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A design constraint for a double-acting telescopic hydraulic cylinder in a hydraulic erecting system

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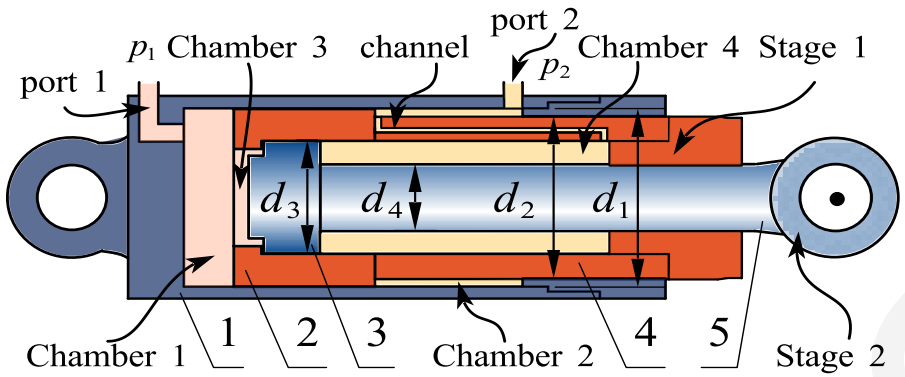
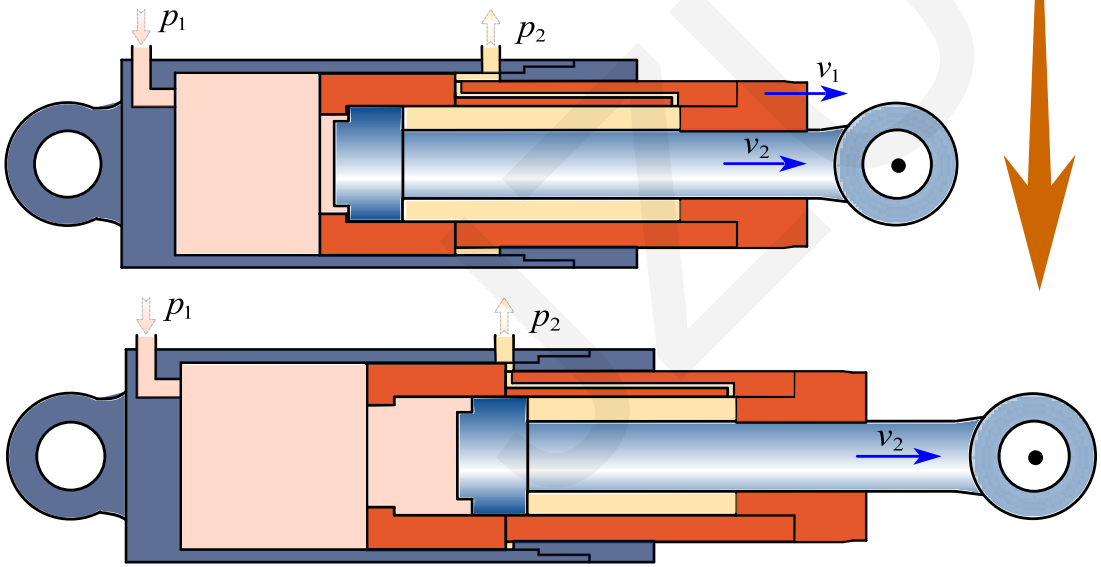
DATHC Description



Extension process

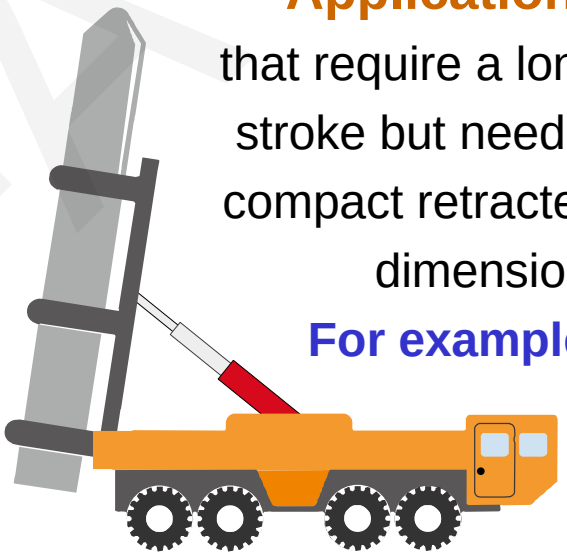
1-barrel, 2-piston 1, 3-piston 2,4-piston rob 1, 5-piston rod 2 Figure 1 Schematic view of DATHC



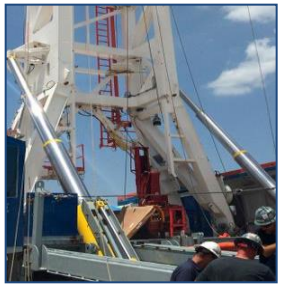
Applications

that require a long stroke but need a compact retracted dimension.

For example:



missile and rocket launchers

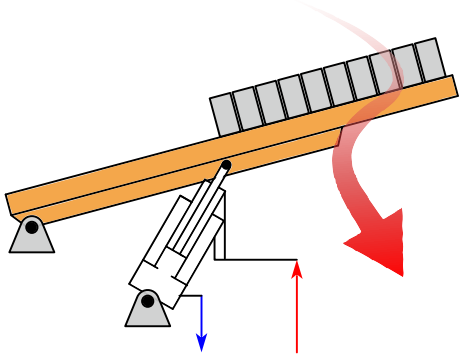


oil rigs

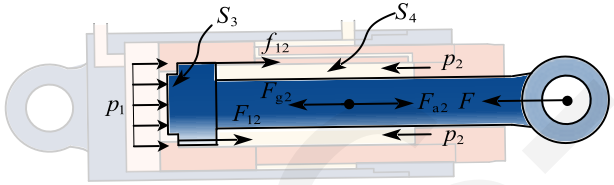
garbage trucks

Derivation of Design Constraint

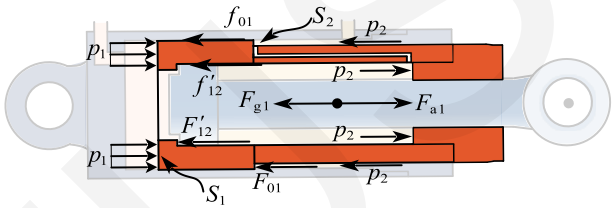
Problem → **Force analysis** → **Constraint**



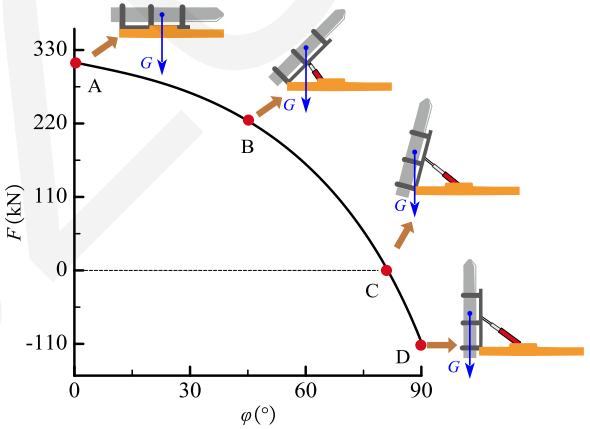
- The improper size of effective areas → **overspeed descent** →severe system damage
- Few related studies have been reported



$$p_1S_3 + f_{12} + F_{12} + F_{a2} = p_2S_4 + F_{g2} + F$$



$$p_1S_1 + p_2S_4 + F_{a1} = p_2S_2 + F'_{12} + f'_{12} + f_{01} + F_{01} + F_{g1}$$



External load-angle relationship

- Simplify and replace variables that are unknown at design :

a) load $F >>$ F_{g1} , F_{g2}

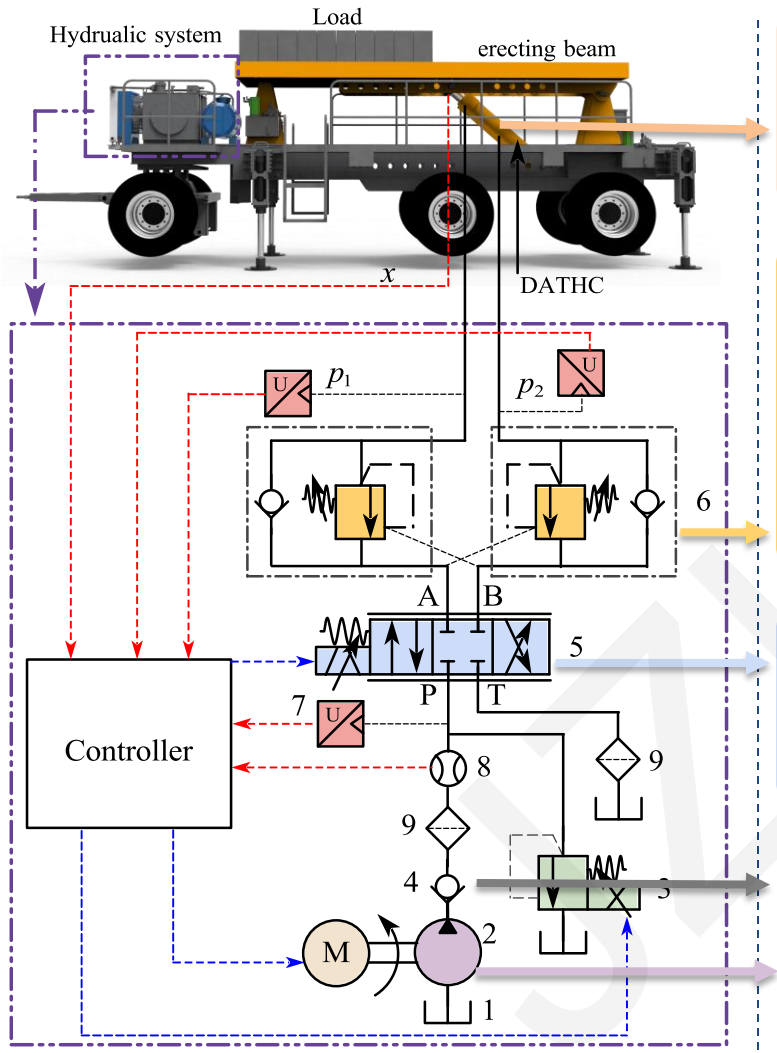
b) smooth operation——inertial force ≈ 0

c) Suppose $f_{01} = f_{12} = f$

Design constraint of a DATHC

$$\lambda = \frac{d_1^2 d_4^2 - d_2^2 d_3^2}{(d_1^2 - d_3^2)(d_3^2 - d_4^2)} < -1$$

Verified by Simulations→Modeling



Typical hydraulic erecting system

$$q_{cv1}=\frac{dx_1}{dt}(S_1+S_3)+\left(\frac{dx_2}{dt}-\frac{dx_1}{dt}\right)S_3+\frac{V_1}{\beta}\frac{dp_1}{dt},$$

$$V_1=x_1(S_1+S_3)+(x_2-x_1)S_3+V_{10},$$

$$x_{1\max}\ge x_1\ge 0,$$

$$q_{cv2}=-\frac{dx_1}{dt}S_2-\left(\frac{dx_2}{dt}-\frac{dx_1}{dt}\right)S_4-\frac{V_2}{\beta}\frac{dp_2}{dt},$$

$$V_1=-x_1S_2-(x_2-x_1)S_4+V_{20},$$

$$x_{2\max}\ge x_2\ge 0,$$

$$q_{m1}=C_mA_{mmax}\chi_{m1}\sqrt{\frac{2\cdot|p_A-p_1|}{\rho}}\operatorname{sign}(p_A-p_1),$$

$$q_{c1}=C_cA_{cmax}\chi_{c1}\sqrt{\frac{2\cdot|p_A-p_1|}{\rho}}\operatorname{sign}(p_A-p_1),$$

$$\chi_{m1}=\frac{p_1+p_B\kappa-p_{mk}}{p_{mmax}-p_{mk}},\quad 0\le\chi_{m1}\le 1,$$

$$\chi_{c1}=\frac{-p_1+p_A-p_{ck}}{p_{cmax}-p_{ck}},\quad 0\le\chi_{c1}\le 1,$$

$$q_{m2}=C_mA_{mmax}\chi_{m2}\sqrt{\frac{2\cdot|p_B-p_2|}{\rho}}\operatorname{sign}(p_2-p_B),$$

$$q_{c2}=C_cA_{cmax}\chi_{c2}\sqrt{\frac{2\cdot|p_B-p_2|}{\rho}}\operatorname{sign}(p_2-p_B),$$

$$\chi_{m2}=\frac{p_2+p_A\kappa-p_{mk}}{p_{mmax}-p_{mk}},\quad 0\le\chi_{m2}\le 1,$$

$$\chi_{c2}=\frac{-p_2+p_B-p_{ck}}{p_{cmax}-p_{ck}},\quad 0\le\chi_{c2}\le 1,$$

$$q_A=C_dW_vx_d\sqrt{\frac{2\cdot|\Delta p_A|}{\rho}}\operatorname{sign}(\Delta p_A),$$

$$\Delta p_A=\begin{cases}p_s-p_A, & x_d>0,\\ p_A-p_o, & x_d<0,\end{cases}$$

$$q_B=C_dW_vx_d\sqrt{\frac{2\cdot|\Delta p_B|}{\rho}}\operatorname{sign}(\Delta p_B),$$

$$\Delta p_B=\begin{cases}p_B-p_o, & x_d>0,\\ p_s-p_B, & x_d<0,\end{cases}$$

$$\begin{cases}q_p=\Delta p_{c4}k_{c4}, & \Delta p_{c4}>0,\\ q_p=0, & \Delta p_{c4}\le 0,\end{cases}$$

$$q_p=\frac{Vn}{60}-\frac{V_p}{\beta}\frac{dp_p}{dt}-c_p\Delta p_p$$

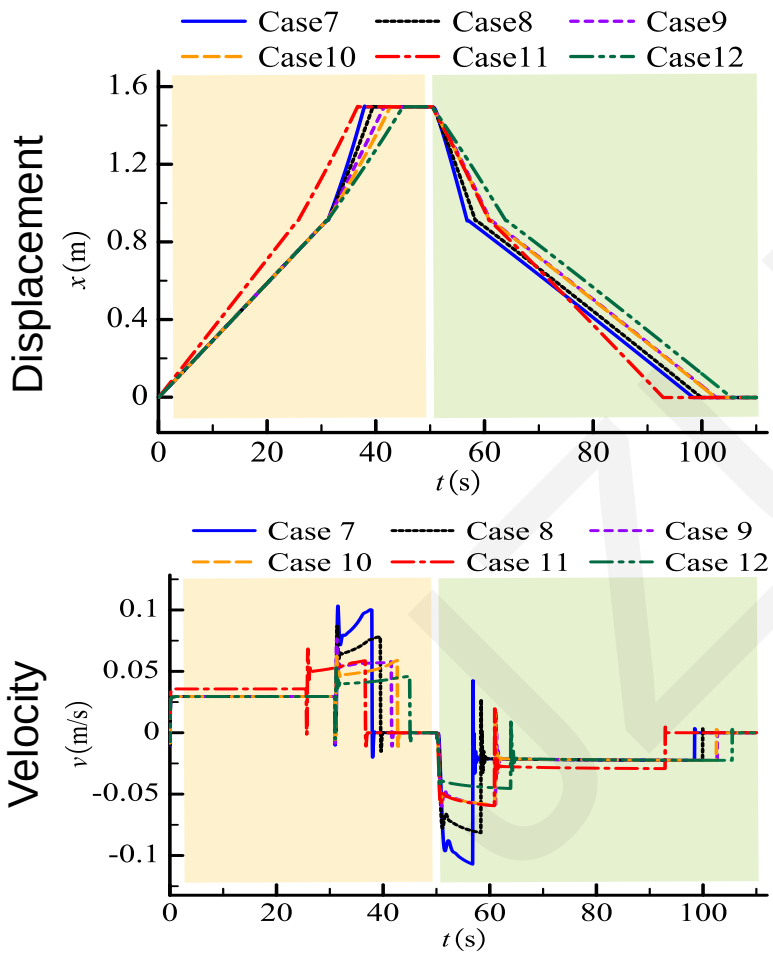
$$\begin{cases}q_r=\Delta p_{r3}k_{r3}-\dfrac{V_r}{\beta}\dfrac{dp_s}{dt}, & \Delta p_{r3}>0,\\ q_r=0, & \Delta p_{r3}\le 0,\end{cases}$$

Model and data transmission diagram

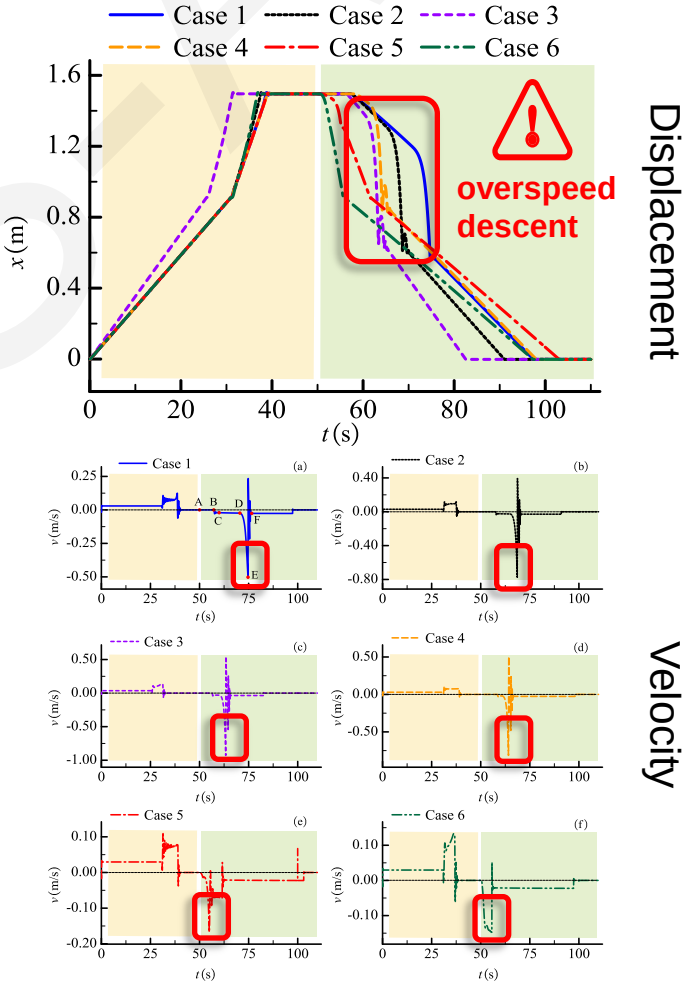
Verified by Simulations→Results

Effectiveness at different λ

$\lambda < -1$ → Meet the constraint



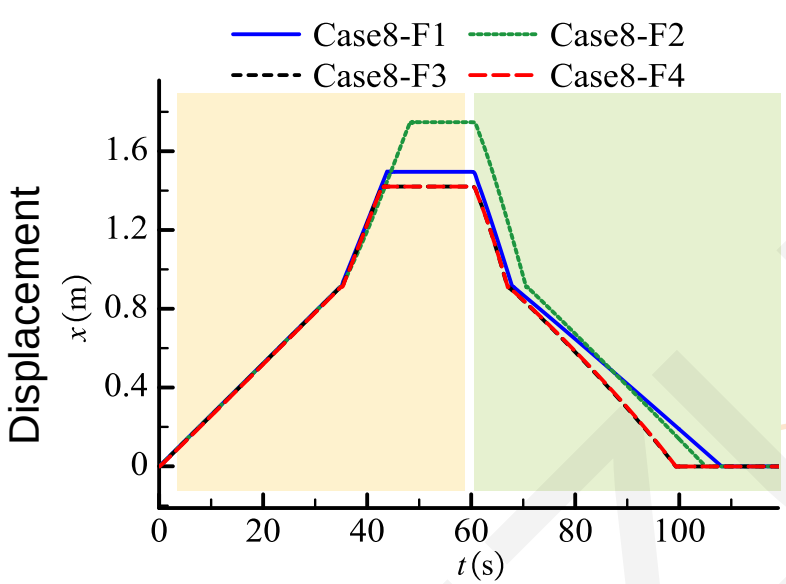
$\lambda > -1$ → Don't meet the constraint



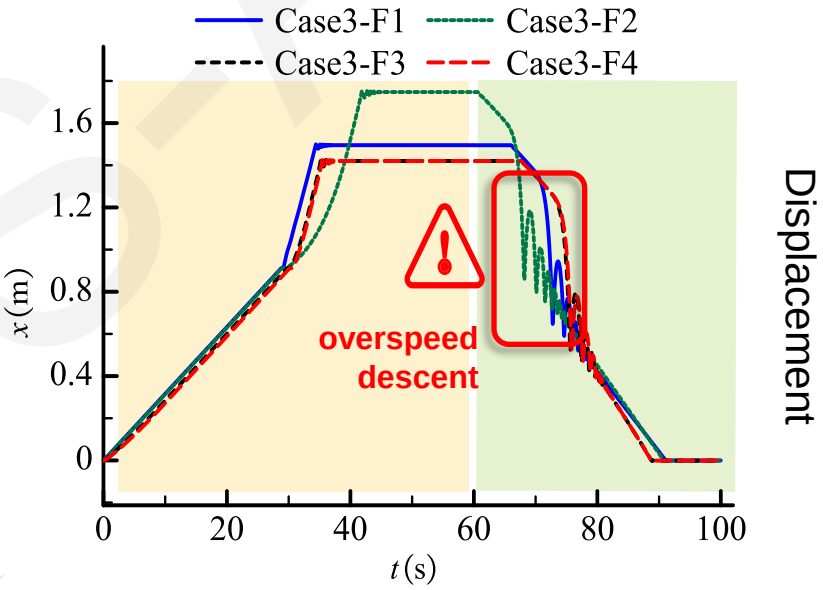
Verified by Simulations→Results

Effectiveness at different external loads F

$\lambda < -1$ → Meet the constraint



$\lambda > -1$ → Don't meet the constraint



The simulation results show：

The proposed design constraint ($\lambda < -1$) is always effective , even under different external loads !

Verified by Experiments→Results

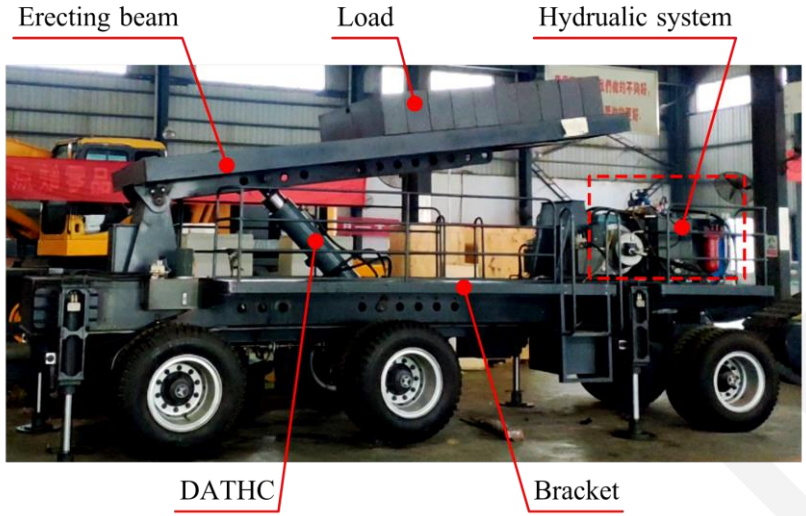
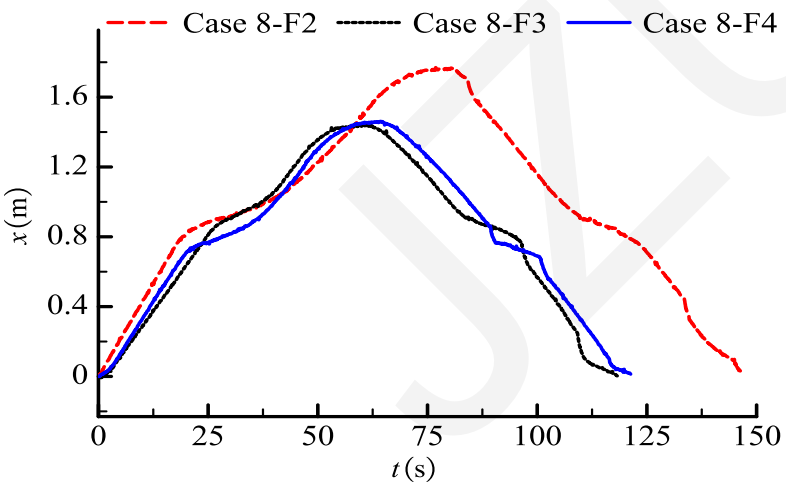


Photo of the experimental platform

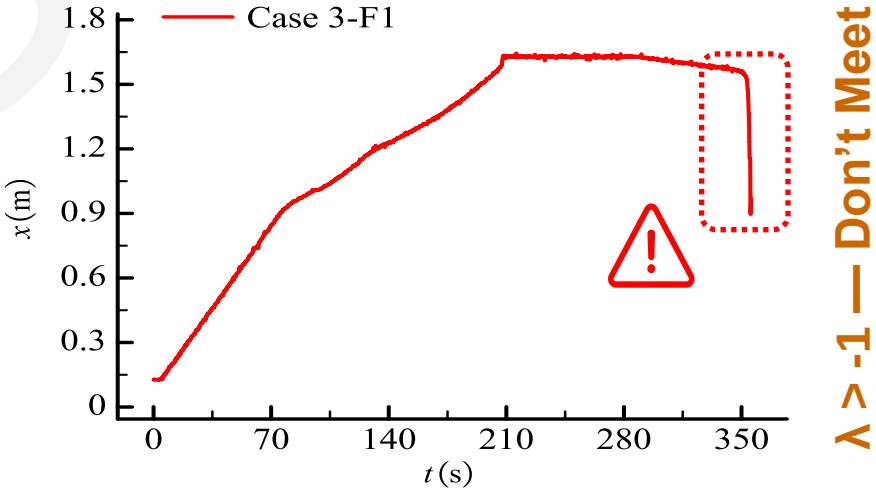
It is further verified that the proposed design constraint ($\lambda<-1$) is effective.
The simplified constraint is only related to diameters d_1, d_2, d_3, d_4 → Easy to use!

λ < -1 — Meet



Experimental displacement

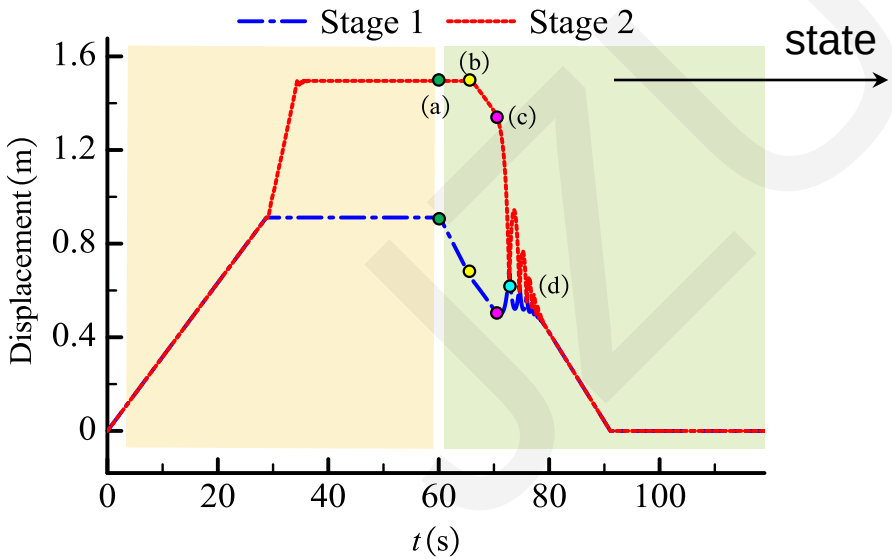
λ > -1 — Don't Meet

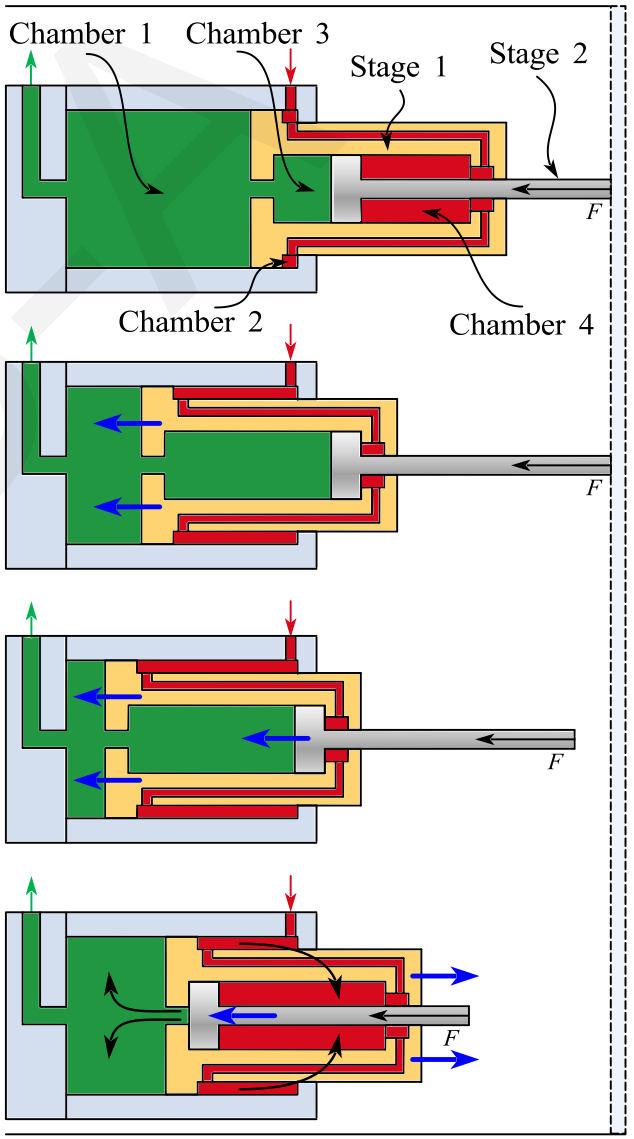


Experimental displacement

Further Discussion → Mechanism

a)→b) Stage 1 first retracts. Beam does not rotate;
b)→c) Stage 1 and Stage 2 retract. Beam is lowered;
c)→d) Stage 1 extends ⇌ Stage 2 quickly retracts → overspeed descent



Displacement of Stage 1 and Stage 2

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