Electronic Supplementary Materials

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Analyzing the strengthening effect of steel-ultra high performance concrete composite on segmental linings

Renpeng CHEN[1,2,3], Meng FAN[1,2,3], Hongzhan CHENG[1,2,3], Huaina WU[1,2,3], Yang ZHANG[4], Bingyong GAO[1,2,3], Shiqiang RUAN[1,2,3]

[1]*Research Center of Underground Space Advanced Technology, Hunan University, Changsha 410082, China*
[2]*Key Laboratory of Building Safety and Energy Efficiency of the Ministry of Education, Hunan University, Changsha 410082, China*
[3]*Department of Civil Engineering, Hunan University, Changsha 410082, China*
[4]*Key Laboratory for Wind and Bridge Engineering of Hunan Province, College of Civil Engineering, Hunan University, Changsha 410082, China*

Table S1 Critical condition under sagging moments

Curvature (m^{-1})	Critical condition	Judgment index	Coefficient adjustment
$\frac{\varepsilon_{ys}}{h_0-h_c}$	/	/	Set α_1~α_5=1， α_6~α_{13}=0.
$\frac{\varepsilon_{ys}}{h_0-h_c}$	Extrados rebars yields in compression.	$\frac{\varepsilon_{ys}}{h_0-h_c}(h_c-a_{se})\geq\varepsilon_{ys}$	Adjust α_2=0, α_6=1.
$\frac{\varepsilon_{ys}}{h_0-h_c}=\frac{\varepsilon_{cu}}{h_c}$	Concrete crush and rebar in tension no longer yields.	$\frac{\varepsilon_{ys}}{h_0-h_c}h_c=\varepsilon_{cu}$	Adjust α_3=0, α_7=1.
$\frac{\varepsilon_{cu}}{h_c}$	Steel plate in tension no longer yields.	$\frac{\varepsilon_{cu}}{h_c}(H+t_{uhpc}+t_{ss}/2-h_c)\leq\varepsilon_{yss}$	Adjust α_5=0, α_8=1.
$\frac{\varepsilon_{cu}}{h_c}$	UHPC in tension no longer yields.	$\frac{\varepsilon_{cu}}{h_c}(H+t_{uhpc}/2-h_c)\leq\varepsilon_{tuhpc}$	Adjust α_4=0, α_9=1.
$\frac{\varepsilon_{cu}}{h_c}$	Full cross-section under compression.	$h_c\geq H$	Adjust α_1=0, α_{10}=1.

$\frac{\varepsilon_{cu}}{h_c}$	Steel plate yields in compression.	$\frac{\varepsilon_{cu}}{h_c}(H+t_{uhpc}+t_{ss}/2-h_c)\le-\varepsilon_{yss}$	Adjust α_7=0, α_{11}=1.
$\frac{\varepsilon_{cu}}{h_c}$	Intrados rebars yields in compression.	$\frac{\varepsilon_{cu}}{h_c}(h_0-h_c)\le-\varepsilon_{ys}$	Adjust α_8=0, α_{12}=1.
$\frac{\varepsilon_{cu}}{h_c}$	UHPC hardens.	$\frac{\varepsilon_{cu}}{h_c}(H+t_{uhpc}/2-h_c)\le-\varepsilon_{cuhpc0}$	Adjust α_9=0, α_{13}=1.

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\begin{aligned}
N = {} & \alpha_1\left[f_c\gamma Bh_c\right]+\alpha_2\left[\frac{\varepsilon_{ys}}{h_0-h_c}(h_c-a_{se})E_sA_{se}\right]+\alpha_3\left[-f_{ysb}A_{si}\right] \\
& +\alpha_4\left[-f_{tuhpc}Bh_{uhpc}\right]+\alpha_5\left[-f_{yss}Bt_{ss}\right] \\
& +\alpha_6\left[f_{ysb}A_{se}\right]+\alpha_7\left[-\frac{\varepsilon_{cu}}{h_c}(h_0-h_c)E_sA_{si}\right] \\
& +\alpha_8\left[-\frac{\varepsilon_{cu}}{h_c}(H+t_{uhpc}+\frac{t_{ss}}{2}-h_c)E_sBt_{ss}\right] \\
& +\alpha_9\left[-\frac{\varepsilon_{cu}}{h_c}(H+\frac{t_{uhpc}}{2}-h_c)E_{uhpc}Bt_{uhpc}\right] \\
& +\alpha_{10}\left[f_c\gamma BH\right]+\alpha_{11}\left[f_{yss}A_{ss}\right] \\
& +\alpha_{12}\left[f_{ysb}A_{si}\right]+\alpha_{13}\left[f_{c\_uhpc}Bt_{uhpc}\right]
\end{aligned} \tag{S1}
$$

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\begin{aligned}
M = {} & \alpha_1\left[f_c\gamma Bh_c(h_0-\frac{h_c}{2})\right]+\alpha_2\left[\frac{\varepsilon_{ys}}{h_0-h_c}(h_c-a_{se})E_sA_{se}(h_0-a_{se})\right] \\
& +\alpha_3\left[0\right]+\alpha_4\left[f_{t\_uhpc}Bt_{uhpc}(a_{si}+\frac{t_{uhpc}}{2})\right] \\
& +\alpha_5\left[f_{yss}Bt_{ss}(a_{si}+t_{uhpc}+\frac{t_{ss}}{2})\right]+\alpha_6\left[f_{ysb}A_{se}(h_0-a_{se})\right] \\
& +\alpha_7\left[0\right]+\alpha_8\left[\frac{\varepsilon_{cu}}{h_c}(H+t_{uhpc}+\frac{t_{ss}}{2}-h_c)E_sBt_{ss}(a_{si}+t_{uhpc}+\frac{t_{ss}}{2})\right] \\
& +\alpha_9\left[\frac{\varepsilon_{cu}}{h_c}(H+\frac{t_{uhpc}}{2}-h_c)E_{uhpc}Bt_{uhpc}(a_{si}+\frac{t_{uhpc}}{2})\right] \\
& +\alpha_{10}\left[f_c\gamma BH(h_0-\frac{H}{2})\right]+\alpha_{11}\left[-f_{yss}Bt_{ss}(a_{si}+t_{uhpc}+\frac{t_{ss}}{2})\right] \\
& +\alpha_{12}\left[0\right]+\alpha_{13}\left[-f_{cuhpc}Bt_{uhpc}(a_{si}+\frac{t_{uhpc}}{2})\right]-N(h_0-\frac{H+t_{uhpc}+t_{ss}}{2})
\end{aligned} \tag{S2}
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Table S2 Critical condition under hogging moments

Curvature (m^{-1})	Critical condition	Judgment index	State coefficient
$\frac{\varepsilon_{ys}}{h_0-h_c}$	/	/	Set α_1~α_5=1, α_6~α_{16}=0.
$\frac{\varepsilon_{ys}}{h_0-h_c}$	Steel plate yields in compression.	$\frac{\varepsilon_{ys}}{h_0-h_c}(h_c+t_{uhpc}+t_{ss}/2)\geq\varepsilon_{yss}$	Adjust α_5=0, α_6=1.
$\frac{\varepsilon_{ys}}{h_0-h_c}$	Concrete hardening in compression.	$\frac{\varepsilon_{ys}}{h_0-h_c}h_c\geq\varepsilon_{c0}$	Adjust α_1=0, α_{12}=1, α_{13}=1.
$\frac{\varepsilon_{ys}}{h_0-h_c}$	Intrados rebars yields in compression.	$\frac{\varepsilon_{ys}}{h_0-h_c}(h_c-a_{si})\geq\varepsilon_{ys}$	Adjust α_2=0, α_7=1.
$\frac{\varepsilon_{ys}}{h_0-h_c}=\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}$	UHPC hardens and rebar in tension no longer yields.	$\frac{\varepsilon_{ys}}{h_0-h_c}(h_c+t_{uhpc}/2)=\varepsilon_{cuhpc0}$	Adjust α_4=0, α_{11}=0, α_{12}=0, α_8=1, α_{13}=1, α_{14}=1.
$\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}$	Intrados rebars yields in compression.	$\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}(h_c-a_{si})\geq\varepsilon_{ys}$	Adjust α_{11}=0, α_7=1.
$\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}$	Extrados rebar in tension no longer yields.	$\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}(h_0-h_c)<\varepsilon_{ys}$	Adjust α_3=0, α_9=1.
$\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}$	Full cross-section under compression.	$h_c\geq H$	Adjust α_{13}=0, α_{14}=0, α_{10}=1, α_{15}=1.
$\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}$	Extrados rebar yields in compression.	$\frac{\varepsilon_{cuhpc0}}{h_c+t_{uhpc}/2}(h_0-h_c)\leq-\varepsilon_{ys}$	Adjust α_9=0, α_{16}=1.

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\begin{aligned}
N = {} & \alpha_1\left[Bf_c\int_0^{h_c}(2\frac{\varepsilon_{ys}}{h_0-h_c}\frac{y}{\varepsilon_{c0}}-(\frac{\varepsilon_{ys}}{(h_0-h_c)\varepsilon_{c0}})^2 y^2)dy\right]+\alpha_2\left[\frac{\varepsilon_{ys}}{h_0-h_c}(h_c-a_{si})E_s A_{si}\right] \\
& +\alpha_3\left[-f_{ysb}A_{se}\right]+\alpha_4\left[\frac{\varepsilon_{ys}}{h_0-h_c}(\frac{t_{uhpc}}{2}+h_c)E_{uhpc}Bt_{uhpc}\right] \\
& +\alpha_5\left[\frac{\varepsilon_{ys}}{h_0-h_c}(\frac{t_{ss}}{2}+t_{uhpc}+h_c)E_s Bt_{ss}\right]+\alpha_6\left[f_{yss}A_{ss}\right] \\
& +\alpha_7\left[f_{ysb}A_{si}\right]+\alpha_8\left[f_{cuhpc}Bt_{uhpc}\right]+\alpha_9\left[-\frac{\varepsilon_{cuphc0}}{h_c+t_{uhpc}/2}(h_0-h_c)E_s A_{se}\right] \\
& +\alpha_{10}\left[Bf_c\int_{h_c-H}^{\frac{\varepsilon_{c0}(t_{uhpc}/2+h_c)}{\varepsilon_{cuhpc0}}}(2\frac{\varepsilon_{cuhpc0}}{t_{uhpc}/2+h_c}\frac{y}{\varepsilon_{c0}}-(\frac{\varepsilon_{cuhpc0}}{(t_{uhpc}/2+h_c)\varepsilon_{c0}})^2 y^2)dy\right] \\
& +\alpha_{11}\left[\frac{\varepsilon_{cuphc0}}{h_c+t_{uhpc}/2}(h_c-a_{si})E_s A_{si}\right] \\
& +\alpha_{12}\left[Bf_c\int_0^{\frac{\varepsilon_{c0}(h_0-h_c)}{\varepsilon_{ys}}}(2\frac{\varepsilon_{ys}}{h_0-h_c}\frac{y}{\varepsilon_{c0}}-(\frac{\varepsilon_{ys}}{(h_0-h_c)\varepsilon_{c0}})^2 y^2)dy\right] \\
& +\alpha_{13}\left[Bf_c(h_c-\frac{\varepsilon_{c0}(h_0-h_c)}{\varepsilon_{ys}})\right] \\
& +\alpha_{14}\left[Bf_c\int_0^{\frac{\varepsilon_{c0}(t_{uhpc}/2+h_c)}{\varepsilon_{cuhpc0}}}(2\frac{\varepsilon_{cuhpc0}}{t_{uhpc}/2+h_c}\frac{y}{\varepsilon_{c0}}-(\frac{\varepsilon_{cuhpc0}}{(t_{uhpc}/2+h_c)\varepsilon_{c0}})^2 y^2)dy\right] \\
& +\alpha_{15}\left[Bf_c(h_c-\frac{\varepsilon_{c0}(t_{uhpc}/2+h_c)}{\varepsilon_{cuhpc0}})\right] \\
& +\alpha_{16}\left[f_{ysb}A_{se}\right]
\end{aligned}
\tag{S3}
$$

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\begin{aligned}
M = {} & \alpha_1 \left[Bf_c \int_0^{h_c} \left(\frac{\varepsilon_{ys}}{h_0 - h_c} \frac{y}{\varepsilon_{c0}}(h_0 - h_c + y) - \left(\frac{\varepsilon_{ys}}{(h_0 - h_c)\varepsilon_{c0}}\right)^2 y^2 (h_0 - h_c + y)\right) dy \right] \\
& + \alpha_2 \left[\frac{\varepsilon_{ys}}{h_0 - h_c}(h_c - a_{si}) E_s A_{si} (h_0 - a_{si}) \right] + \alpha_3 [0] \\
& + \alpha_4 \left[\frac{\varepsilon_{ys}}{h_0 - h_c}\left(\frac{t_{uhpc}}{2} + h_c\right) E_{uhpc} B t_{uhpc} \left(h_0 + \frac{t_{uhpc}}{2}\right) \right] \\
& + \alpha_5 \left[\frac{\varepsilon_{ys}}{h_0 - h_c}\left(\frac{t_{ss}}{2} + t_{uhpc} + h_c\right) E_s B t_{ss} \left(h_0 + t_{uhpc} + \frac{t_{ss}}{2}\right) \right] \\
& + \alpha_6 \left[f_{yss} A_{ss} \left(h_0 + t_{uhpc} + \frac{t_{ss}}{2}\right) \right] + \alpha_7 \left[f_{ysb} A_{si} (h_0 - a_{si}) \right] \\
& + \alpha_8 \left[f_{cuhpc} B t_{uhpc} \left(h_0 + \frac{t_{uhpc}}{2}\right) \right] + \alpha_9 [0] \\
& + \alpha_{10} \left[Bf_c \int_{h_c - H}^{\frac{\varepsilon_{c0}(t_{uhpc}/2 + h_c)}{\varepsilon_{cuhpc0}}} \left(\frac{\varepsilon_{cuhpc0}}{t_{uhpc}/2 + h_c} \frac{y}{\varepsilon_{c0}}(h_0 - h_c + y) - \left(\frac{\varepsilon_{cuhpc0}}{(t_{uhpc}/2 + h_c)\varepsilon_{c0}}\right)^2 y^2 (h_0 - h_c + y)\right) dy \right] \quad \text{(S4)} \\
& + \alpha_{11} \left[\frac{\varepsilon_{cuphc0}}{h_c + t_{uhpc}/2}(h_c - a_{si}) E_s A_{si} (h_0 - a_{si}) \right] \\
& + \alpha_{12} \left[Bf_c \int_0^{\frac{\varepsilon_{c0}(h_0 - h_c)}{\varepsilon_{ys}}} \left(\frac{\varepsilon_{ys}}{h_0 - h_c} \frac{y}{\varepsilon_{c0}}(h_0 - h_c + y) - \left(\frac{\varepsilon_{ys}}{(h_0 - h_c)\varepsilon_{c0}}\right)^2 y^2 (h_0 - h_c + y)\right) dy \right] \\
& + \alpha_{13} \left[Bf_c \left(h_c - \frac{\varepsilon_{c0}(h_0 - h_c)}{\varepsilon_{ys}}\right)\left(h_0 - \frac{h_c}{2} + \frac{\varepsilon_{c0}(h_0 - h_c)}{2\varepsilon_{ys}}\right) \right] \\
& + \alpha_{14} \left[Bf_c \int_0^{\frac{\varepsilon_{c0}(t_{uhpc}/2 + h_c)}{\varepsilon_{cuhpc0}}} \left(\frac{\varepsilon_{cuhpc0}}{t_{uhpc}/2 + h_c} \frac{y}{\varepsilon_{c0}}(h_0 - h_c + y) - \left(\frac{\varepsilon_{cuhpc0}}{(t_{uhpc}/2 + h_c)\varepsilon_{c0}}\right)^2 y^2 (h_0 - h_c + y)\right) dy \right] \\
& + \alpha_{15} \left[Bf_c \left(h_c - \frac{\varepsilon_{c0}(h_0 - h_c)}{\varepsilon_{ys}}\right)\left(h_0 - \frac{h_c}{2} + \frac{\varepsilon_{c0}(h_c + t_{uhpc}/2)}{2\varepsilon_{cuhpc0}}\right) \right] \\
& + \alpha_{16} [0] - N\left(h_0 - \frac{H + t_{uhpc} + t_{ss}}{2}\right)
\end{aligned}
$$