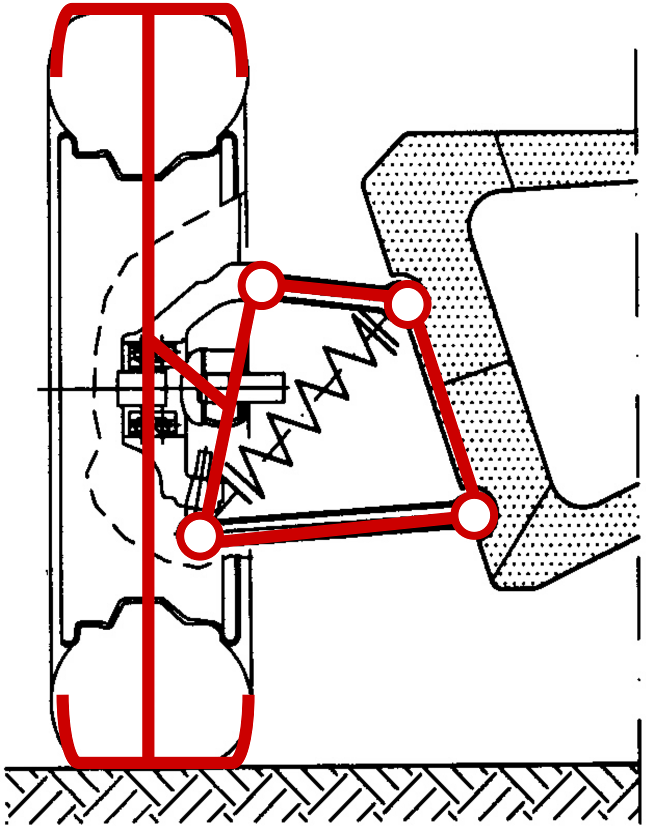
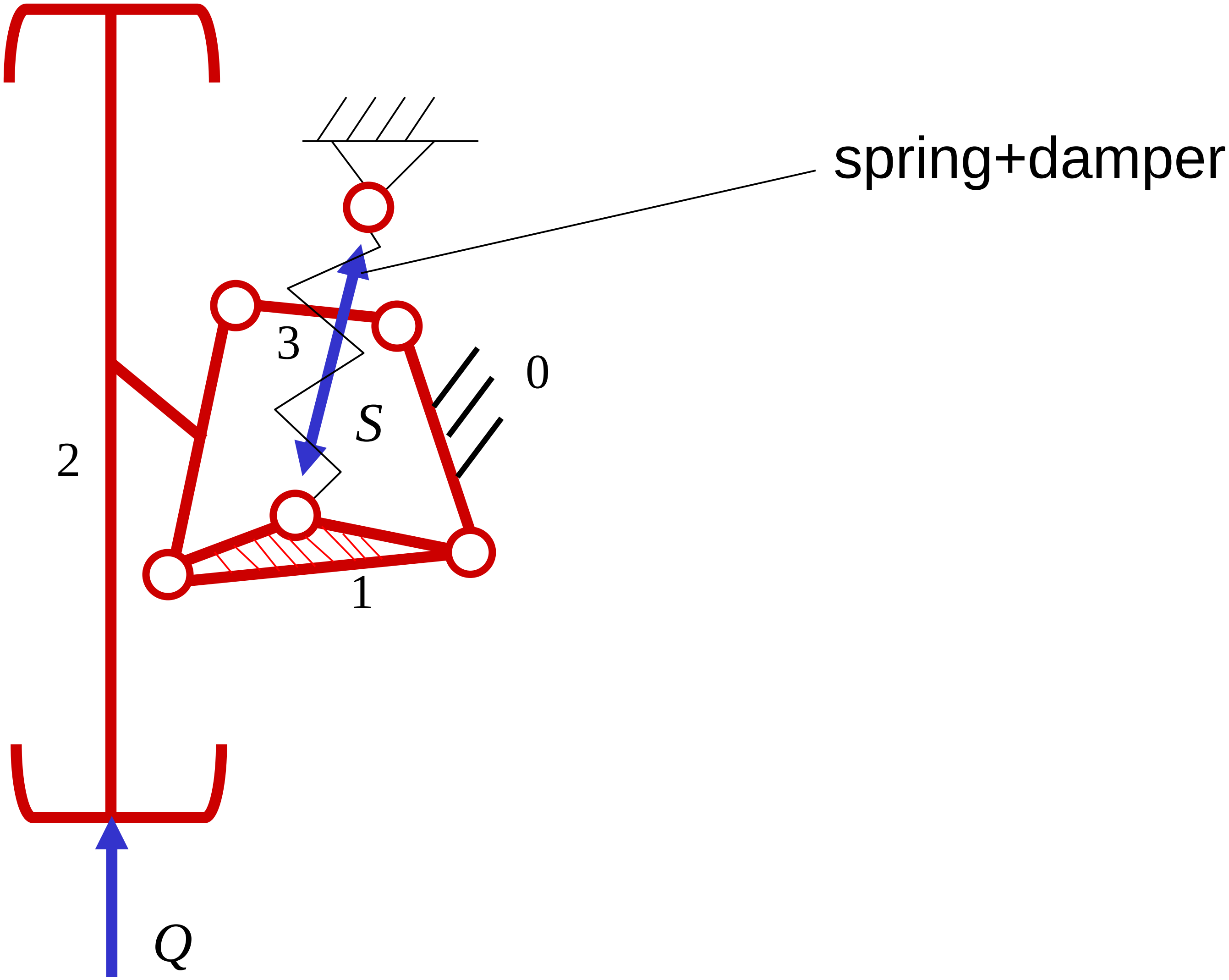
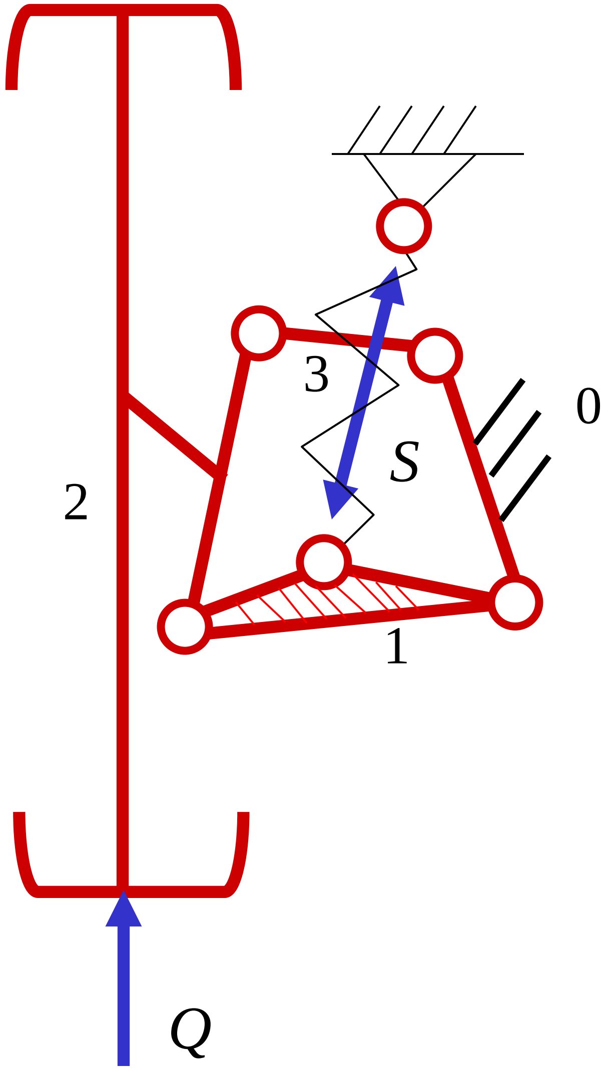
Suspension system




spring+damper
3
0
S
2
1
Q

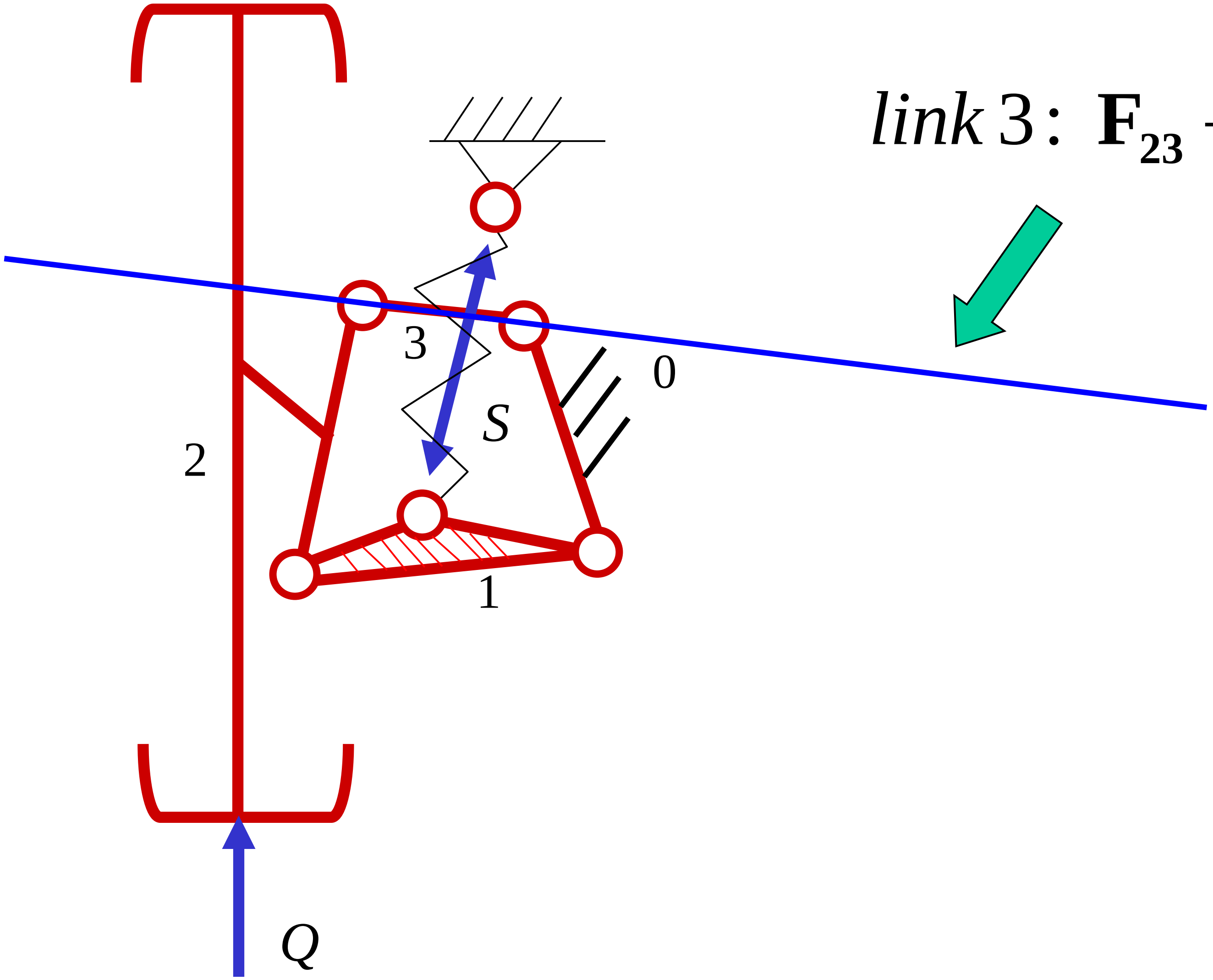


$$link\ 2:\ \mathbf{F}_{32}+\mathbf{Q}+\mathbf{F}_{12}=0$$

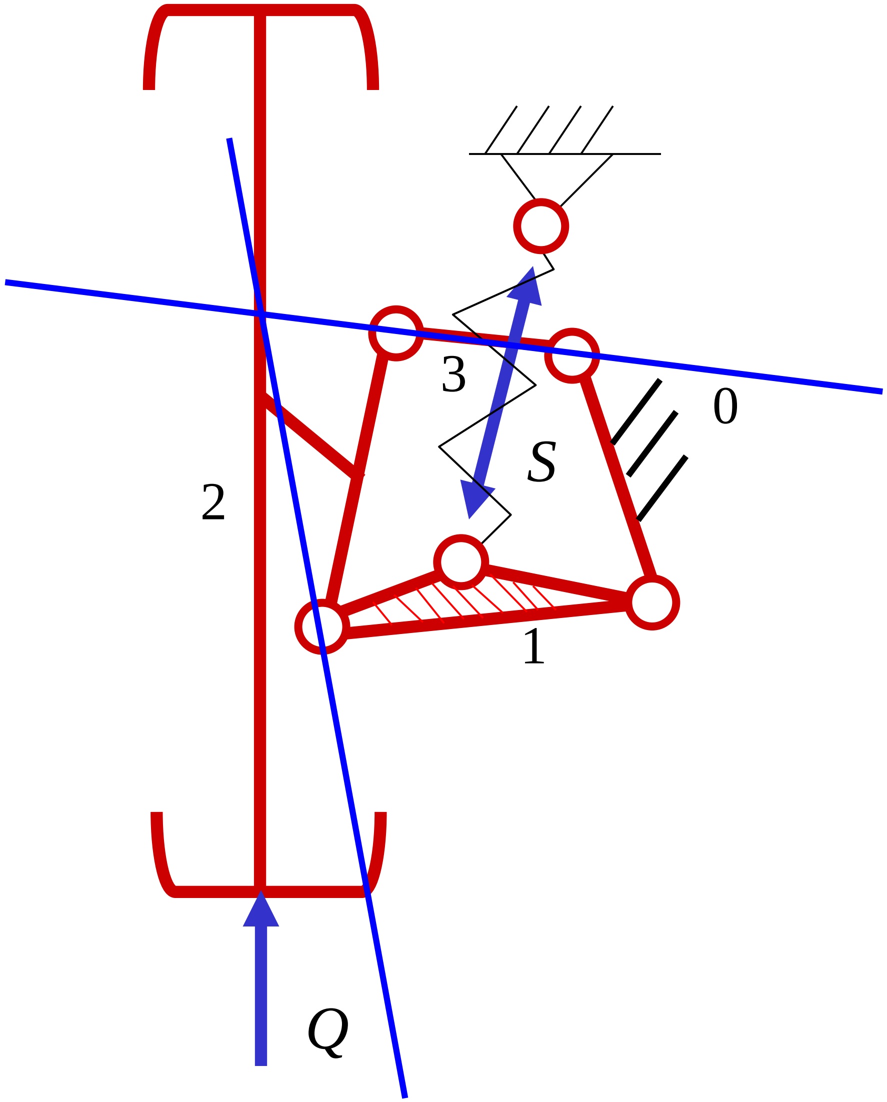
points of
application only

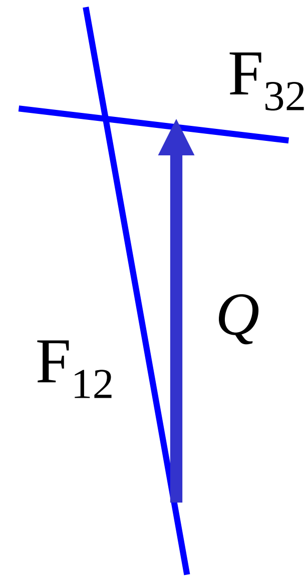
?

$$link\,3:\ \mathbf{F}_{23}+\mathbf{F}_{03}=0$$

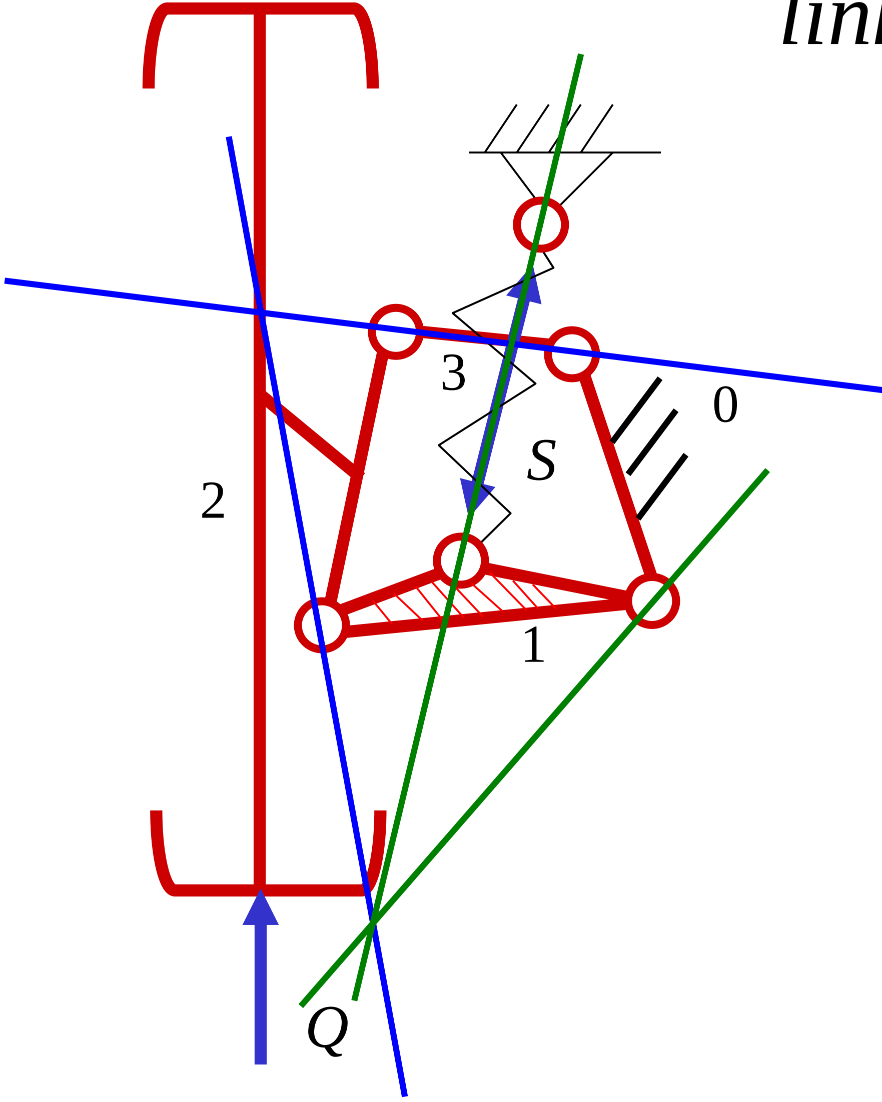


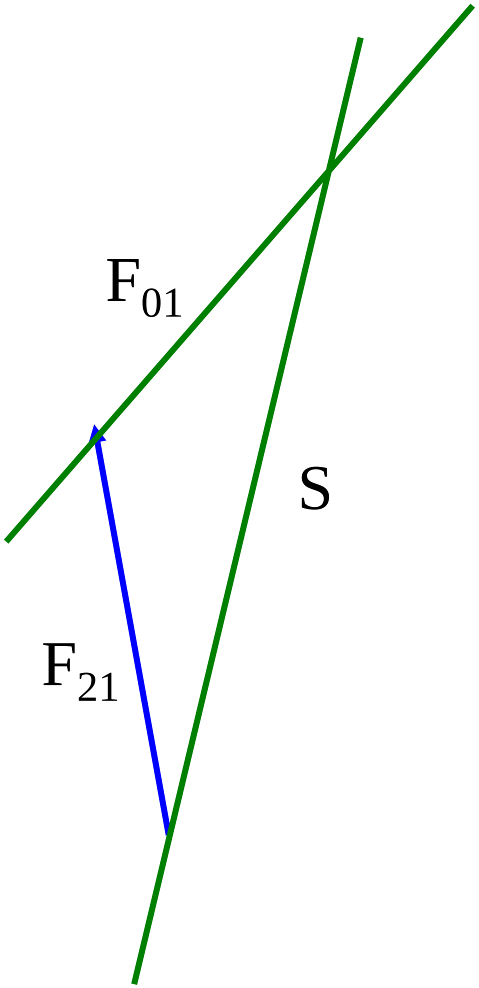
$$\mathbf{F}_{32} + \mathbf{Q} + \mathbf{F}_{12} = 0$$



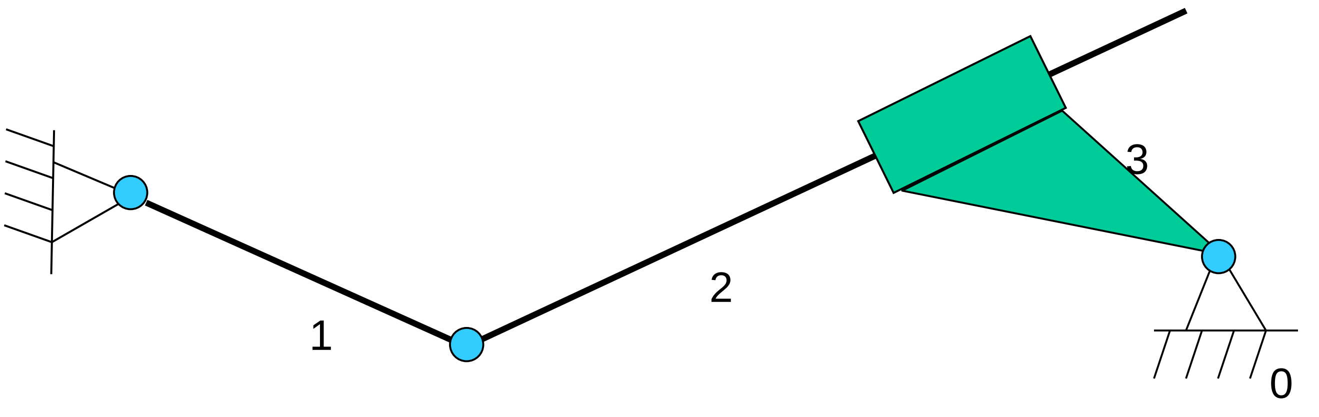


$$link\,1: \mathbf{F_{21}} + \mathbf{F_{01}} + \mathbf{S} = 0$$

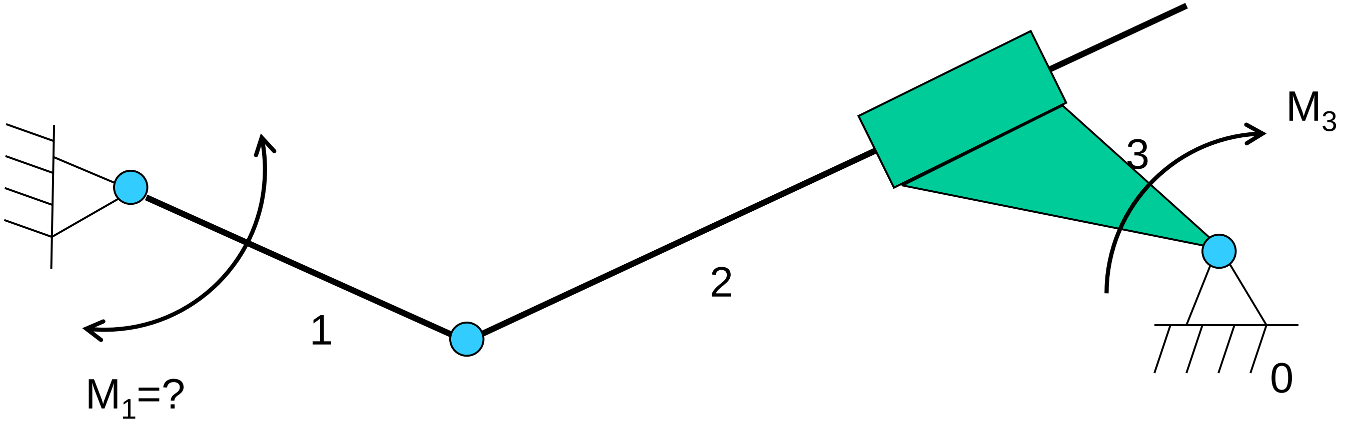




RRTR example (1)

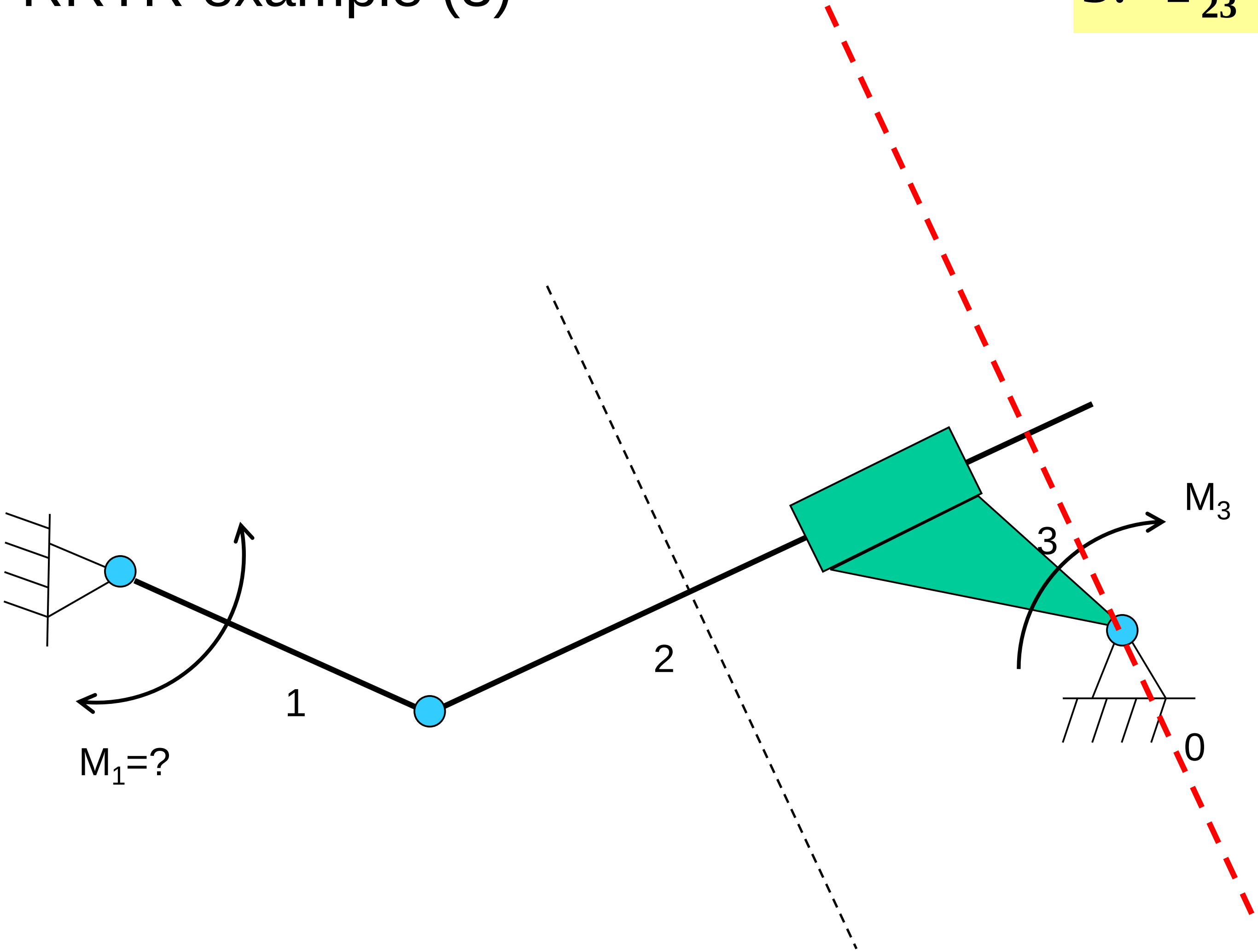


RRTR example (2)



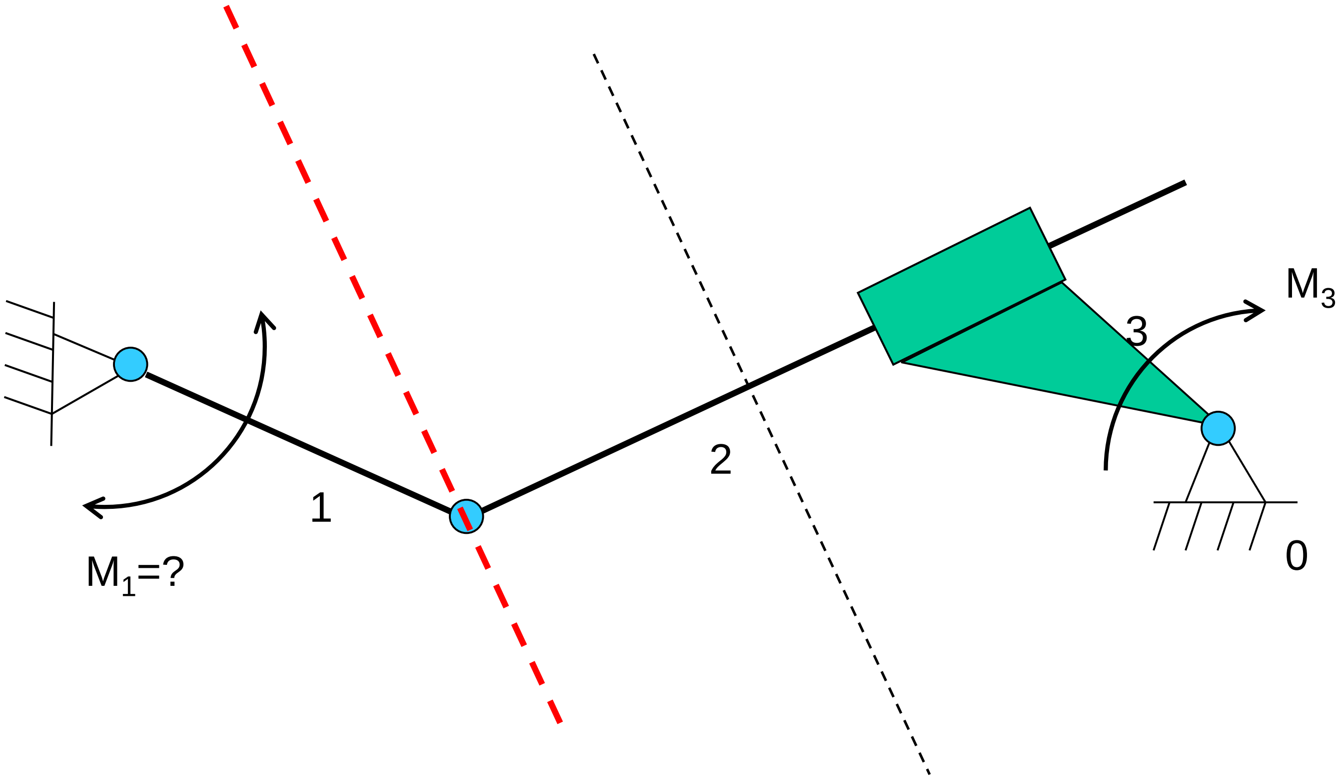
RRTR example (3)

$$3.\quad \mathbf{F_{23}} + \mathbf{F_{03}} = 0$$



RRTR example (3)

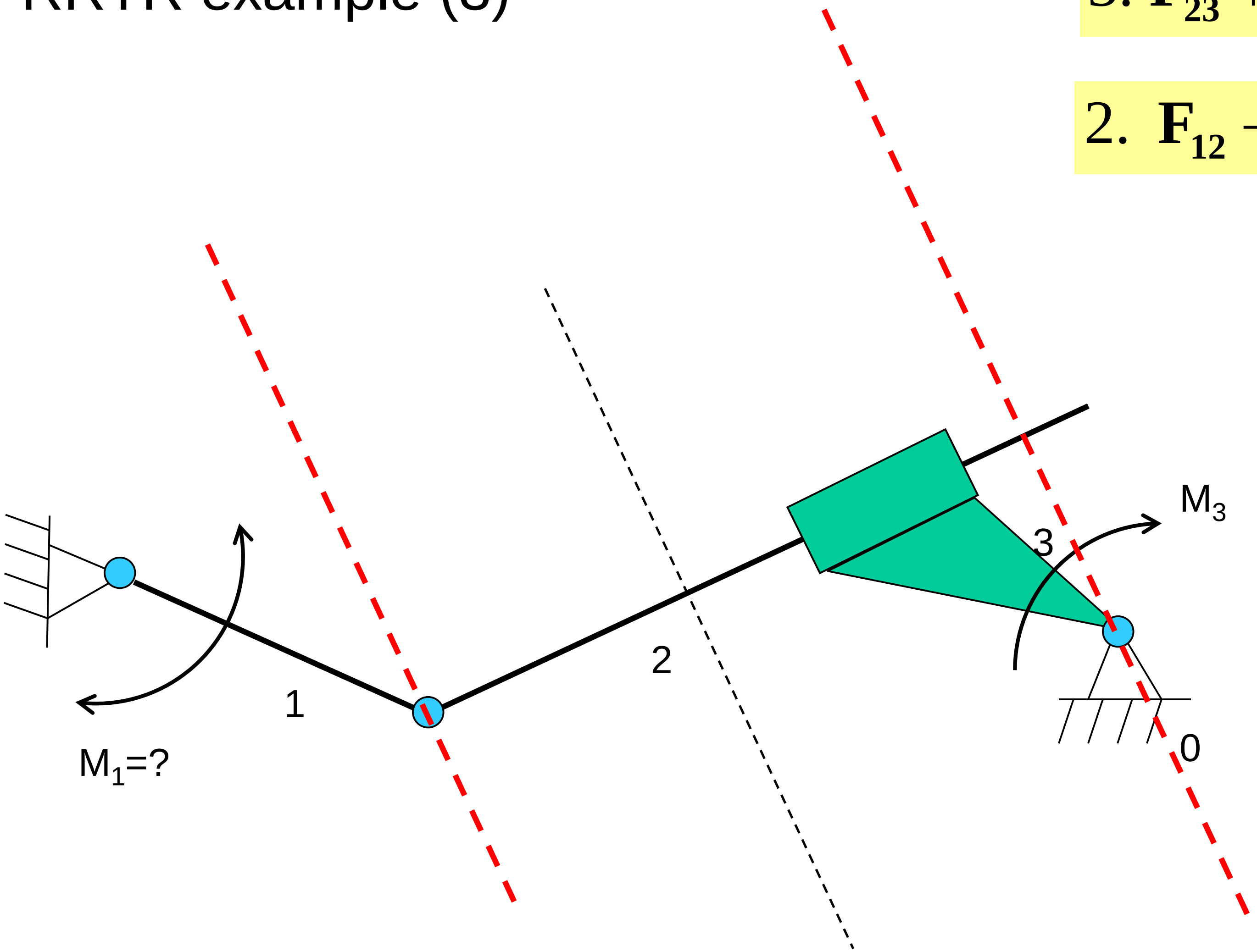
$$2.\ \mathbf{F_{12}} + \mathbf{F_{32}} = 0$$



RRTR example (3)

$$3.\ \mathbf{F_{23}} + \mathbf{F_{03}} = 0$$

$$2.\ \mathbf{F_{12}} + \mathbf{F_{32}} = 0$$

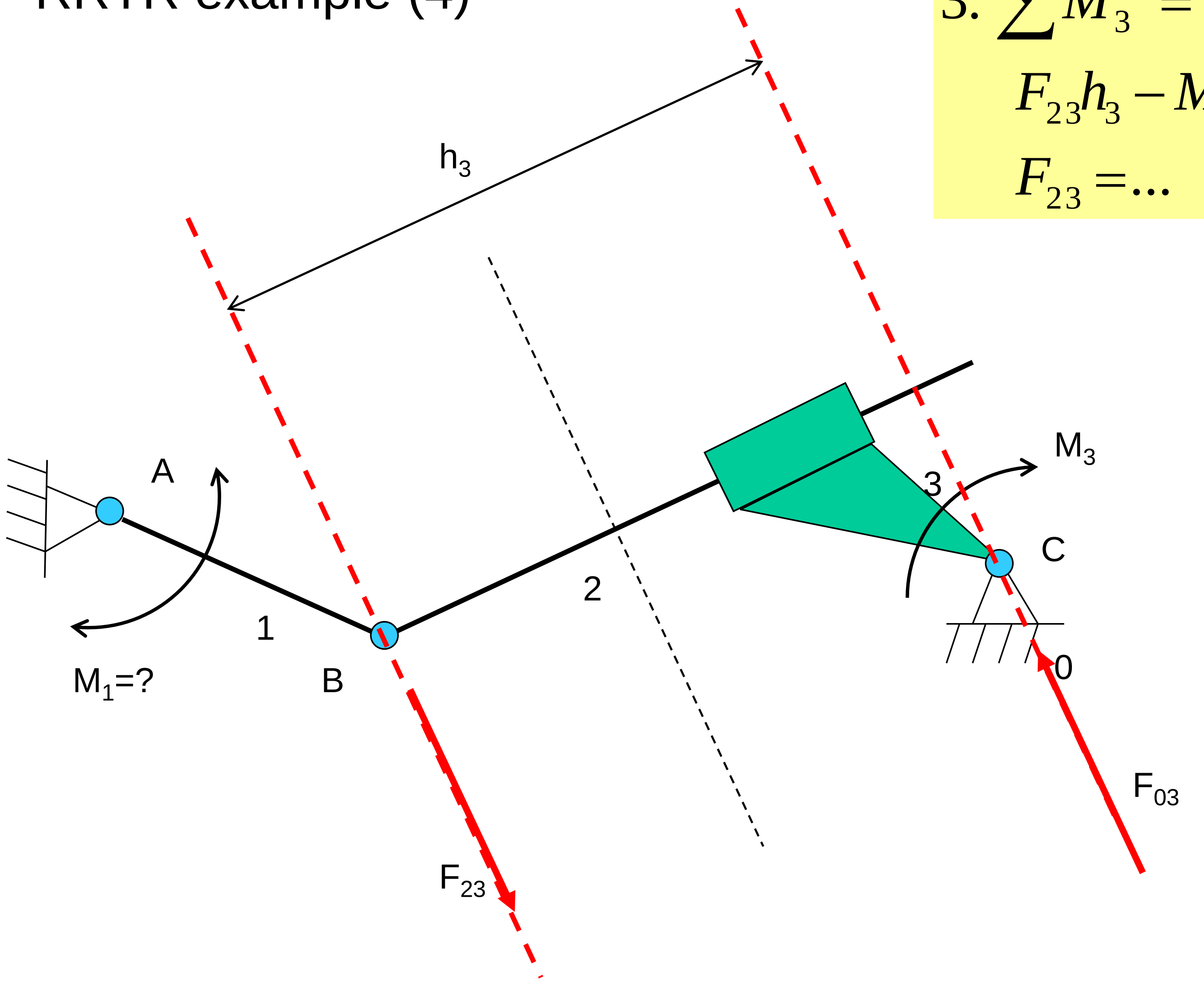


RRTR example (4)

3. $\sum M_3^C = 0$

$$F_{23} h_3 - M_3 = 0$$

$$F_{23} = \ldots$$

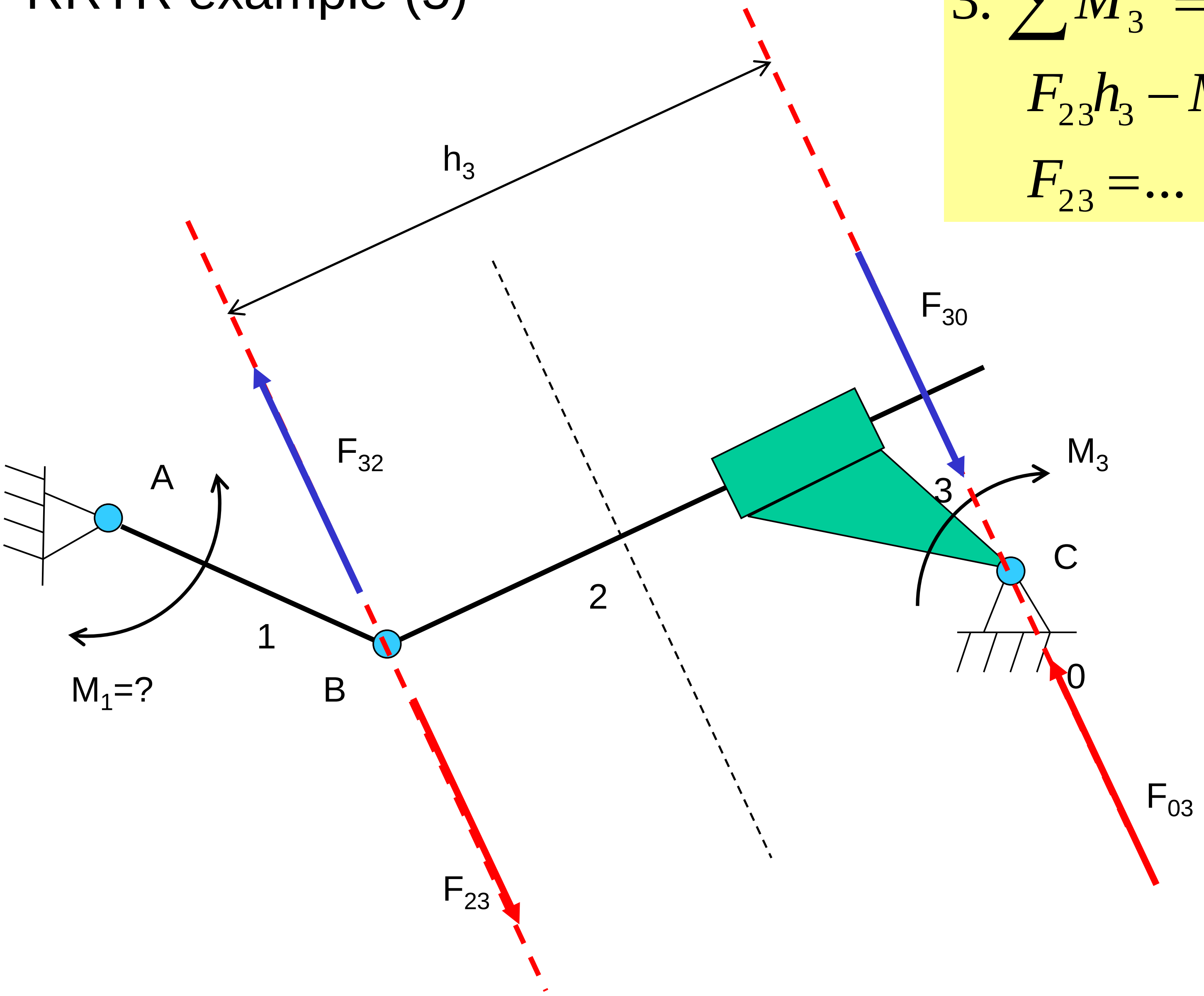


RRTR example (5)

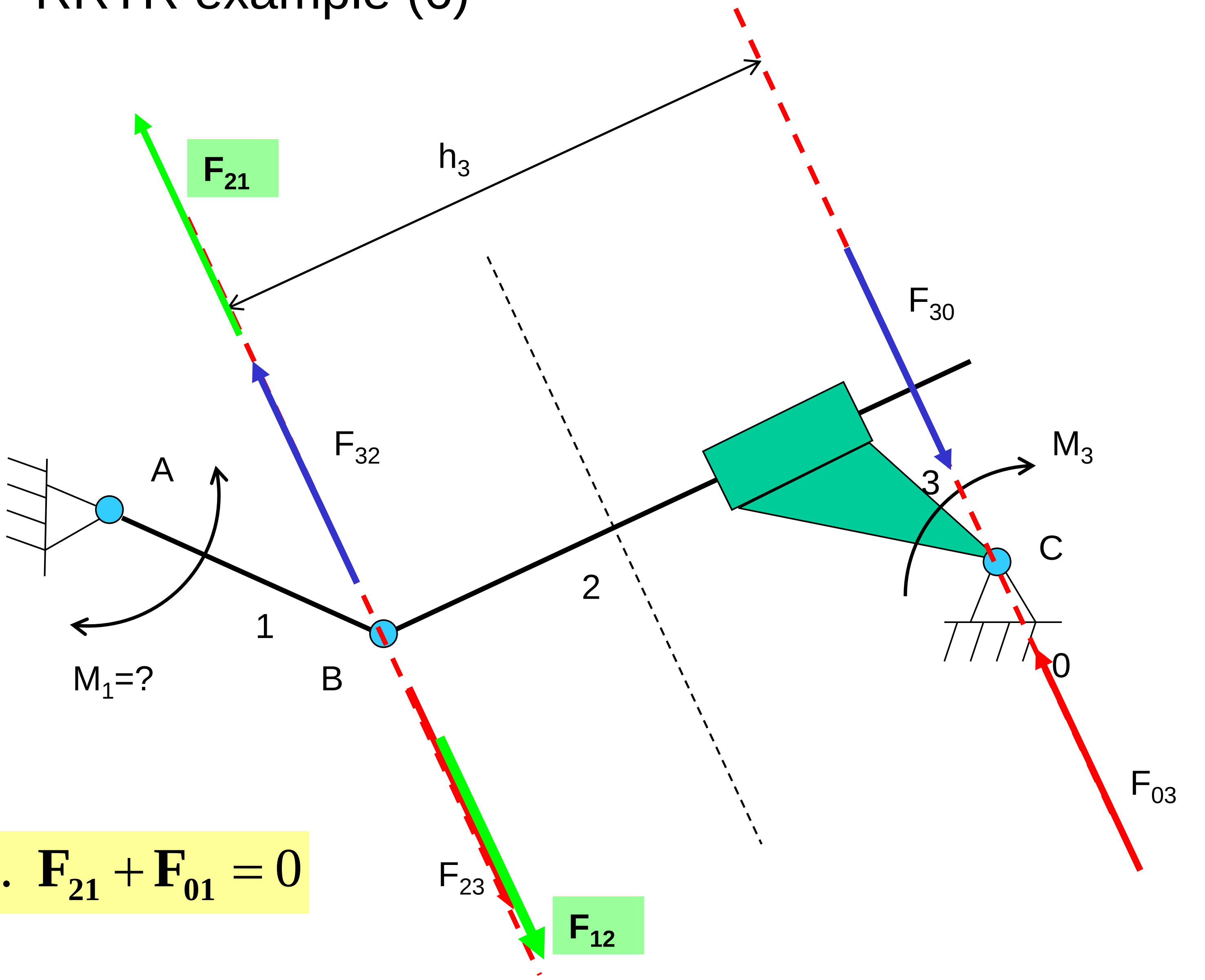
3. $\sum M_3^C = 0$

$$F_{23}h_3 - M_3 = 0$$

$$F_{23} = \ldots$$



RRTR example (6)

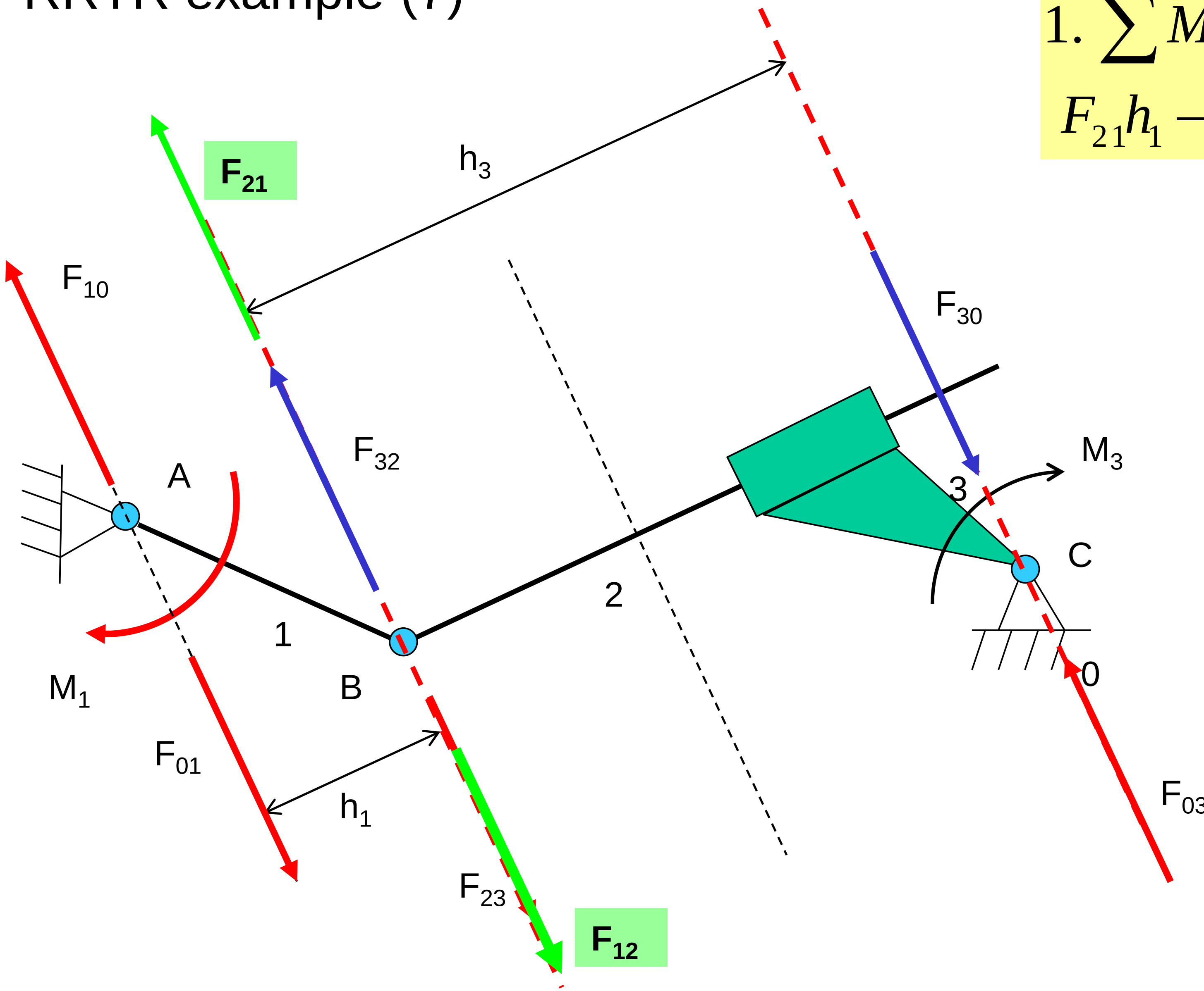


$$1.\ \mathbf{F}_{21} + \mathbf{F}_{01} = 0$$

RRTR example (7)

$$1.\ \sum M_1^A = 0$$

$$F_{21}h_1 - M_1 = 0$$



IN KINETOSTATICS

THE MOTION OF MASS BODIES (LINKS)

IS REPRESENTED BY INERTIA FORCES

Inertia forces

$$\mathbf{F} = m\mathbf{a}$$

$$\mathbf{F} - m\mathbf{a} = 0 \leftrightarrow \mathbf{F} + \mathbf{F}_b = 0$$

$$\mathbf{F}_b = -m\mathbf{a}$$

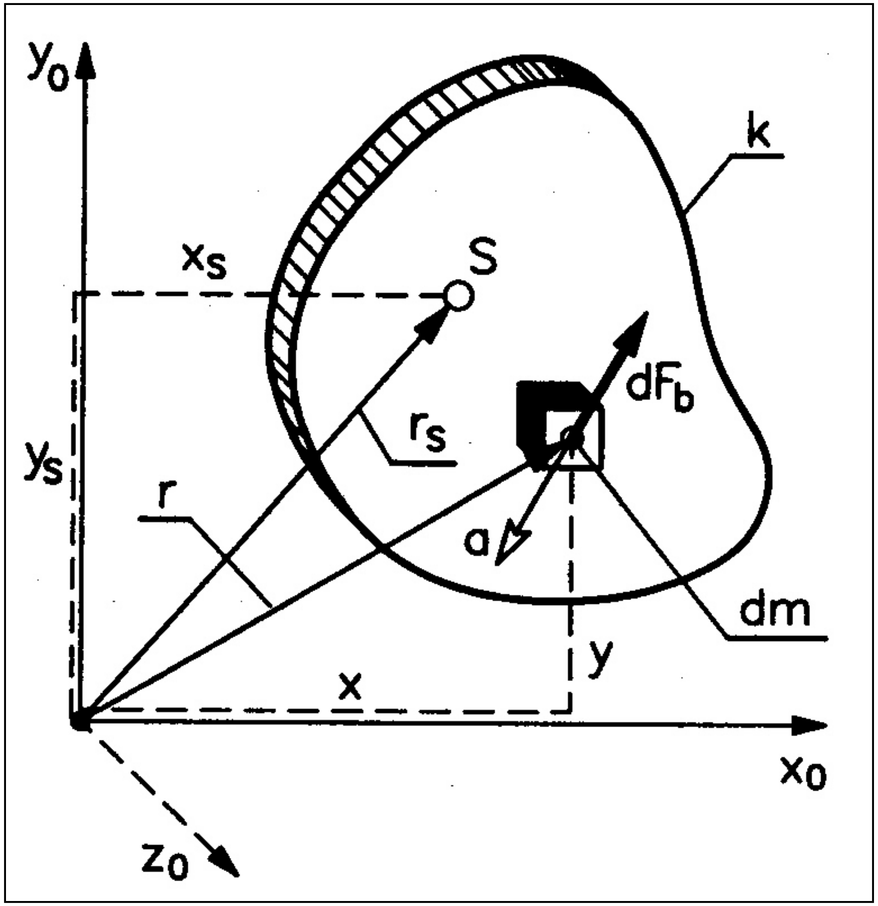
$$\mathbf{M} = I_S \boldsymbol{\varepsilon}$$

$$\mathbf{M} - I_S \boldsymbol{\varepsilon} = 0 \leftrightarrow \mathbf{M} + \mathbf{M}_b = 0$$

$$\mathbf{M}_b = -I_S \boldsymbol{\varepsilon}$$

Newton, Euler, D'Alembert

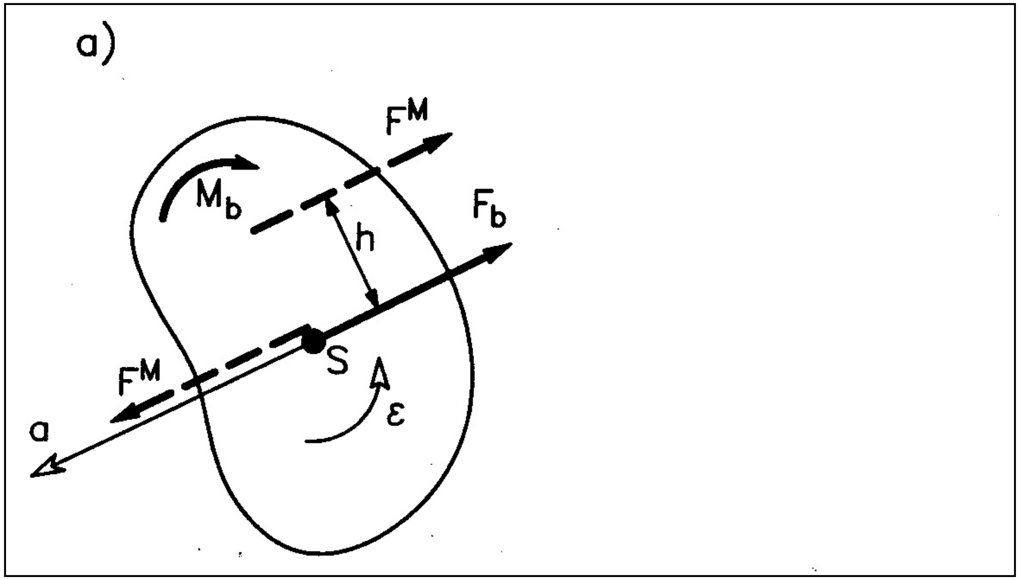
Mass moment of inertia



$$I_Z = \int_m (x^2 + y^2)\,dm$$

$$I_Z = I_S + m(x_S^2 + y_S^2)$$

FORCE (F_b) and MOMENT (M_b) OF INERTIA



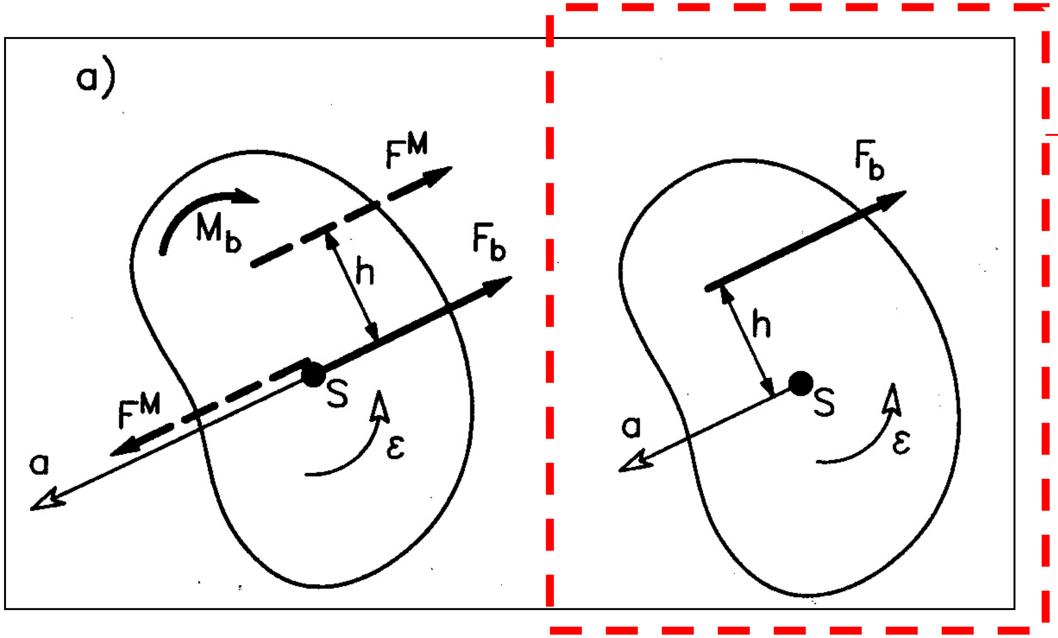
Given:
m, I_S, a, ε

$$\mathbf{F}_b = -m\mathbf{a}$$

$$\mathbf{M}_b = -I_S\boldsymbol{\varepsilon}$$

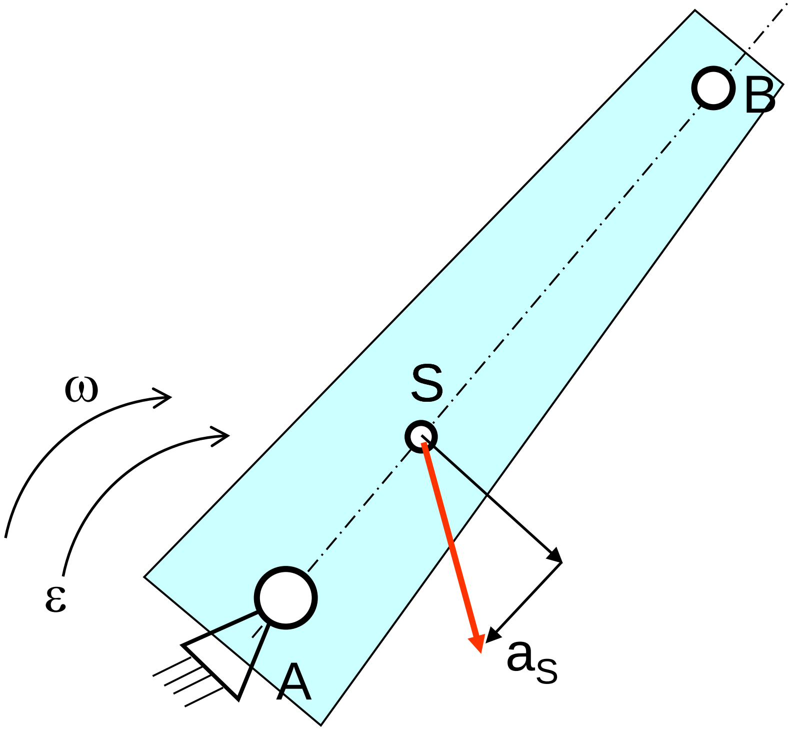
$$h = \frac{M_b}{F^M} = \frac{M_b}{F_b} = \frac{I_S \varepsilon}{ma}$$

FORCE (F_b) and MOMENT (M_b) OF INERTIA



resultant inertia force

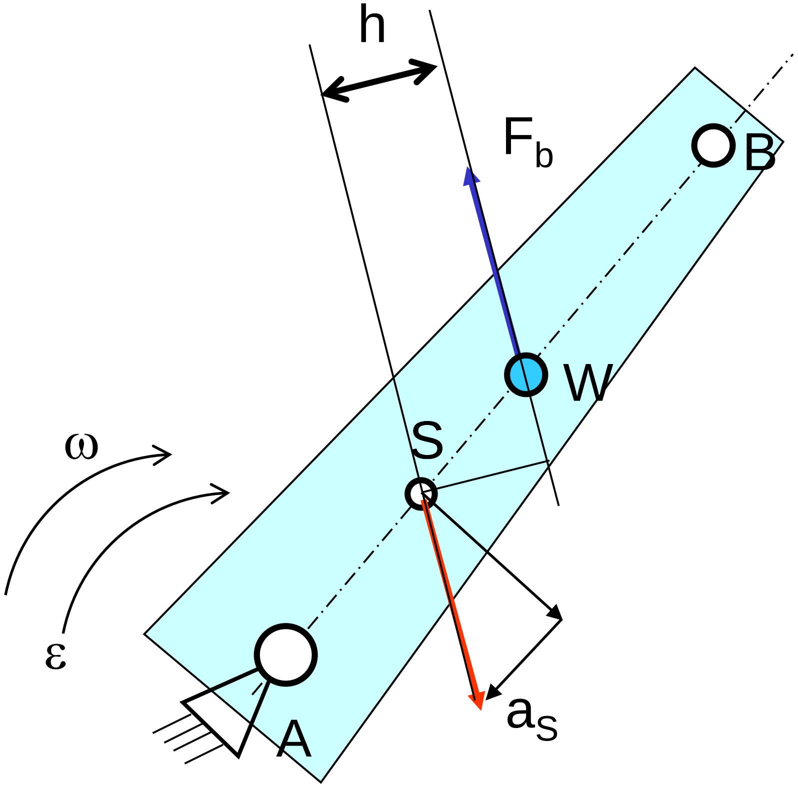
Center of percussion



$$\mathbf{a}_S = \mathbf{a}_S^n + \mathbf{a}_S^t$$

$$\mathbf{a}_S^n = \omega^2 AS; \quad \mathbf{a}_S^t = \varepsilon AS$$

Center of percussion

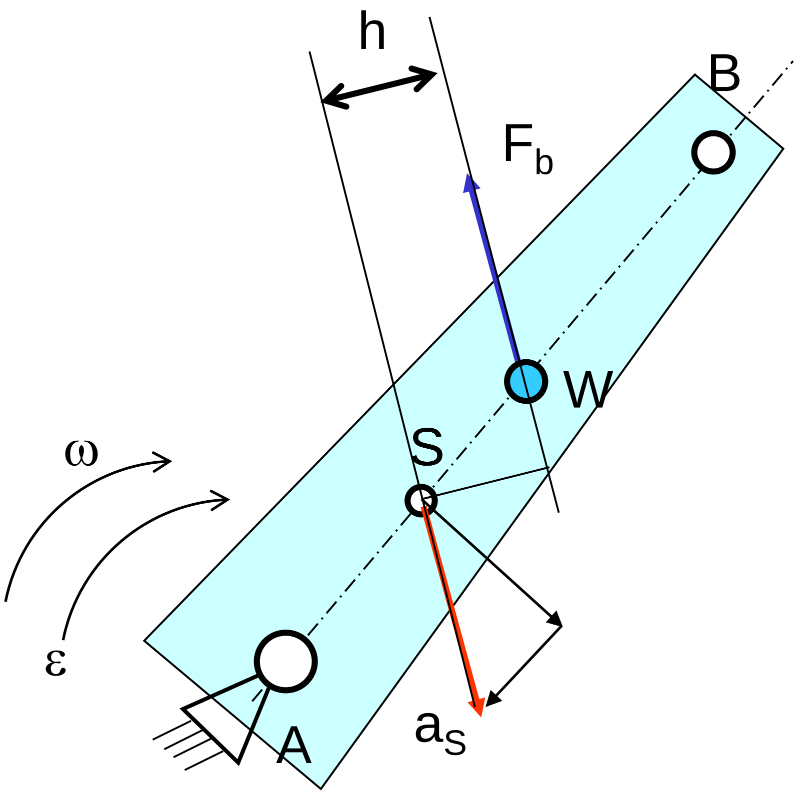


$$\mathbf{F_b} = -\mathbf{a_S} m$$

$$\mathbf{M_b} = -\boldsymbol{\varepsilon} I_S$$

$$h = \frac{M_b}{F_b} = \frac{I_S \varepsilon}{m a_S}$$

Center of percussion



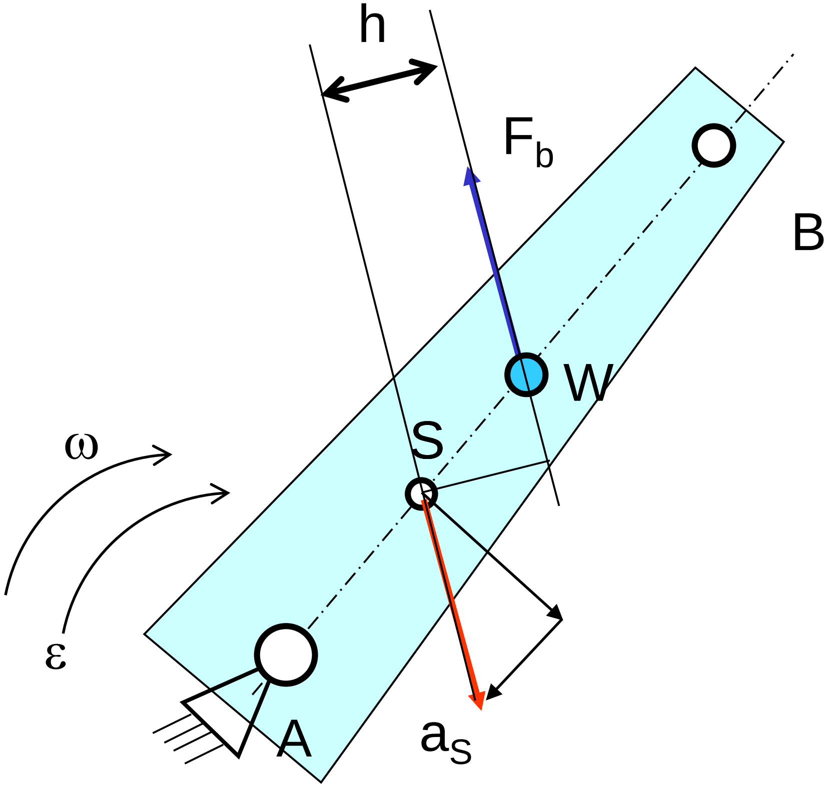
$$\frac{h}{SW} = \frac{a_S^t}{a_S} = \cos(?)$$

$$SW = h\frac{a_S}{a_S^t} = \left(\frac{I_S\varepsilon}{ma_S}\right)\left(\frac{a_S}{a_S^t}\right) =$$

$$= \left(\frac{I_S \frac{a_S^t}{AS}}{ma_S}\right)\left(\frac{a_S}{a_S^t}\right) =$$

$$= \frac{I_S a_S^t}{ma_S AS}\frac{a_S}{a_S^t} = \frac{I_S}{mAS}$$

Center of percussion



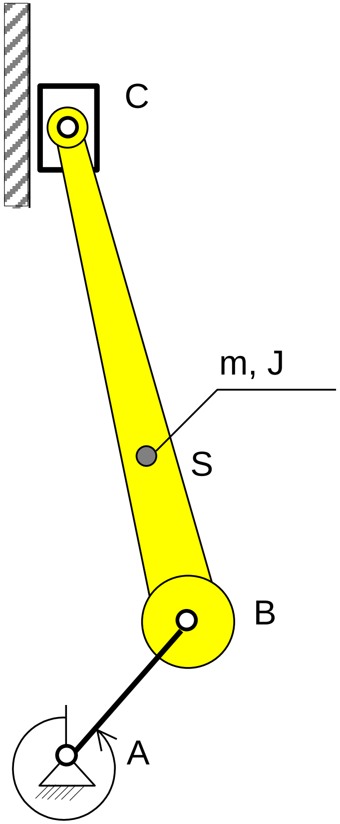
$$SW = \frac{I_S}{mAS} = \frac{m i_S^2}{mAS} = \frac{i_S^2}{AS}$$

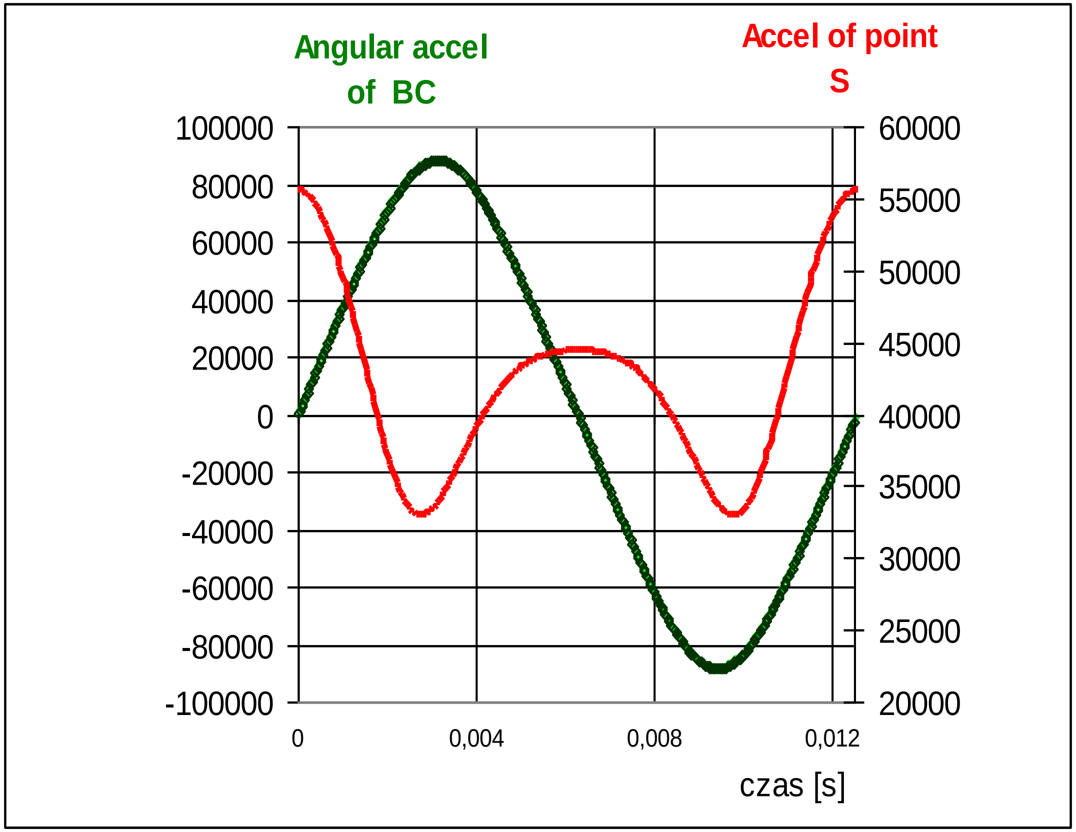
i_S – radius of inertia

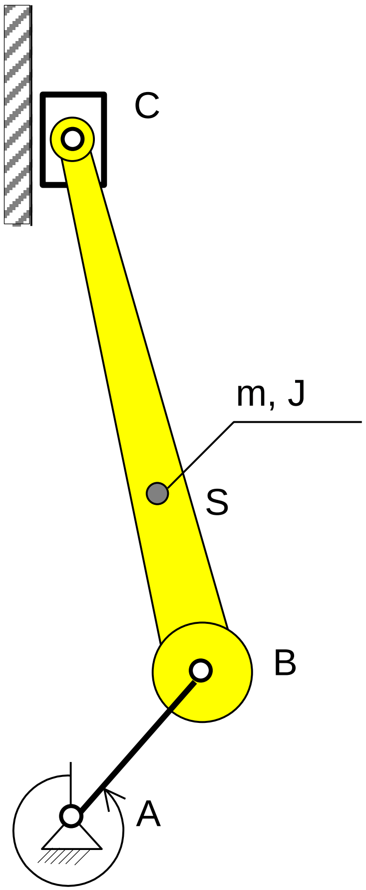
BC = 0,2 m

$\omega_1 = 500\ s^{-1}$ (ω_1 = const)

(n_1 = 5000 rev/min)



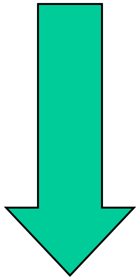




$a_{Smax} = 55000\ ms^{-2}$

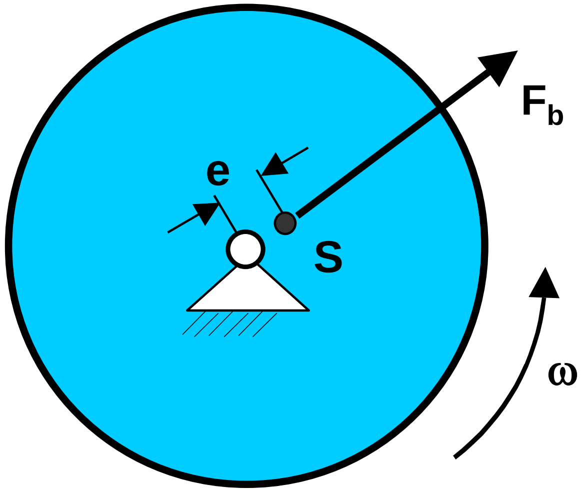
$\varepsilon_{Bcmax} = 90\ 000\ s^{-2}$

$m=0{,}2\ kg,\ \ J=0{,}01\ kgm^2$



$F_{bmax} = -\ ma = 11000\ N$!!!

$M_{bmax} = -\ J\varepsilon = 900\ Nm$!!!



$$e = 0{,}001 m$$

$$\omega = 500[1/s]$$

$$a_S = e\omega^2 = 250[m/s^2]$$

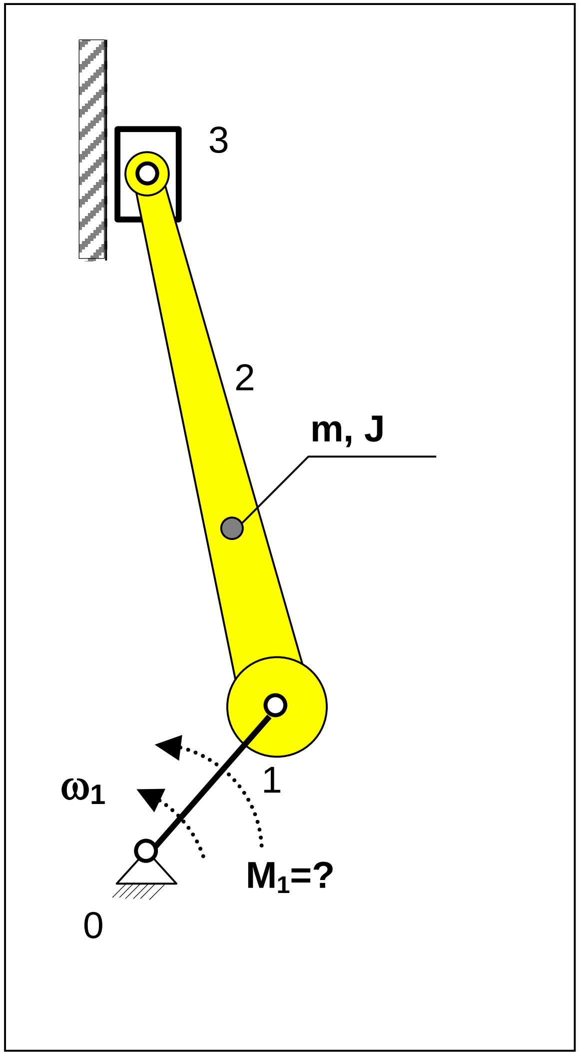
$$m = 1kg$$

S – center of gravity

$$F_b = -ma = 250N$$

$$\frac{F_b}{F_{STATIC}} = 25$$

Example of analysis (kinetostatics)

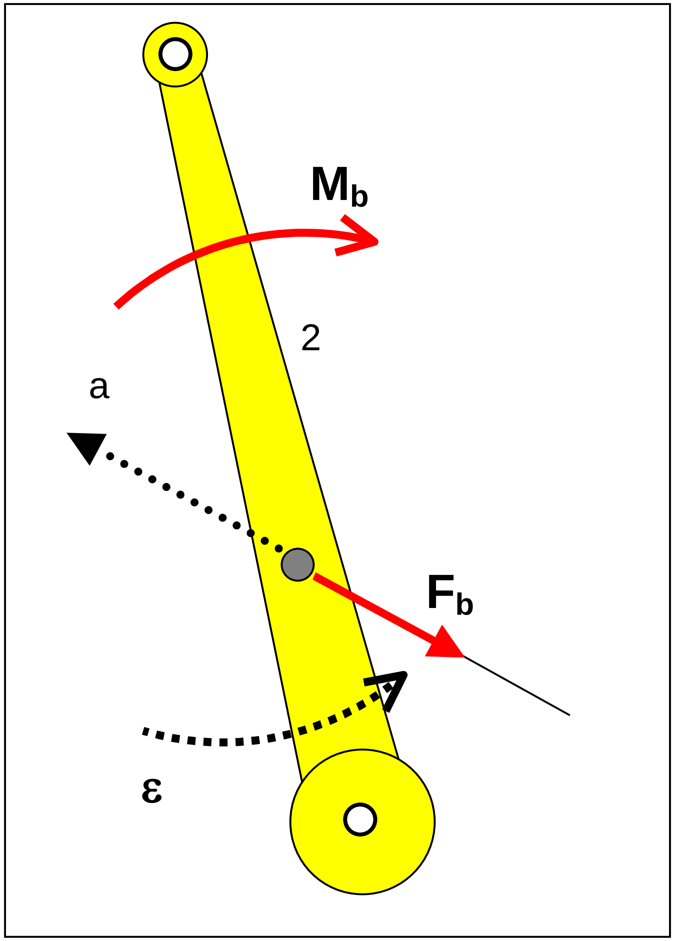


Data:

m, J – mass, mass moment of inertia

ω_1 – angular velocity of link 1

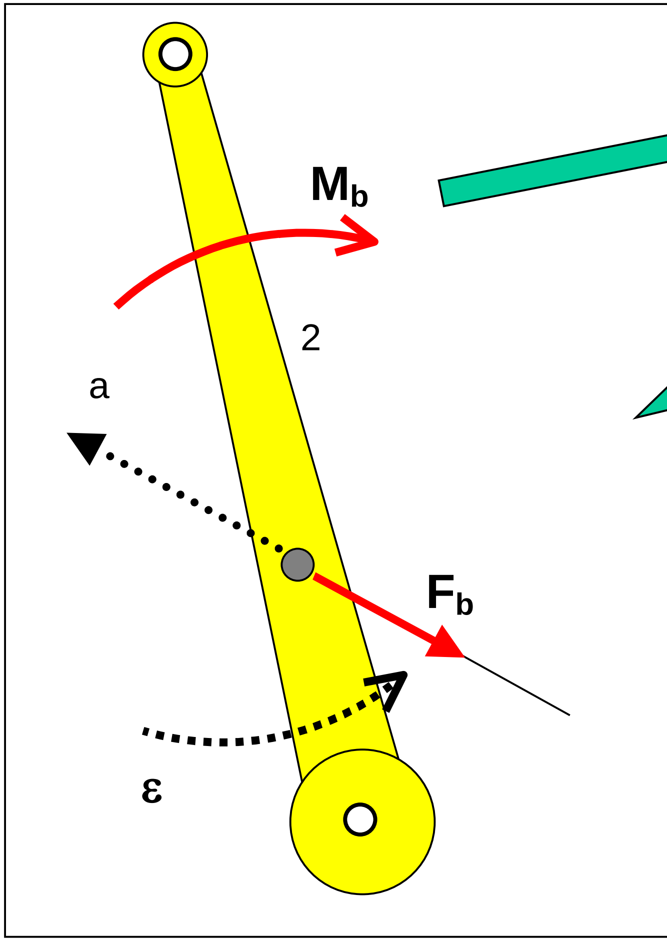
M_1 = ? and joint forces

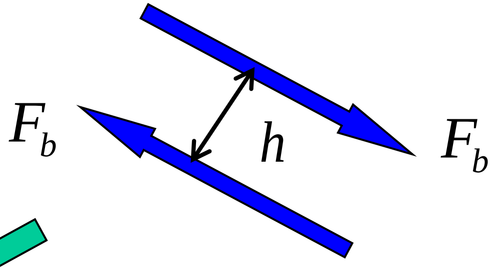


$$F_b = -ma$$

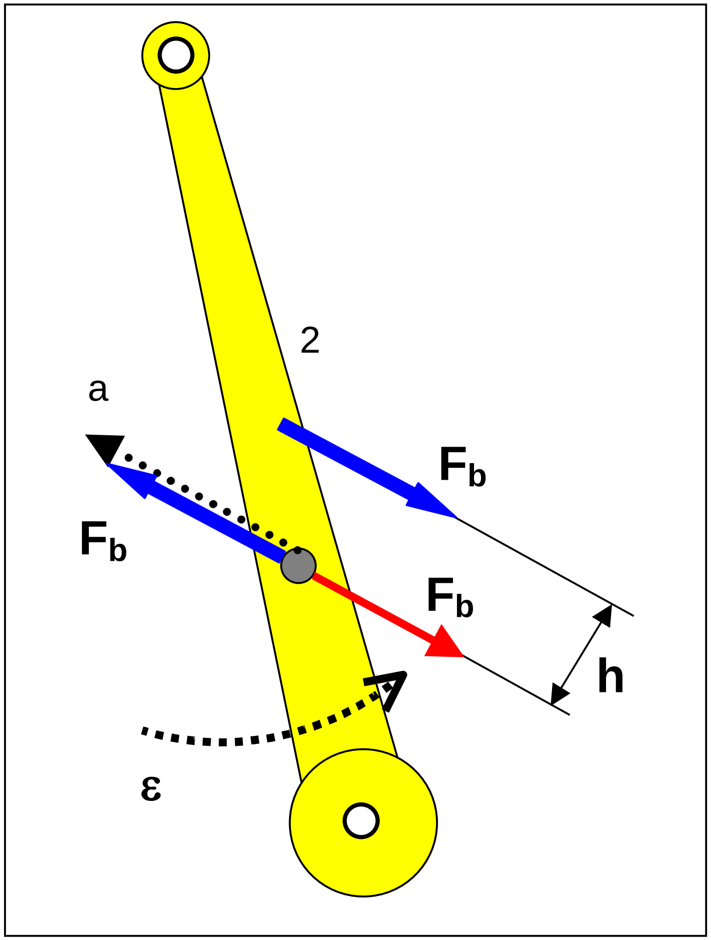
$$M_b = -J\varepsilon$$

M_b → Couple of forces F_b

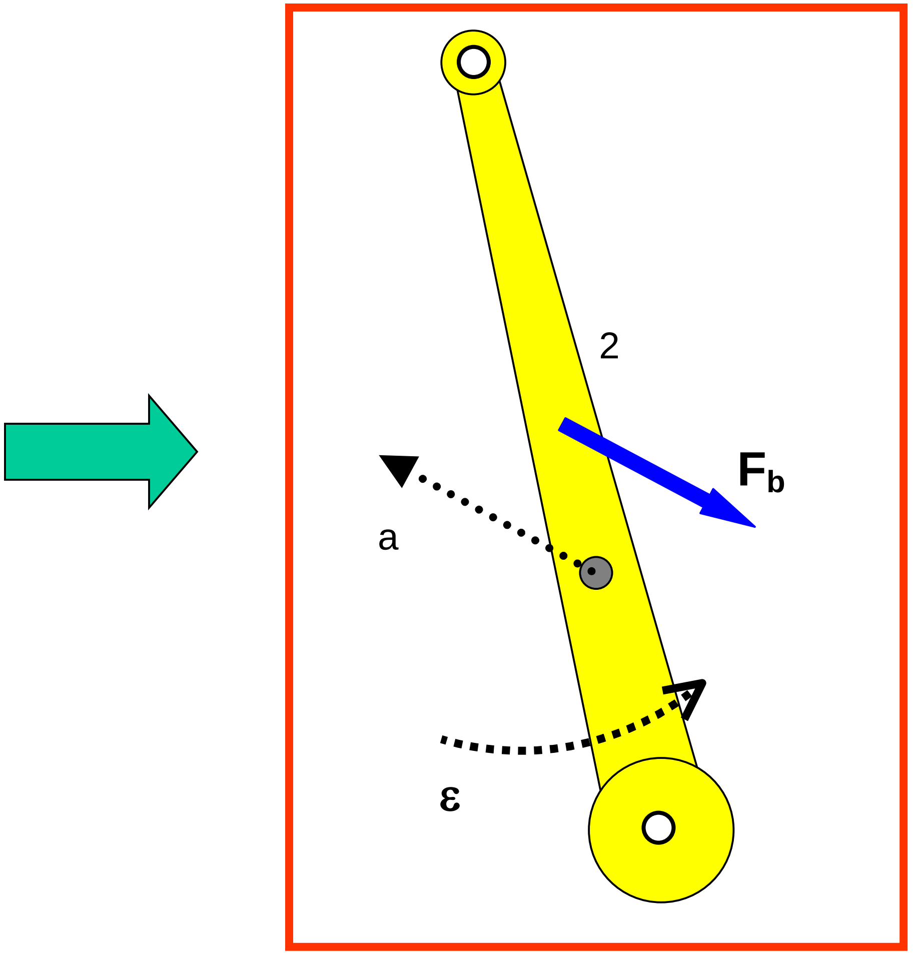




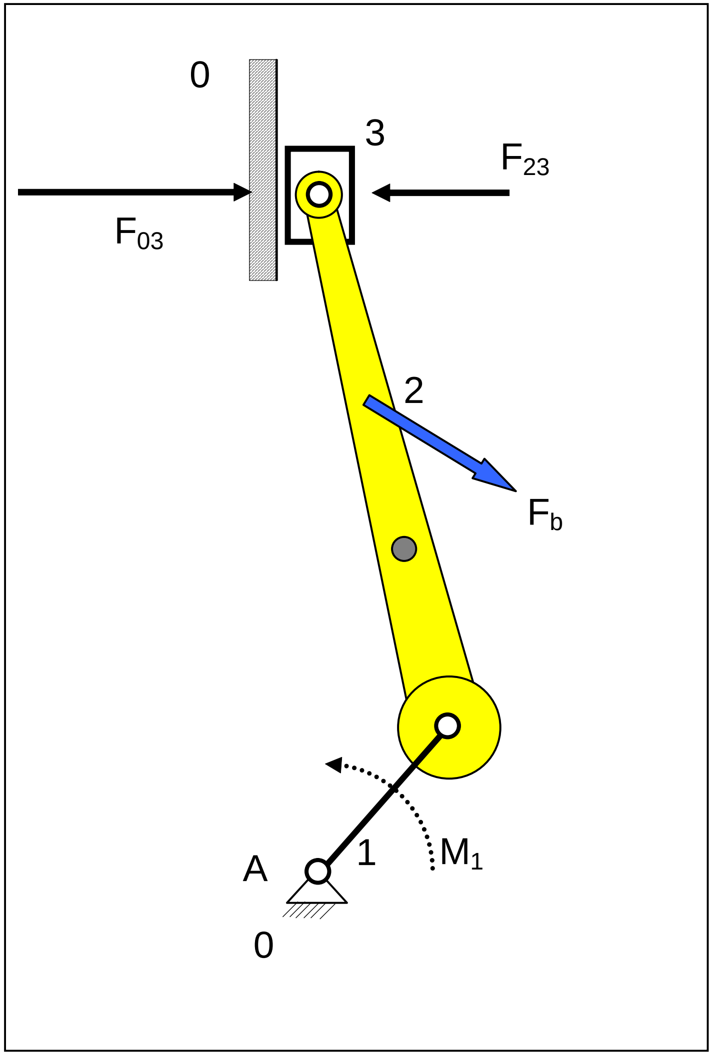
$$h = \frac{M_b}{F_b} = \frac{J\varepsilon}{ma}$$



2
a
Fb
Fb
Fb
h
ε

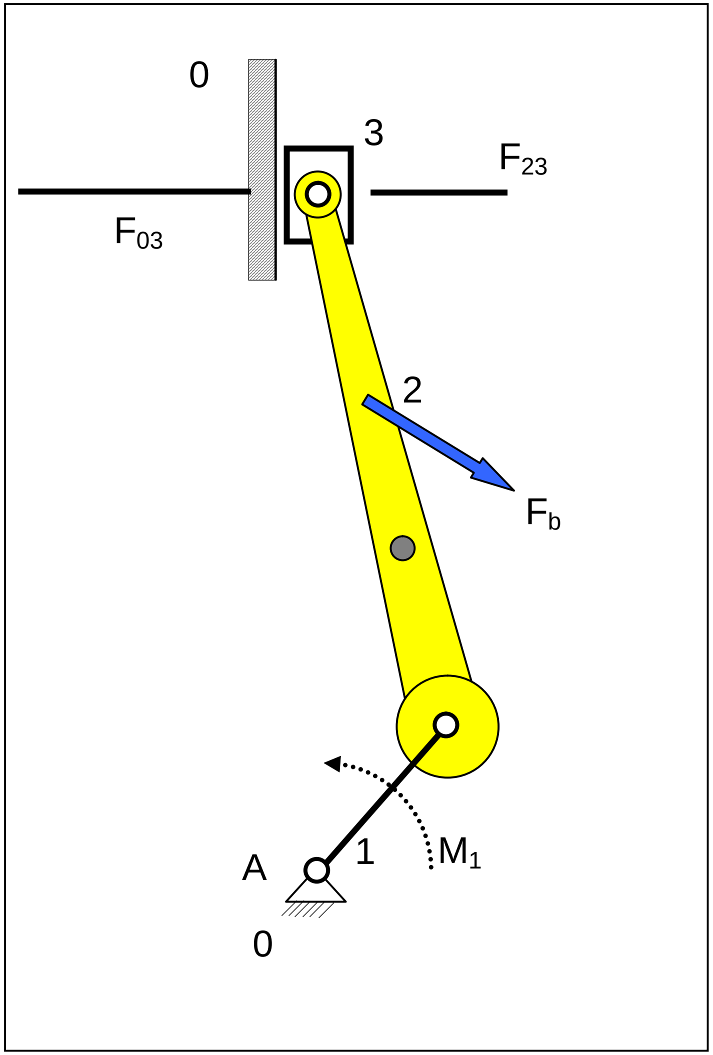


2
a
Fb
ε



Link 3:

$$\mathbf{F_{23}} + \mathbf{F_{03}} = 0$$

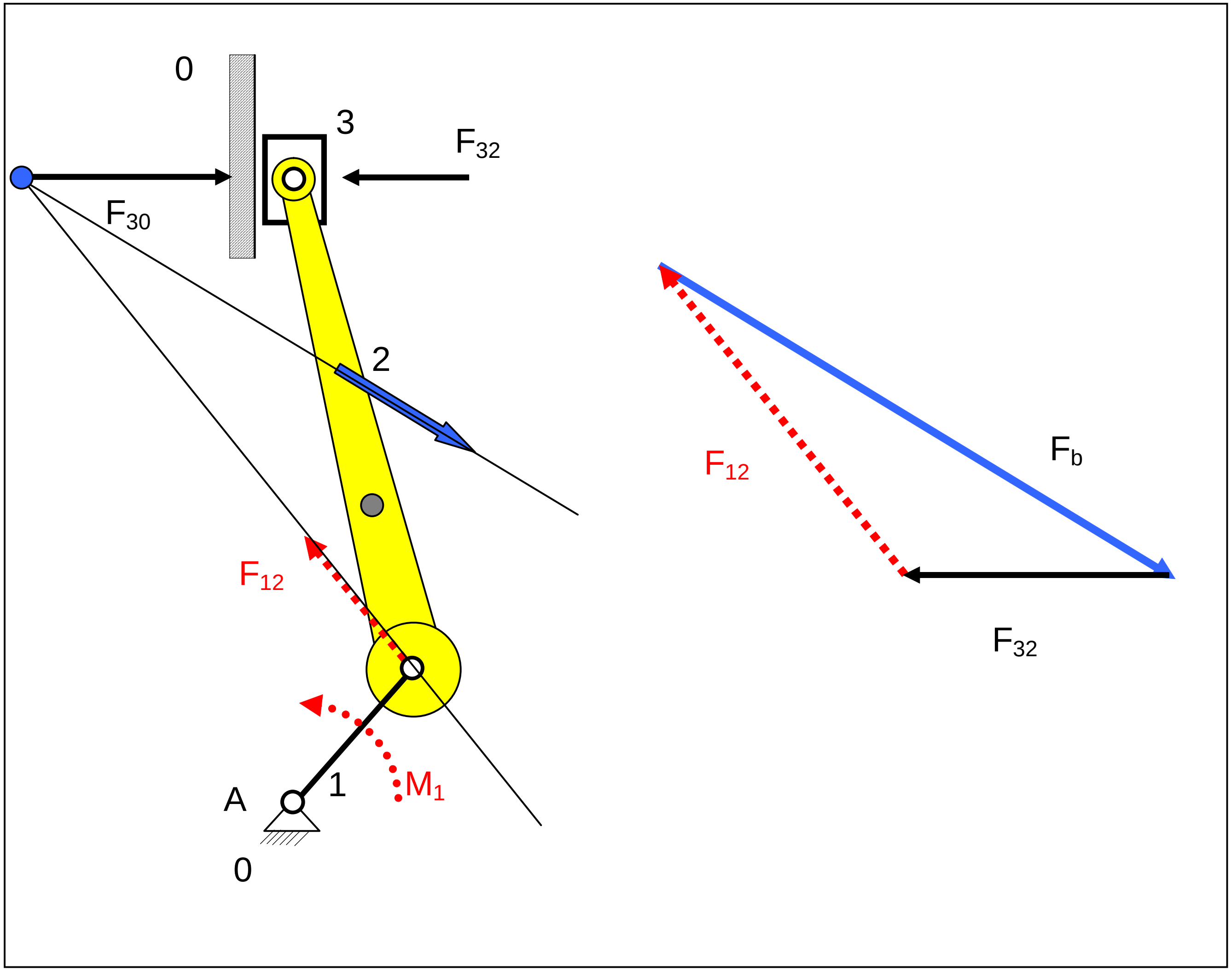


Link 3:

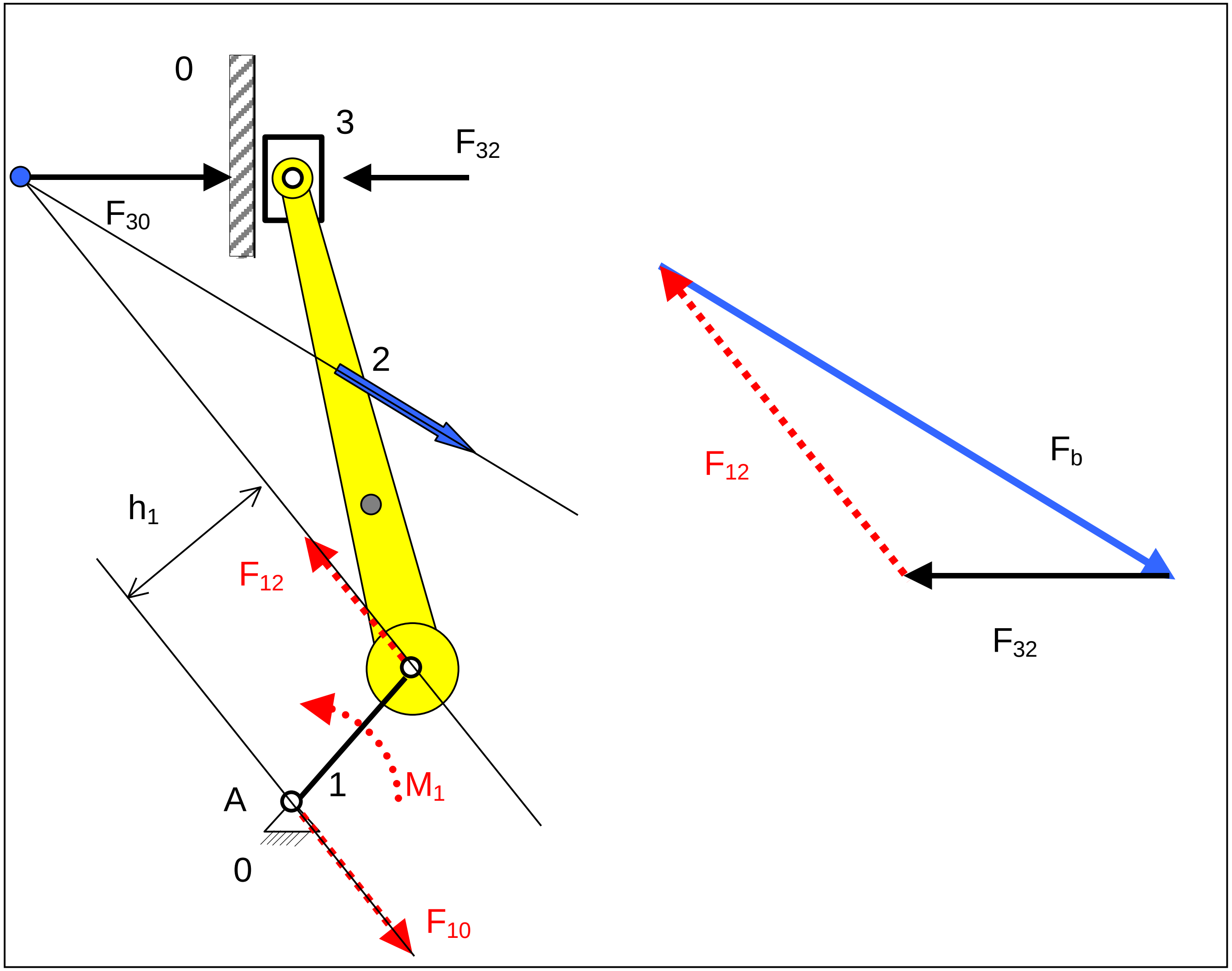
$$\mathbf{F_{23}} + \mathbf{F_{03}} = 0$$

Link 2:

$$\mathbf{F_{32}} + \mathbf{F_b} + \mathbf{F_{12}} = 0$$

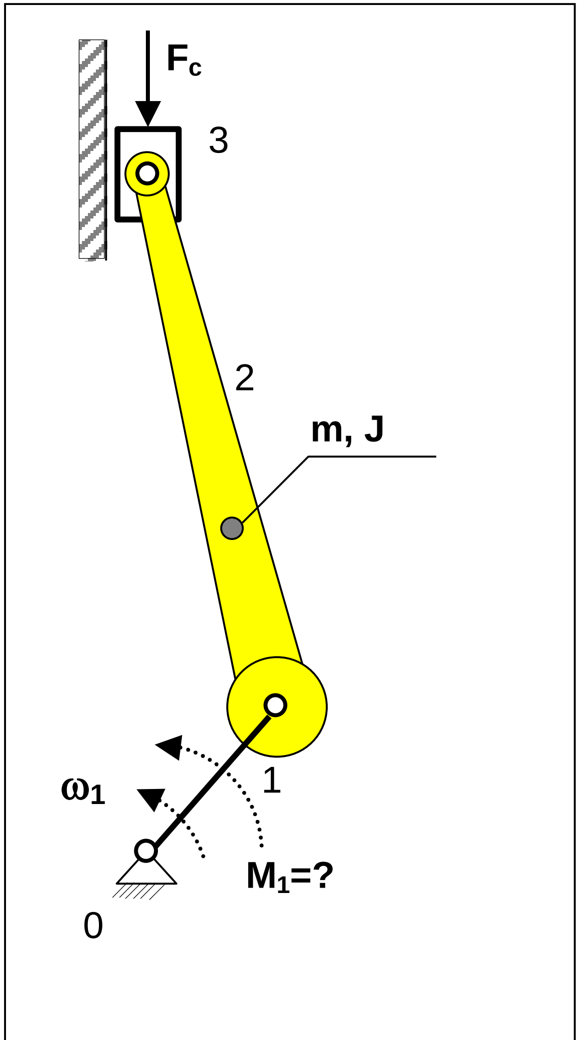


$$\mathbf{F}_{32} + \mathbf{F}_{b} + \mathbf{F}_{12} = 0$$



$$\mathbf{F}_{21} + \mathbf{F}_{01} = 0 \qquad \sum M_1^A = 0 \rightarrow M_1 - F_{21} h_1 = 0$$

Example of analysis (kinetostatics)



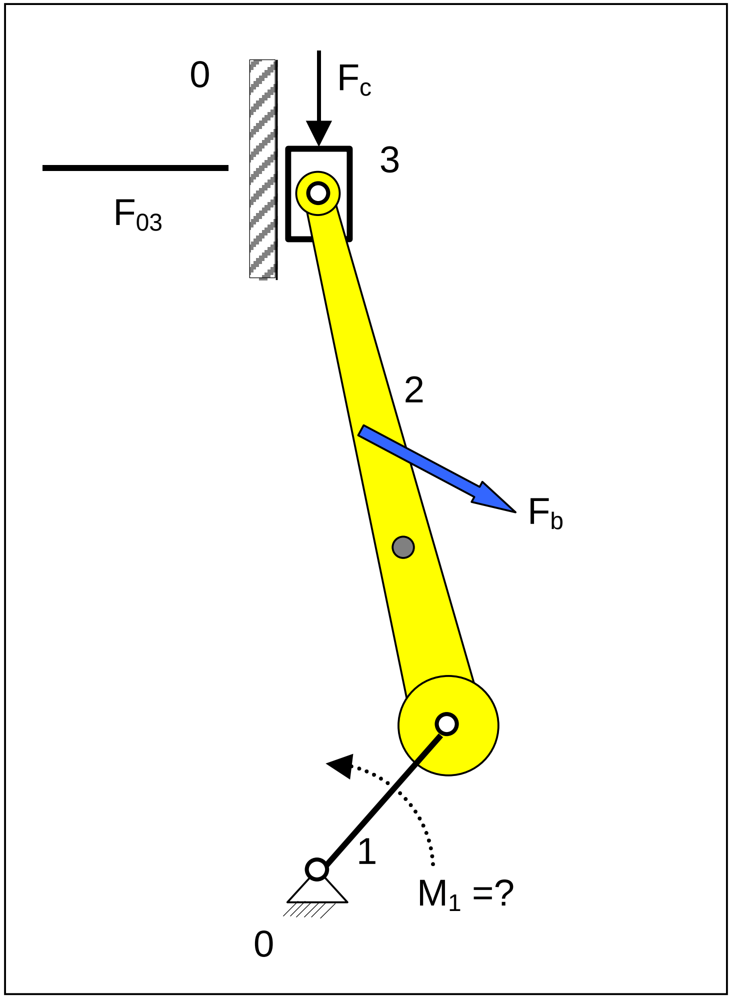
Data:

F_C – input force (driver)

m, J – mass, mass mom. of inertia

ω_1 – angular vel of crank 1

M_1 = ? and joint forces = ?



Slider 3:

$$\mathbf{F_C} + \mathbf{F_{03}} + \mathbf{F_{23}} = 0$$

Coupler 2:

$$\mathbf{F_{32}} + \mathbf{F_b} + \mathbf{F_{12}} = 0$$

???

Statically determined group (of links)

forces may be fully determined using the six (three) equations of 3D (2D) statics without using deflection and stiffness criteria.

kinematic system in equilibrium

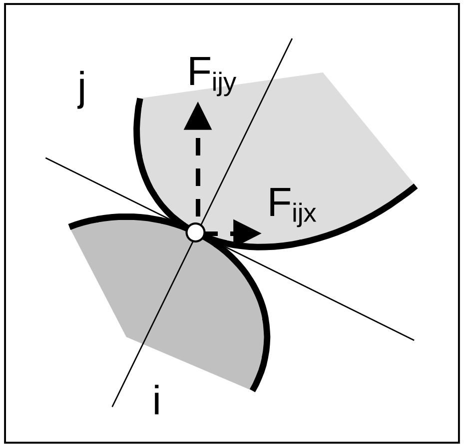
↓

every link in equilibrium

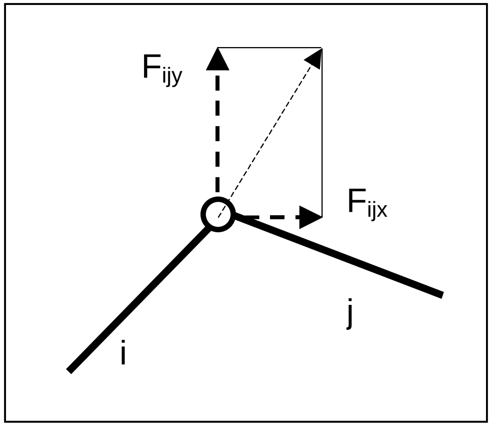
↓

any group of links in equlibrium

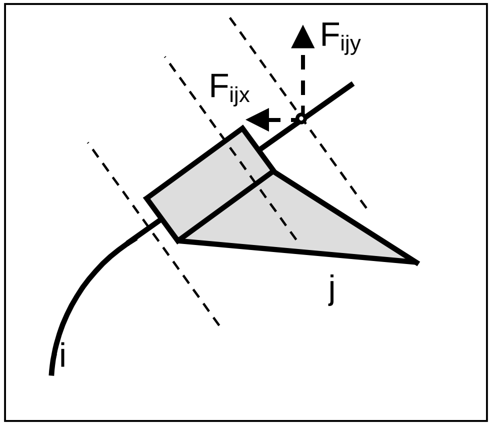
In kinetostatics unknowns are joint forces



1 unknown



2 unknowns



2 unknowns

Number of equations	=	*Number of unknowns*
3k	**=**	$\mathbf{2p_1 + p_2}$

Examples of static. determined groups

$$DOF = 3(n-1) - 2p_1 - 1p_2$$

Mobility

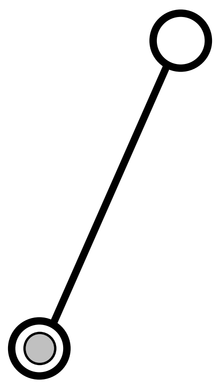
$$3k - 2p_1 - 1p_2 = 0$$

Condition of static determination

k	1	2	…	4	
p_1	1	3	…	6	
p_2	1	0	…	0	
$(k-p_1-p_2)$	(1-1-1)	(2-3-0)		(460)	

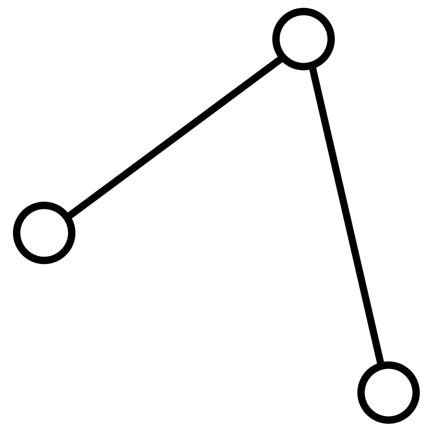
group (1-1-1)

I kl - R lub T



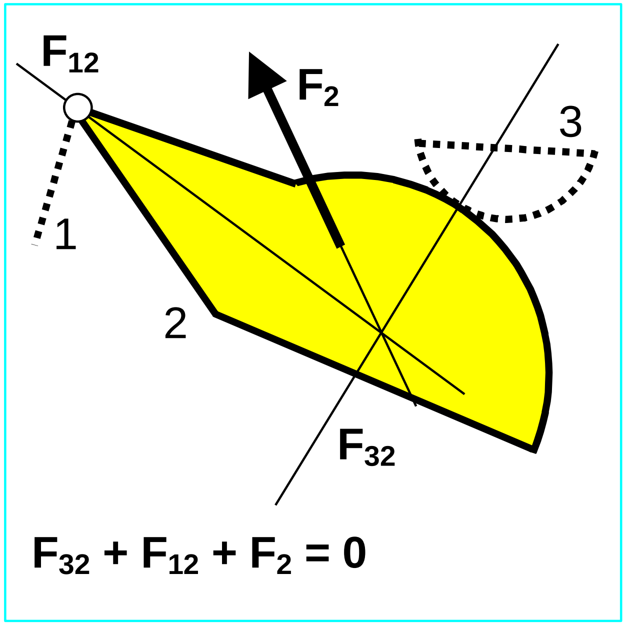
II class - K or J or Z

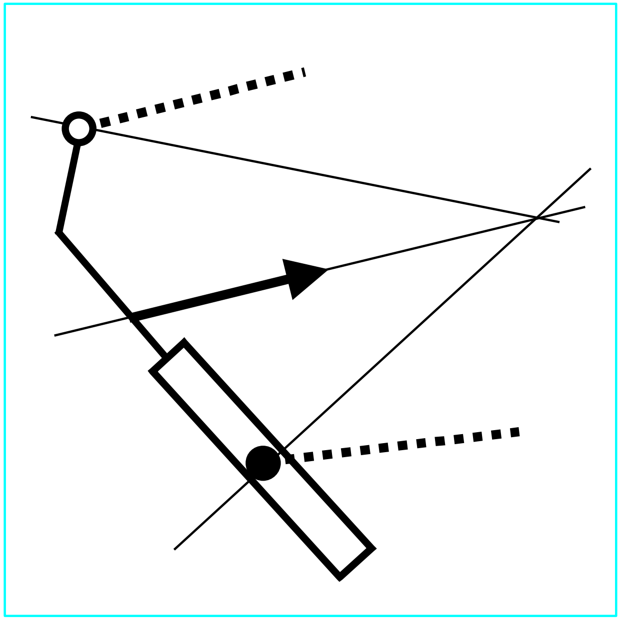
group (2-3-0)



II class - R or T

1-1-1 stat. determined group (one link)





2-link groups (k-p_1-p_2 = 230)