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Strengthening of Pre-stressed Steel–Concrete Composite Beams Using Carbon Fiber Tendons – A Parametric Study

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Abstract

[illegible] element model using ANSYS program is set up to study the impact of composite [illegible]

Keywords Composite; Post-tensioning; Finite element modelling; CFRP; ANSYS

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[illegible]

[illegible]

[illegible] have established a lot of advantages like increase the load [illegible]

[illegible]

[illegible] pre-stressed CFRPs in the strengthening of composite beams are [illegible]

[illegible] concrete structures in Japan, UK, China, Europe and Canada have [illegible]

[illegible] paper discusses strengthening steel-concrete composite beam [illegible] experimental outcomes. A parametric study is presented to inspect the impact of FRP tendons on strengthened composite

temperature in the beam elements applied to model the tendons.

Methodology

Finite element model

is used for represent the material non-linear behavior of the

dimensional modeling of solid structures. Three-dimensional

65) that is able to crack in tension and crush in compression. In

each node is used to represent the shear connector's conduct to

used to simulate the external tendons.

Figures 1 and 2. For prevent stress

area.

Material modeling

Modeling is performed on ANSYS-15. The element damaged

modeling all types of structures using concepts of isotropic

steel- concrete beams. The choice of the suitable elements for

Modeling of concrete: The concrete is simulated to be

Figure 3.

Modeling of steel I-beam:

Figure 4 is used in this study.

Modeling of reinforcing steel bars and external pre-stressing steel tendons: As the reinforcing steel and post-tensioning

Modeling of external pre-stressing FRP tendons: Pre-stressed FRPs have limited strain capacity and premature debonding

index can be used as a major tool to avoid this phenomenon. By pre-stressing the FRP reinforcement, the stress in the internal

Figure 1 Contact element (178).

Figure 2

Œ]v(}Œ]vP •š o v G Ÿ}v• Á]oo Z]PZ Œ µŸo]Ì Ÿ}v }(šZ &ZW u š Œ] o•X dZ Œ o Ÿ}v•Z]‰]v Figure 5 is used in this study.

Real constants

dZ]v]Ÿ o Wd (}Œ]• .v Ç v]v]Ÿ o •šŒ]v ‰Œ}ÀŒ]•, o µo š • P]À v Ç ‹µ Ÿ}v ~í•

Figure 3 Stress-strain curve for concrete.

Figure 4 Stress-strain curve for steel.

Figure 5 Stress–strain behavior of pre-stressed materials (tendons).

Œ • v šZ Œ Á]oo initial temperature $= \frac{F}{\alpha E A_p}$ Œ •šŒ ••r•šŒ]v (1)

ÁZ Œ &]• šZ]v]Ÿ o Wd (}Œ U]• šZ š v }vU r]• šZ Œu o Æ‰ v•]}v } 8] v šU

s Œ]. Ÿ}v

&Œ}u o]š Œ šµŒ Á • Z}}• Z v š oX compared to varify the accuracy of the proposed FE model. The]u v•]}v•U š]o•U v ‰Œ}.o • }(šZ ‰ šZ Æ u]v u• ÁZ] Z Figure 6. The examined u• Z À š}š o o vPšZ }(ñíñì uu v Á ñìì uu •]u‰o •‰ vX o•}U]ší• o} ‹ š} P š o ŒoÇ v]vPX dÁ} Œ}Á• }(íò u o vPšZ •Z Œ }vv š}Œ •šµ • Œ © Z a transverse spacing of 76 mm symmetric to the centerline of the š}‰ G vP v o]v Œ]•š v }(îìì uuX Á • }u‰o]•Z Á]šZ] vŸšÇ ^ñðìì W Œš Á Œ •šŒ vPšZ v Á]šZ "ô (}Œu Œ• šÁ} }ŒšZ}P}v o]Œ Ÿ}v•X

d v }v ‰Œ}.o Á • Figure 6 Œ dZ š] w }v ‰Œ} •šŒ]PZš š v }v ÁZ] Z • š šZ šÁ} v • }À Œ šZ }©}u G vP v Æ‰ v }v šZ }À Œ šZ ÁZ}o o vPšZ }(šZ uX

dZ }v oµ•]}v }(šZ u š Œ] o• ‰Œ}‰ ŒŸ are listed on Table 1 X dZ À Œ]. Ÿ}v }(šZ .v]š

Table 1 ^µuu ŒÇ }(u š Œ] o ‰Œ}‰ ŒŸ •X

Pressing Tendons					f_y (MPa)		f_u(MPa)	
f_y Mpa	f_u Mpa	A_P (mm^2)	F (KN)	f_c (MPa)	Web	Flange	Web	Flange
1680	1860	137.4	112.6	40	327.7	406.5	ðõîXò	ðõïXò

Figure 6 Details of studied beam (All dimensions in mm).

Á • Z] À Á]šZ µŒ Ç õò9 šZŒ}µ ... u} o }µš }u • Á]šZ Æ‰ Œ]u vš o Œ •µ... €íó•X dZ À Œ]. Ÿ}v • }v šZ u Æ]u... u} o v o•} šZ G Ÿ}v }(šZ }u‰}•... in Figure 7.

Figure 7 D}u všt G Ÿ}v µŒÀ X

Table 2 }u‰ Œ]•}v }(‰Œ}‰ Œ Ÿ • }(‰Œ r•šŒ ••]vP š...

D Z v] o WŒ}‰ Œ Ÿ •	Prestressing Steel	AFRP Tendon	CFRP Tendon	GFRP Tendon
Nominal Yield Stress (MPa)	íìïðrííõò	N/A	N/A	N/A
Tensile Strength (MPa)	íïóõríôòì	1200-2068	1650-2410	íïóõr 1724
o •Ÿ D} µoµ•	~186-200	50-74	152-165	48-62
Yield Strain (%)	1.4-2.5	N/A	N/A	N/A
Rupture strain (%)	>4	2-2.6	1-1.5	3-4.5
Density (kg/m³)	óõìì	1250-1400	1500-1600	1250-2400

Table 3 ^ Ÿ}v ‰Œ}‰ ŒŸ • }(D} o• ~^dU dU Z...

Strand Strength (MPa)	o •Ÿ Modulus (Gpa)	Tendon Material	Model	No.
1860	200	Steel	ST	1
2410	165	CFRP	CT	2
2068	70	AFRP	AT	3
1724	62	'&ZW	'd	4

Parametric study

+ š }(Œ ‰]vP (Œ‰ š v }v•W d o î •Z}Á šZ šÇ‰] o š v•]o ‰Œ}‰ ŒŸ • }(À Œ]}µ• šÇ‰ • }(‰Œ r•šŒ •• •šŒ vPšZ v]vP u š Œ] o• €íôUíõ•X d} Æ‰o}Œ šZ + ŸÀ v •• }(Œ ‰]vP &ZW š v }v• }v šZ ‰ Œ(}Œu v }(šZ }u‰}•]š uU ‰ Œ u šŒ] •šµ Ç Á • }u‰o]•Z }v (}µŒ v Á À v u} o• ~^dU dU dU v 'd• Á]šZ • À Œ o š v }v• u š Œ] o Œ š •š X ... }(íôòì DW µoŸu š •šŒ vPšZ ~(•µ•U v îìì '‰ u} µoµ• }(o •Ÿ]šÇ ~ •U ~ d• (}Œ &ZW š v }v }(îðíì DW µoŸu š •šŒ vPšZ ~(•µ•U v íòñ '‰ u} µoµ• }(o •Ÿ]šÇ ~ •U ~ d• (}Œ &ZW š v }v }(îìòô DW µoŸu š •šŒ vPšZ ~(•µ•U v óì '‰ u} µoµ• }(o •Ÿ]šÇ ~ •U v ~'d• (}Œ '&ZW š v }v }(íóîð DW µoŸu š •šŒ vPšZ ~(•µ•U v ðô '‰ u} µoµ• }(... stress force per bar P=112.6 KN. The geometrical advantages of the used models same as Figure 6 and a summary of material and • Ÿ}v ‰Œ}‰ ŒŸ • (}Œ šZ À Œ]. v u} o }u‰}•]š u• Œ •Z}Áv]v Tables 2 and 3. Figure 8 •Z}Á• .v]š o u vš u•ZX &}Œ u} o ~^d•U šZ]v]Ÿ o ‰Œ r•šŒ ••]vP (}Œ íí î Xò lE X dZ u}u vš t G Ÿ}v µŒÀ ‰‰ Œ•... ÁZ v šZ u}u vš Á • îñì lE uU Á]šZ ‰Œ r•šŒ ••]vP (}Œ }(íñì lE]v Z š v }vU ÁZ]o šZ G Ÿ}v Á • ïïî lE uU ÁZ]o šZ uuU v šZ µoŸu š ‰Œ r•šŒ ••]vP (}Œ ... kN.

Figure 8 Finite element mesh.

Discussion

&}Œ u} o ~ d•U šZ]v]Ÿ o ‰Œ r•šŒ ••]vP (}Œ íí î Xò lE X dZ u}u vš Á • íóì lE uU Á]šZ ‰Œ r•šŒ ••]vP ...]v Z š v }vU ÁZ]o šZ G Ÿ}v Á • íï uu u}u vš Á • ïóì lE uU ÁZ]o šZ G Ÿ}v Á • ... µoŸu š ‰Œ r•šŒ ••]vP (}Œ }(šZ š v }v• Á • îôð lE X

&}Œ u} o ~ d•U šZ]v]Ÿ o ‰Œ r•šŒ ••]vP (}Œ íí î Xò lE X dZ u Æ]uµu u}u vš Á • îóõ ... G Ÿ}v Á • íð uu ... šZ µoŸu š ‰Œ r•šŒ ••]vP (}Œ }(šZ š v }v• Á • îôð lE X

&}Œ u} o ~'d•U šZ]v]Ÿ o ‰Œ r•šŒ ••]vP (}Œ ... Á • íí î Xò lE X dZ u Æ]uµu u}u vš Á • îïð ... G Ÿ}v Á • íí uuU v šZ µoŸu š ‰Œ r•šŒ ••]vP (}Œ }(šZ š v }v• Á • îïð lE X

Figure 9 D}u všt G Ÿ}v µŒÀ (}Œ À Œ]}µ• u}uš• tendon.

Figure 9 o Œ]. • šZ u}u vš r G Ÿ}v Œ •‰}v• • šZ u] •‰ v (}Œ šZ }u‰}•]š u Á]šZ]+ Œ vš šÇ‰ • }(Æš Œv o tendons. It is observed that CFRP tendon (model (CT)) had high •šŒ vPšZ Á]šZ •u oo G Ÿ}v }u‰ Œ (model (ST)) had high strength compared to AFRP tendon (model ~ d•• v '&ZW š v }v ~u} o ~'d••U •š Z Z]PZ G Ÿ}v }u‰ Œ š} }šZ Œ•U ~u} o ~'d•• Z •u oo •šŒ vPšZ v •u oo G Ÿ}v }u‰ Œ to others.

Modes of failure

dÁ} D} • }(&]oµŒ } µŒŒ]v šZ }u‰}•]š uW }v Œ š Œµ•Z]vP v &ZW Œµ‰šµŒ X &}Œ u} o ~^d• šZ u} }(( ]oµŒ Á • }v Œ š Œµ•Z]vPU ÁZ]o šZ u Æ]uµu u}u vš Á • ïíñ lE u µ š} o}vP ‰o š • }(µ Figure 9. For model ~ d• šZ u} }(( ]oµŒ Á • &ZW Œµ‰šµŒ U ÁZ]o šZ u Æ]uµu u}u vš Á • ïóì lE uX &}Œ u} o ~ d• šZ u} }(( ]oµŒ Á • &ZW Œµ‰šµŒ U ÁZ]o šZ u Æ]uµu u}u vš Á • ïîð lE uX &}Œ u} o ~'d• šZ u} }(( ]oµŒ Á • '&ZW Œµ‰šµŒ U ÁZ]o šZ u Æ]uµu u}u vš Á • îïð lE uX

Figure 10 Concrete crushing failure.

+ š }(‰Œ r•šŒ •• o À o

d} Æ‰o}Œ šZ + ŸÀ v •• }(‰Œ r•šŒ •• > À o }v šZ ‰ Œ(}Œu v }(šZ }u‰}•]š u •šŒ vPšZ v Á]šZ Æš Œv o ‰Œ r•šŒ •• &ZW š v }vU ‰ Œ u šŒ] •šµ Ç Á • d} Æ‰o}Œ šZ À v u} o• ~ díU dîU dïU v dð• Á]šZ Œ š •š X ~ dí• (}Œ &ZW š v }v Œ WAîì9 }( ]š• µoŸu š •šŒ vPšZX ~ dî• &ZW š v }v ‰Œ r•šŒ •• (}Œ ‰ Œ Œ WAïì9 }( ]š• µoŸu š •šŒ vPšZX ~ dï• &ZW š v }v Á]šZ ‰Œ r•šŒ •• (}Œ ‰ Œ Œ WAðì9 }( ]š• µoŸu š •šŒ vPšZX ~ dð• (}Œ &ZW š v }v Á]šZ ‰Œ r•šŒ •• (}Œ WAñì9 }( ]š• µoŸu š •šŒ vPšZX

•µuu ŒÇ }(š v }v ‰Œ}‰ ŒŸ • v ‰Œ r•š Œ •Z}Á] Table 4. Figure 8 •Z}Á• dZ P }u šŒ] o } u} o•XZ •µoš• Figure 11Á v]v

Table 4 WŒ}‰ ŒŸ • }(u} o• ~ díU dîU dïU v

Prestress Level %	Strand strength (MPa)	o •Ÿ Modulus (Gpa)	Tendon material	Model	No.
20	2410	165	CFRP	CT1	1
30	2410	165	CFRP	CT2	2
40	2410	165	CFRP	CT3	3
50	2410	165	CFRP	CT4	4

From Figure 11 it is observed that :

D} o ~ dí• u Æ]uµu u}u vš Á • ïôñ lE G Ÿ}v Á • íòXðð uuX

D} o ~ dî• u Æ]uµu u}u vš Á • ïóð lE G Ÿ}v Á • íñXíî uuX

D} o ~ dï• u Æ]uµu u}u vš Á • ïòï lE G Ÿ}v Á • íðXîó uuX

D} o ~ dð• u Æ]ûµu u}u vš Á • ïñî lE G Ÿ}v Á • ííXîó uuX

Figure 11 D}u všt G Ÿ}v µŒÀ (}Œ ‰Œ r•š

Figure 11 cl Œ]. • šZ u}u vš r G Ÿ}v Œ • u] •‰ v (}Œ šZ }u‰}•]š u Á]šZ]+ •šŒ •• o À oX/š]• } • ŒÀ šZ š u} o ~ d Z]PZ G Ÿ}v }u‰ Œ š} }šZ Œ•X

+ š }(š v }v šÇ‰ }v ‰Œ r•šŒ •• o À o

d} Æ‰o}Œ šZ + ŸÀ v •• }(š v }v ‰Œ r•šŒ •• ‰ Œ u šŒ] •šµ Ç Á • }v Æš Œv o ‰Œ r•šŒ •• &ZW š v }v Á]šZ Æ‰Œ r•šŒ •• o À o &ZW š v }v Œ WAñì9 }( ]š• µoŸu š •šŒ vPšZX u G vP }v Œ •‰ ŸÀ oÇX

Table 5 W Œ } ‰ Œ Ÿ • } (u } o• ~ , í U , î U , ï U v D } , ð o

he % of steel beam height	P.T Force (KN)	Model	No.
10	112.6	CH1	1
15	112.6	CH2	2
20	112.6	CH3	3
25	112.6	CH4	4

Figure 12 ' } u š Œ] o } (š Z µ • u } o• ~ o o] u v •] } v •] v u u X

• µ u u Œ Ç } (š v } v ‰ Œ } ‰ Œ Ÿ • v š v } v ‰ Œ } . o o À š } (Z u } o Œ Table 5 Figure 12 • Z } Á • d Z P } u š Œ] o } (š Z µ • u } o• X Z • µ o š Figure 13. • Z } Á v] v

Figure 13 D } u v š t G Ÿ } v µ Œ À (} Œ š v } v ‰ Œ } . o o À š X

From Figure 13 it is observed that :

D } o ~ , í • U d Z u Æ] u µ u u } u v š Á • ï ó ì [E u U Á Z] o š Z G Ÿ } v Á • ï ì u u X

D } o ~ , î • U d Z u Æ] u µ u u } u v š Á • ï î ð G Ÿ } v Á • í ò X õ u u X

D } o ~ , ï • U d Z u Æ] u µ u u } u v š Á • ï ì ò G Ÿ } v Á • í ñ u u X

D } o ~ , ð • U d Z u Æ] u µ u u } u v š Á • î ó õ G Ÿ } v Á • í í X î u u X

Figure 13 o Œ] . • š Z u } u v š r G Ÿ } v Œ • u] • ‰ v (} Œ š Z } u ‰ } •] š u Á] š Z] + o À š (Œ } u š Z } © } u • µ Œ (} (• š o observed that model (CH1) had high strength compared to others.

Conclusion

In this research, a non-linear parametric analysis for composite u • Æ š Œ v o o Ç ‰ } • š r š v •] } v Á] š Z evaluated. The FE model is validated using experimental results. And, a parametric study is accomplished to survey the various Ÿ } v • } (• š Œ v P š Z v } (u • Á] š Z ‰ Œ r • d Z u i } Œ } v o µ •] } v • Œ • (} o o } Á • W

1. W Œ r • š Œ • • & Z W • Æ Z]] š P } } ‰ • š Œ µ š µ Œ o ‰ Œ } ‰ Œ Ÿ •] v o µ] v P Z] P Z š Z µ o Ÿ u š o } Œ Œ Ç] v P ‰] š Ç U Œ • š Œ v P š Z U Z] P Z • Ÿ + v • • U v Z] P Z v Œ stressed steel.

2. & Œ } u o o & Z W • U & Z W] • š Z • š š Ç ‰ ‰ Œ r • š Œ • • & Z W] v Œ • š Z G Æ µ Œ of the composite beam. The other advantages of pre-stressed & Z W • Œ š Z o } Á Á] P Z š U Z] P Z š v •] Œ o Æ Ÿ } v o } • • • X

3. d Z u i } Œ ( ] o µ Œ u } • Œ } P v] Ì µ v in pre-stressed strengthened beams are concrete crushing for steel tendon, and FRP rupture for all FRPs tendon.

4. / v Œ • ‰ Œ r • š Œ • • o À o } (& Z W š strength and deformability of pre-stressed composite beam Á] š Z & Z W š v } v X

5. / v Œ • š v } v ‰ Œ } . o o À š (Œ } u š • š o u G v P Á] o o Œ • š Z µ Ÿ o] š } u ‰ } •] š u Á] š Z & Z W š v } v v Œ capacity.

References

1 , µ •] v , D U µ o r D i Y U z } µ •] (v Ç , U < } Œ] • • / E ~ î ì ì õ • Z À] } Œ } (} u ‰ } •] š • š o r } v Œ š u • µ i š š } v P Œ Ÿ À u } u v š bending. Eng Technol J 27: 53-71.

2 D] Œ Ì K U h Ç ~ î ì ì í • + š • } (š Z } u] v Ÿ } v } (Œ Æ] o v • Z Œ loading on the behaviour of headed stud steel anchors. Eng Struc ï î W õ ï r í ì ñ X

3 • } v U Z v Ì] ' ~ î ì í í • &] v] š o u v š u } o • (} Œ • š o t } v Œ š } u ‰ } •] š u • Á] š Z ‰ Œ } Ÿ o • š o l } u] v v] v P v • Z Œ X &] v] š o u v o • ð ó W õ ô r í ì ò X

4 Qureshi J, Lam D (2012) Behaviour of Headed Shear Stud in Composite u • Á] š Z W Œ } . o D š o l] v P X À ^ š Œ µ š v P ï ñ W í ñ ð ó r í ñ õ X

5 El-Shihy AH, Shaaban HF, Mustafa SA (2015) Finite element modeling of Æ š Œ v o o Ç ‰ } • š r š v •] } v } u ‰ } •] š u • X : } µ Œ v o } (} v • š Œ µ Ÿ } v P] v Œ] v P X >] (• }] v]] î î W ñ ì r ò ó X

6 El-Shihy AH, Shaaban HF, Abd Elkader HM, Hassanin AI (2016) + š } (µ •] v P ‰ Œ Ÿ o } v Ÿ v µ } µ •] v š Ç Æ š Œ v o o Ç •] u ‰ o } u ‰ } •] š u • • š Œ v P š Z v] v P š Ç ‰ • } (r • • š Œ Ÿ À v ( ]] v v } v r o] v Œ] v P ^] v • 311.

7 E } Œ] v , ~ î ì ì ñ • ^ š Œ v P š Z v] v P • š Œ µ š µ Œ • Á] š Z Æ š Œ v o o Ç ‰ Œ r • š Œ • • Z À] } Œ X d Z v] o Z ‰ } Œ š X

8 o r , Z Z U ' (Œ D ~ î ì ì ô • ^ š Œ v P š Z v] v P } v & Z W } u ‰ } •] š •]

õ o r , Z ZU ' (Œ D ~îìíí• &o ÆµŒ o •šŒ concrete beams using prestressed, near-surface mounted CFRP bars. PCI J 56: 134-151.

10 oŒ Zu v U Z]Ìl oo ^, ~íõõó• ^ ŒÀ] beams prestressed by carbon-fiber-reinforced-plastic bars. ACI ^šŒµ š : õðW ðX

11 ZÇvP] Œ <U • v}Á] Ì > ~îìíñ• WŒ r•šŒ ••]vP CFRP composite tendons. Eng Trans 63: 407-20.

12 v } EU D š•µl Á ,U < Á uµŒ DU &µi]] DU • ÆE‰ Œ]u vš o •šµ] • }v šZ o}vPrš Œu š š v }v•X WŒ}]vP• &Z D K^rïU ' Œu vÇX

13 D Z] U h}u}š} d ~íõõó• Z }uu v Ÿ}v (}v•šŒµ Ÿ}v }(}v Œ š •šŒµ šµŒ • µ•]vP }vŸvµ}µ• materials. Japan Society of Civil Engineers, Japan.

14 dP šÇ} Z]v‰ }(šŒ~íõ()Œ d Zv] o š }v & U

15 E^z^ ~îìíñ• o u vš u vµ oU ^Á v•}v Canonsburg, Pennsylvania, USA.

16 Ali MSM, Oehlers DJ, Callary D, Knight D (2010) Pre-stressed . Œ Œ]v(}Œ ‰}oÇu Œ ~&ZW• o u]v š • }(Œ]v(}Œ }v Œ š •šŒµ šµŒ •X /vš Œ Sustainable Built Environment (ICSBE 2010).

17 Z v ^U 'µ W ~îìììñ• >} ŒŒÇ]vP ‰]šÇ • DŒÇ•P ÁÁ]šZ~íõõó• Œv o š v }v• µv Œ ‰}•] Steel Res 61: 515-530.

18 ^ r^ôìò ~îìììî• •]Pv v }v•šŒµ Ÿ}v }(µ] ÁŒšZ •.]PŒ Œ]v(}Œ ‰}oÇu Œ•X Kvš Œ] •Ÿµ]}vU Œ Œ]v(}Œ]vP

íõ v /^/^ ~îììó• WŒ r•šŒ ••]vP }v Œ š Œ]v(}Œ ‰}oÇu Œ•X /^/^ v µ Ÿ}v o