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Combined migration results in GPR prospecting

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Abstract **– In this contribution we will show the combination of different migration results calculated on the same Bscan. This allows to account for the variation of the propagation velocity in the soil below the measurement line. Horizontal and vertical variations of the propagation velocities will be considered. A validation vs. real data will be provided, in a case where reinforced concrete was tested.**

I. INTRODUCTION

Analysis of reinforced concrete is of interest in applications of interest for civil engineering [1]. Moreover, the reinforcing bars present in the concrete offer the possibility to achieve a detailed velocity analysis of the propagation medium, due to the many available diffraction hyperbolas [2-3]. This provides the possibility to measure possible changes of the propagation velocity of the electromagnetic waves in the medium. Here we will consider separately the possibility of horizontal variations and vertical variations of the propagation velocity, but in general they can be present together. Moreover, we will assume here the hypothesis of a linear transition of the velocity between two zones of the Bscan where the propagation velocity is instead quite constant. Possibly, however, more than one transition can be present in the Bscan. The hypothesis of a linear transition between adjacent areas with different propagation velocity of the waves might seem restrictive, but even if the transition is more complicated, usually we do not have a sufficient information for a precise characterisation of the phenomenon.

Here, we will show some results achieved from the combination of the same Bscan migrated according to the different values of the propagation velocity retrieved from the diffraction hyperbolas. Possibly, some correction on the value of the propagation velocity achieved from trial migrations will imposed too. The underlying idea that we will apply is simple: some parts of the underground scene will be better reconstructed considering a certain value of the propagation velocity $v=v_1$, and some parts will be instead better focused with a different value $v=v_2$. Consequently, joining in a suitable way the two relative migration results, the comprehensive focalization of the image can be better than that achieved assuming a unique average value of the propagation velocity (as customarily is done). We will show results achieved on real data gathered in the framework of a measurement campaign in a square covered with concrete, reinforced in some points.

II.DESCRIPTION OF THE ALGORITHM

We have (or assume to have) a case with horizontal variations of the propagation velocity when the diffraction hyperbolas present in the data show that the propagation velocity is equal to $v=v_1$ at any abscissa before an identified (or chosen) point $x=x_1$, and that $v=v_2$ after another abscissa point $x_2>x_1$. In order to achieve an image without seam lines (spatial discontinuities of the first kind) we impose a gradual transition of the propagation velocity between the abscissas point x_2 and x_1 so that propagation velocity is a function of the abscissa (but not of the return time) that can be expressed as:

$$v(x) = v_1 \; for \; x < x_1$$
$$v(x) = \frac{(x_2-x)}{(x_2-x_1)} v_1 + \frac{(x-x_1)}{(x_2-x_1)} v_2 \; for \; x_1 < x < x_2$$
$$v(x) = v_2 \; for \; x > x_2 \qquad (1)$$

Coherently, we propose a combined migration where the retrieved image is given by the migration result achieved with $v=v_1$ under any abscissa x smaller than or equal to x_1 and is equal to the image achieved with $v=v_2$ under any abscissa x equal to or larger than x_2. In the range $x_1 < x < x_2$ the most coherent choice in relationship with eq. 1 is to combine the two migration results with the same weights provided by the second relationship in eq. 1, so that the final image transforms gradually from the migration result achieved for $v=v_1$ into the migration result achieved for $v=v_2$. There is some degree of arbitrariness in identifying the abscissas of the transition, but if the diffraction hyperbolas suggests two different values of the propagation velocity vs. the abscissa, the combination of the images gives back the best focusing for all the meaningful targets all over the processed Bscan.

The case with vertical variations of the propagation velocity (e.g. the case of a layered medium) is theoretically more delicate, because the migration algorithm should account for the possible refraction effect at the buried interface, which customarily is not done. Even the evaluation of the propagation velocity in the second media should not be done on the basis of the diffraction hyperbolas in the second medium, because the refraction at the interface between the two layers deforms them [3]. Notwithstanding, as customarily done in the praxis, at the moment we will neglect these incongruences. The achieved results are in general better than those achieved applying the propagation velocity of the upper layer also for the migration of the targets embedded in the lower layer. On this premix, in the case of a vertical variation of the propagation velocity (i.e. a variations of this parameter only vs. the return time of the signal and not vs. the abscissa point), we will identify again two zones (this time piled on each other) with two constant values of the propagation velocity $v=v_1$ and $v=v_2$, respectively, and a vertical transition zone between two time instants t_1 and $t_2>t_1$. The assumed law for the propagation velocity is therefore in this case given by:

$$v(t) = v_1 \; for \; t < t_1$$
$$v(t) = \frac{(t_2-t)}{(t_2-t_1)} v_1 + \frac{(t-t_1)}{(t_2-t_1)} v_2 \; for \; t_1 < t < t_2$$
$$v(t) = v_2 \; for \; t > t_2 \qquad (2)$$

It is straightforward that the two migration results achieved for $v=v_1$ and $v=v_2$ will be combined together with a transition between the starting images that follows the same law of eq. 2 assumed for the propagation velocity.

In the case of two or more transitions (ether horizontal or vertical) the algorithm can be straightforwardly applied in two or more steps.

III. RESULTS

We will show here a result achieved for horizontal variations of the propagation velocity and a result achieved in a case for vertical variations. As said, the results are taken from a real measurement campaign carried out by Geostudi Astier, so that the measurements do not come from a test site. Consequently, when speaking of horizontal (vertical) variations of the propagation velocity of the waves, this has to be meant that these variations are preponderant with respect to the vertical (horizontal) ones. The exploited system was a RIS Hi-Mode manufactured by IDScorporation and equipped with an antenna at 3 GHz.

In fig. 1, the diffraction hyperbolas of a case with horizontal variations is shown. The data have been pre-processed with zero timing (1.7 ns), linear and exponential gain and a Butterworth filter in the range 500-6000 MHz. On the basis of the hyperbola matching, we choose $v=v_1=10.5$ cm/ns for $x<x_1=2.8$ m and $v=v_2=9.5$ cm/ns for $x>x_2=3.1$ m. The two migration results achieved choosing $v=v_1$ and $v=v_1$ are shown in fig. 2. Choosing as horizontal transition range the interval equal to $[x_1,x_2]$ we achieve the combined migration result shown in fig. 3.

In fig. 4, the diffraction hyperbolas of a case with vertical variations is shown. The data have been pre-processed with zero timing (1.3 ns), background removal with running average on 25 traces [4], linear and exponential gain, Butterworth filtering in the band 500-6000 MHz. After this pre-elaboration, aimed to put into evidence the diffraction hyperbolas, the data have been re-processed from the beginning without background removal, in order to preserve the layered structure of the medium, probably due to the presence of a liner. From the pre-elaboration we see that there are a few shallow targets (five hyperbolas are well clear) well matched by a value of propagation velocity equal to 13 cm/ns (making use of 20 traces), whereas the lower sequence of hyperbolas are well matched by a propagation velocity equal to 10.2 cm/ns (making use of 60 traces). In Fig. 5, the two migration results achieved for $v=v_1=10.2$ ns and $v=v_2=13$ cm/ns are shown. The number of traces exploited for the migration, on heuristic basis was 61 and 31 in the two cases, respectively. Before the migration, the data have been zero timed (1.3 ns), enhanced with an AGC with scaling factor 4, and a Butterworth filtering in the band 500-6000 MHz. After migration, the data were cut at 9.4 ns, because beyond this time-depth level only the ringing of the antennas was visible. In Fig. 6, the two migration results have been joined in a unique image, with vertical transition in the time interval 1.8-2.2 ns.

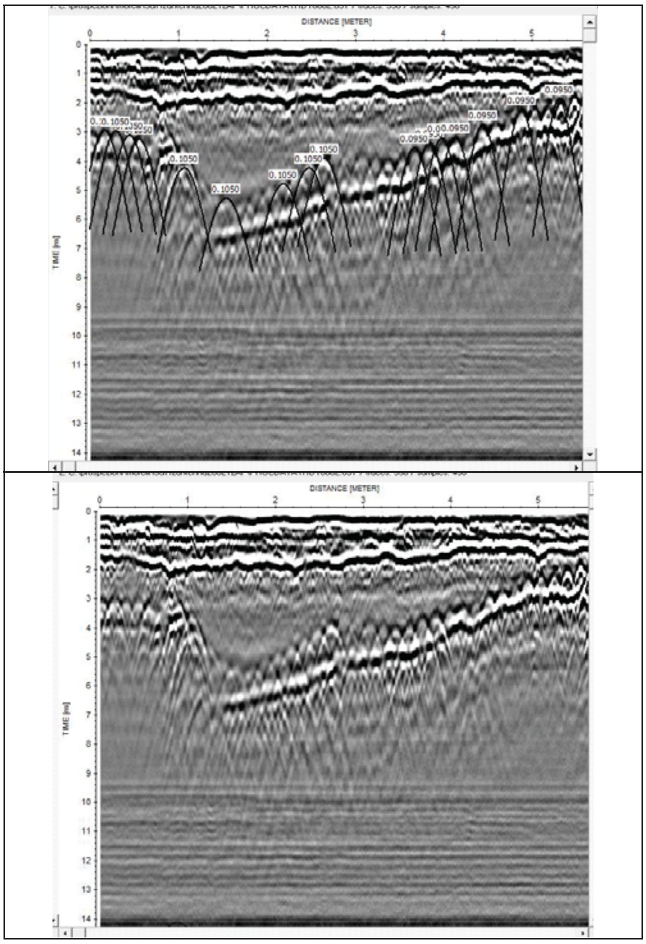
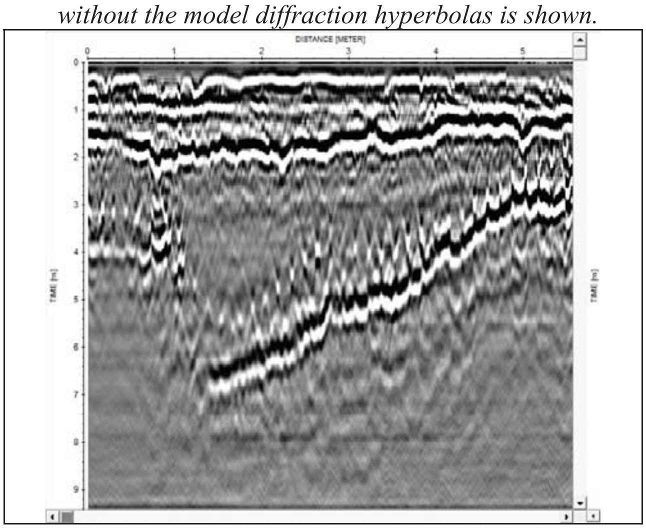


Fig. 1. Bscan with horizontal variation of the propagation velocity. In the lower panel the same data without the model diffraction hyperbolas is shown.



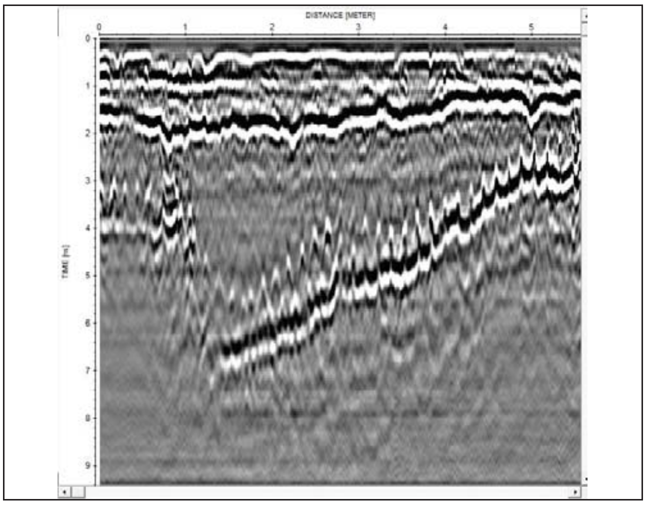


Fig. 2. Two migration results achieved on the data of fig. 1. Upper panel $v=v_1=10.5$ cm/ns. Lower panel $v=v_2=9.5$ cm/ns.

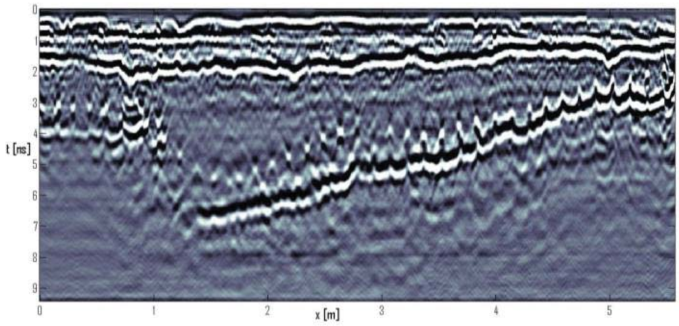
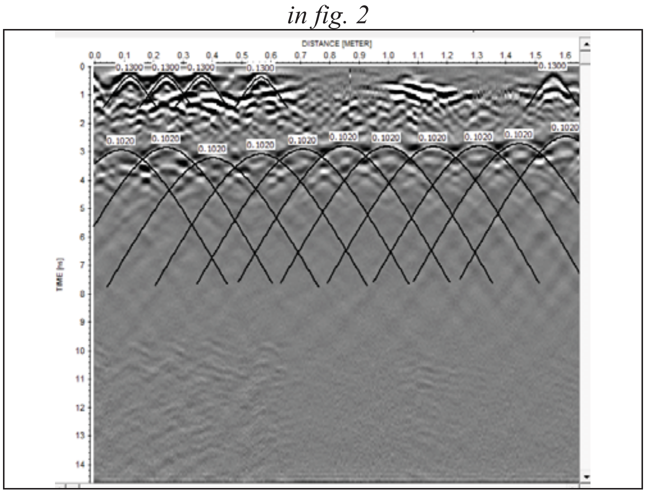


Fig. 3. Combination of the migration results achieved in fig. 2



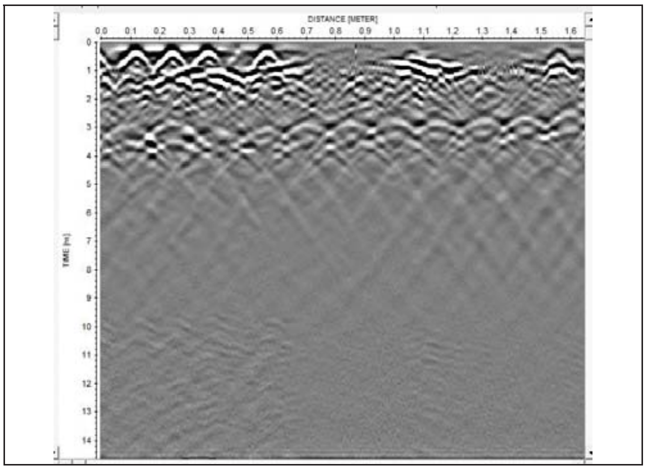


Fig. 4. Bscan with vertical variation of the propagation velocity. In the lower panel the same data without the model diffraction hyperbolas is shown.

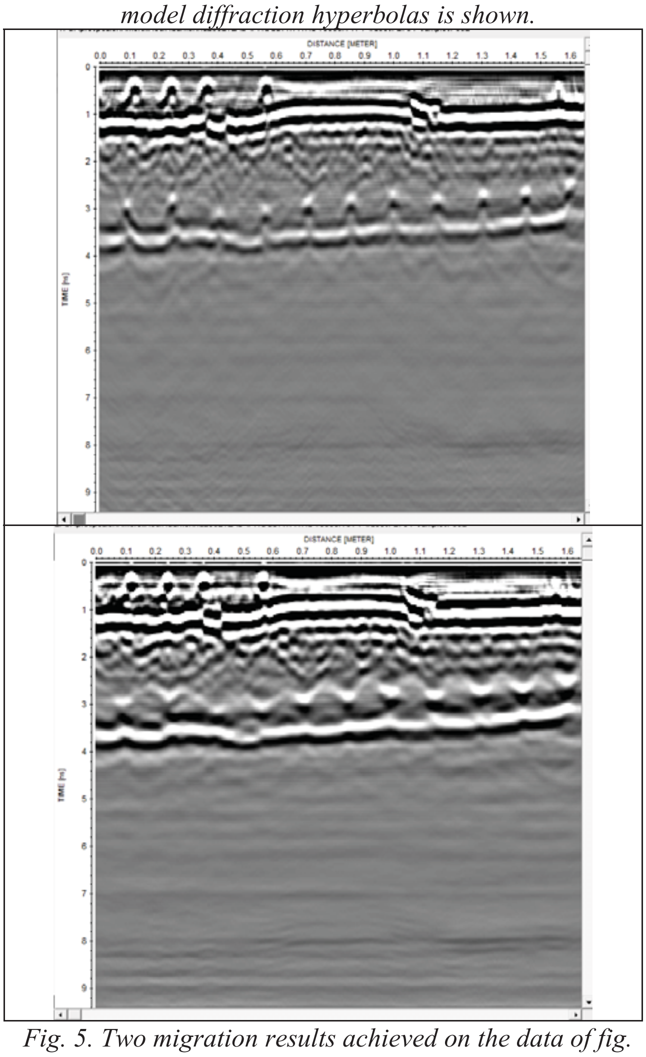


Fig. 5. Two migration results achieved on the data of fig. 4. Upper panel v=v_1= 10.2 cm/ns. Lower panel v=v_2=13 cm/ns.

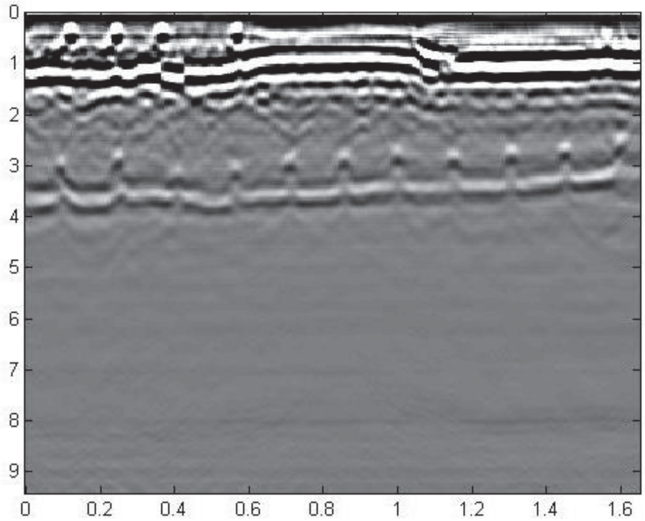


Fig. 6. Combination of the migration results achieved in fig. 5.

IV. CONCLUSIONS

In the present contribution we have proposed the combination of different migration results achieved from different evaluations of the propagation velocity of the electromagnetic waves in the soil, considering the case of horizontal and vertical variations of the propagation velocity, respectively.

This offers new possibilities for the optimal focusing of the target, being the propagation velocity possibly varying within a GPR Bscan, especially if the measurement line is quite long.

The problem of a time-depth conversion coherent with the combined migration is being afforded [5], and possibly more details will be provided at the conference.

As a future development, the combination of cases with both horizontal and vertical variations of the propagation velocity are in order.

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