The influence of steel reinforcement on ultrasonic pulse velocity measurements in concrete of different strength ranges

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Abstract. The present paper reports on the assessment of concrete strength, using non-destructive testing devices. The study focuses on Ultrasonic Pulse Velocity (UPV) as a non-destructive tool for estimating the compressive strength of the concrete in real structures, using a UPV-strength correlation model. The objective is to highlight the steel reinforcement influence on the ultrasound pulse velocity (UPV) measurement as a mean of a non-destructive strength assessment of the concrete. UPV-strength correlation models are built on the basis of laboratory plain concrete specimens tested to destruction. However, the real life structures contain steel reinforcement which interferes with UPV measurements, resulting in the distortion of these measurements, particularly when the reinforcement bars lie in the wave propagation path. Thus, when assessing the quality of the concrete in real structures, it is recommended to avoid reinforcement rebars, which is often difficult, if not impossible to ensure, especially for highly reinforced structural elements. This work proposes an alternative which consists of assessing the influence of steel reinforcement on UPV measurements through a correction factor for UPV readings that will allow the user to take account of the presence of steel reinforcement when assessing the concrete strength of real structures through an ultrasound pulse velocity testing. In the study, concretes in three different strength ranges were targeted; the aim being to assess the role of the concrete density and the manner with which it interacts with reinforcement rebars when measuring UPV in reinforced concrete structures. The strength ranges considered vary from ordinary, to moderate, to the high strength concrete. Cylindrical moulds made of concrete from three different strength ranges were cast; some of these moulds were reinforced with different longitudinal steel ratios (low, moderate, high) to simulate real practical cases. These concrete moulds were then subjected to UPV tests in the parallel and perpendicular directions to the rebars disposition in order to study the reinforcement influence on UPV from the two directions. A correction factor was then developed to work out of the real ultrasonic pulse velocity of concrete that can be used in the UPV-strength correlation model to determine the compressive strength. For the three concrete strength ranges considered in this study, the presence of steel reinforcement was found to affect the UPV measurements. The results show also that the effect of steel rebar on UPV measurements is more accentuated with a low concrete density, particularly in the presence of a high steel ratio and rebar lying in the parallel direction to the wave propagation path. Indeed, for high performances concrete, which is a higher density concrete, a high steel ratio was found to slightly modify the pulse velocity; moderate and low steel ratios did not affect the pulse velocity. For moderate and normal strength concretes, however, high and moderate steel ratios had noticeable effects on the UPV measurements, especially in the parallel direction; showing
that UPV testing is not only affected by the presence of steel reinforcement in concrete, but it is also related to the steel ratio, the rebar disposition, and the concrete density. A correction factor is then necessary for UPV measurements to correlate the strengths of reinforced concrete structures.

1. Introduction

The diagnosis and the assessment of the loading state and the service conditions of an existing reinforced concrete structure for the prediction of its remaining resisting capacity is a major challenge in the built environment. Such structural assessment of a building should be carried out before any rehabilitation and maintenance work. For this aim, the development of non-destructive tests as tools for technical diagnosis and a control of concrete structures has known a great deal of interest, these last decades [1-3]. Non-destructive tests represent an interesting approach to rely on, since they allow for an evaluation of the quality of the material in the structure itself and its continuous monitoring. In addition, these types of testing are easy to experiment without any disturbances of the occupants at a relatively lesser cost [4].

The ultrasonic pulse velocity technique (UPV) is one of the most popular and frequently used non-destructive techniques for the assessment of concrete properties. However, this non-destructive measurement may be affected by various factors, such as the mixing ingredients of concrete, humidity inside the internal structure of concrete or the presence of steel reinforcement. In effect, the reinforcement rebar have a significant influence since they increase the ultrasonic wave propagation in the highly reinforced concrete as opposed to a non-reinforced one.

The effective velocity in the concrete-steel medium is higher than the velocity in the plain concrete, but lower than the value obtained by testing the steel bar in the air [5]. When crossing a reinforced concrete specimen, the ultrasonic wave will transit partly through the concrete and partly through the steel (Figure 1). Since steel is much denser than the concrete, the corresponding UPV values are likely to be greater. Ultrasonic pulse velocity (UPV) through an infinite steel medium is generally about 5.90 km/s. However, as shown in Figure 2, the velocity decreases with the diameter in the case of reinforcing bars due to the inadequate path width, and even more when lower frequency is used [6]. In the reinforced concrete, the effective pulse velocity in the concrete-steel medium increases with the size of the embedded steel bar, provided that it is not less than 12 mm in diameter. It is also dependent on the quality of the concrete surrounding the steel bar; the transit time of the ultrasonic wave in the strong concrete is shorter than that in the weaker concrete; this is due to the nature of the bond between the concrete and the steel bar [5]. Thus, for the same reinforcement ratio, UPV is expected to be higher for the reinforced high performances concrete (HPC) than for the reinforced normal strength concrete, since the bond developed with steel reinforcement is of better quality in the first type of concrete.
Figure 1. Wave front in the concrete-steel medium [5].

Figure 2. Pulse velocity as a function of the bar diameter through reinforcing bars in the air [6].

The effect of reinforcing bars depends also on the proximity of the measurements to the reinforcing bar, on the number of the reinforcing bars, on their orientation regarding the propagation path, and on the pulse velocity in the surrounding concrete. With due allowance to these parameters, Jones and Facaorau [7] proposed a method to convert the measured pulse velocity in a concrete-steel medium to a pulse velocity of the surrounding concrete. The pulse velocity in the concrete may be estimated by multiplying the measured pulse velocity by a correction factor ‘k’ which takes account of the rebar
position, the path length, the distance between the embedded rebar and the measure line, and the assumed pulse velocity in the actual plain concrete.

In the same direction, BS 1881-203:1986 [8] proposed a formula to derive the pulse velocity of the concrete from the measured apparent pulse velocity in the concrete containing steel reinforcement:

$$V_c = k \ V_m$$  \hfill (1)

‘k’ is the correction factor which accounts for the influencing factors cited above.

The accuracy of this formula is likely to be in the order of 5% for bars lying directly in line with the transducers, provided that there is a good bond between the steel and the concrete and that there is no cracking of the concrete in the test zone [8].

The present research looks at the effect of the reinforcing steel on the pulse velocity when it crosses the reinforced concrete medium, particularly when higher steel ratio is used. Three strength ranges were considered, namely high performances concrete, moderate strength concrete, and normal strength concrete. The idea of a correction factor adopted in BS 1881-203:1986 [8] was used in the present study where the influence of the reinforcing steel on the UPV was taken into consideration by a modification factor ‘k’ applied to the ultrasonic pulse velocity to be used in a UPV-strength correlation model. This modification factor ‘k’ corresponds to the ratio of the UPV measured on a plain concrete over the UPV measured on a reinforced concrete.

2. Experimental program and research methodology

2.1. Concrete mixing ingredients and mix proportions

Concretes in three different strength ranges varying from ordinary, to moderate, to a high strength concrete were designed. The aggregate content, being one of the most influencing factors on UPV, was kept constant for those three concrete types to minimize the effects of influencing factors other than steel reinforcement and hence to reduce the sources of variability and uncertainty in UPV measurements. The strength variation was obtained by varying the cement past contents of those concretes.

The concrete mixes were designed using a Portland cement with additives (CPJ-CEM II/A – 52.5 N) alongside with silica fume for the high performances concrete; the cement used had a specific gravity of 2.24 and a specific surface area of 23 m²/g. Local limestone coarse aggregates (crushed limestone rock) were used with a maximum size of 15 mm and a specific gravity of 2.69. Two types of local sands were used as fine aggregates: a coarser river sand with a fineness modulus of 3.68 and a specific gravity of 2.65, and a dune sand with a fineness modulus of 0.32 and a specific gravity of 2.63. The two types of sand were mixed at proportions of 75% of the coarse sand and 25% of the dune sand to give fine aggregates having a fineness modulus of 3.68 and a specific gravity of 2.65, and a dune sand with a fineness modulus of 0.32 and a specific gravity of 2.63. The two types of sand were mixed at proportions of 75% of the coarse sand and 25% of the dune sand to give fine aggregates having a fineness modulus of 2.8. The superplasticizer used to improve the workability is based on Polycarboxylate polymers, with a specific gravity of 1.06 ± 0.01 and 30.2 ± 1.3 % solid content. The mixes had water/cement ratios (W/C) of 0.315, 0.35, 0.55 for HPC, moderate strength concrete and ordinary strength concrete respectively. More details on the concrete mix proportions are given in Table 1.
## Table 1. Concrete mix proportions and characteristics

| Constituent          | High performance concrete | Moderate strength concrete | Ordinary strength concrete | Unit |
|----------------------|---------------------------|---------------------------|---------------------------|------|
| Aggregates           |                           |                           |                           |      |
| Fine sand            | 177                       | 177                       | 177                       | kg/m³|
| Coarse sand          | 536                       | 536                       | 536                       | kg/m³|
| Gravel 3/8           | 119                       | 119                       | 119                       | kg/m³|
| Gravel 8/15          | 1168                      | 1168                      | 1168                      | kg/m³|
| Cement CPJ 52.5      | 450                       | 400                       | 300                       | kg/m³|
| Silica fume          | 36 (8%)                   | /                         | /                         | kg/m³|
| Superplasticizer     | 9 (2%)                    | 8 (2%)                    | /                         | kg/m³|
| Water                | 142                       | 140                       | 165                       | kg/m³|
| W/C                  | 0.315                     | 0.35                      | 0.55                      | /    |
| Slump                | 16                        | 16                        | 0                         | cm   |
| Density of fresh concrete | 2.516                  | 2.515                      | 2.456                      | g/cm³|
| Density of hardened concrete | 2.496                  | 2.485                      | 2.443                      | g/cm³|

2.2 Reinforcement design, casting of the concrete specimens and curing

Concrete specimens in the form of cylinders of dimensions 160mm x 320mm were cast, a number of them were reinforced to simulate a reinforced concrete column. The longitudinal reinforcement area was designed to simulate three types of reinforced concrete sections with respect to the local practice recommendations; that is (Table 2):

- Lightly reinforced concrete section: As/B < 1%.
- Moderately reinforced concrete section: 1% ≤ As/B ≤ 5%.
- Heavily reinforced concrete section: As/B > 5%.

## Table 2. Reinforcement details

| Type of Reinforced Section | Type of reinforcement | Elastic Limit f_c (MPa) | Diameter (mm) | Number of bars | A_s (cm²) | B (cm²) | A_s/B (%) |
|----------------------------|-----------------------|-------------------------|---------------|----------------|-----------|---------|-----------|
| Light                      | Mild steel            | 235                     | 6             | 4              | 1.13      | 200.96  | 0.56      |
| Moderate                   | High Yield deformed bars | 500                    | 10            | 8              | 6.03      | 200.96  | 3.0       |
| Heavy                     | High Yield deformed bars | 500                    | 16            | 8              | 16.08     | 200.96  | 8.0       |

The length of bars was fixed at 280 mm so that once introduced, in the cylinders of 320 mm high, 20 mm concrete cover will be left at each end of the specimen. The longitudinal reinforcement bars were tied together with circular transverse steel ties of 6 mm diameter (Figure 3), and fitted in the cylinder moulds, leaving 24 mm as lateral concrete cover. When casting the reinforced concrete cylinders, a thin layer of the concrete was placed in the bottom of the moulds, then the reinforcement was placed over it and held while half of the mould was being filled of concrete and compacted; the second concrete layer was then placed and compacted (Figure 4).
All the concrete specimens, reinforced and non-reinforced, were cast in the steel moulds, compacted and kept covered with a damp hessian and a plastic sheeting covering, in the laboratory of the room temperature for 24 hours until demoulding. The specimens were then weighed, placed outdoors and covered with plastic sheeting until the age of testing to reproduce in-situ curing conditions.

A total number of 270 cylindrical concrete specimens were made, 126 in high strength concrete, 72 in moderate strength concrete, and 72 in ordinary strength concrete. Each batch of concrete provided six cylinders, three of which were reinforced and the other three were plain. Three different steel ratios were used for the three reinforced cylinders, the first one was lightly reinforced, the second one was moderately reinforced, and the third one was heavily reinforced. UPV measurements were performed on the three reinforced concrete cylinders and also on the three plain concrete ones. The distribution of the total number of concrete specimens, according to the testing age and the source batch, is shown on Table 3 where the term “series” refers to the concrete batch.

Table 3. Age, type and number of specimens tested

| Strength range                      | Age (days) | Non-reinforced | Light reinforcement | Moderate reinforcement | Heavy reinforcement |
|------------------------------------|------------|----------------|--------------------|------------------------|---------------------|
|                                     | 3          | Series 1       | 03                 | 01                     | 01                  |
|                                     | 3          | Series 2       | 03                 | 01                     | 01                  |
|                                     | 3          | Series 3       | 03                 | 01                     | 01                  |
| High performances concrete          | 7          | Series 4       | 03                 | 01                     | 01                  |
|                                     | 7          | Series 5       | 03                 | 01                     | 01                  |
|                                     | 7          | Series 6       | 03                 | 01                     | 01                  |
|                                     | 14         | Series 7       | 03                 | 01                     | 01                  |
|                                     | 14         | Series 8       | 03                 | 01                     | 01                  |
|                                     | 14         | Series 9       | 03                 | 01                     | 01                  |
|                                     | 28         | Series 10      | 03                 | 01                     | 01                  |
|                                     | 28         | Series 11      | 03                 | 01                     | 01                  |
|                                     | 28         | Series 12      | 03                 | 01                     | 01                  |
|                                     | 56         | Series 13      | 03                 | 01                     | 01                  |
|                                     | 56         | Series 14      | 03                 | 01                     | 01                  |
2.3 UPV testing

The longitudinal ultrasonic pulse velocity (UPV) was measured accordingly to the standard NF EN 12504-4 [10], using a 58-E0048 ultrasonic potable tester “Controls”. The cylindrical receiver and transmitter have 50 mm in diameter and a maximum resonance frequency of 54 kHz. UPV measurements were performed first; for a given series, each one of the three non-reinforced specimens was tested in the longitudinal direction, transit time was measured in three spots, the mean value of the transit time was used to determine the UPV value for the specimen. The transit time in the reinforced specimens was measured in two directions:

a) Longitudinal direction; that is when the axis of the reinforcement is parallel to the direction of the wave propagation. In this case, UPV is calculated using the mean value of transit time measured in three different spots.

b) Transvers direction; that is when the axis of the reinforcement is perpendicular to the direction of the wave propagation. In order to measure the transit time in this direction, the reinforced specimens had to be carved along two opposite sides in two perpendicular directions to insure a good contact between transducers and the concrete surface (Figure 5). Three measures of transit time were taken on each pair of opposites sides, giving a total of six measures taken in the transvers direction; UPV in this direction was calculated using the mean value of the six measurements. Such procedure aims at evaluating the effect of the presence of reinforcing bars along two different directions on the UPV measurements.
3. Results and discussions

UPV measurements on reinforced and non-reinforced concrete specimens were performed in the parallel direction for non-reinforced cylinders and both directions (parallel and perpendicular) for the reinforced specimens. Results for HPC, the moderate strength concrete, and the ordinary strength concrete are respectively reported in Tables 4, 5, and 6 down below where the UPV measured on a plain concrete corresponds to the mean value obtained on three non-reinforced specimens originated from the same series (Table 3). The UPV measured on a reinforced concrete is that obtained on a reinforced specimen originated from the same series (same batch of concrete).

The results of the correction factor ‘k’ for the measurements on HPC in the two directions and for the three reinforcement ratios considered are presented in Table 4. The results show that the influence of steel reinforcement on the UPV measurements depends on the steel ratio used. For smaller steel ratios, that is for lightly reinforced structural members, the ‘k’ value is very close to 1.0 and the measured UPV for lightly reinforced concrete is similar to that of plain concrete and hence, the presence of steel reinforcement has no effect on the UPV of the plain concrete. When increasing the steel ratio, the ‘k’ value decreases from the unity but could still be neglected for a moderate steel reinforcement ratio (As/B =3%, Table 2). Indeed, the UPV measurements in table 4 show comparable velocities for both HPC with light and moderate reinforcement ratios and for HPC without reinforcement. In HPC with heavy steel reinforcement ratio, however, a relatively more apparent effect on UPV and thus on the strength prediction is recorded as in Table 4; the UPV measurements exceed 5000 m/s and approach those in a steel medium reported to be in the order of 5900 m/s. This justifies the use of the correction factor ‘k’ to get the UPV of high performances concrete for predicting the strength of such higher strength concrete material. From the present results, the correction factor ‘k’ was found as 0.980.

When varying the direction of the UPV measurements, the correction factor ‘k’ has nearly the same value, and this applies to all three reinforcement ratios. For normal strength concrete, a reinforcing bar perpendicular to the wave propagation path does not have a great influence on UPV measurement, particularly for smaller bar diameters [5][6][8]. For higher bar diameters and higher number of bars
However, a moderate influence may exist. For high performances concrete, the effects of steel reinforcing bars on the UPV in both directions were found comparable since the material is denser, and this, whatever the steel ratio used.

Table 4. UPV measurements for plain HPC and reinforced HPC

| Age (Days) | Parallel direction | Perpendicular direction |
|------------|---------------------|-------------------------|
|            | UPV_{pc} (km/s)    | UPV_{lr} (km/s) k UPV_{ms} (km/s) k UPV_{ir} (km/s) k | UPV_{px} (km/s) k UPV_{mx} (km/s) k UPV_{ix} (km/s) k |
| 3          | 4.789              | 4.799 0.998 4.863 0.985 4.900 0.977 | 4.803 0.997 4.826 0.992 4.886 0.980 |
| Series 1   | 4.796              | 4.767 1.006 4.871 0.985 4.893 0.980 | 4.795 1.000 4.821 0.995 4.890 0.981 |
| Series 2   | 4.815              | 4.836 0.996 4.871 0.989 4.908 0.981 | 4.810 1.001 4.858 0.991 4.900 0.983 |
| Series 3   | 4.862              | 4.841 1.004 4.885 0.995 4.923 0.988 | 4.842 1.004 4.949 0.982 4.949 0.982 |
| Series 4   | 4.866              | 4.863 1.001 4.900 0.993 4.931 0.987 | 4.836 1.006 4.900 0.993 4.934 0.986 |
| Series 5   | 4.863              | 4.851 1.002 4.893 0.994 4.923 0.988 | 4.854 1.002 4.870 0.999 4.966 0.979 |
| Series 6   | 4.828              | 4.836 0.998 4.946 0.976 4.992 0.967 | 4.837 0.998 4.916 0.982 5.000 0.966 |
| Series 7   | 4.93               | 4.948 0.996 4.977 0.991 5.024 0.981 | 4.954 0.995 4.985 0.989 5.000 0.986 |
| Series 8   | 4.932              | 4.941 0.998 4.984 0.990 5.025 0.981 | 4.932 1.000 5.000 0.986 5.019 0.983 |
| Series 9   | 4.987              | 4.969 1.004 5.008 0.996 5.063 0.985 | 4.983 1.001 5.016 0.994 5.070 0.984 |
| Series 10  | 5.009              | 4.992 1.003 5.024 0.997 5.071 0.988 | 4.983 1.005 4.995 1.003 5.122 0.978 |
| Series 11  | 4.966              | 4.961 1.001 5.000 0.993 5.112 0.971 | 4.949 1.003 5.000 0.993 5.051 0.983 |
| Series 12  | 5.001              | 4.984 1.003 5.008 0.999 5.079 0.985 | 4.967 1.007 5.017 0.997 5.068 0.987 |
| Series 13  | 4.973              | 4.992 0.996 5.024 0.990 5.079 0.979 | 5.000 0.995 5.051 0.985 5.138 0.968 |
| Series 14  | 5.036              | 5.008 1.006 5.055 0.996 5.104 0.987 | 4.983 1.011 5.017 1.004 5.119 0.984 |
| Series 15  | 5.022              | 5.018 1.001 5.047 0.996 5.112 0.982 | 5.034 0.998 5.085 0.988 5.119 0.981 |
| Series 16  | 4.973              | 4.992 1.000 5.031 0.992 5.153 0.969 | 4.984 1.002 5.048 0.989 5.085 0.982 |
| Series 17  | 4.994              | 4.992 1.000 5.031 0.992 5.153 0.969 | 4.984 1.002 5.048 0.989 5.085 0.982 |
| Series 18  | 4.996              | 4.961 1.001 5.000 0.993 5.112 0.971 | 4.949 1.003 5.000 0.993 5.051 0.983 |
| Series 19  | 5.000              | 5.008 0.998 5.047 0.991 5.128 0.975 | 5.020 0.996 5.051 0.990 5.132 0.974 |
| Series 20  | 5.221              | 5.167 1.010 5.205 1.003 5.251 0.994 | 5.264 0.992 5.240 0.996 5.186 1.007 |
| Series 21  | 5.160              | 5.150 1.002 5.217 0.989 5.266 0.980 | 5.211 0.990 5.213 0.990 5.269 0.979 |
| Series 22  | 5.097              | 5.142 0.991 5.198 0.981 5.240 0.973 | 5.161 0.988 5.183 0.983 5.200 0.980 |
| Mean       | /                  | / 1.001 / 0.991 / 0.980 / 1.000 / 0.992 / 0.981 |
| SD         | /                  | / 0.004 / 0.006 / 0.007 / 0.006 / 0.006 / 0.008 |
| cv (%)     | /                  | / 0.417 / 0.605 / 0.688 / 0.561 / 0.601 / 0.781 |

Notations: UPV_{pc}, UPV_{lr}, UPV_{ms}, UPV_{ir}: Ultrasonic pulse velocity for respectively: plain, lightly reinforced, moderately reinforced, and heavily reinforced HPC; k=UPV of plain HPC / UPV of reinforced HPC

UPV results for the moderate strength concrete are presented in table 5. For both perpendicular and parallel directions, the presence of a high steel ratio has more influence on UPV than smaller ratios. Indeed, for a high reinforcement ratio (8%), “k” values are 0.970 in the parallel direction, and 0.982 in the perpendicular direction. Those values are 0.987 and 0.990 for a moderate reinforcement ratio (3%), and 0.991 and 0.990 for a light reinforcement ratio (0.56%), respectively.
From the results in the table 5, it can be seen that for all three steel ratios, the influence of steel reinforcement is more important in the parallel direction to the wave propagation path than it is in the perpendicular direction. This is due to the fact that, compared to the parallel direction where the wave keeps alternating continuously between the steel and the concrete mediums, in the perpendicular direction, the steel represents only a small proportion of the crossed path, thus the resulting velocity in the perpendicular direction is closer to that of plain concrete resulting in relatively higher "k" values.

Both, in the parallel and in the perpendicular directions considered, the “k” factors obtained for moderate strength concrete are smaller than those obtained for HPC. These results translate a more marked effect of the presence of steel reinforcement on UPV measurements when the density decreases. When the wave crosses the reinforced specimens, it speeds up in the steel reinforcement and slows down in the concrete medium. Hence, the presence of the steel in higher ratios increases the wave velocity in reinforced moderate strength concrete compared to plain moderate strength concrete. The effect is at a relatively larger scale than it is for HPC. Indeed, HPC has a higher density which could be considered as close to that of the steel; this makes the wave crossing from concrete to steel medium without a noticeable velocity variations.

### Table 5 UPV measurements for plain and reinforced moderate strength concrete.

| Age (Days) | Parallel direction | | | | | Perpendicular direction | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | UPV<sub>P</sub> | UPV<sub>L</sub> | k | UPV<sub>MR</sub> | k | UPV<sub>H</sub> | k | UPV<sub>L</sub> | k | UPV<sub>MR</sub> | k | UPV<sub>H</sub> | k |
| 7 | Series 22 | 4,966 | 5,055 | 0.98 | 5,039 | 0.985 | 5,153 | 0.964 | 4,965 | 1,000 | 4,963 | 1,000 | 5,175 | 0.956 |
| | Series 23 | 4,894 | 5,109 | 0.95 | 5,106 | 0.958 | 5,215 | 0.939 | 4,980 | 0.983 | 4,935 | 0.992 | 5,206 | 0.940 |
| | Series 24 | 4,957 | 5,066 | 0.97 | 5,053 | 0.981 | 5,170 | 0.959 | 4,940 | 1,003 | 5,063 | 0.979 | 5,203 | 0.953 |
| 28 | Series 25 | 5,104 | 5,123 | 0.99 | 5,101 | 1,001 | 5,178 | 0.986 | 5,118 | 0.997 | 5,126 | 0.996 | 5,143 | 0.992 |
| | Series 26 | 5,070 | 5,134 | 0.98 | 5,131 | 0.988 | 5,198 | 0.975 | 5,026 | 1,009 | 5,206 | 0.974 | 5,188 | 0.977 |
| | Series 27 | 5,049 | 5,077 | 0.99 | 5,272 | 0.958 | 5,304 | 0.952 | 5,191 | 0.973 | 5,168 | 0.977 | 5,156 | 0.979 |
| 91 | Series 28 | 5,176 | 5,101 | 1,01 | 5,106 | 1,014 | 5,255 | 0.985 | 5,115 | 1,012 | 5,080 | 1,019 | 5,084 | 1,018 |
| | Series 29 | 5,011 | 5,156 | 0.97 | 5,096 | 0.983 | 5,195 | 0.965 | 5,192 | 0.965 | 5,095 | 0.984 | 5,110 | 0.981 |
| | Series 30 | 5,103 | 5,104 | 1,00 | 5,153 | 0.990 | 5,275 | 0.967 | 5,219 | 0.978 | 5,189 | 0.983 | 5,187 | 0.984 |
| 182 | Series 31 | 5,158 | 5,164 | 0.99 | 5,232 | 0.986 | 5,272 | 0.978 | 5,234 | 0.985 | 5,225 | 0.987 | 5,259 | 0.981 |
| | Series 32 | 5,191 | 5,189 | 1,00 | 5,217 | 0.995 | 5,260 | 0.987 | 5,243 | 0.990 | 5,239 | 0.991 | 5,129 | 1,012 |
| | Series 33 | 5,136 | 5,104 | 1,00 | 5,098 | 1,007 | 5,252 | 0.978 | 5,184 | 0.991 | 5,164 | 0.995 | 5,090 | 1,009 |

UPV measurements for ordinary strength concrete specimens are presented in the table 6. The presence of rebars in the parallel direction causes a relatively important increase in the ultrasonic pulse velocity for highly and moderately reinforced concrete, translating a lower “k” factor. Indeed, the values of “k” in the parallel direction are 0.936 and 0.974 for highly and moderately reinforced concrete, respectively. The influence of the steel reinforcement in higher quantity appears to be more significant for ordinary strength concrete compared to HPC and moderate strength concrete. It can be concluded that the effect of the steel reinforcement on UPV is more significant when the concrete
density decreases, as it is in ordinary concrete. For lower quantity of steel reinforcement, the effect seems to be negligible even for lower concrete densities; a value of 0.997 was obtained for the “k” value.

The effect of rebars is less significant in the perpendicular direction to the wave propagation path. Indeed, the correction factors are 0.994, 0.990, and 0.986 respectively for light, moderate, and high reinforcement ratios. These values are justified since the steel represents only a small proportion of the perpendicular crossed path, thus modifying very lightly the UPV in reinforced concrete compared to the plain concrete. The correction factors obtained in that case are close to those obtained for HPC and moderate strength concrete in the same direction, showing that the quality of concrete becomes secondary in the perpendicular direction, only the steel ratio is primary, or rather, the bars diameter since by increasing the bar diameter we also increase the steel portion of the wave path.

### Table 6. UPV measurements for plain and reinforced ordinary strength concrete.

| Age (Days) | Parallel direction | Perpendicular direction |
|------------|--------------------|-------------------------|
|            | UPV<br>*,<br> (km/s) | UPV_R<br>k | UPV_M<br>k | UPV_H<br>k | UPV_L<br>k | UPV_R<br>k | UPV_M<br>k | UPV_H<br>k |
| 7          | 4,58<br>5          | 4,545 | 1,000 | 4,748 | 0,966 | 4,844 | 0,946 | 4,583 | 1,000 | 4,604 | 0,996 | 4,583 | 1,000 |
|            | Series 34          | 4,57<br>7          | 4,61 | 0,993 | 4,678 | 0,978 | 4,839 | 0,946 | 4,687 | 0,977 | 4,671 | 0,980 | 4,711 | 0,972 |
|            | Series 35          | 4,58<br>7          | 4,57 | 1,002 | 4,722 | 0,971 | 4,858 | 0,944 | 4,529 | 1,013 | 4,665 | 0,983 | 4,768 | 0,962 |
| 28         | 4,66<br>6          | 4,727 | 0,987 | 4,814 | 0,969 | 4,984 | 0,936 | 4,69 | 0,995 | 4,687 | 0,995 | 4,693 | 0,994 |
|            | Series 37          | 4,65<br>0          | 4,656 | 0,999 | 4,769 | 0,975 | 4,910 | 0,947 | 4,684 | 0,993 | 4,682 | 0,993 | 4,689 | 0,992 |
|            | Series 38          | 4,64<br>5          | 4,715 | 0,985 | 4,774 | 0,973 | 4,941 | 0,940 | 4,676 | 0,993 | 4,733 | 0,981 | 4,741 | 0,980 |
| 91         | 4,64<br>9          | 4,704 | 0,988 | 4,729 | 0,983 | 4,982 | 0,933 | 4,675 | 0,994 | 4,807 | 0,967 | 4,81 | 0,967 |
|            | Series 40          | 4,67<br>1          | 4,578 | 1,020 | 4,708 | 0,992 | 4,984 | 0,937 | 4,614 | 1,012 | 4,687 | 0,997 | 4,691 | 0,996 |
|            | Series 41          | 4,68<br>2          | 4,631 | 1,011 | 4,715 | 0,993 | 5 | 0,936 | 4,591 | 1,020 | 4,693 | 0,998 | 4,659 | 1,005 |
| 182        | 4,66<br>5          | 4,724 | 0,987 | 4,853 | 0,961 | 5,074 | 0,919 | 4,783 | 0,975 | 4,60 | 1,014 | 4,685 | 0,995 |
|            | Series 43          | 4,67<br>4          | 4,715 | 0,991 | 4,834 | 0,967 | 5,077 | 0,921 | 4,720 | 0,990 | 4,740 | 0,986 | 4,693 | 0,996 |
|            | Series 45          | 4,71<br>8          | 4,741 | 0,995 | 4,913 | 0,960 | 5,115 | 0,922 | 4,861 | 0,971 | 4,785 | 0,986 | 4,852 | 0,972 |

| Mean       | / | / | 0,997 | / | 0,974 | / | 0,936 | / | 0,994 | / | 0,990 | / | 0,986 |
| SD         | / | / | 0,011 | / | 0,010 | / | 0,100 | / | 0,015 | / | 0,011 | / | 0,014 |
| cv (%)     | / | / | 0,073 | / | 0,071 | / | 1,036 | / | 1,489 | / | 1,134 | / | 1,414 |

### 4. Conclusions

The presence of the steel reinforcement laying in the parallel direction to the wave propagation direction was found to affect the UPV measurements, particularly for the lower density concrete. Its influence is mainly governed by two factors; the reinforcement ratio and the quality of the surrounding concrete. For high performances concrete, the presence of steel reinforcement was only noticeable for heavy reinforcement (8%).

For moderate and normal strength concretes, even moderate reinforcement ratios (3%) had effects on UPV measurements, with increasing amplitudes as the concrete density decreases.
In the reinforced concrete, a good quality compact concrete combined with a heavy steel ratio makes a homogenous bloc of nearly the same density, through which the wave velocity remains almost constant while crossing from the concrete to the steel medium. In this case, the UPV appears unaffected by the presence of rebars.

Poor quality concrete, however, has a much lower density than steel and hence the presence of rebars affects the ultrasonic pulse velocity, especially for heavily reinforced concrete. A correction factor becomes then necessary to amend the correlation models used in estimating the strength of the concrete put in place.

The values of the correction factor obtained in the perpendicular direction for HPC, the moderate strength concrete, and the normal strength concrete are very close for the same reinforcement ratio. These results show that in the perpendicular direction, UPV depends less on the quality of the surrounding concrete and more on the reinforcement ratio. Indeed, the rebars effect is more pronounced for the heavy reinforced concretes.

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