

【SAP2000与结构力学】系列课程

SAP2000 梁结构分析

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2024年5月22日

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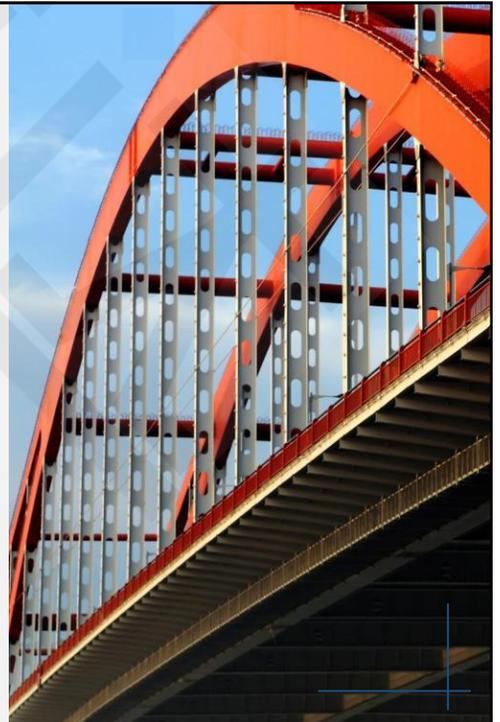
简支梁/连续梁/变截面梁

梁的横向剪切变形

线荷载与温度荷载

弯矩图和挠曲线

弹性支座



1

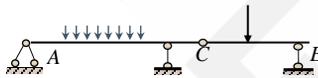
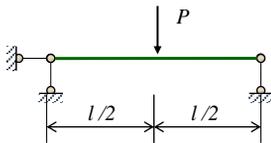
简支梁/连续梁/变截面梁



讯信达

简支梁和连续梁

❖ 刚性支座



❖ 铰接节点

- 默认：刚接节点
- **端部释放**/连接单元/节点约束
- 避免节点的转动约束不足

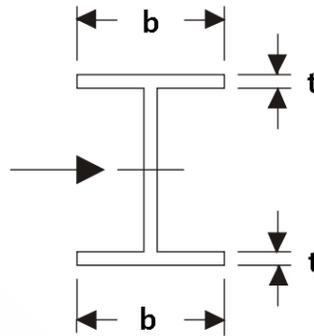
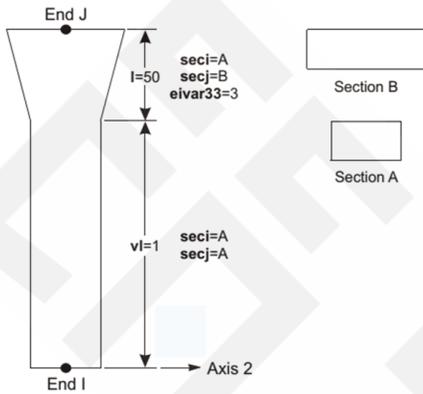


讯信达

变截面梁

❖ 抗弯刚度

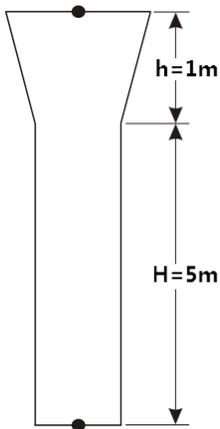
- 线性插值，二次插值，三次插值



筑信达

变截面梁

❖ 可变长度与绝对长度



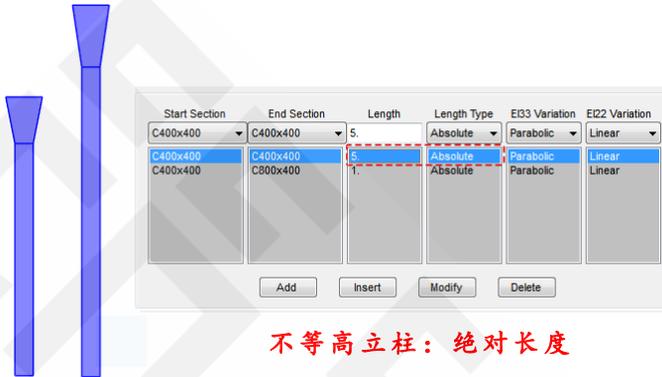
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C400x400	C400x400	5	Absolute	Parabolic	Linear
C400x400	C400x400	5	Absolute	Parabolic	Linear
C400x400	C800x400	1	Absolute	Parabolic	Linear

Add Insert Modify Delete

筑信达

变截面梁

❖ 可变长度与绝对长度

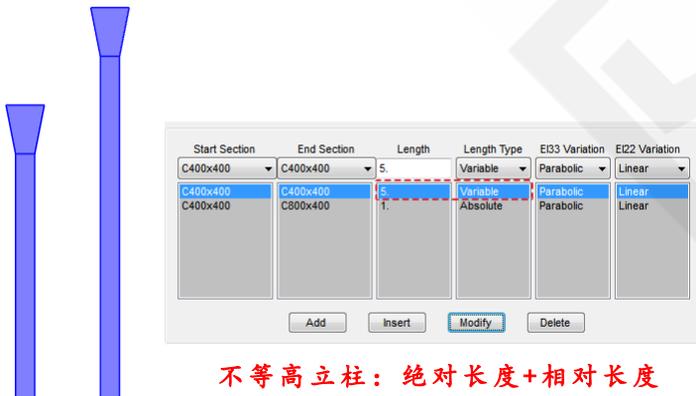


不等高立柱：绝对长度

筑信达

变截面梁

❖ 可变长度与绝对长度

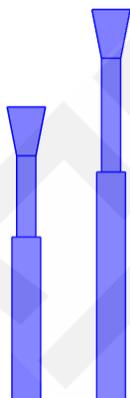


不等高立柱：绝对长度+相对长度

筑信达

变截面梁

❖ 可变长度与绝对长度



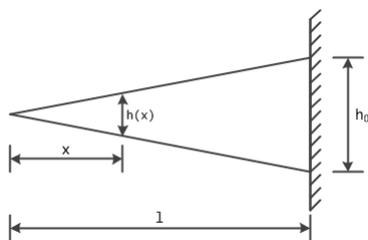
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C400x400	C800x400	1.	Absolute	Parabolic	Linear
C600x400	C600x400	2.	Variable	Parabolic	Linear
C400x400	C400x400	1.	Variable	Parabolic	Linear
C400x400	C800x400	1.	Absolute	Parabolic	Linear

不等高立柱2：绝对长度+相对长度

筑信达

变截面梁

❖ 楔形悬臂梁



模型信息

$$l = 6m, E = 30GPa, \rho = 2550kg/m^3, h(x) = \frac{h_0 x}{l}, h_0 = 1m$$

自振频率

$$\omega = \frac{1.534h_0}{l^2} \sqrt{\frac{E}{\rho}} = \frac{1.534 \times 1.0}{6^2} \sqrt{\frac{30 \times 10^9}{2550}} = 146.15$$

$$f = \frac{\omega}{2\pi} = \frac{146.15}{2 \times 3.1416} = 23.26Hz$$

	单元数量	单元尺寸 (m)	自振频率 (Hz)	误差 (%)
解析解	--	--	23.26	0.00
数值解一	1	6.0	3.39	-85.43
数值解二	5	1.2	16.26	-30.09
数值解三	20	0.3	23.15	-0.47
数值解四	50	0.12	23.25	-0.04

筑信达

2

梁的横向剪切变形



筑信达

梁的位移计算方法

❖ 材料力学

- 等直梁的挠曲线近似微分方程

$$EI\omega' = M(x) \longrightarrow EI\omega = -\int\int M(x)dx dx + C_1x + C_2$$

❖ 结构力学

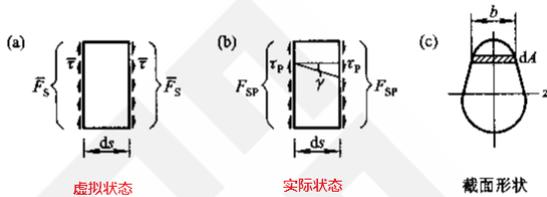
- 变形图虚功原理 → **单位荷载法** → 图乘法

$$\Delta_{XP} = \sum \int \bar{M}d\varphi_p + \sum \int \bar{F}_N du_p + \sum \int \bar{F}_S \gamma_p ds$$

筑信达

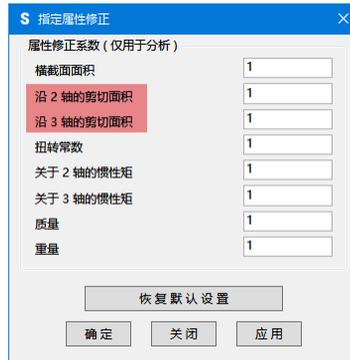
梁的横向剪切变形

$$\Delta_{FP} = \sum \int \bar{M} d\varphi_P + \sum \int \bar{F}_N du_P + \sum \int \bar{F}_S \gamma_P ds$$



$$\bar{F}_S \gamma_P ds = ds \int_A \frac{\bar{F}_S F_{SP} S^2 dA}{GI^2 b^2} = \frac{\bar{F}_S F_{SP} ds}{GA} \cdot \frac{A}{I^2} \int_A \frac{S^2}{b^2} dA = \frac{k \bar{F}_S F_{SP} ds}{GA}$$

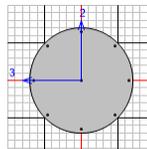
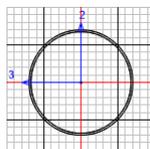
$$k = \frac{A}{I^2} \int_A \frac{S^2}{b^2} dA$$



筑信达

梁的横向剪切变形

❖ 组合截面的悬臂梁



$$EI = E_s I_s + E_c I_c = 2.06 \times 10^8 \times 0.05616 + 3 \times 10^7 \times 0.4042 = 2.3696 \times 10^7 \text{ kNm}^2$$

($\phi 150 \times 28$ 钢管复合)

$$\Delta = \frac{F_P L^3}{3EI} = \frac{1 \times 1^3}{3 \times 2.3696 \times 10^7} = 1.4067 \times 10^{-8} \text{ m}$$

Pt Obj: 2
Pt Elm: 2
U1 = 0
U2 = 0
U3 = 4.712E-08
R1 = 0
R2 = -2.11E-08
R3 = 0

筑信达

3

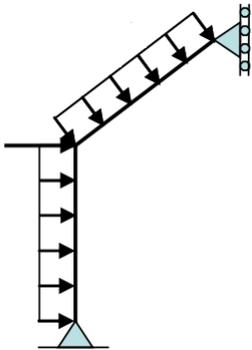
线荷载与温度荷载



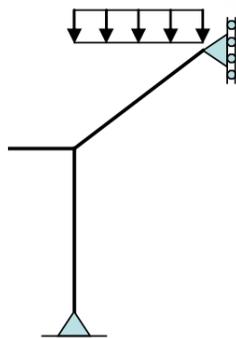
筑信达

线荷载

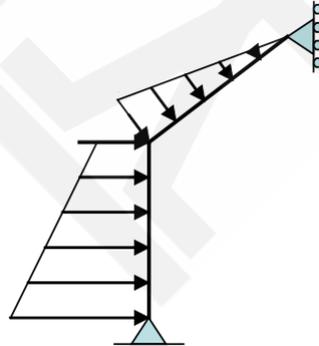
❖ 荷载大小与作用方向



坐标轴方向



投影方向

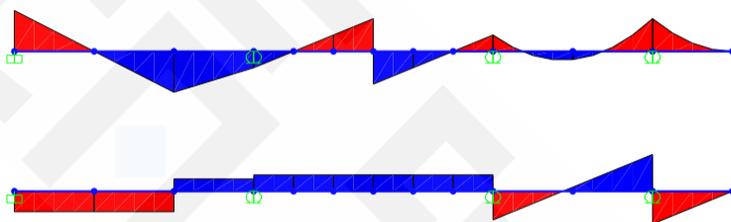


三角形分布和梯形分布

筑信达

线荷载

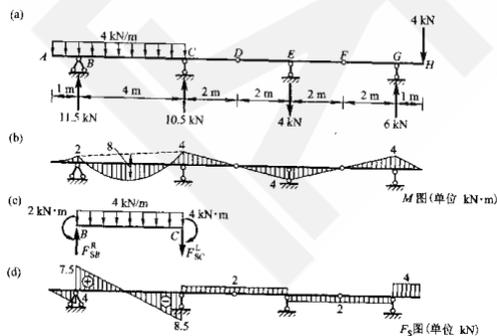
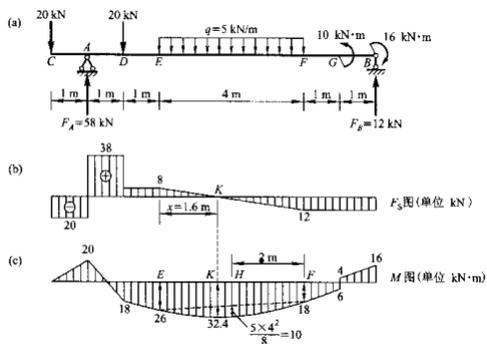
多跨静定梁



筑信达

线荷载

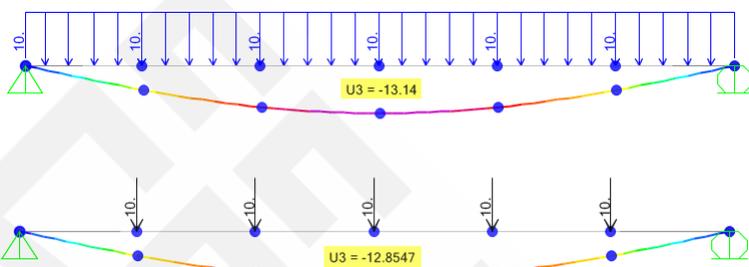
多跨静定梁



筑信达

线荷载

均布线荷载的等效集中荷载

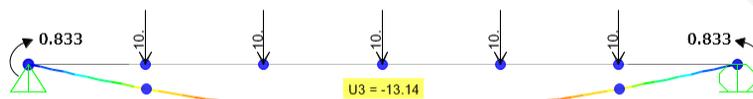


筑信达

线荷载

均布线荷载的等效集中荷载

梁的简图	弯矩		剪力	
	M_{AB}	M_{BA}	F_{SAB}	F_{SBA}
	$\frac{ql^2}{12}$	$\frac{ql^2}{12}$	$\frac{ql}{2}$	$-\frac{ql}{2}$

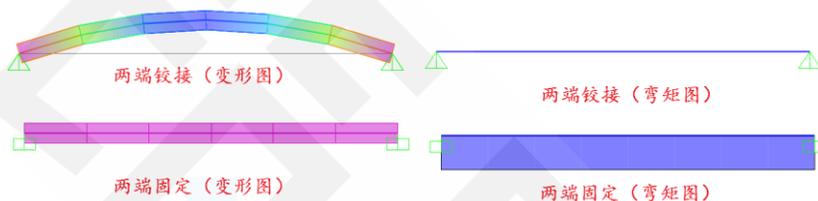


筑信达

温度荷载

❖ 温度荷载与温度应力

- 材料温差 \rightarrow 应变/变形 \rightarrow 应力/内力
- 静定结构：自由变形，内力/应力 **为零**
- 超静定结构：约束变形/无变形，内力/应力 **非零**

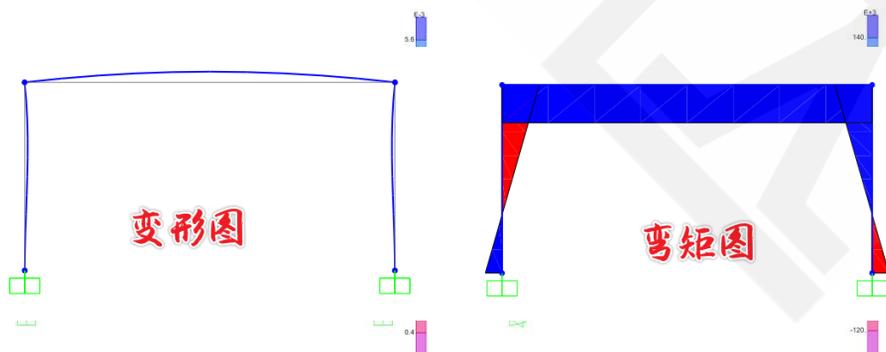


水平梁的顶面温度高于底面温度

筑信达

温度荷载

❖ 门式刚架



水平梁的顶面温度高于底面温度

筑信达

4

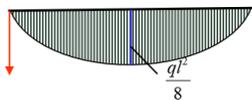
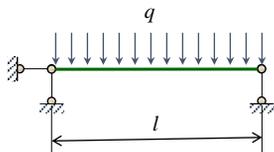
弯矩图和挠曲线



筑信达

测站

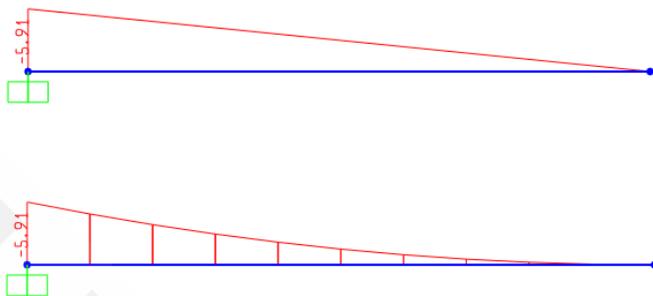
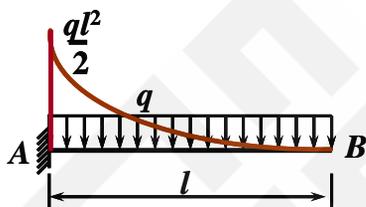
❖ 线性插值



筑信达

测站

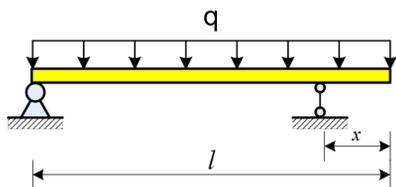
❖ 线性插值



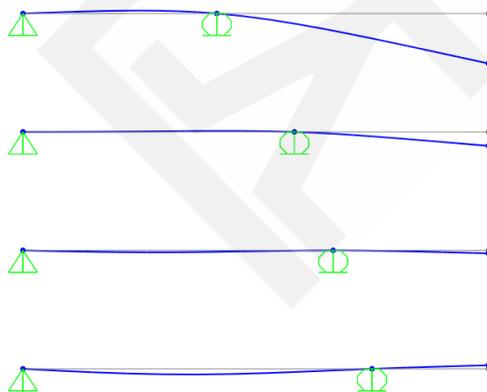
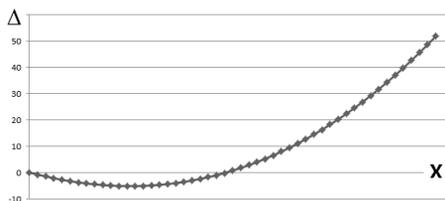
筑信达

节点位移

❖ 外伸梁的自由端挠度



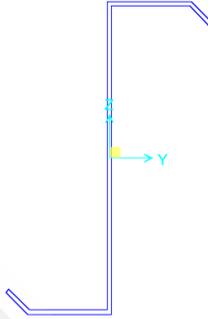
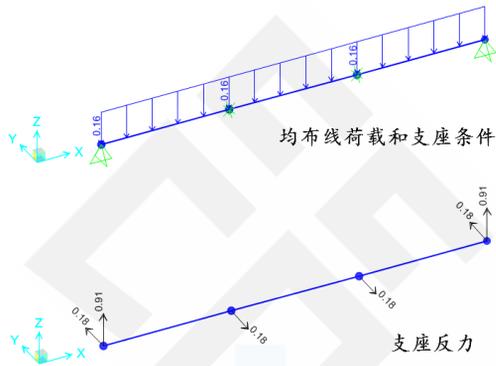
$$\Delta = \frac{1}{24EI} [4x^3(l-x) + 3x^4 - x(l-x)^3]$$



筑信达

挠曲线

❖ 非对称弯曲（斜弯曲）

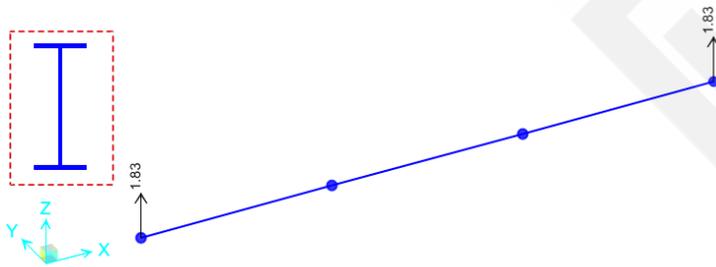


几何属性	
截面名称	Z-shape
几何属性	
横截面面积	1.066E-03
关于 3 轴的惯性矩	7.185E-06
关于 2 轴的惯性矩	9.199E-07
关于 2-3 轴的惯性积	-1.910E-06
沿 2 轴的剪切面积	5.220E-04
沿 3 轴的剪切面积	1.648E-04
扭转常数	3.197E-09

筑信达

挠曲线

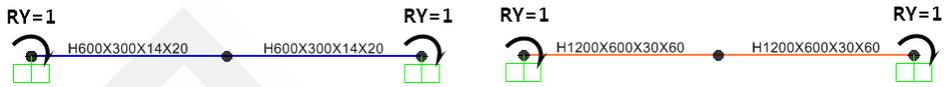
❖ 对称弯曲



筑信达

挠曲线

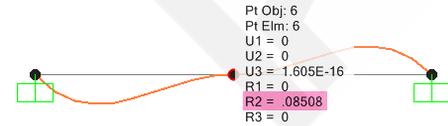
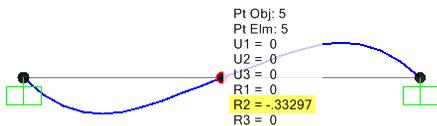
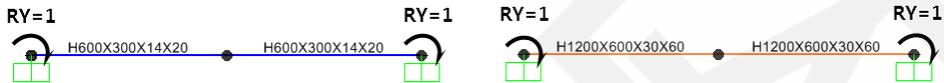
❖ 两端固定的等直梁



梁的简图	弯矩		剪力	
	M_{AB}	M_{BA}	F_{SAB}	F_{SBA}
	$4i$	$2i$	$-\frac{6i}{l}$	$-\frac{6i}{l}$
	$(i = \frac{EI}{l}, \text{下同})$			

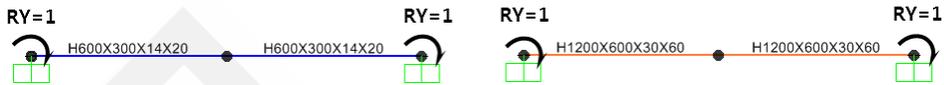
挠曲线

❖ 两端固定的等直梁



挠曲线

❖ 两端固定的等直梁



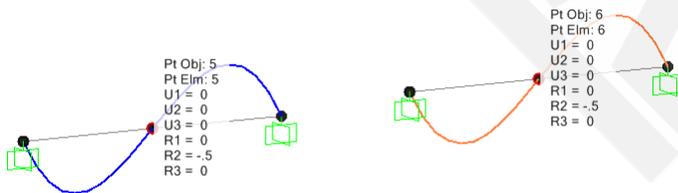
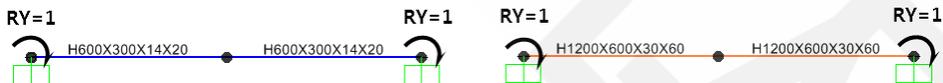
$$EI\omega'' = M(x) \longrightarrow EI\omega = -\int\int M(x)dx dx + C_1x + C_2$$

梁的简图	弯矩		剪力	
	M_{AB}	M_{BA}	F_{SAB}	F_{SBA}
	$4i$ $(i = \frac{EI}{l}, \text{下} \text{同})$	$2i$	$-\frac{6i}{l}$	$-\frac{6i}{l}$

筑信达

挠曲线

❖ 两端固定的等直梁



忽略剪切变形

筑信达

5

弹性支座



筑信达

弹性支座

❖ 支座类型

• 刚性支座：零位移，零转角

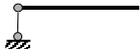
• 固定支座



• 固定铰支座



• 可动铰支座



• 定向支座



• 柔性支座：非零的位移或转角

• 线性（弹性）支座

• 非线性支座

6-22 图示梁 EI = 常数, B 处有一弹性支座, 弹簧的刚度系数(产生单位位移所需的力)为 k (注: 弹簧的柔度系数 f 即单位力作用下的位移, 是与刚度系数互为倒数的, 即 $f = \frac{1}{k}$)。试求 C 点竖向位移。已知 $k = \frac{EI}{a^3}$ 。



筑信达

谢 谢

“The idea that an expert-system computer program, with artificial intelligence, will replace a **creative human is an insult to all structural engineers.”**



加州大学伯克利分校终身名誉教授 Edward L. Wilson (著名的结构分析设计软件 SAP 的创始人) 在《Three Dimensional Static and Dynamic Analysis Of Structures》(<http://www.edwilson.org/Book/book.htm#Personal>) 一书中提到:

"Don't use a structural analysis program unless you fully understand the theory and approximations used within the program"

"Don't create a computer model until the loading, material properties and boundary conditions are clearly defined"