x)+sin(2*x)



ET damping with init sin(x)+sin(10*x)



ET damping with init 4*x+sin(x)+sin(10*x)

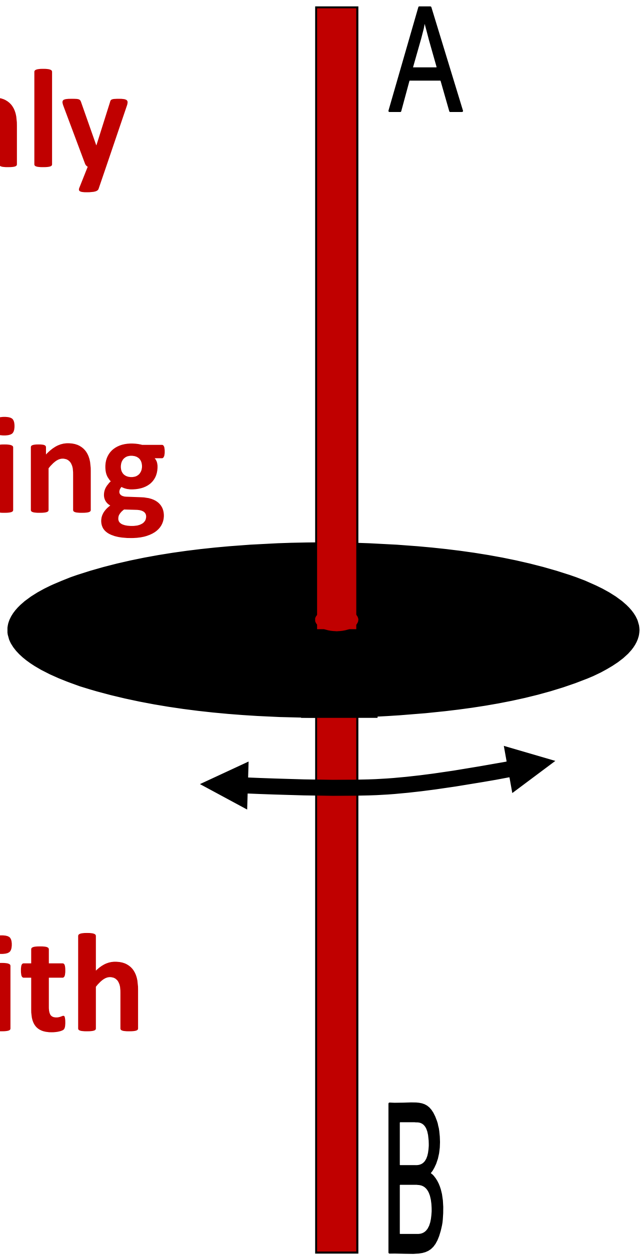
Plane stress

$$\text{SWI}=\text{sign}\left(\begin{bmatrix} 1 & \gamma & 0 \\ \gamma & 1 & 0 \\ 0 & 0 & \dfrac{1-\gamma}{2} \end{bmatrix}\begin{pmatrix} ux \\ vy \\ uy+vx \end{pmatrix}\bullet\begin{pmatrix} uxt \\ vyt \\ uyt+vxt \end{pmatrix}^{T}\right)$$

$E_{dyn}=E(1+\alpha \text{SWI})$

(insert directly in structural mode)

ET damping is the only damping model that predicts more damping of a torsionally vibraiting disk if axis A-B is prestressed with a torsion moment



1. The idea of Energy transformation damping originated in Januari of 2006 in Novosibirsk, Siberia when the construction works of the Heineken brewery ground to a halt.
2. Problems with two railroad bridges. Very conservative design and yet heavily wind induced vibration of the hangers. Left constructed in 2002. Tube Ø 0.40 m l=35m amplitude=50mm. Right constructed in 2004. Tube Ø 0.2 m l=20 m, filled with stone. Amplitude =25 mm Damping over estimated and or vortex lock in effect under estimated. Existing building codes not appropriate.
3. This is not an absolute fact but roughly true. It can be concluded from the experiment of Kimball and Lovell of 1927. A successful damping model should at least be able to express this frequency and amplitude independency. That means the area of the hysteresis loop is always proportional to the energy content. Linear viscous and Coulomb damping do not comply with this requirement; energy transformation damping does.
4. Viscous damping: damping force proportional to speed. Equation: mδtt+γδt+kδ=0. Coulomb damping: damping force constant. Equation: mδtt+βsign(δt)+kδ=0. ET damping: damping force proportional with force in spring. Equation: mδtt+k(1+αsign(δ(δt)))=0
5. There is always a constant friction between A and B. Damping force is the horizontal component of the force in the red bar. This damping force is in the same direction as the force in the spring if elastic energy is stored in the spring, effectively increasing the spring stiffness. The damping force is in the opposite direction as the spring force if elastic energy is released from the spring, effectively decreasing the spring stiffness.
6. The red area is the hysteresis loop. The area of the blue outlined triangle is the energy content of the system. If the amplitude is multiplied by "a" then both the energy and the hysteresis loop will be multiplied by α^2. This **is** in line with real world damping. If the frequency is multiplied by "α" then the hysteresis loop is multiplied by 2α but the energy remains unaltered. This **is not** in line with real world damping.
7. If the amplitude is multiplied by "α" then the energy will be multiplied by α^2 but the hysteresis loop will be multiplied by "α". This **is not** in line with real world damping. If the frequency is multiplied by "α" then both the hysteresis loop and the energy remain the same. This **is** in line with real world damping.
8. If the amplitude is multiplied by "α" then both the energy and the hysteresis loop will be multiplied by α^2. This **is** in line with real world damping. If the frequency is multiplied by "α" then both the energy and the hysteresis loop remain the same. This **also is** according to real world damping.
9. Coulomb damping results in linear amplitude decay. The figure is of a longitudinally vibrating bar with coulomb damping, viewed in direction of the bar and perpendicular to t-axis. The amplitude decay was checked by a manual calculation. The conclusion is that Comsol MPH properly captures the very steep pulse of the first derivative of the smoothed sign function. Width of the pulse approximately 10% of one element.
10. In case of viscous damping the damping of the high frequency is too high (if the low frequencies are correct). Here the high frequencies are nearly critically damped in contrast with the low frequencies. Hysteretic damping tries to remedy this flaw by giving each principle mode a damping parameter inversely proportional to the frequency. This model is either incomplete or inconsistent.
11. This picture shows the hysteretic loop together with the spring force. Important to note that energy loss is not related to harmonic vibration but holds true for every F-δ path. Energy loss can be compared with loss of money by changing back and forward dollars into Euro's even if the exchange rate is fixed. The bank uses a "dynamic" exchange rate in contrast with the official "static" rate.
12. Use ux instead of δ and uxt instead of δt and find E_{dyn}. SWI is short for flsmsign(ux(uxt)).Take the equation of the vibrating rod with E a function of x. Substitute E_{dyn} for E and obtain the equation of the longitudinally vibrating elastic rod with ET damping. SWIx (red box) makes the system non linear and increases damping in case of pre-stressing.
13. Horizontal axis x, vertical axis t. The pictures show SWI. Blue=-1 red=+1. Every horizontal line shows SWI over the full length of the rod. In case of single mode vibration no horizontal transition blue red / red blue so SWIx=0. In case of multimode vibration SWIx= +2 or -2 on the transition blue red or red blue and elsewhere 0.
14. Both sin(x) and sin(2x) disappear in a total different shape. This proves that ET damping is non linear.
15. High frequency vibrations survive much longer than in the case of viscous damping of slide 10. This looks like hysteretic damping but look at the pre stressed case of slide 16.
16. Pre-stressing (or more in general eigen stresses) can have a tremendous impact on damping. Init 4x means pre-stressing. After solving, 4x was subtracted from the solution. This picture would be the same as that of slide 15 if ET damping would be linear.
17. In case of 2D or 3D problems only the argument of the sign function changes.
18. Can anybody carry out this or a similar experiment to validate the concept of ET damping?