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Research Article

THE INFLUENCE OF FRP REINFORCEMENT ON ULTRASONIC PULSE VELOCITY TESTING

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ABSTRACT

The researches have shown that embedded reinforcements have effects on ultrasonic pulse velocity measurements taken through structural concrete members, so reliable corrections are essential to give an estimate of ultrasonic pulse velocity in plain concrete (Tarun *et al.*, 2004). In this paper, effects of both steel and FRP reinforcements on ultrasonic pulse velocity in longitudinal and transverse positions are studied. Moreover, the influences of reinforcements on moist cured concrete with air dried concrete are compared. The results show that: effects of both FRP and steel reinforcement in longitudinal position are more than transverse position. For each size, effects of FRP bars are more than steel bars, longitudinally and transversely. Effects of both FRP and steel bars on air dried concrete are more than moist cured concrete. At last, the correction factors are proposed for combinations of bar size and orientation for both steel and FRP bars.

Keywords: *Ultrasonic Pulse Velocity, FRP Bars, Correction, Longitudinal Position*

INTRODUCTION

In the ultrasonic pulse velocity method, one of the factors that influences the pulse velocity passed through the structural concrete members, is the vicinity of reinforcing bars. The pulse velocity measured in reinforced concrete is higher than plain concrete of the same composition, because the pulse velocity in steel is higher than concrete (Tarun *et al.*, 2004). The apparent increase in pulse velocity depends on the proximity of the measurements to the reinforcing bar, the dimension and number of the reinforcing bars, their orientation with respect to the propagation path and the pulse velocity in the surrounding concrete. If test locations cannot avoid the influence of the steel bar, it is necessary to make a correction to the measured value to give an estimate of the velocity of pulses in plain concrete. The correction factor, K, shows the measure of reinforcing effect on pulse velocity (below formula) (Tarun *et al.*, 2004).

$$K=\frac{V_C}{V_m}$$

V_C : pulse velocity in plain concrete

V_m : apparent pulse velocity in concrete where steel bar is present

The correction factors are presented in Europe standard (Tarun, 1979). British Standard (1974) and RILEM (1972). Chung (1978), (Chung and Law, 1983) demonstrated the importance of bar diameter and proposed the correction procedure for bars running in the same direction as the pulse. Bungey (Bungey, 1983) proposed correction procedure for bar diameter ranging between 6mm and 50mm combined with a variety of concrete mixes and moisture conditions for longitudinal and transverse bars. In longitudinal bars, the axis of reinforcing bar is parallel to direction of propagation and in transverse bars is perpendicular. Bungey demonstrated that:

-The influence of longitudinal bars is more than the transverse bars
-In both longitudinal and transverse bars, the correction factor reduced with increasing of bar diameter.
-The transverse bars with diameter below 20mm have a small effect.
-There are no major difference between round and square bars effect, transversely and longitudinally.
-End cover thickness has no significant effect on correction factors.
-Longitudinal steel bars influence the results when the ratio $\frac{a}{c}$ lies between 0 and 2. *a*, is perpendicular distance from edge of bar to nearest edge of transducer and *c* , is the cover thickness.

In this paper, the influences of both steel and FRP transverse and longitudinal bars with diameters of 12, 16 and 25 mm, have been determined in normal weight concrete. In this study, a comparison has been made for steel and FRP bars with diameter of 25 mm effects between wet and air dried concrete. At last, the correction factors are proposed for combinations of bar type, size and orientation for both steel and FRP bars.

MATERIALS AND METHODS

Experimental Program

Materials

Cement

Type II Portland cement produced at KHAZAR factory, with specific gravity of 3.15 $\frac{gr}{cm^3}$and blaine fineness of 2900 $\frac{gr}{cm^3}$. The used cement confirms the requirements of ASTM.

Aggregates

In this study, crushed coarse and fine aggregates were used. Nominal maximum size of coarse aggregate was 12 mm. Specific gravity and water absorption of aggregates are given in table 1.

Table 1: Properties of aggregates

	Coarse aggregate	Fine aggregate
Specific gravity $\frac{kg}{m^3}$	2.63	2.76
Water absorption	0.82	1.8

Water

The used water was from Rasht city water distribution system.

Reinforcing Bars

In this study, steel and FRP bars with diameters of 12, 16 and 25 mm were used. Steel and FRP bars were produced at Amirkabir and Firep factories.

Concrete Mix Design

A predetermined compressive strength of 300 $\frac{kg}{cm^2}$ was decided for the resulting concrete at the age of 28days. The mix proportion obtained through ACI mix design method. The mix proportion is as given in table 2.

Table 2: Quantities of materials required per 1 cum of ordinary concrete

Cement (kg)	Water (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	w/c ratio
367	189	811.11	922.22	0.515

Test Specimens

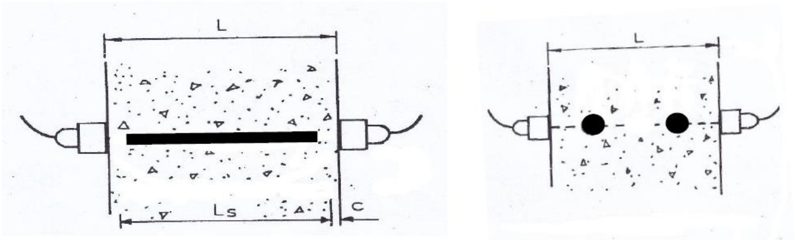
The used specimens were 500*250*250 mm reinforced beams and 150 mm plain concrete cubes. The end cover thickness in beam specimens was 35 mm. The properties of specimens are given in table 3.

Test Methods

Compressive strength was studied on three 150 mm cubes at curing ages of 3, 5,7,28 and 90 days in accordance with ASTM C39 at the rate of loading was 0.25 $\frac{MPa}{s}$. The Ultrasonic pulse velocity test was conducted according to ASTM C597 on cube and beam specimens at the mentioned ages. On beam specimens, the ultrasonic pulse velocity test was conducted in longitudinal and transverse positions as shown in figure 1.

Table 3: Properties of specimens

Series	Specimen dimension (mm)	Bar diameter/type	Curing condition
A	500*250*250	12 – steel	Air dried
B	500*250*250	16 – steel	Air dried
C	500*250*250	25 – steel	Air dried
D	500*250*250	25 – steel	wet
E	500*250*250	12 – FRP	Air dried
F	500*250*250	16 – FRP	Air dried
G	500*250*250	25 – FRP	Air dried
H	500*250*250	25 – FRP	wet
I	150*150*150	Plain concrete	Air dried
J	150*150*150	Plain concrete	wet



(a) (b)

Figure 1: (a) transverse and (b) longitudinal positions

RESULTS AND DISCUSSION

The results of compressive strength test are shown in figure 2. It can be observed that the compressive strength of both air dried and moist cured concretes increased by the age of concrete. Moreover, curing the concrete in wet condition enhanced the compressive strength.

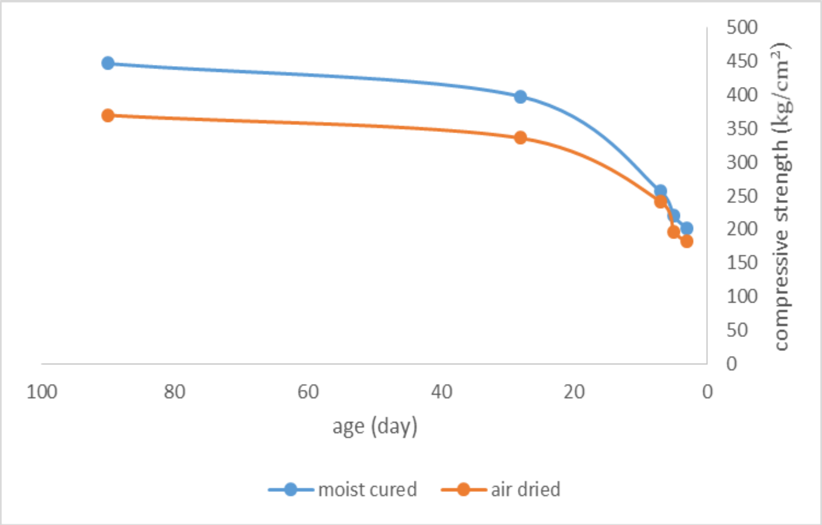


Figure 2: Compressive strength of concrete

Values of pulse velocity in concrete are shown in figure 3. The obtained results show that the pulse velocity in moist cured concrete is higher than air dried concrete and the velocities increased by the age of concrete.

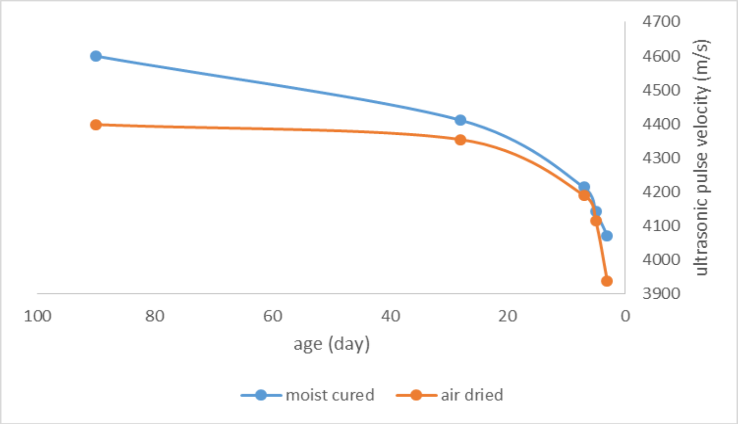


Figure 3: UPV test results

The relationship between compressive strength and ultrasonic pulse velocity of moist cured and air dried concrete are shown in figure 4 and figure 5.

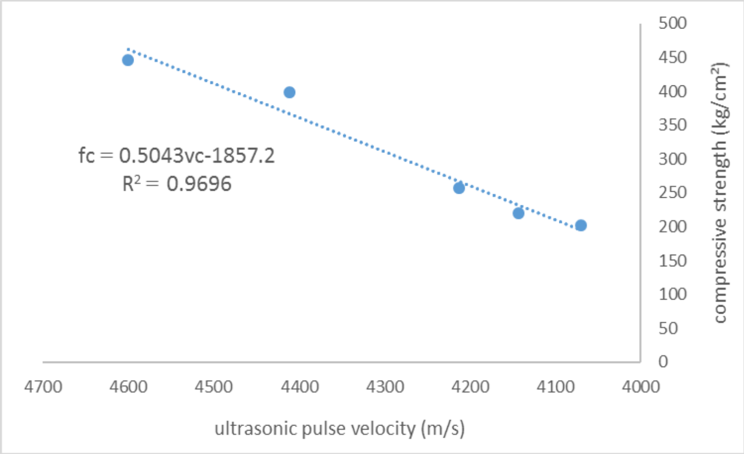


Figure 4: Relationship between compressive strength and pulse velocity of moist cured concrete

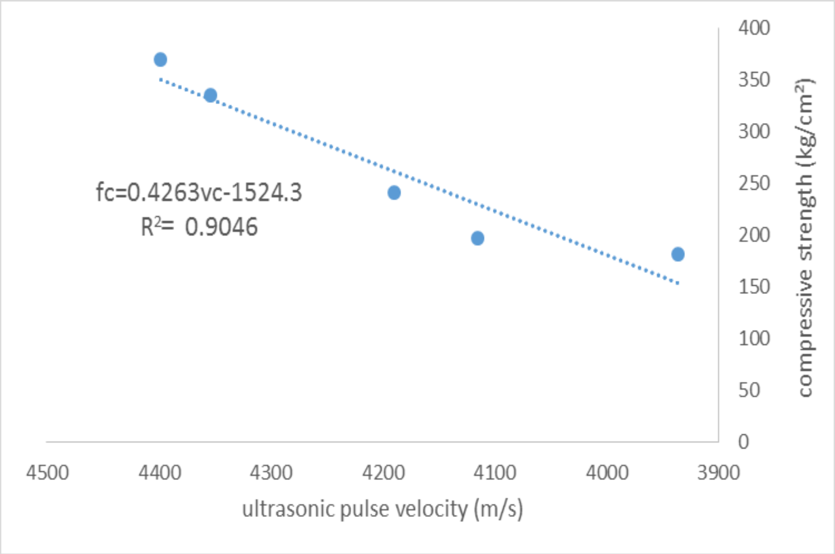
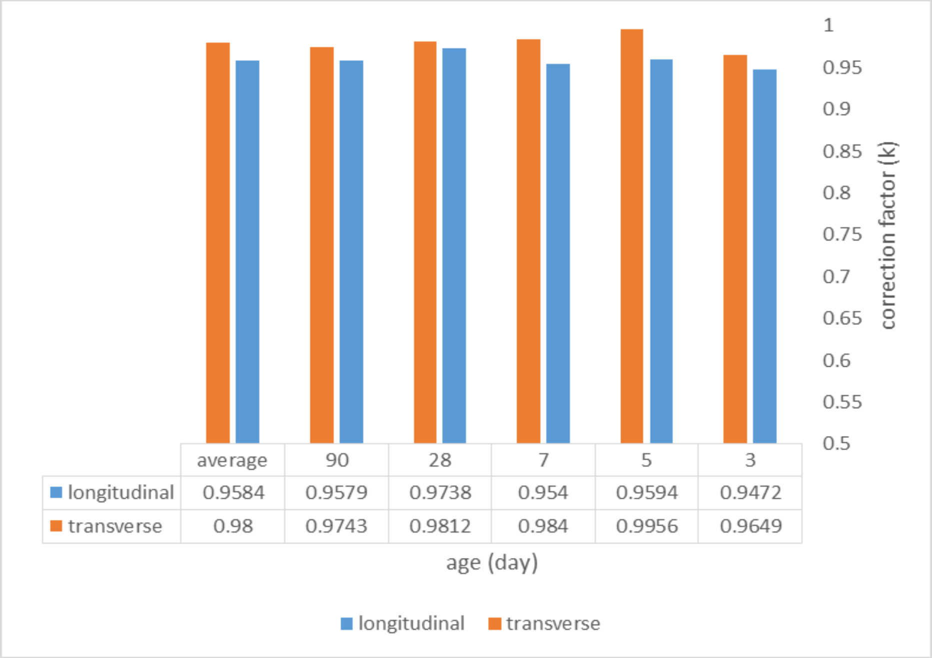
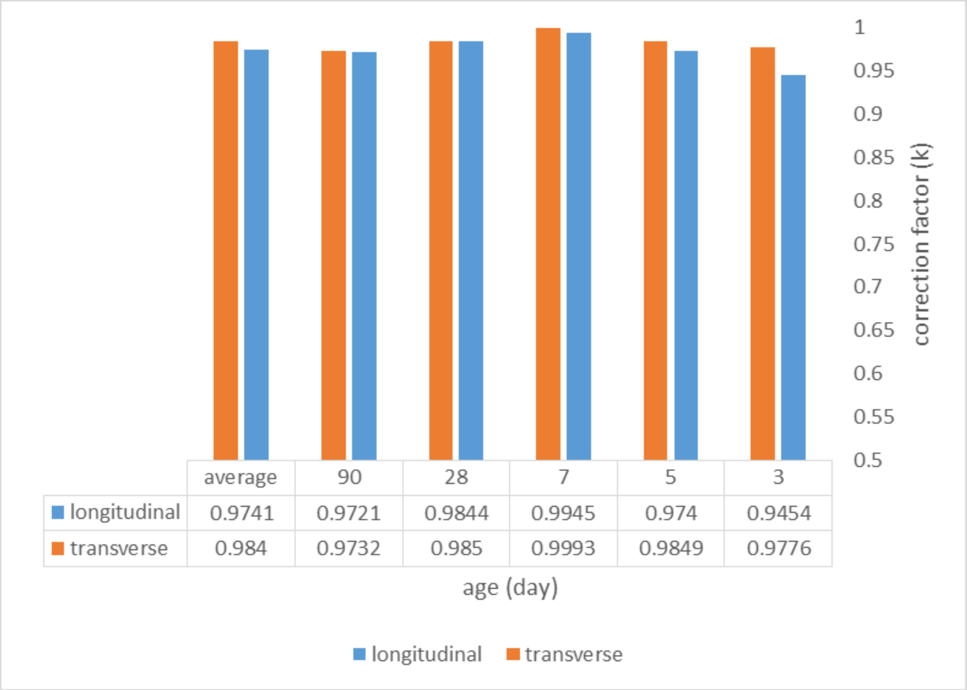


Figure 5: Relationship between compressive strength and pulse velocity of air dried concrete

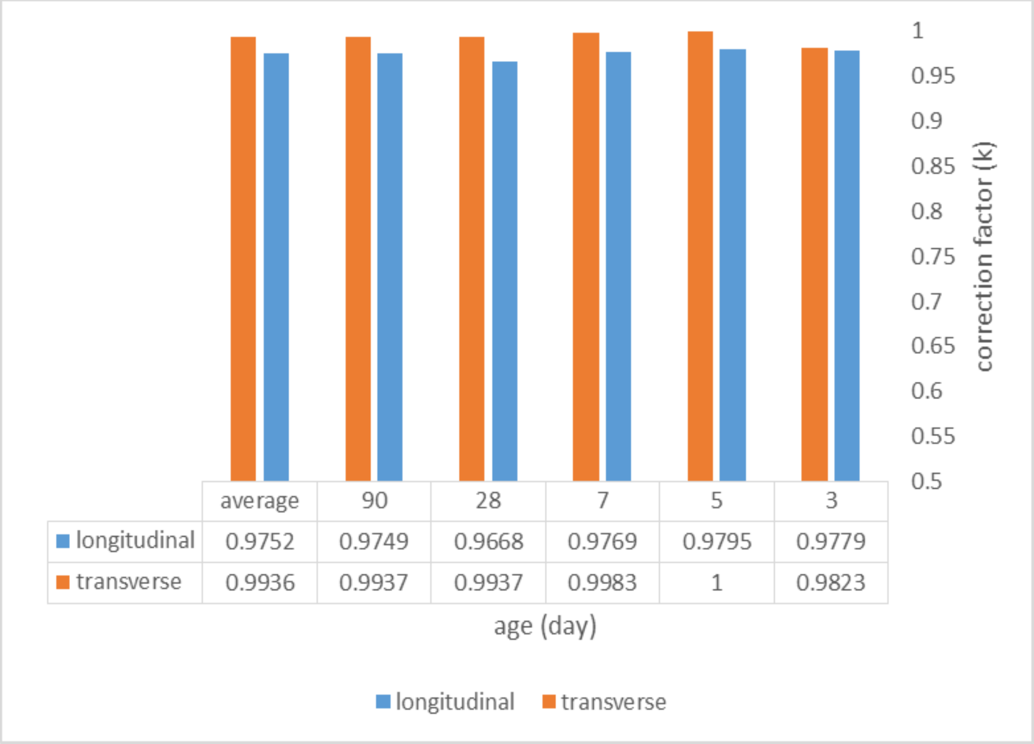
Values of pulse velocity in the plain concrete (V_c) and reinforced concrete (V_m) were obtained from measurements upon cubic and beam specimens. The correction factors were evaluated from equation 1. The correction factors of steel and FRP bars in longitudinal and transverse positions at each age are shown in figure 6 and 7. Moreover, the average of correction factors is presented. The results show that the correction factors in transverse position are greater than longitudinal position. It means that influences of transverse bars are lower than longitudinal bars on UPV test results.



(a)

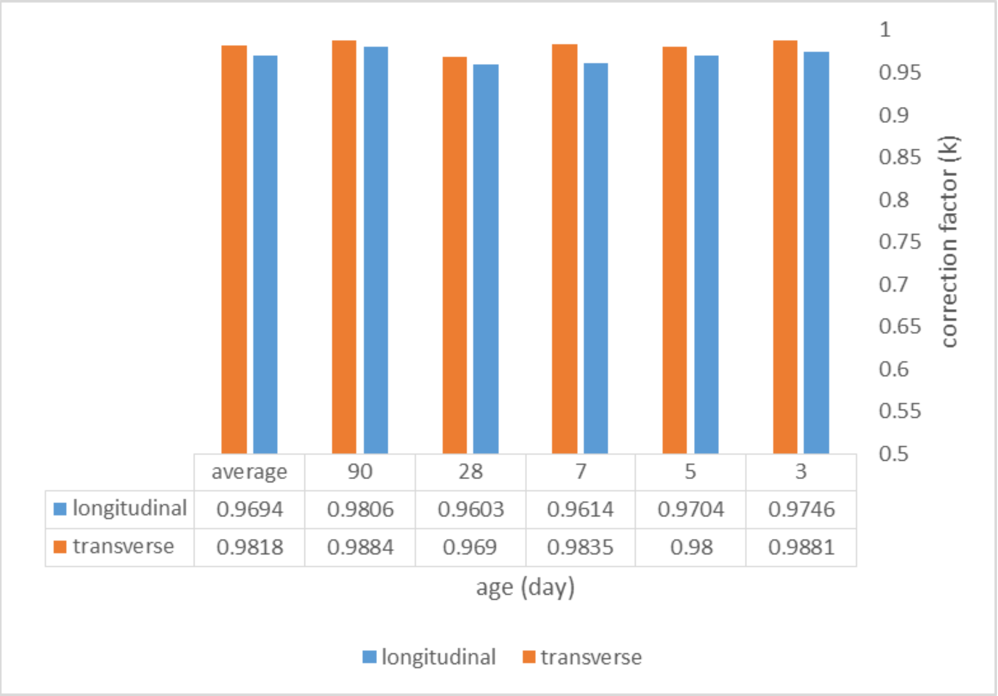


(b)



	average	90	28	7	5	3
■ longitudinal	0.9752	0.9749	0.9668	0.9769	0.9795	0.9779
■ transverse	0.9936	0.9937	0.9937	0.9983	1	0.9823

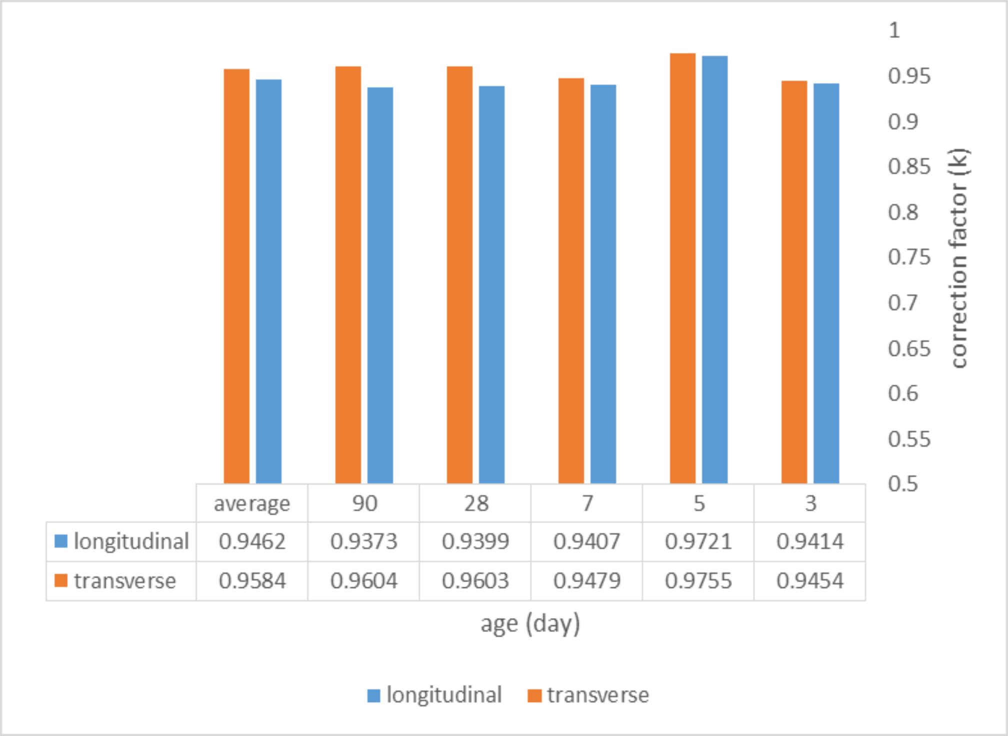
(c)



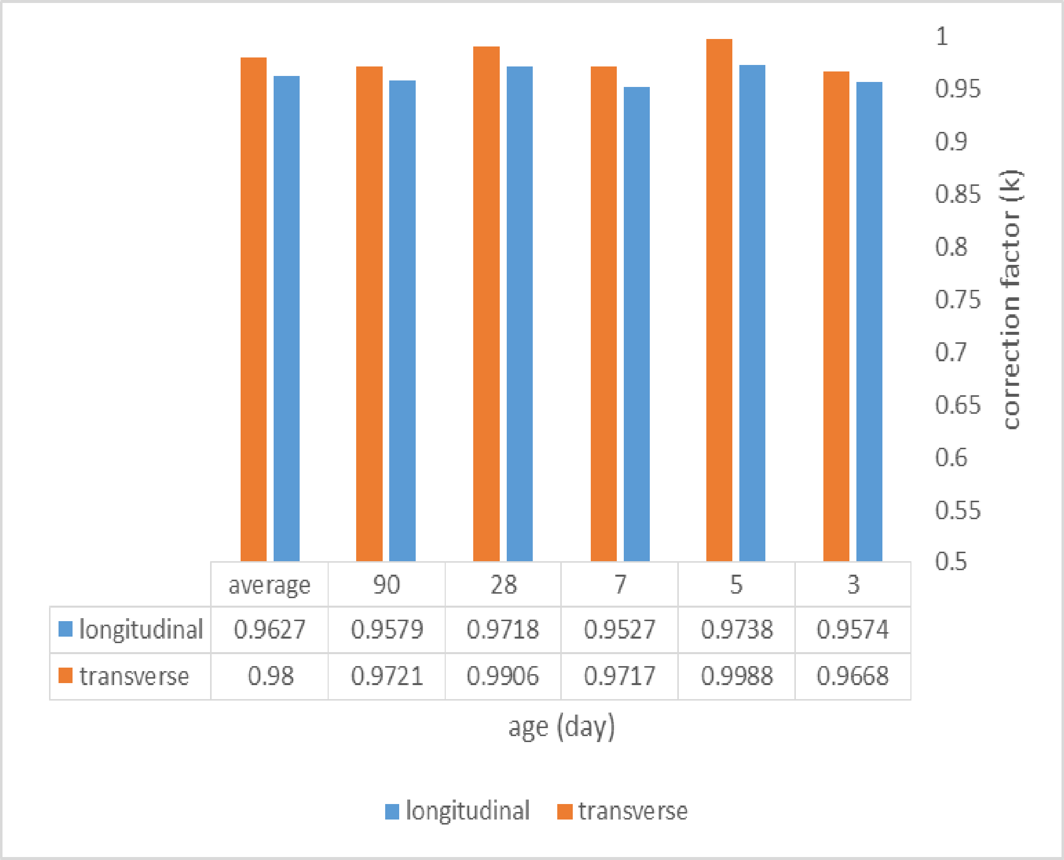
	average	90	28	7	5	3
■ longitudinal	0.9694	0.9806	0.9603	0.9614	0.9704	0.9746
■ transverse	0.9818	0.9884	0.969	0.9835	0.98	0.9881

(d)

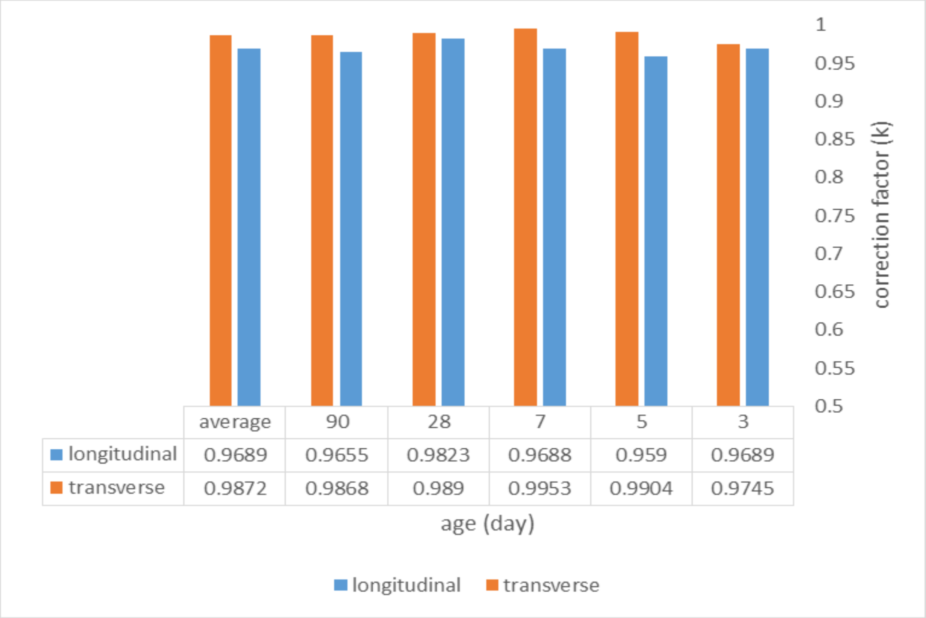
Figure 6: Correction factors of steel bars
(a) 25 mm diameter – air dried concrete
(b) 16 mm diameter – air dried concrete
(c) 12 mm diameter – air dried concrete
(d) 25 mm diameter – moist cured concrete


1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
correction factor (k)
average
90
28
7
5
3
longitudinal 0.9462 0.9373 0.9399 0.9407 0.9721 0.9414
transverse 0.9584 0.9604 0.9603 0.9479 0.9755 0.9454
age (day)
longitudinal
transverse

(a)

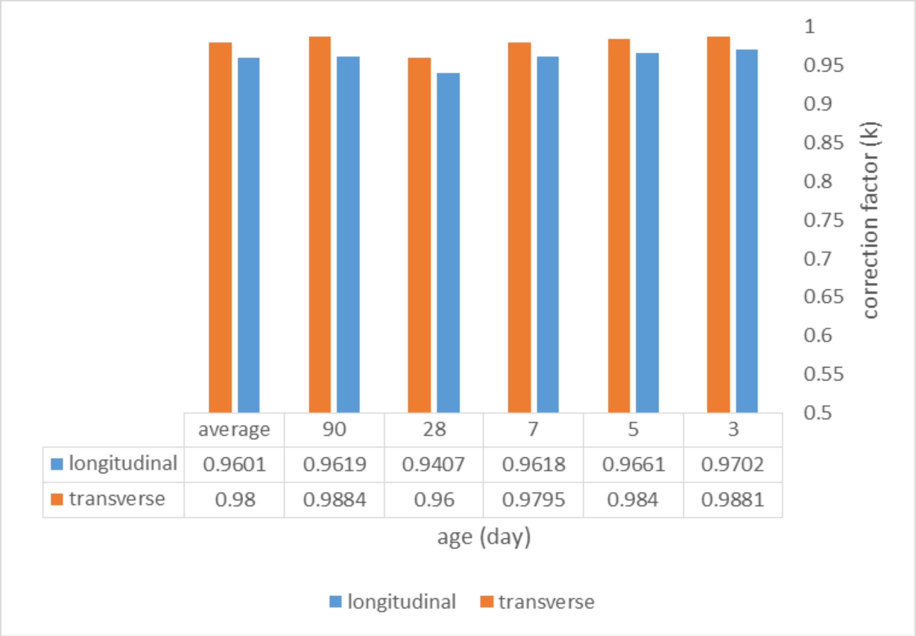

1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
correction factor (k)
average
90
28
7
5
3
longitudinal 0.9627 0.9579 0.9718 0.9527 0.9738 0.9574
transverse 0.98 0.9721 0.9906 0.9717 0.9988 0.9668
age (day)
longitudinal
transverse

(b)



	average	90	28	7	5	3
■ longitudinal	0.9689	0.9655	0.9823	0.9688	0.959	0.9689
■ transverse	0.9872	0.9868	0.989	0.9953	0.9904	0.9745

(c)

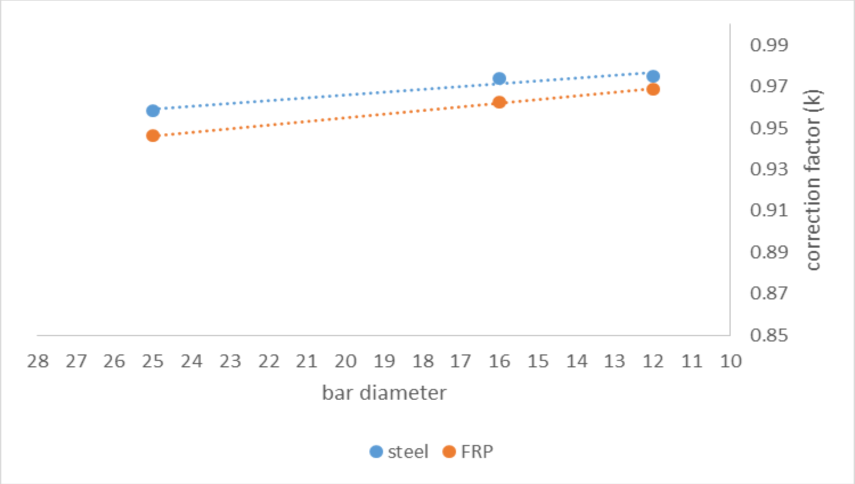


	average	90	28	7	5	3
■ longitudinal	0.9601	0.9619	0.9407	0.9618	0.9661	0.9702
■ transverse	0.98	0.9884	0.96	0.9795	0.984	0.9881

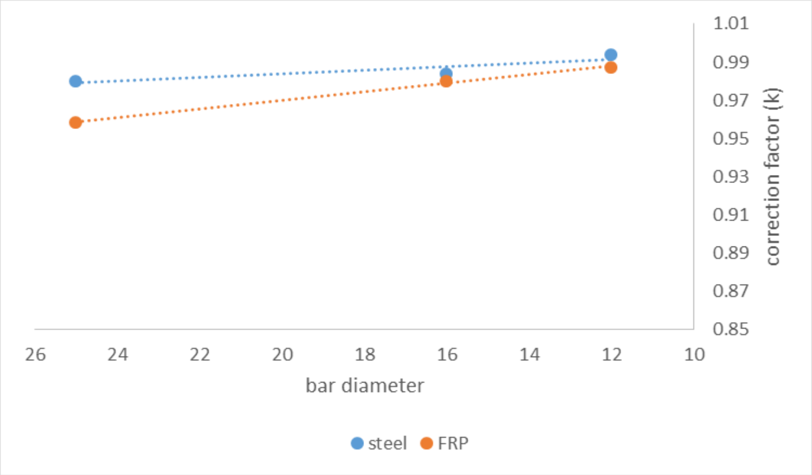
(d)

Figure 7: Correction factors of FRP bars
(a) 25 mm diameter – air dried concrete
(b) 16 mm diameter – air dried concrete
(c) 12 mm diameter – air dried concrete
(d)25 mm diameter – moist cured concrete

The correction factors of steel and FRP bars in longitudinal and transverse positions, for each bar size, are shown in figure 8. It can be seen that for a particular size, correction factor of steel bar is more than FRP bar, means effect of FRP bar is more than steel bar. It can be observed that there is a linear variation of correction factors with bar diameters for both steel and FRP longitudinally and transversely bars.



(a)



(b)

Figure 8: Correction factor-bar diameter diagram for (a) longitudinal and (b) transverse position

The results of UPV tests on moist cured and air dried concrete specimens are shown in figure 9. The specimens were reinforced by 25 mm diameter steel and FRP bars. The figure shows that the correction factors of steel bar are more than FRP bar in longitudinal and transverse positions.

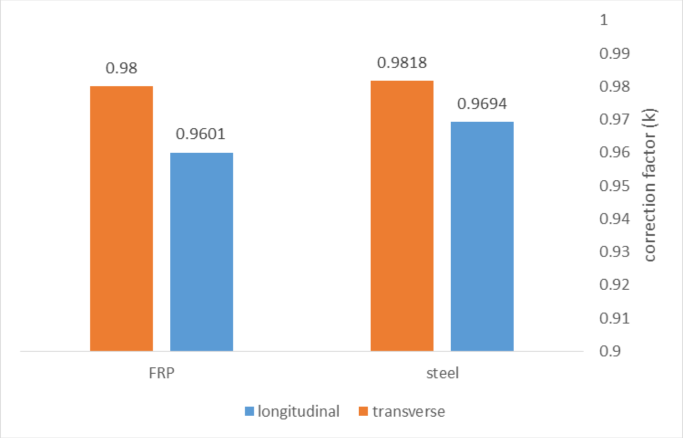
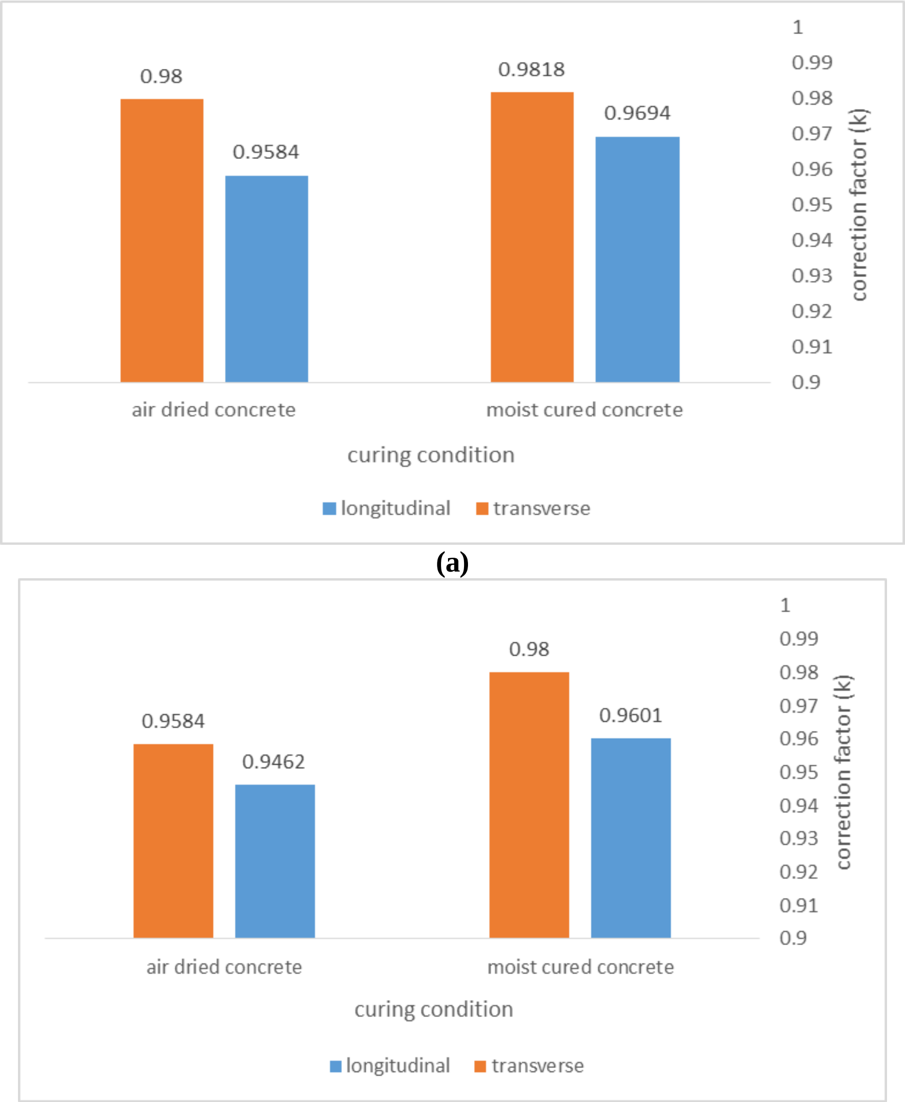


Figure 9: Correction factors of steel and FRP bars in longitudinal and transverse position – moist cured concrete

In figure 10 the correction factors of longitudinal and transverse FRP and steel bars in moist cured concrete with air dried concrete specimens are compared. It is observed that effects of both FRP and steel bars on air dried concrete are more than moist cured concrete.



(a)

(b)

Figure 10: Comparison of 25 mm diameter (a) steel and (b) FRP bars effects on air dried concrete with moist cured concretes

Conclusion

-Compressive strength of both air dried and moist cured concretes increased by the age of concretes.
-Curing concrete in wet condition enhanced the compressive strength.
-Values of ultrasonic pulse velocity in moist cured concrete are greater than air dried concrete.
-Effects of both FRP and steel bars in longitudinal position are more than transverse position.
-For each bar size, effect of FRP bar is more than steel bar, longitudinally and transversely.
-Variation of correction factors with bar diameters for both steel and FRP bars is linear in longitudinal and transverse positions.
-Effects of both FRP and steel longitudinal and transverse bars on air dried concrete are more than moist cured concrete.

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