ARCHITECTURAL STRUCTURES:
FORM, BEHAVIOR, AND DESIGN
ARCH 331
DR. ANNE NICHOLS
FALL 2013

lecture
seven

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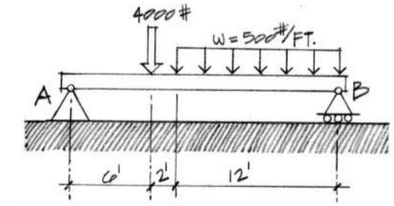
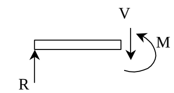
beams –
internal forces

Beams

- span horizontally
  - floors
  - bridges
  - roofs

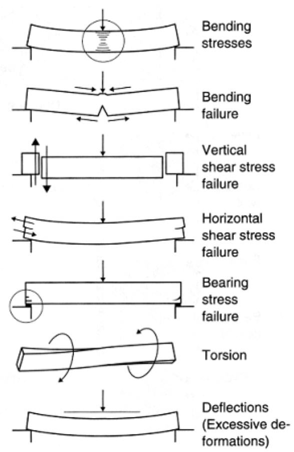


- loaded transversely by gravity loads
- may have internal axial force
- <u>will have</u> internal shear force
- <u>will have</u> internal moment (bending)



Beams

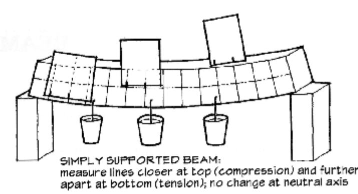
- transverse loading
- sees:
  - bending
  - shear
  - deflection
  - torsion
  - bearing
- behavior depends on cross section shape

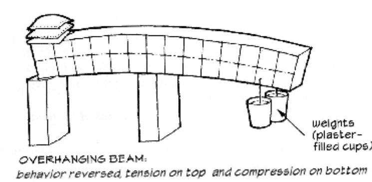


Transverse Loadings

Beams

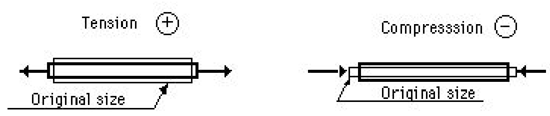
- bending
  - bowing of beam with loads
  - one edge surface stretches
  - other edge surface squishes

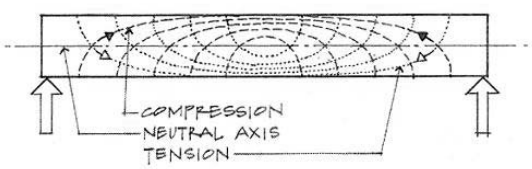




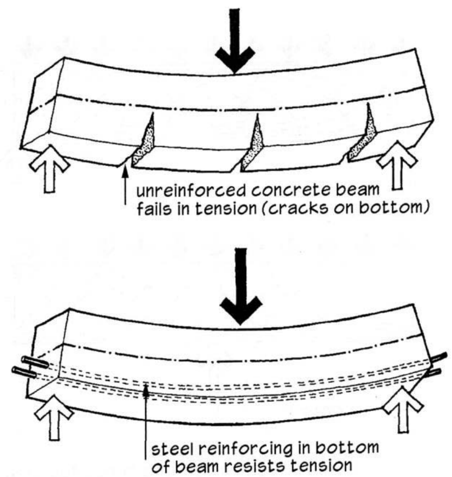
Beam Stresses

- stress = relative force over an area
  - tensile
  - compressive
  - bending
    - tension and compression + ...



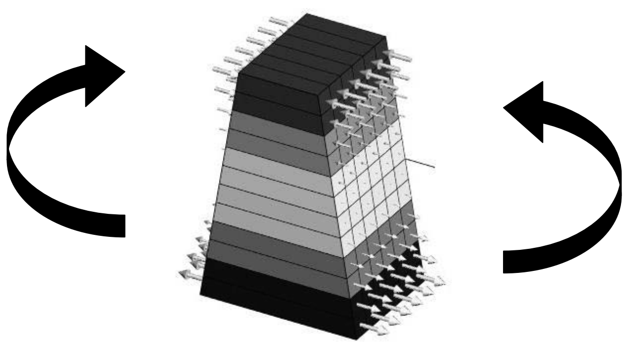


Beam Stresses



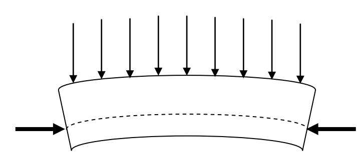
Beam Stresses

- tension and compression
  - causes moments



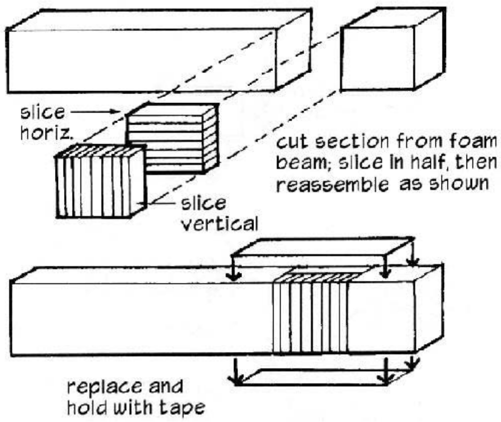
Beam Stresses

- prestress or post-tensioning
  - put stresses in tension area to "pre-compress"



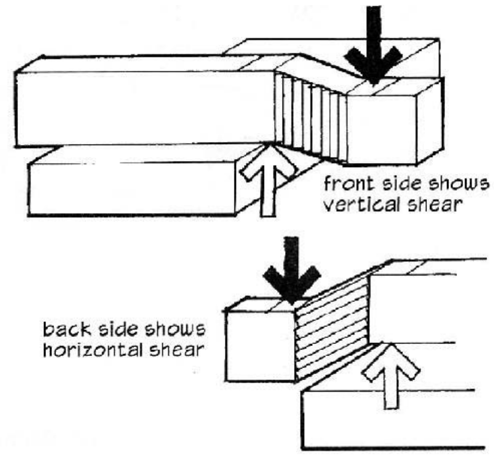
Beam Stresses

- *shear – horizontal & vertical*



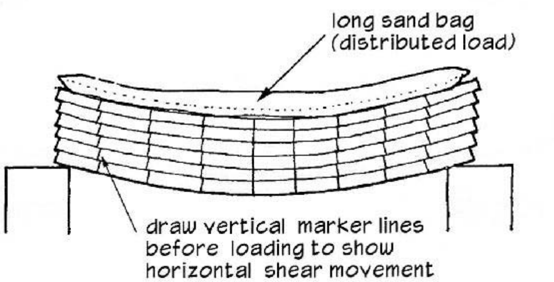
Beam Stresses

- *shear – horizontal & vertical*



Beam Stresses

- *shear – horizontal*



Beam Deflections

- *depends on*
  - *load*
  - *section*
  - *material*

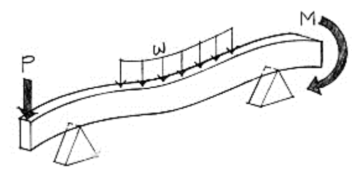
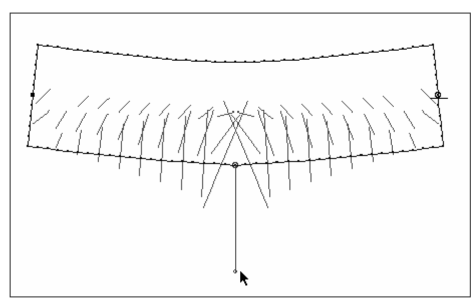
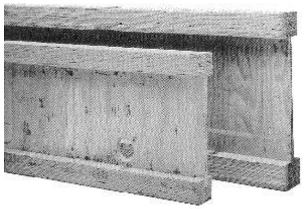


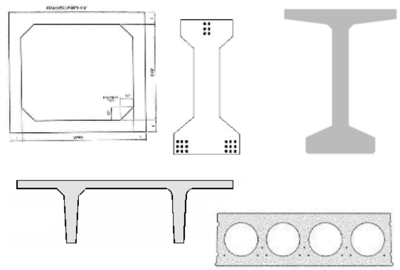
Figure 5.4 Bending (flexural) loads on a beam.

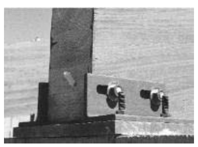


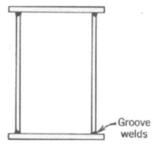
Beam Deflections

- *"moment of inertia"*









(e) Welded box girder.

Beam Styles

- *vierendeel*

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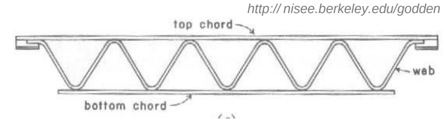
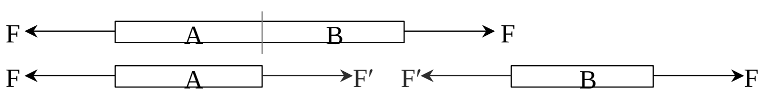
- *open web joists*
- *manufactured*

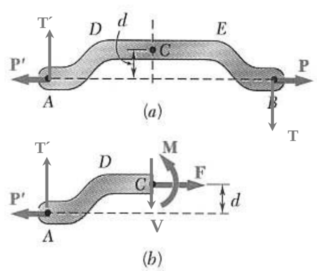


Internal Forces

- *trusses*
  - *axial only, (compression & tension)*

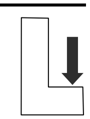


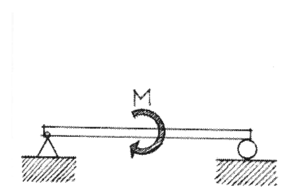
- *in general*
  - *axial force*
  - *shear force, V*
  - *bending moment, M*



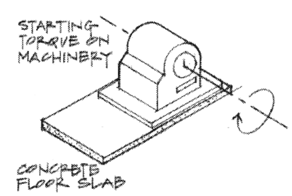
Beam Loading

- *concentrated force*
- *concentrated moment*
  - *spandrel beams*



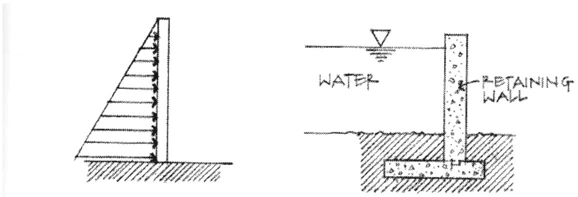


(d) Pure moment.



Beam Loading

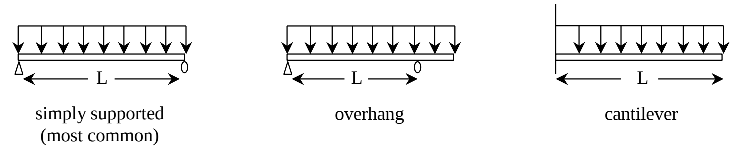
- *uniformly distributed load (line load)*
- *non-uniformly distributed load*
  - *hydrostatic pressure = γh*
  - *wind loads*



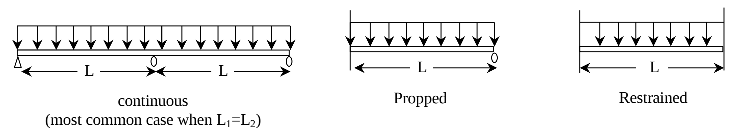
(c) Nonuniformly distributed load.

Beam Supports

- *statically determinate*

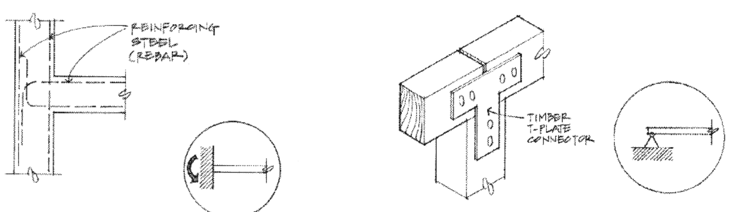


- *statically indeterminate*

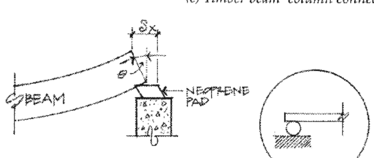


Beam Supports

- *in the real world, modeled type*



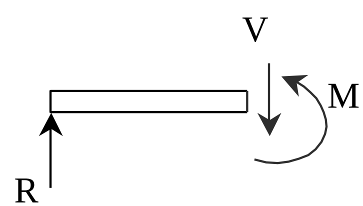
(c) Timber beam–column connection with T-plate.



(a) Beam supported by a neoprene pad.

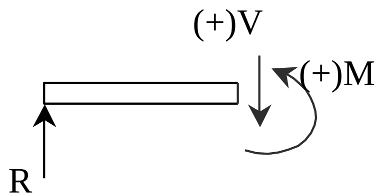
Internal Forces in Beams

- *like method of sections / joints*
  - *no axial forces*
- *section <u>must</u> be in equilibrium*
- *want to know where biggest internal forces and moments are for designing*



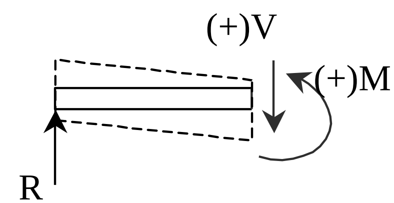
V & M Diagrams

- tool to locate V_{max} and M_{max} (at V = 0)
- <u>necessary</u> for designing
- have a <u>different sign convention</u> than external forces, moments, and reactions

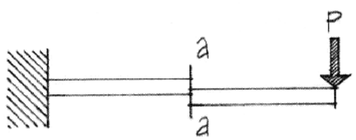


Sign Convention

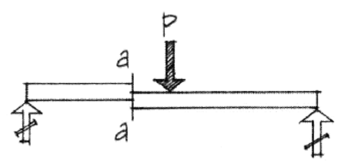
- shear force, V:
  - cut section to LEFT
  - if $\sum F_y$ is positive by statics, V acts down and is POSITIVE
  - beam has to resist shearing apart by V



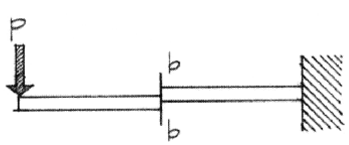
Shear Sign Convention



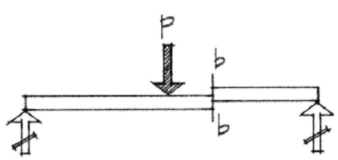
(+) Shear.



(+) Shear.



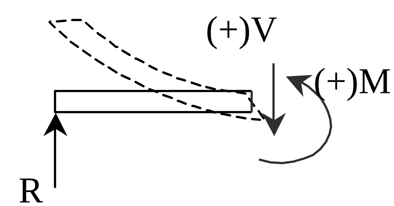
(–) Shear.



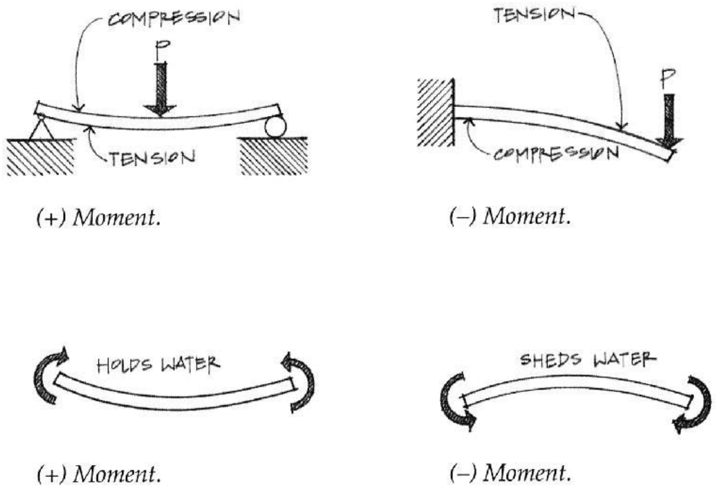
(–) Shear.

Sign Convention

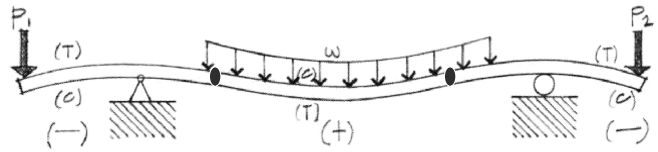
- bending moment, M:
  - cut section to LEFT
  - if $\sum M_{cut}$ is clockwise, M acts ccw and is POSITIVE – flexes into a “smiley” beam has to resist bending apart by M



Bending Moment Sign Convention



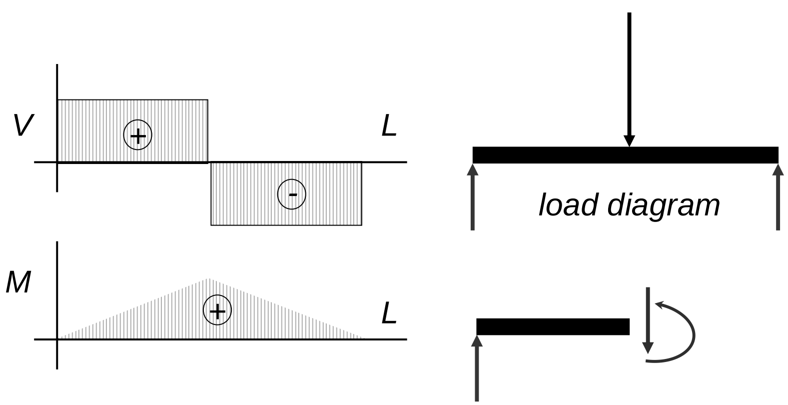
Deflected Shape



- *positive bending moment*
  - *tension in bottom, compression in top*
- *negative bending moment*
  - *tension in top, compression in bottom*
- *zero bending moment*
  - *inflection point*

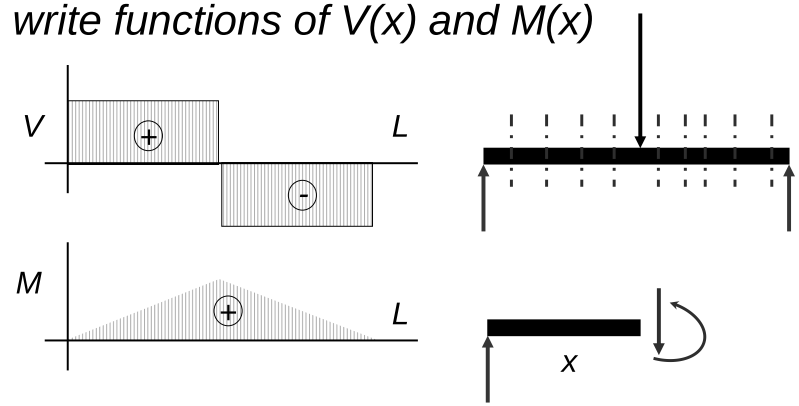
Constructing V & M Diagrams

- *along the beam length, plot V, plot M*



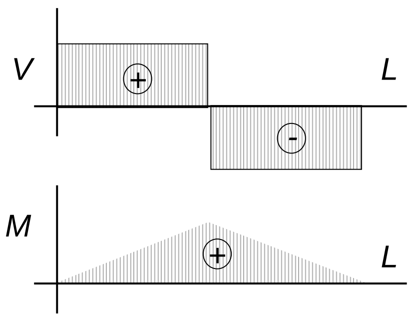
Mathematical Method

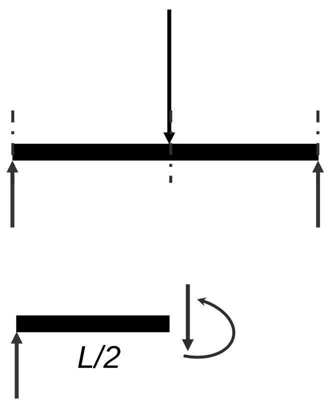
- *cut sections with x as width*
- *write functions of V(x) and M(x)*



Method 1: Equilibrium

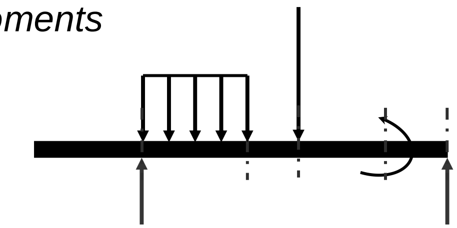
- cut sections at important places
- plot V & M





Method 1: Equilibrium

- important places
  - – supports
  - – concentrated loads
  - – start and end of distributed loads
  - – concentrated moments
- free ends
  - – zero forces



Method 2: Semigraphical

- by knowing
  - – area under loading curve = change in V
  - – area under shear curve = change in M
  - – concentrated forces cause "jump" in V
  - – concentrated moments cause "jump" in M

$$V_D - V_C = -\int_{x_C}^{x_D} w\,dx \qquad M_D - M_C = \int_{x_C}^{x_D} V\,dx$$

Method 2

- relationships

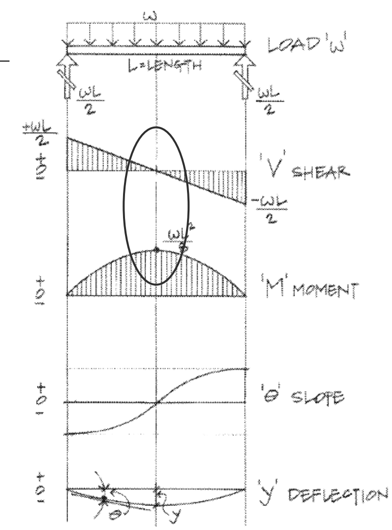
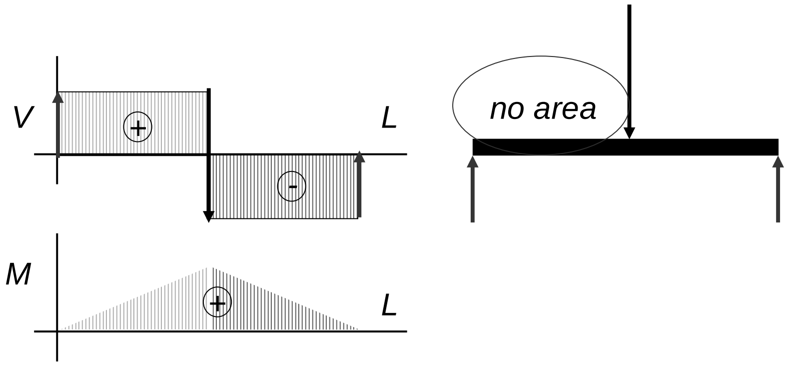


Figure 7.11 Relationship of load, shear, moment, slope, and deflection diagrams.

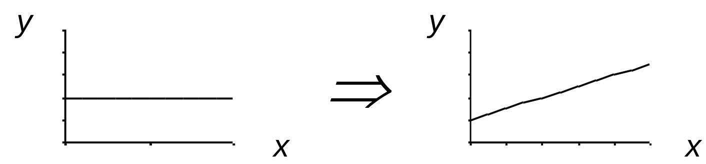
Method 2: Semigraphical

- M_{max} occurs where V = 0 (calculus)



Curve Relationships

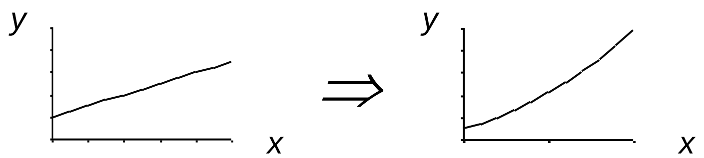
- integration of functions
- line with 0 slope, integrates to sloped



- ex: load to shear, shear to moment

Curve Relationships

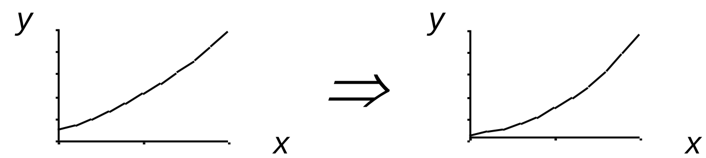
- line with slope, integrates to parabola



- ex: load to shear, shear to moment

Curve Relationships

- parabola, integrates to 3rd order curve



- ex: load to shear, shear to moment

Basic Procedure

1. Find reaction forces & moments

   Plot axes, underneath beam load diagram

V:

2. Starting at left
3. Shear is 0 at free ends
4. Shear has 2 values at point loads
5. Sum vertical forces at each section

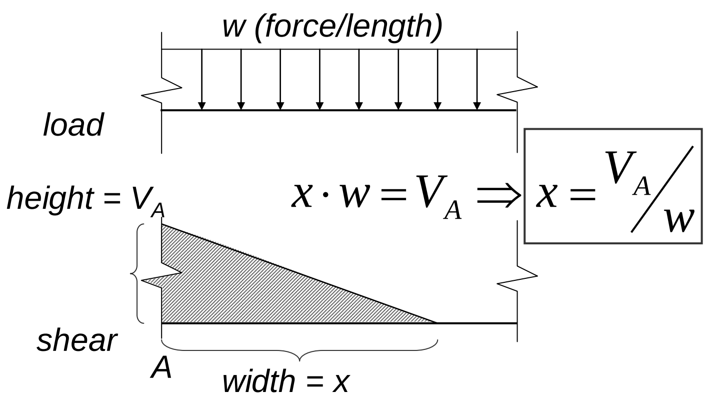
Basic Procedure

M:

6. Starting at left
7. Moment is 0 at free ends
8. Moment has 2 values at moments
9. Sum moments at each section
10. Maximum moment is where shear = 0! (locate where V = 0)

Shear Through Zero

- slope of V is w (-w:1)



Parabolic Shapes

- cases