复材约束海水海砂混凝土应力-应变统一模型

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- 随着对海洋资源开发的增加，海洋和沿海基础设施的需求也在大量增长。
- SSC（海水海砂混凝土，Seawater sea sand concrete）在沿海城市和近海岛屿具有明显优势。
- 由于SSC的氯化物浓度高，钢容易被腐蚀。

1 简介

- 当SSC受到FRP的外部约束时，FRP可以有效减缓和抑制氯化物对混凝土的渗透，从而确保FRP-SSC结构在海洋环境中的耐久性。

- 一些学者对FRP约束SSC的轴压行为进行了研究。


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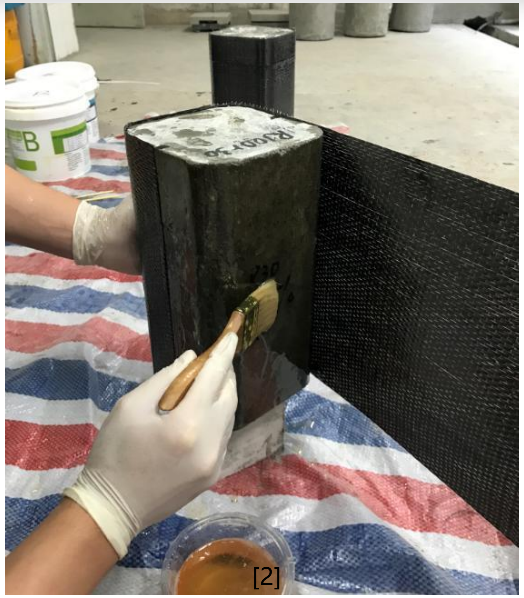

[2]


[3]

[1] Z.B. He, Compressive behaviors of CFRP-confined seawater and sea-sand concrete cylinders, in, Guangdong University of Technology, 2018.
[2] T.Q. Yang, Mechanical properties study on CFRP-confined recycled aggregate-seasand concrete columns, in, Shenzhen University 2018.
[3] Y. Yuan, Behavior of FRP confined simulated sea water concrete short columns, in, Wenzhou University 2018.

2 数据库

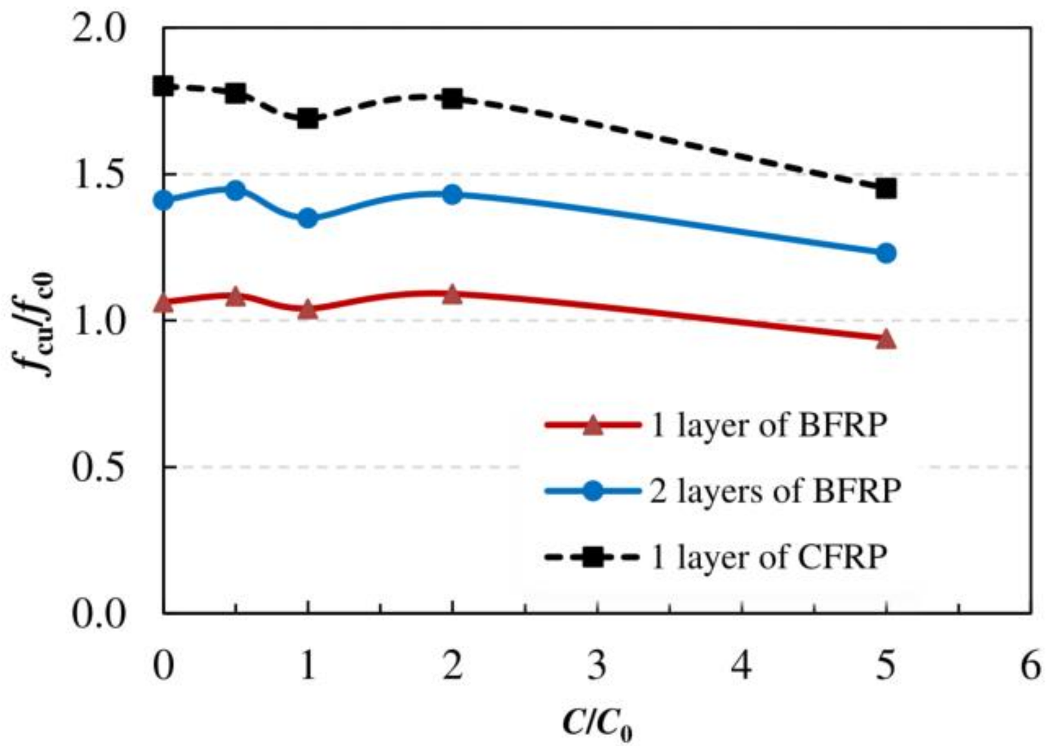
数据库中共361个FRP约束SSC柱的实验结果。

Shape	Literature	n	D	H	r	f_{c0}	FRP	E_{frp}	t_{frp}
Circular	Zeng, 2017	117	150	300	-	23.5~36.9	BFRP CFRP	94.1, 257.1	0.15~0.30
	He, 2018	60	150	300	-	42.4~52.5	CFRP	247.0	0.17~0.33
	Yuan, 2018	120	150	300	-	28.0~39.4	BFRP CFRP	94.1, 257.1	0.15~0.30
	Yang et al. 2020	4	150	300	-	32.8	CFRP	235.0	0.17~0.33
	Zeng et al. 2020	18	150	300	-	39.1~40.6	CFRP	238.3	0.17~0.50
Square	Yang, 2018	30	150	300	0~75	34.8~36.7	CFRP	248.4	0.33
	Zeng et al. 2020	12	150	300	30	39.1~40.6	CFRP	238.3	0.17~0.50

3

既有模型评价

对于相同的FRP约束，普通混凝土和SSC的性能仍有差异[4].



氯离子浓度影响

- 对于FRP约束普通混凝土，对于1层BFRP约束、2层BFRP限制和1层CFRP约束下的试样，f_{cu}/f_{c0}分别等于1.06、1.41和1.80。
- 结果表明，氯离子的存在削弱了FRP对混凝土的增强作用。

[4] Y. Yuan, Behavior of FRP confined simulated sea water concrete short columns, in, Wenzhou University 2018

既有模型预测性能

Model	Prediction of f_{cu}			Prediction of ε_{cu}		
	AAE [%]	M [%]	SD [%]	AAE [%]	M [%]	SD [%]
Circular columns						
Lam and Teng, 2003	10.0	103.0	12.6	30.2	109.8	46.4
Ozbakkalogu and Lim, 2013	10.3	103.9	12.8	27.7	99.8	44.6
Wei and Wu, 2012	12.6	88.1	8.6	35.0	84.1	52.2
Square columns						
Lam and Teng, 2003	12.4	91.0	11.6	31.9	68.1	15.6
Wei and Wu, 2012	18.2	81.9	13.7	43.9	56.1	15.5
Lim and Ozbakkalogu, 2014	16.8	83.2	10.3	14.3	91.5	21.9

$$\mathrm{AAE} = \frac{\sum_{i=1}^{n}\left|\frac{Mod_i - Exp_i}{Exp_i}\right|}{n}$$

$$\mathrm{M} = \frac{\sum_{i=1}^{n}\frac{Mod_i}{Exp_i}}{n}$$

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\left(\frac{Mod_i}{Exp_i} - M\right)^2}{n-1}}$$

4 应力-应变统一模型

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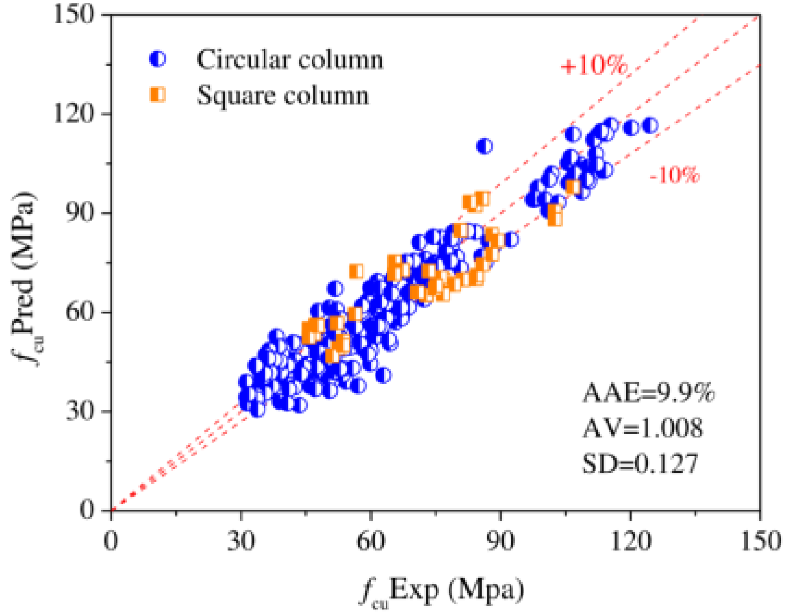
极限强度统一模型

$$\frac{f_{cu}}{f_{c0}} = 1 + k\frac{f_l}{f_{c0}}\left(a_1 + a_2\frac{2r}{L}\right)$$

$$f_l = \frac{2E_{frp}t_{frp}\varepsilon_{h,rup}}{L}$$

- 通过回归分析得到k, a_1 及 a_2 的值为3.4, 0.52 and 0.48。



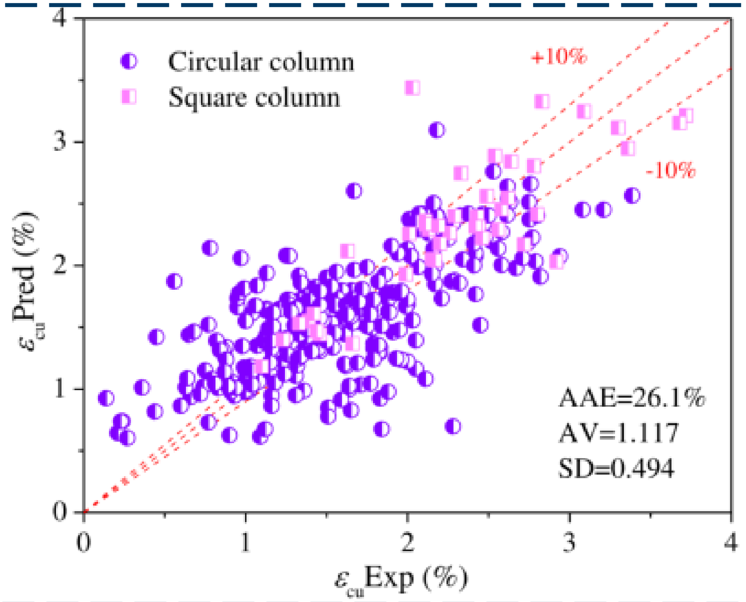
- 对于圆形柱和方形柱，极限强度统一方程获得了良好的精度，AAE、AV和SD分别等于9.9%、1.008和0.127。

极限应变统一模型

$$\frac{\varepsilon_{cu}}{\varepsilon_{c0}} = m_1 + m_2\left(0.9 + 0.1\frac{2r}{L}\right)\left(\frac{K_1}{f_{c0}}\right)^{m_3}\left(\frac{\varepsilon_{h,rup}}{\varepsilon_{c0}}\right)^{m_4}$$

$$K_1 = \frac{2E_{frp}t_{frp}}{L}$$

- 通过回归分析得到m_1, m_2 ,m_3 及m_4的值为3.16，0.03，0.9 and 1.35。



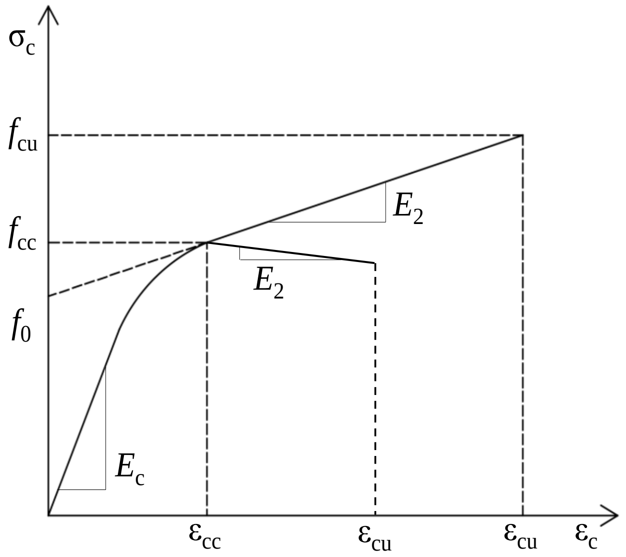
- 极限应变模型显示出更高的精度，AAE等于26.1%，AV等于1.117，SD等于0.494。

轴向应力-轴向应变统一模型

基准模型[5]**：**

$$\frac{\sigma_c}{f_{cc}}=\frac{ax}{a-1+x^{a(x+\delta)^b+c}}$$

$x=\varepsilon_c/\varepsilon_{cc}$;
f_{cc}、ε_{cc} 为峰值应力及峰值应变;
a,b,c 及 δ 为模型参数, b 和 δ 等于-0.1 及 0.01.



$$a=\frac{E_c}{E_c-\dfrac{\sigma_{cc}}{\varepsilon_{cc}}}$$

E_c：未约束混凝土弹性模量。

$$c=\frac{\ln\left(\dfrac{f_{cc}\varepsilon_{cu}a}{f_{cu}\varepsilon_{cc}}-a+1\right)}{\ln\varepsilon_{cu}-\ln\varepsilon_{cc}}-a\left(\frac{\varepsilon_{cu}}{\varepsilon_{cc}}+\delta\right)^{-0.1}$$

[5]S. Popovics, A numerical approach to the complete stress-strain curve of concrete, Cement & Concrete Research, 1973, 3: 583-599.

$$f_{cc} = f_{cu} - E_2\left(\varepsilon_{cu} - \varepsilon_{cc}\right)$$

$$\varepsilon_{cc} = \frac{2f_0}{E_c - E_2} = \frac{2\left(f_{cu} - E_2\varepsilon_{cu}\right)}{E_c - E_2}$$

Only ε_{cu}、f_{cu}、E_2 are needed

FRP约束圆形SSC柱的E_2：

$$E_2 = 2.82\rho f_{c0}$$

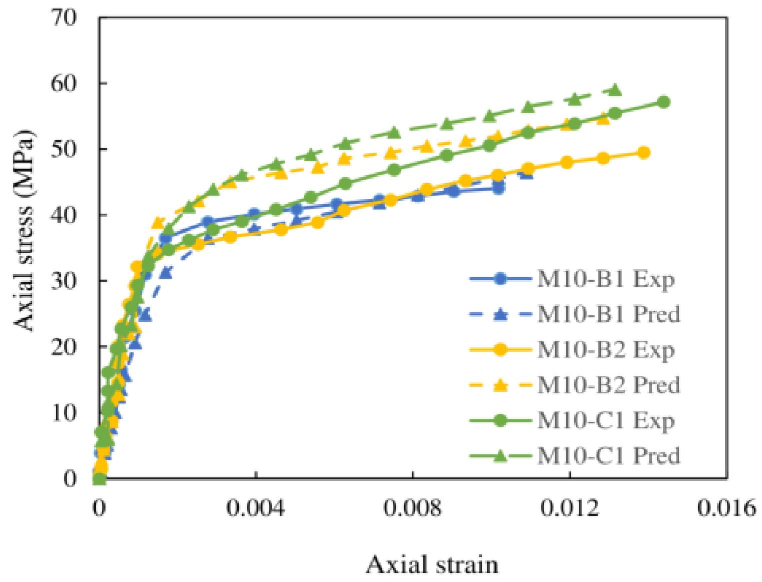
$$\rho = \frac{K_1}{f_{c0}} = \frac{2E_{frp}t_{frp}}{Df_{c0}}$$

FRP约束方形SSC柱的E_2, 考虑倒角半径：

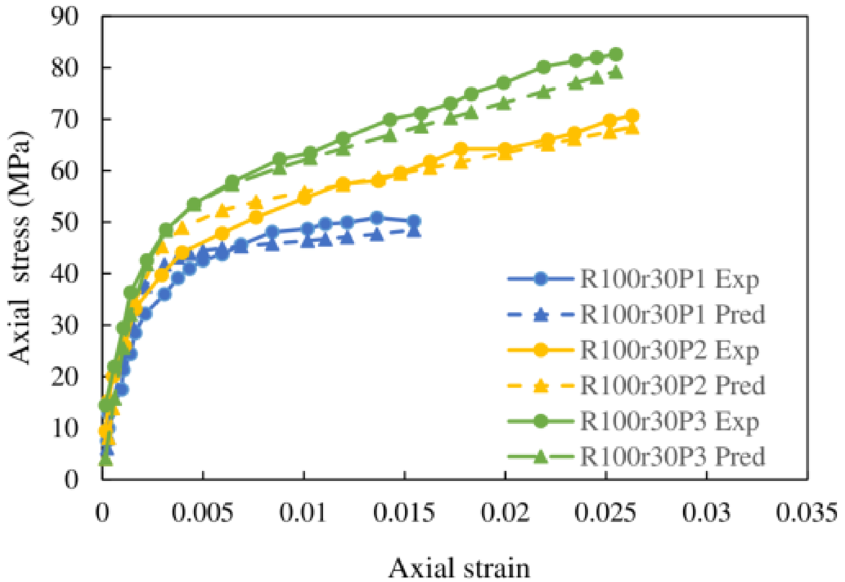
$$E_2 = 2.82\rho f_{c0}\left(\frac{2.2r}{L} - 0.1\right)$$

4 应力-应变统一模型

○ FRP约束圆形和方形SSC柱统一模型的预测性能



FRP约束SSC圆柱



FRP约束SSC方柱

○ 应力-应变统一模型预测精度可靠，六个试件的平均AAE、AV和SD分别等于0.18、1.00和0.28。

5 结论

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- FRP约束SSC柱极限强度模型的预测精度通常高于极限应变模型。在典型的设计型模型中，Lam和Teng模型在极限应力预测精度最高，而Lim和Ozbakkaloglu模型在极限应变预测方面精度最高。

- 应力-应变统一模型通过改变参数角半径，可以同时适用于FRP约束的圆形和方形SSC柱。

- 应力-应变统一模型对FRP圆形和方形SSC柱的极限应力、极限应变和应力-应变曲线的预测结果较好。

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感谢聆听！