Effect of steel reinforcement distribution on ultrasonic pulse velocity measurements

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Abstract. Non-destructive tests (NDTs) represented one of the solutions that aid the engineers to evaluate the strength of materials. However, the results obtained using such tests still questionable as they may be affected by different factors. One of these factors is the presence of steel reinforcement in concrete. An experimental investigation is presented in the current study to investigate the effect of the distribution of steel reinforcement on the one of the most common NDTs named Ultrasonic Pulse Velocity (UPV). However, two small-scale concrete slabs were tested and the results were successfully obtained. Two different spacing between the longitudinal reinforcement were considered. Also, the effect of measuring the UPV in the top and bottom surface of the RC slab was studied. The effect of direct path length was also investigated. The results showed that the presence of reinforcement considerably affects the UPV values. Besides, no judgement was made to decide the effect of path length as fluctuated results were obtained.

1. Introduction

Non-destructive tests have been mostly used to obtain the mechanical properties of the structural members of reinforced concrete structures especially for members have not achieved the required properties such as compressive strength [1–9]. Moreover, the usage of such tests was expanded to include other purposes such as specifying the location of steel reinforcement embedded in concrete and concrete covers. Both Ultrasonic Pulse Velocity (UPV) and Schmidt Hammer tests can be considered as the most applicable and favourable methods amongst others to predict the performance of concrete material. This may be attributed to their ease and accuracy; however, this accuracy may face some obstacles which may affect the obtained results. Therefore, a considerable amount of studies was carried out to estimate the efficiency of the aforementioned methods to estimate the physical and mechanical properties of concrete. Adnan et al. [9] presented a comparison study between visual rating and strength from Schmidt hammer test in bridge decks. Good correlation between the two methods was obtained and hammer test was found to provide an acceptable result to evaluate bridge conditions. The pulse velocity measured in reinforced concrete members in the vicinity of reinforcing bars is usually higher than that measured in plain concrete [10]. Besides, pulse velocity in steel is around twice that in plain concrete. The actual enhancement in pulse velocity depends on the vicinity of the measurements.
to the diameter and number of bars and their orientation to the wave path [11]. However, the pulse velocity in concrete \( (V_c \text{ km/s}) \) can be expressed using the following equation:

\[
V_c = \frac{2aV_s}{\sqrt{(2a^2 + (T + L))^2}} \quad V_s > V_c
\]  

(1)

Where, \((V_s)\) is the pulse velocity in steel reinforcement, \((a)\) is the distance from the surface of the steel reinforcement to the line linking the adjacent point of both transducers. \((T)\) represents the transient time and \((L)\) is the direct length path between both transducers.

In general, the steel reinforcements existed in the concrete affect the magnitude of velocity obtained by the UPV test [12]. British Standard confirmed that the location and the direction impulse path should be selected properly far away from steel reinforcing. This case is hard to be obtained in most structural members such as slabs, columns and beams. However, more research required to explore the effect of taking UPV test closed to the reinforcement. Hence, some corrections will be needed to estimate the velocity [13-15]. Different factors play a significant role to affect the pulse velocity readings such as w/c ratio, the temperature of hardened concrete, length of path and reinforcement density rate. It is known that the pulse velocity in reinforcement may be more than twice the velocity in plain concrete. However, any intersection to the path of the pulse will affect the acquired velocity then the concrete strength. Hence, in the current study, a series of experimental tests have been carried out to investigate the effect of the arrangements of steel reinforcement embedded in concrete on the pulse velocity obtained by UPV test using the indirect method as it is the most common equipment used in practice in addition to its suitability for slabs.

2. Experimental Procedure

The experimental programme includes casting two reinforced concrete slabs of 500 x 500 x 180 mm. An appropriate wood mould was fabricated then used for the aforementioned purpose. The first slab was reinforced with one layer of steel rebars in both directions using a spacing of 90 mm, while the other spacing was 150 mm for the second slab. A concrete cover of 25 mm was used. The materials including, fine aggregate, coarse aggregate, cement and steel reinforcement, were tested prior to carrying out the mixing process of concrete. The validity of such materials was then emphasized according to the relevant Iraqi standards. Then, a concrete mix was designed and a mix proportion of 1:1.57:2.45 was selected. Different locations were selected on the slab in order to investigate the effect of arrangements of steel reinforcement. In addition to the top surface, the readings were taken on the bottom surfaces where the reinforcement was placed. In the UPV, the transmitted transducer was placed in a point named \((1)\) as shown in Fig. 1, while the receiving one was located in the other points having the same colours. The material properties of steel reinforcement were obtained by applying direct tensile test and the results showed that the modulus of elasticity and yield stress were 201 GPa and 402 MPa, respectively. Concrete compressive strength was obtained by testing the control cubes for each slab after 28 days and the average compressive strength was 40.2 and 38.7 MPa for the first and second slab, respectively. The mix proportion used was by weight of 1:1.57:2.45 (cement: sand: gravel) with a water/cement ratio of 48%. This offered an average cubes compressive strength of 41.8 MPa at age of 28 days. Two slabs were cast in timber moulds then vibrated with a concrete cover of 25 mm. Curing of concrete slabs was continued for 28 days using hessian saturated with water while the cubes were cured in a water tank. The ultrasonic testing device used in the current study includes a pulse generation circuit, comprising of an electric circuit for producing pulses and a transducer for converting electric pulse into mechanical one having an oscillation frequency in a range of 40 to 50 kHz, in addition to a pulse reception circuit that collects the signal.
3. Results and discussion

As mentioned before, the ultrasonic pulse velocity-indirect method was used to evaluate the results. The tests were carried out for five points (A, B, C, D and E) as shown in Fig. 1. Point A represents the readings above one layer of the reinforcement while point B refers to readings where no reinforcement is provided. Point C represents readings horizontally distributed above the intersections of the reinforcement. Whilst, both point D and E refer to readings distributed diagonally on the specimens but readings of point D were located in the point of reinforcement intersections and readings of point E were distributed diagonally. Two cases of the test were adopted in the current study to investigate the effect of the location of transducers whether it is in the reinforced or unreinforced face of the slab. This is to justify the readings that may be taken in practice in places with positive or negative reinforcements. It should be mentioned that the tests were carried out by keeping the location of a transducer in point 1 and changing the location of the other transducer in the other decided locations. Table 1 shows the results obtained in terms of spacing of reinforcement, reading location and standard deviation. It is clear that all values of standard deviation are acceptable if compared with the values of velocity obtained.

3.1. Effect of spacing between steel reinforcement

Fig. 2 shows the effect of spacing between longitudinal reinforcement for readings taken in the top surface of slabs. It can be seen that most readings of spacing 90 mm were higher than those with 150 mm. Then, the average difference between both cases was calculated to be 0.382 km/s. Again, for readings taken on the reinforced surface, all the results for spacing 90 mm were higher than those of 150 mm as shown in Fig. 3. The average difference in the latter case was higher than that in the first case, which emphasizes the role played by steel reinforcement on the UPV readings. However, higher readings were obtained when the transducers were placed near the surface of steel rebars.
Figure 2. Effect of spacing between reinforcement on UPV readings that measured on the unreinforced surface of RC slab.

Figure 3. Effect of spacing between reinforcement on UPV readings that measured on the reinforced surface of RC slab.

3.2 Effect of steel reinforcement location

In slabs, the indirect UPV test may be measured either from the bottom or top extreme fibre. However, the presence of steel reinforcement may be in the bottom only (positive bending moment) or in the top and bottom (negative reinforcement). Thus, the first case was selected to be investigated as it is the control case. The results obtained closed and far away the reinforcement are discussed here. Figs. 4 and 5 show the effect of taking the UPV readings on the face of tension reinforcement and the other face with no reinforcement (which is the case where the reinforcements for the positive bending moment are placed). It should be mentioned here that in the current study, the bottom surface represents the tension surface of the slab where the reinforcement exists while the top one represents the compression surface of the slab where no reinforcement is provided. Generally, fluctuated trend was observed as can be seen in Figs. 5 and 6 but approximately similar trend between both figures can be concluded.
Figure 4. Effect of taking the UPV readings on the face of tension reinforcement and the other face with no reinforcement (spacing 150 mm).

![Figure 4](image)

Figure 5. Effect of taking the UPV readings on the face of tension reinforcement and the other face with no reinforcement (spacing 90 mm).

![Figure 5](image)

Table 1. Summary of results obtained for different spacing of reinforcement on the top and bottom surface of RC slab.

| Location of transducer | UPV (km/s) |
|------------------------|------------|
| **Top Surface**        | **Bottom Surface** |
| A                      | 2.9, 2.93  | 3.42, 3.3   |
| B                      | 2.95, 3.2  | 3.16, 3.3   |
| C                      | 2.87, 2.77 | 2.96, 3.3   |
| D                      | 2.83, 2.2  | 3.3, 3.3    |
| E                      | 3.2, 2.9   | 3.2, 3.2    |

| Location of transducer | UPV (km/s) |
|------------------------|------------|
| **Top Surface**        | **Bottom Surface** |
| A                      | 3.42, 3.3  | 3.4, 3.44  |
| B                      | 3.5, 3.16  | 3.72, 3.4  |
| D                      | 3.3, 2.96  | 3.2        |
| D'                     | 3.2        | 3.4        |
3.3 Effect of path length
As presented in Section 1, the direct path length between both transducers may affect the UPV value. However, the results obtained in the current study were collected and analyzed carefully to find the effect of such length on the UPV readings with different steel reinforcement configurations. Unfortunately, fluctuated results were observed in which no judgement can be taken to explore the effect of path length. In general, the minimum difference in the results was obtained for the readings obtained in point C-spacing 150 mm-bottom surface, which was only 0.1 km/s. Whilst, the maximum one was for the readings obtained in point A-spacing 90 mm-bottom surface, which was equal to 0.45 km/s.

4. Conclusions
Two RC slabs were used to measure the UPV on different locations as an attempt to investigate the effect of steel reinforcement distribution on the UPV test results. The following conclusions were obtained:

- Higher readings of the UPV were obtained when the transducers were placed near the surface of steel rebars.
- Generally, Higher readings of the UPV were obtained if the spacing of longitudinal reinforcement decreased.
- The effect of path length seems to be vague and more tests are required to explore such effect. Also, another technique should be employed for such evaluation.

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