Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)

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

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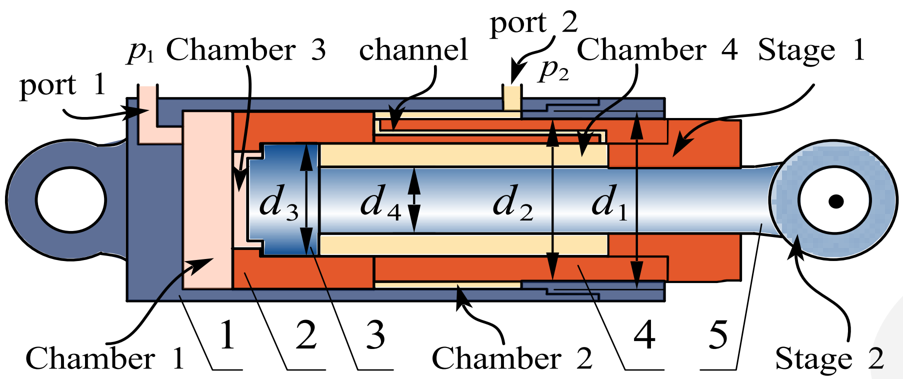
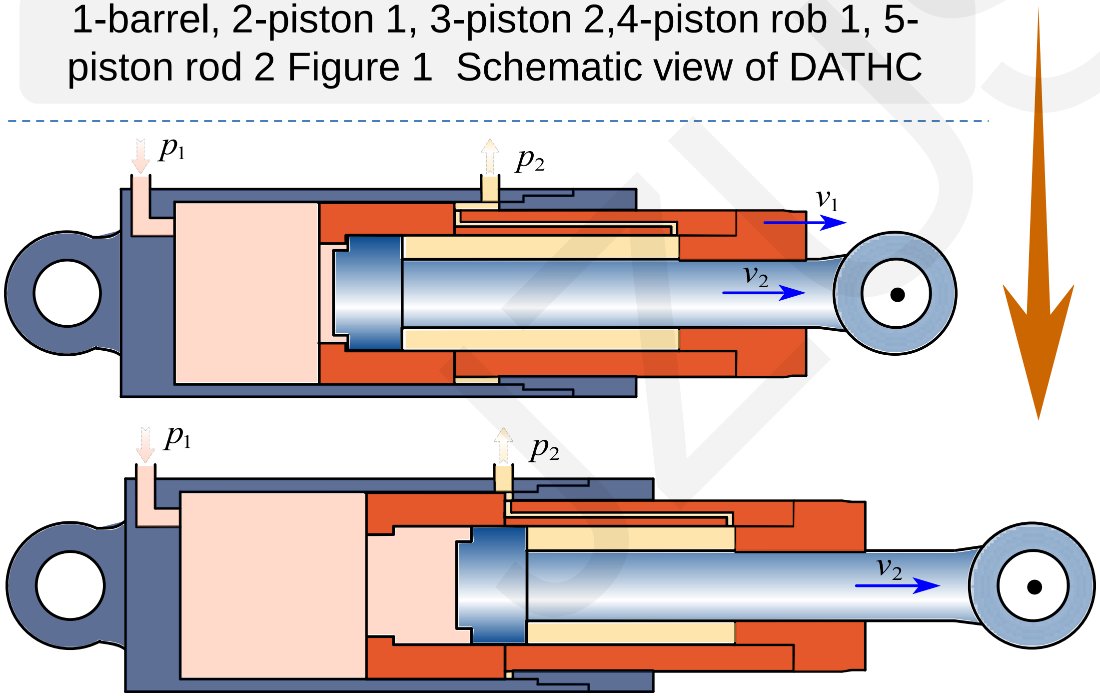
Cite this as: Xiao-long ZHANG, Jun-hui ZHANG, Min CHENG, Shen ZHENG, Bing XU, Yu FANG, 2022. A design constraint for a double-acting telescopic hydraulic cylinder in a hydraulic erecting system. *Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering)*, 23(1):1-13.
https://doi.org/10.1631/jzus.A2100214

DATHC Description



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

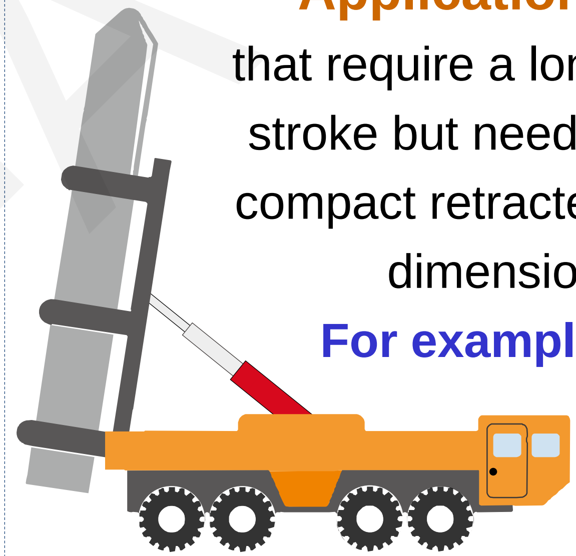
Extension process



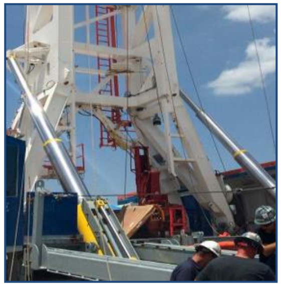
Applications

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

For example:



missile and rocket launchers

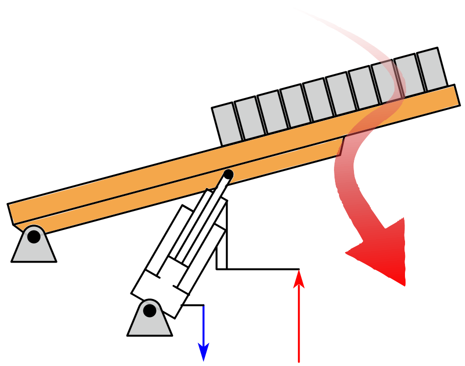


oil rigs

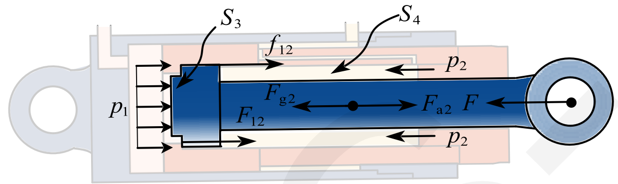
garbage trucks

Derivation of Design Constraint

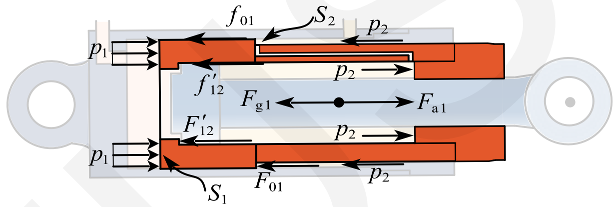
Problem → **Force analysis** → **Constraint**



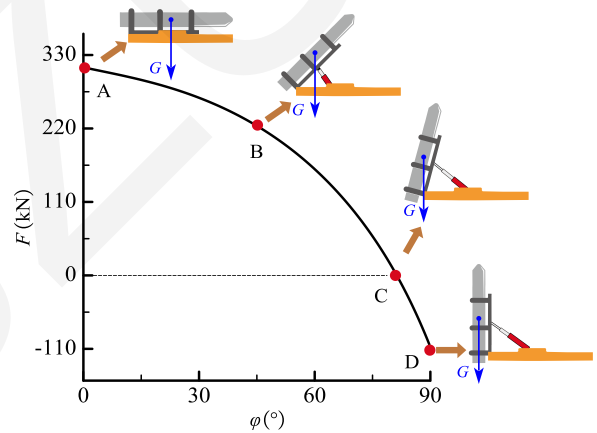
- The improper size of effective areas → **overspeed descent** →severe system damage
  - Few related studies have been reported



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



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



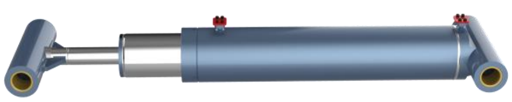
External load-angle relationship

- Simplify and replace variables that are unknown at design :

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

b) smooth operation——inertial force ≈ 0

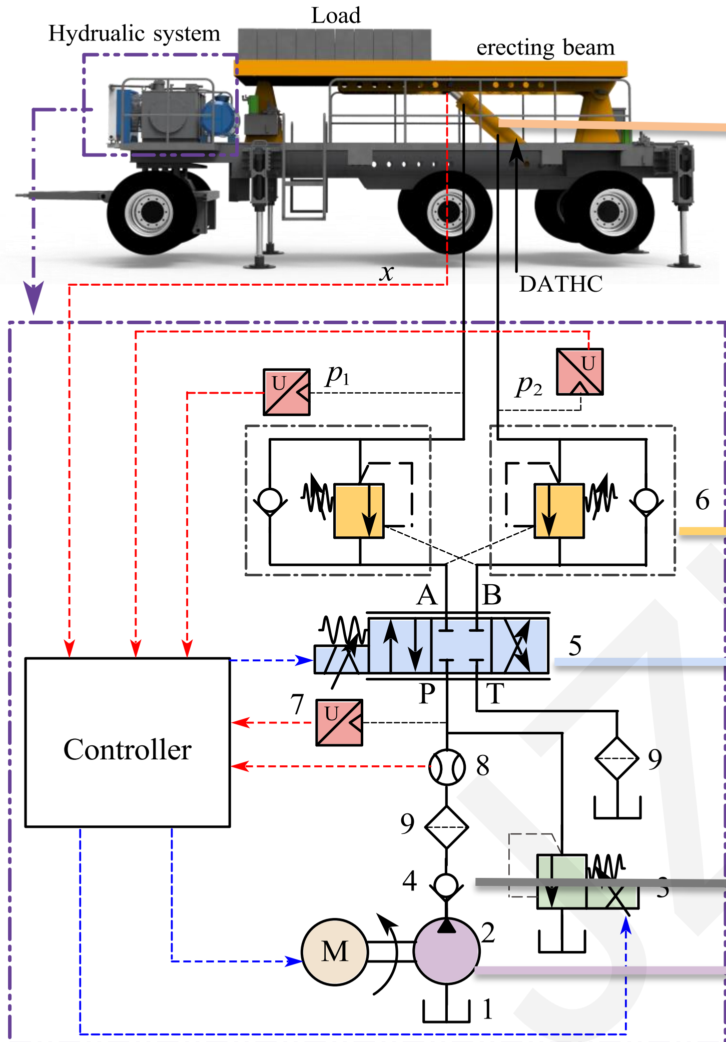
c) Suppose $f_{01} = f_{12} = f$



Design constraint of a DATHC

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

Verified by Simulations→Modeling



Typical hydraulic erecting system

$$q_{cv1}=\frac{dx_1}{dt}(S_1+S_3)+\left(\frac{dx_2}{dt}-\frac{dx_1}{dt}\right)S_3+\frac{V_1}{\beta}\frac{dp_1}{dt},$$
$$V_1=x_1(S_1+S_3)+(x_2-x_1)S_3+V_{10},$$
$$x_{1\max}\geq x_1\geq 0,$$

$$q_{cv2}=-\frac{dx_1}{dt}S_2-\left(\frac{dx_2}{dt}-\frac{dx_1}{dt}\right)S_4-\frac{V_2}{\beta}\frac{dp_2}{dt},$$
$$V_1=-x_1S_2-(x_2-x_1)S_4+V_{20},$$
$$x_{2\max}\geq x_2\geq 0,$$

$$q_{m1}=C_m A_{m\max}\chi_{m1}\sqrt{\frac{2\cdot|p_A-p_1|}{\rho}}\operatorname{sign}(p_A-p_1),$$
$$q_{c1}=C_c A_{c\max}\chi_{c1}\sqrt{\frac{2\cdot|p_A-p_1|}{\rho}}\operatorname{sign}(p_A-p_1),$$
$$\chi_{m1}=\frac{p_1+p_B\kappa-p_{mk}}{p_{m\max}-p_{mk}},\quad 0\leq\chi_{m1}\leq 1,$$
$$\chi_{c1}=\frac{-p_1+p_A-p_{ck}}{p_{c\max}-p_{ck}},\quad 0\leq\chi_{c1}\leq 1,$$

$$q_{m2}=C_m A_{m\max}\chi_{m2}\sqrt{\frac{2\cdot|p_B-p_2|}{\rho}}\operatorname{sign}(p_2-p_B),$$
$$q_{c2}=C_c A_{c\max}\chi_{c2}\sqrt{\frac{2\cdot|p_B-p_2|}{\rho}}\operatorname{sign}(p_2-p_B),$$
$$\chi_{m2}=\frac{p_2+p_A\kappa-p_{mk}}{p_{m\max}-p_{mk}},\quad 0\leq\chi_{m2}\leq 1,$$
$$\chi_{c2}=\frac{-p_2+p_B-p_{ck}}{p_{c\max}-p_{ck}},\quad 0\leq\chi_{c2}\leq 1,$$

$$q_A=C_d W_v x_d\sqrt{\frac{2\cdot|\Delta p_A|}{\rho}}\operatorname{sign}(\Delta p_A),$$
$$\Delta p_A=\begin{cases}p_s-p_A, & x_d>0,\\ p_A-p_o, & x_d<0,\end{cases}$$

$$q_B=C_d W_v x_d\sqrt{\frac{2\cdot|\Delta p_B|}{\rho}}\operatorname{sign}(\Delta p_B),$$
$$\Delta p_B=\begin{cases}p_B-p_o, & x_d>0,\\ p_s-p_B, & x_d<0,\end{cases}$$

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

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

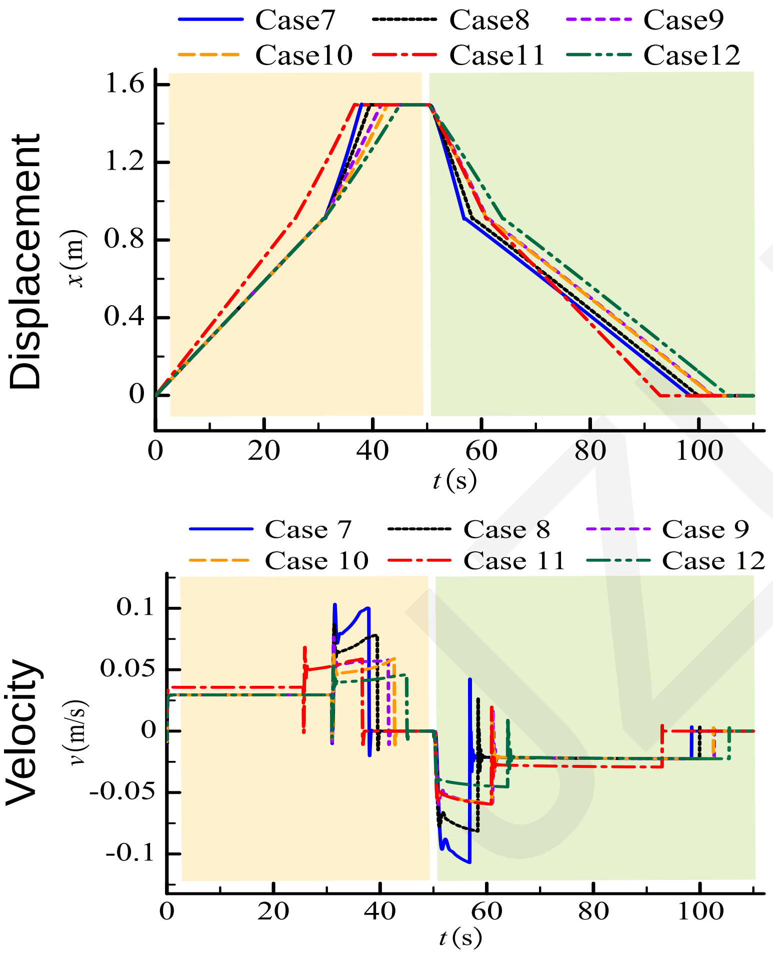
$$q_p=\frac{Vn}{60}-\frac{V_p}{\beta}\frac{dp_p}{dt}-c_p\Delta p_p$$

Model and data transmission diagram

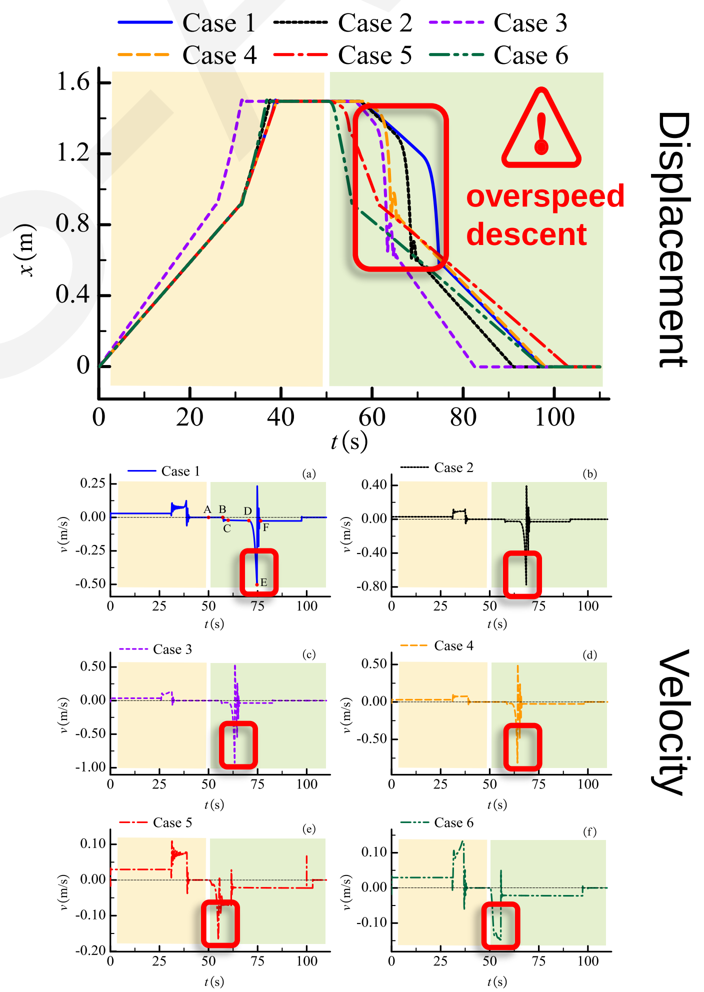
Verified by Simulations→Results

■ Effectiveness at different λ

$\lambda < -1$ → **Meet the constraint**



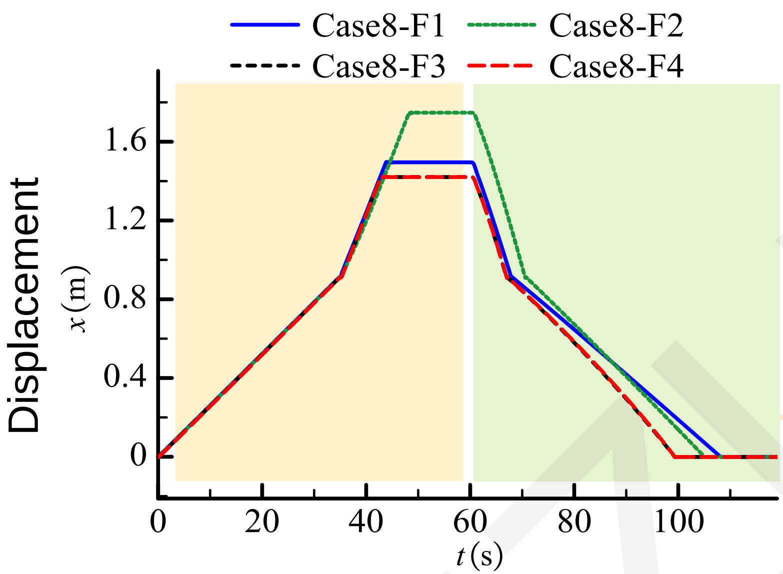
$\lambda > -1$ → **Don't meet the constraint**



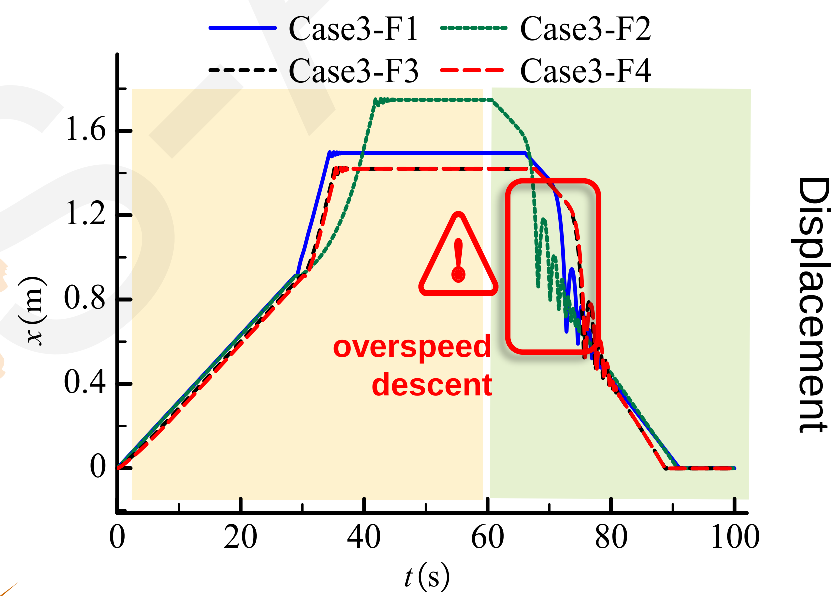
Verified by Simulations→Results

■ **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

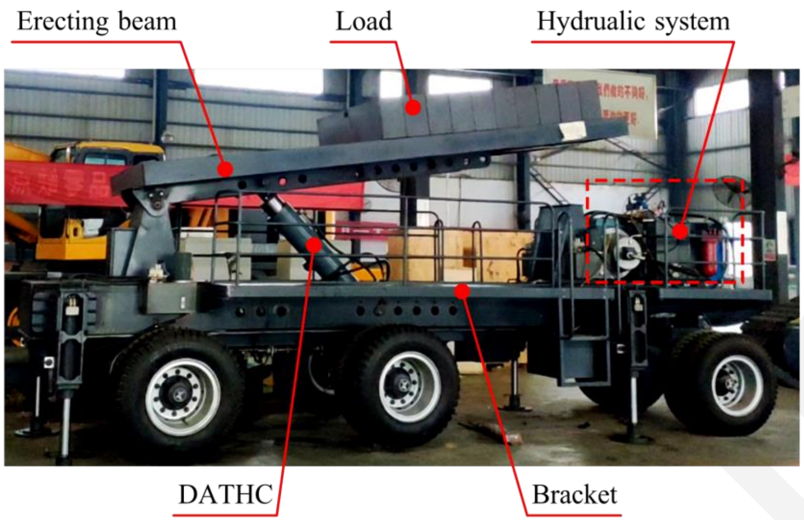
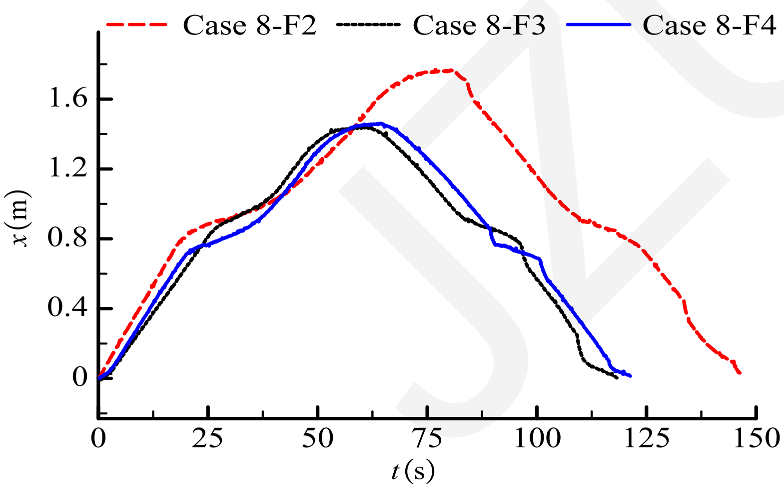


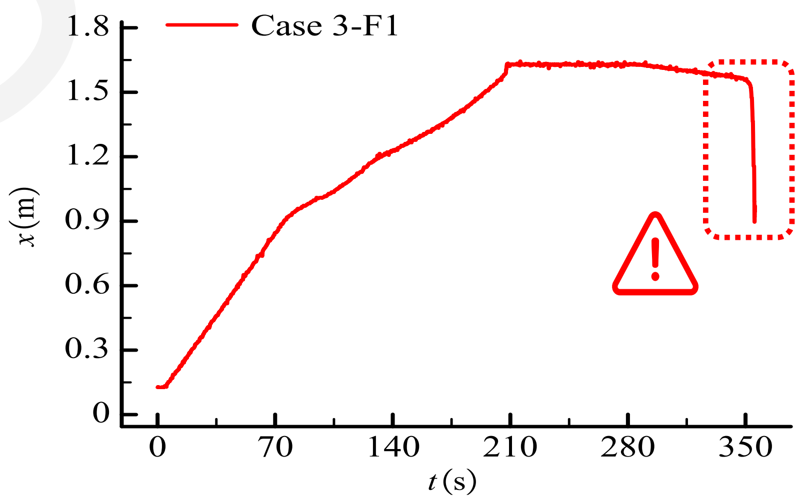
Photo of the experimental platform

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

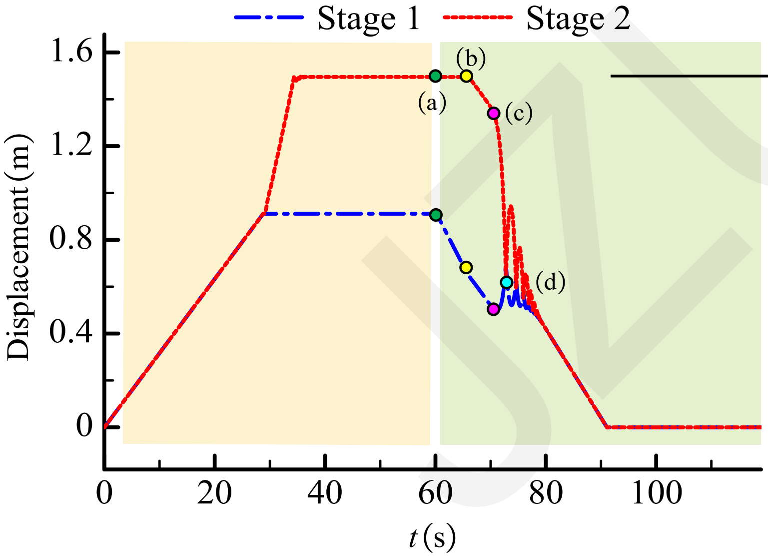


Experimental displacement

λ > -1 — Don't Meet

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

state