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STUDY OF DISTANCE AND NUMBER OF REBARS ON VELOCITY MEASUREMENT USING NON-DESTRUCTIVE TEST

*Christin Remayanti Nainggolan[1], Indradi Wijatmiko[2], Hendro Suseno[3], Ananda Insan Firdausy[4]

[1,2,3,4]Department of Civil Engineering, Brawijaya University, Indonesia

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ABSTRACT: The quality of constructions can be evaluated by using the non-destructive test (NDT) method, one of them is an ultrasonic pulse velocity (UPV) test. Velocity is one of the parameters that can indicate the density of the material that will affect the strength of the material. The difference in density of concrete and rebars could affect the velocity measurement of reinforced concrete. It is common knowledge as there are factors that affect the velocity measurement and some of them are the position of transducers and the number of rebars. An experiment was conducted to get a better understanding of the velocity measurement of reinforced concrete determined by the position of the transducers, the several rebars, and the distance between rebars and transducers using the UPV test. The specimens were reinforced concrete beams with different numbers of rebars, however, had the same tensile strength and diameter. The number of rebars used for specimens is 4; 8 and 12 rebars with the varied position of transducers. It can be concluded that the pulse velocity of reinforced concrete, when measured with a perpendicular position was ower than in the parallel position, and also the average transmission time in the parallel position, was 52% faster than the perpendicular. In the case of rebar parallel to pulse path, the velocity of reinforced concrete decreased as the distance between rebar and transducers increased, however, the number of rebars did not affect the velocity. On the other hand, in the case of rebar perpendicular to the pulse path, the number of rebars resulted in an insignificant effect on the velocity measurement (less than 1%).

Keywords: Velocity, Rebar, Ultrasonic pulse velocity, Non-destructive test

1. INTRODUCTION

Every structure must be in good condition and meet the safety standard therefore it can perform good serviceability. Evaluate the condition of the existing structure then it is needed reliable inspection techniques. Recently, non-destructive test (NDT) methods are an assessment technique that getting popular among engineers and are often used to evaluate buildings. NDT methods represent the approach to the quality and condition of materials in the structure, furthermore, they are used to diagnose and predict the structure condition. In addition, NDT methods have a major advantage in their capability to evaluate an existing building [1] and become promising techniques for in-situ examination [2]. Even now, these methods are still being developed to meet the expectation of the user.

Ultrasonic Pulse Velocity (UPV) is one of the NDT methods that is frequently used to evaluate the quality of materials, especially concrete. Many researchers propose the relationship between UPV measurement and compressive strength to estimate the strength of concrete [3]-[6]. Therefore, it is important to know the validity of the UPV results by studying and evaluating many kinds of UPV measurements.

The basic idea of UPV methods is using pulse wave propagation which has a velocity that depends on elastic properties and density of the materials. Therefore, it is a challenge to evaluate an existing structure especially reinforced concrete structure using UPV because even though this technique is easy to conduct however it is affected by various factors. These factors can be divided into two categories: (1) factors from concrete properties such as type and amount of aggregate, cement type, water-cement ratio, admixture and age of concrete, curing condition [7,8]; and (2) other factors such as transducers contact, size of the specimen and presence of steel reinforcement. From several factors that have already been mentioned, this study discusses further specifically the presence of steel reinforcement.

According to some research, elasticity properties and density of rebar are higher than in concrete, therefore the pulse velocity in rebar is 1.4 to 1.7 times that of concrete [9]. The pulse velocity of steel medium is generally up to 5.90 km/s, however, the value decreases as well as the diameter [10]. The pulse velocity of the rebar in reinforced concrete is lower than the rebar in the air because it is affected by the velocity of concrete and the bond condition between rebar and concrete.

Several research on UPV measurements have been carried out on reinforced concrete and the presence of rebar commonly affected the pulse velocity of reinforced concrete. The effect can be an increase or decrease [11] in the measurement of pulse velocity where this value is also influenced by the condition of the concrete [12], the quality of the concrete, and the rebar [13]. In addition, the position between the rebar and the transducers will also affect the pulse velocity value and the transmission time because, at a certain position, the first pulse wave received by the receiving transducers is partly passed through the concrete and partly pass through the rebar.

Many things affect the measurement of the pulse velocity of reinforced concrete therefore it still needs to be studied further. This present experiment focuses on the effect of rebar on the pulse velocity and the transmission time of the pulse wave of reinforced concrete based on the proximity of the measurements to the rebars, the number of rebars, and the position of the transducers (parallel and perpendicular to rebars).

2. STUDY LITERATURE

UPV measurement on reinforced concrete should not be at the point where the rebar is located to prevent the pulse wave path pass through the rebar. However, if this is unavoidable, then it is needed correction due to the influence of rebar. BS 1881-203:1986 [14] provides a formula of the correction factor for the pulse velocity of reinforced concrete where the approximate pulse velocity of concrete will be reduced due to the influence of rebar.

$$V_c = kV_m \quad (1)$$

Where V_c is the pkm/s) , k is the correction factor and V_m is the measured apparent pulse velocity (km/s)

The correction factor will be affected by the distance between the transducers and the nearest rebar, the diameter of the rebar, and the pulse velocity surrounding the concrete. When the pulse path is parallel to the rebar then the correction factor can be obtained by the following formula:

$$k = \gamma + 2\left(\frac{a}{L}\right)\sqrt{1-\gamma^2} \quad (2)$$

in which

$$\gamma = \frac{V_c}{V_s} \quad (3)$$

Where γ is velocity ratio, V_s is pulse erebarin thea r (kthe the a is distance from the surface of the rebar to the nearest point of both transducers, L is the direct path length between transducers (mm).

If the value of a is greater than two times the distance from the end of the concrete to the end of the rebar (b) then Eq. 2 can apply, otherwise using Eq.4.

$$k = \gamma + 2\left(\frac{\sqrt{a^2+b^2}-\gamma b}{L}\right) \quad (4)$$

If the rebar is in line with the transducers (a = 0) then

$$k = 1 - \frac{L_s}{L}(1-\gamma) \quad (5)$$

Where L_s is the length of the bar (mm).

When the position of the rebar is parallel to the transducers then the velocity ratio can be obtained according to Fig.1, while Fig. 2 can be used for the case when the rebar is perpendicular to the transducers.

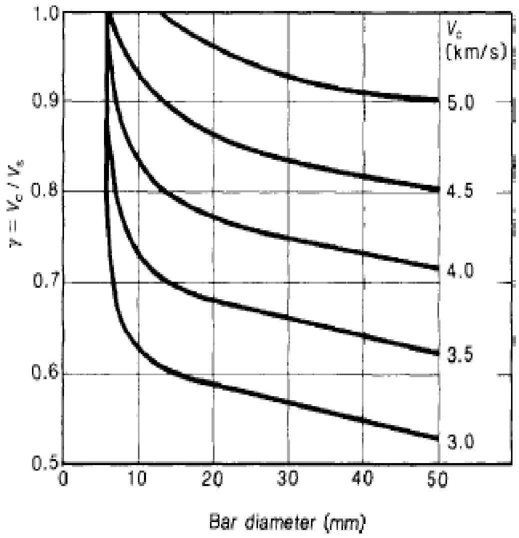

Fig. 1 Relationship between velocity ratio and bar diameter for bar parallel to pulse path [10,14]

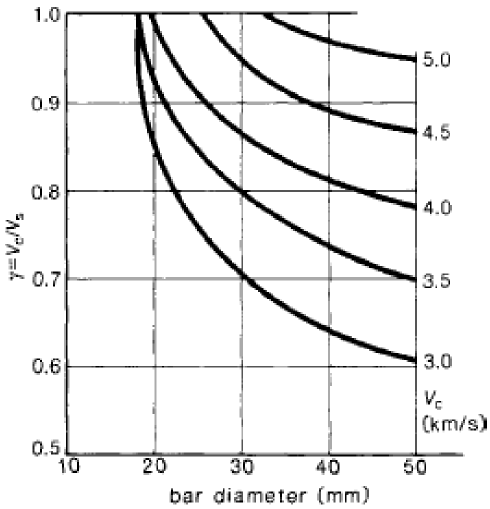

Fig. 2 Relationship between velocity ratio and bar diameter for bar perpendicular to pulse path

[10,14]

Furthermore, the influence of rebar on reinforced concrete is considered non-existent if:

$$\frac{a}{L} > \frac{1}{2}\sqrt{\frac{V_s - V_c}{V_s + V_c}} \qquad (6)$$

The effect of rebar is considered to exist when $a/_L$ < 0.5 in high strength concrete or $a/_L$ < 0.25 in low strength concrete.

3. EXPERIMENTAL METHOD

UPV test was conducted on the reinforced concrete and unreinforced concrete with dimensions of specimens as follows: length, 60 cm; width, 30 cm, and height, 40 cm. The rebars were deformed bars of the same diameter (22 mm) and plain bars (diameter 8 mm) as the stirrup. The rebars had the same tensile strength and the concrete had the same mixture.

The specimens differ from each other depending on the number of bars and the arrangement of the position of the transducer as follows:

- ✓ BC1, unreinforced concrete beam (Fig. 3 (g)-(h))
- ✓ BC2, 4 deformed bar - Ø 22 mm as the rebar (Fig. 3 (a)-(b))
- ✓ BC3, 8 deformed bar - Ø 22 mm as the rebar (Fig. 3 (c)-(d))
- ✓ BC4, 12 deformed bar - Ø 22 mm as the rebar (Fig. 3 (e)-(f))

Figure 3 (a)-(f) show the arrangement of rebars: Fig. 3 (a), Fig. 3 (c) and Fig. (e) are the long section of the specimens, and Fig. 3 (b), Fig. 3 (d) and Fig. (f) are the cross-sections of the specimIns.

At the beginning, performed a bar scanner on the specimenfindfound the elocationiothe the n of rebars. Afterwdetermineminedlocationiothe placement of the transducerement. The specimens were tested with 2 transducers positions: (1) parallel to the rebar wivarvarof iety distance (***a***); (2) perpendicular to the rebar.

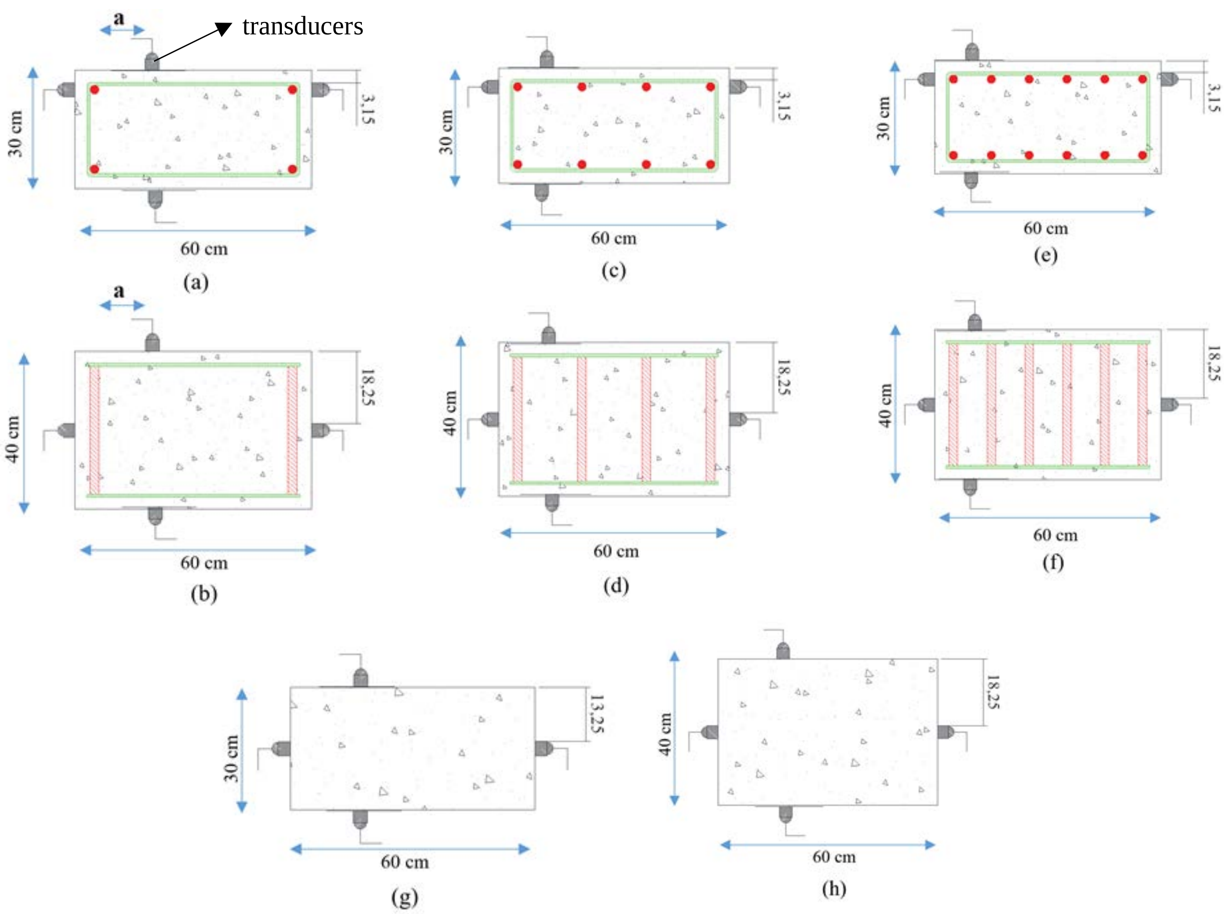

Fig. 3 (a)-(f) Reinforced concrete; (g)-(h) unreinforced concrete

4. RESULTS AND DISCUSSION

Ts , when measurwiththe th position the rebar r ar,bis parallel transduceduandand rs can be seen in Table 1 – 3. Moreover, it can also be seen in the results of the calculation of Evaluabcluelesslue helhe tof correction factor. The diameter of the rebar and the pulvelocityiconcreere we insertintotin at Fig.1 to estimate the velocity ratio and afterward, used to calculate the pulse velocity thee of rebar. Table 1 shows that rebGAAgaa ve higheffusioneon to the pulse velocity of reinforced concrete when the transducewerewas at the center of rebar (a = 0) than the other value of a. At that point (a = 0), the pulse wave fully passes through the rebar as shown in Fig.4.

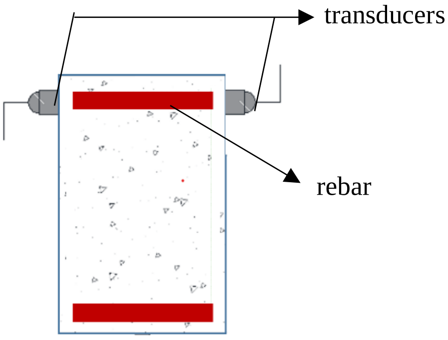

Fig. 4 Cross-section of reinforcement concrete with rebar parallel to transducers

When it is compared to the pulse velocity of unreinforced concrete, which is 4.31 km/s, there was an increasetee ofyof 13% due to the presence of rebarMoreovernththesee pulseevelocy oftheityhrebarr was 5 kmwhrichhwassmaller thee rebar in the air because of the influence of the bond betweenrebranddconcreteethatcould nott beedefinee. At the measurement point where a = 12 mm, the pulse velocity of reinforced concrete decreased by 9.8% compared to when a = 0, and when compared to the pulse velocity of unreinforced concrete, there was an increase by 2%. At this point, the pulse wave only passed through the concrete, however, the influence of rebar was still extant and made the pulse velocity of reinforced concrete incre although not significant.

Table 2 gives information about the results of specimen BC3 when measured witconditionon of rebar parallel to transducers. In this specimen, the pulse velocity of reinforced concrete measured at a = 50 mm was nearly the same as wh tionn it was measured at a = 70 mm. As for the specimen BC4, the result can be seen in Table 3. In specimen BC4, the value of distance was 20 mm and 40 mm. This value was smaller than the specimen BC3 because of the limited space between the rebar on BC4. Same as the specimen BC3, the pulse velocity of reinforced concrete slightly decreased as the distance a increased.

Table 1 Measurement condition: rebar parallel to transducers on specimen BC2

a (mm)	V (km/s)	k	V_c (km/s)	V_s (km/s)	$^a/_L$
0	4.89	0.84	4.1	5	0
12	4.41	0.85	3.73	4.54	0.03
32	4.41	0.89	3.9	4.75	0.08
52	4.36	0.94	4.1	4.99	0.13
72	4.31	0.96	4.13	5.03	0.18
92	4.31	1	4.29	5.23	0.23

Table 2 Measurement condition: rebar parallel to transducers on specimen BC3

a (mm)	V (km/s)	k	V_c (km/s)	V_s (km/s)	$^a/_L$
50	4.31	0.93	4.03	4.90	0.13
70	4.26	0.95	4.07	4.95	0.18

Table 3 Measured condition: parallel to transducers on specimen BC4

a (mm)	V (km/s)	k	V_c (km/s)	V_s (km/s)	$^a/_L$
20	4.6	0.87	4	4.81	0.05
40	4.45	0.91	4.08	4.9	0.10

Figure 5 illustrates the relationship between pulse velocity (reitheeconcretee ncrconcreteoncrethe te) and ratio of distance and path length. When the distance between the transducers and rebar increaddecreasefolladdecrecreased in the pulse velocity of reinforced concrete ($\boldsymbol{V}$). This happened because the position of the rebar was far from the whichtcausingcers that causing the pulse wave only passed through concrete material. On the other hand, the farther the distance between rebar and transducers, the higher the pulse velocity of concrete (, although the value was still smaller than the pulse velocity of reinforced concrete.

Figure 5 also shows at whthethereintoe the presence of rebar on the reinto to forced concrete was still considered give effect. Based on the regulation BS 1881-203:1986 (Eq. 6), there is a condition on the distance of rebar that can affect the pulse velocity of reinforced concvaluethis study, the length of the svaluen had a constant valufromromhivalues, while the distance fm the revalueso the transducers had a various value. From Eq. 6 was obtained the requirement value of $\boldsymbol{a}/\boldsymbol{L}$ = 0.16 (green line at Fig.5), therefore the UPV measurements at the value of $\boldsymbol{a}$ = 70 mm, 72 mm and 92 mm were considered not affected by the presence of rebar.

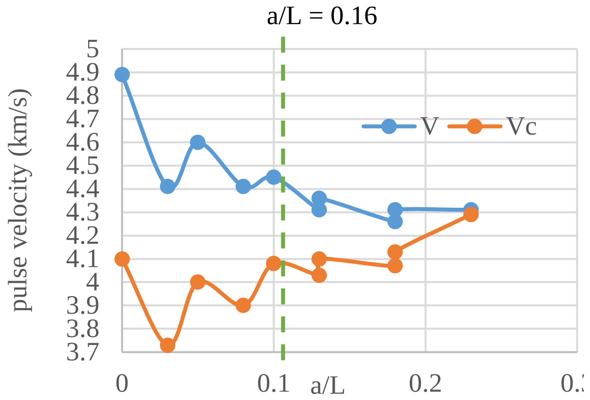

Fig.5 Relationship of pulse velocity and a/L for test condition: rebar parallel to transducers

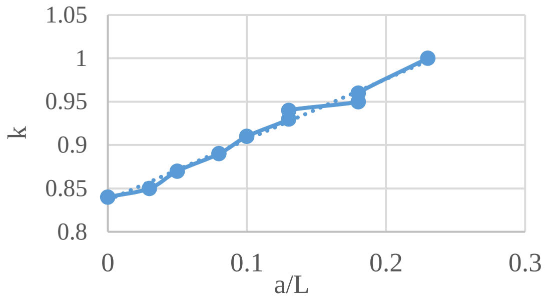

Fig. 6 Relationship of correction factor k and a/L for test condition: rebar parallel to transducers

From Fig. it cananbee seennthat'sthee rato offffdistanceandd pathhlengthhincreaseevaluesvaluef I o correction factor increased gradually. This could signify that the effectofrebarr o the UPVmeasurementsbecamesmallertcorrectionn factor can be seen in Fig. 5 where the pulse velocity of concrete increased as the length a increased and the values were nearly the same with the pulse velocity of reinforced concrete at position a = 92 mm which the value of k = 1.

The measurement results with the position of the rebar perpendicular to the transducers can be seen in Table 4. The value of the correction factor was obtained by using Eq. 5 and to obtain the value of the velocity ratio, interpolation was carried out on the graph in Fig. 2.

Table 4 shows that the effect of rebar on the UPV measurements in the perpendicular position was not as significant as in the parallel position because the pulse wave did not completely pass through the rebar as shown in Fig. 7.

Table 4 Measured condition: rebar perpendicular to transducers

Specimen	L_s (mm)	V (km/s)	k	V_c (km/s)	V_s (km/s)
BC2	44	4.23	0.93	3.92	4.41
BC3	88	4.27	0.85	3.64	4.06
BC4	132	4.23	0.78	3.30	3.89

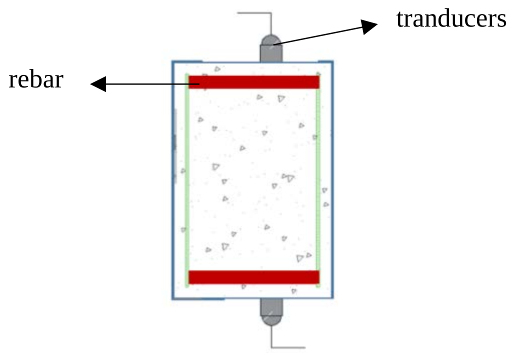

Fig.7 Cross-section of reinforcement concrete with rebar perpendicular with transducers

The pulse velocity of unreinforced concrete (4.32 km/s) was not much different from the pulse velocity of reinforced concrete BC2, BC3, and BC4 with decre of 2%, 1.6%, and 2% respectively. Although the pulse velocity of reinforced concrete did not differ between specimens, however, the addition of more rebars gave a reduced effect on the correction factor by 8,2% - to 8,6%. Increasing the number of rebars caused an increase to tose the length of bars and reduced the correction factor, consequently higher the effect of rebar on the UPV measurement. In this measurement position, the magnitude of rebar influence was still uncertain because there was another factor that affect the reinforced concrete which was the bond between rebar and concrete.

Table 5 Results of transmission time (T0)

Variation	$\boldsymbol{L}$ (mm)	T0 (μs)	Measurement position
BC1	600	140	Rebar perpendicular with transducers
BC2	600	142.2	
BC3	600	144.1	
BC4	600	145.1	

BC1	400	93.7	Rebar parallel to transducers
a = 0 mm	400	86.8	
a = 12 mm	400	92.4	
a = 32 mm	400	97.5	
a = 52 mm	400	96	
a = 72 mm	400	94.8	
a = 92 mm	400	96.3	

The presence of rebar in reinforced concrete also influenced the value of transmission time. Table 5 shows the transmission time when the first pulwasais ve detected (T0) between 2 points (transmitter transducer and receiver transducer) with differelengthsgdependingnin on the measurement position. The smaller the value of transmission time, the faster the pulse was received by the receiver and signified that the density of material was high. The transmission time when measured with the transducers position perpendicular to the axis of rebar was higher than when measured with the transducers position parallel to the axis of rebar. This indicated that the time required to receive pulwavesave a in perpendicular position was longer than a in parallel position. This is caused by the difference in path length L as well as the homogeneity and density of the material where the pulse wave passes through when the transducers were in parallel position and perpendicular position.

The transmission parallel position and the rebarweres in line with the transducers (a = 0) were red the smallest than the other distances because, in this position, the pulse wave passes through the rebar. Rebar density is higher than concrete therefore the time needed to detect pulse waves is faster than concrete. At the distance a = 12 mm, the transmission time increased because the pulse wave path was only on the concrete. At several distances, the transmission time fluctuated due to the level of homogeneity of the concrete material. While on the transducer’s position perpendicular to the rebar, the addition of more rebars caused the transmission time increased slightly.

5. CONCLUSIONS

From the experiment, several conclusions were obtained:

1. When UPV is measured with condition rebar parallel to the transducers:
   a) the farther the transducers from the rebar ($\boldsymbol{a}$), the pulse velocity of reinforced concrdecreeeusedased on and the other hand the value of the correction factor ($\boldsymbol{k}$) increased and followed by the pulse velocity of concrete e.
   b) with the dimension of sp men, the requirement of a/L was 0.16, therefore the effecconsidereddered torexistedisted in the specimen with $\boldsymbol{a}$ = 70 mm, 72 mm and 92 mm.
2. When UPV was measured with the position of the rebar perpendicular to the transducers, it was known that the addition of more rebars gave a slightly increased (less than 1%) pulse velocity of reinforced concrete.
3. The pulse velocity of reicountermeasureemeasure measura ed with perpendicuposiposition osition lower than the parallel position due to the difference in path length ($\boldsymbol{L}$) and the level of homogeneity in the pulse path.
4. The position of the transducers and the number of rebars also affect the transmission time (T0) where the average transmission time in the parallel position was 52% faster than perpendicular due to the difference in the level of homogeneity and density of the material in the pulse wave path.

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