Guidelines on Test Procedure Using Time Domain Reflectometry (TDR) to Determine the Length of Installed Soil Nails

1. General

1.1 The guidelines are applicable to using time domain reflectometry (TDR) test on pre-installed copper wire to determine the length of steel soil nail. The copper wire shall be installed alongside the steel reinforcement with details as shown in Figure A1.

1.2 TDR measurements shall be conducted on the copper wire using two distinct pulse widths, one less than 5 nanosecond (*ns*) and one greater than 5 *ns*.

2. Preparation for TDR tests

2.1 No TDR test shall be carried out on a soil nail within one day after the completion of grouting.

2.2 The head of the steel reinforcement and the copper wire shall be electrically accessible. All loose materials shall be removed from the exposed portion of the steel reinforcement and the copper wire, such that good electrical contact to the test lead of the TDR equipment can be made.

3. Test Procedures and Interpretation of Test Results

3.1 Determination of Reference Pulse Propagation Velocity

3.1.1 In the TDR tests, a Reference Pulse Propagation Velocity, v_r is used to deduce the length of test soil nails. The Reference Pulse Propagation Velocity can be applied to determine the length of other soil nails (different lengths and diameters) with the same type of copper wire and the same approved grout mix. The Reference Pulse Propagation Velocity shall be the average pulse propagation velocity from a minimum of three calibration soil nails.

3.1.2 Select three soil nails of known length for determination of Reference Pulse Propagation Velocity. If soil nails of different lengths and different bar diameters are available for testing, the longest three nails of any bar diameter shall be selected for calibration.

3.1.3 In case the waveforms of a selected nail are atypical, e.g. presence of significant ripples before the major pulse reflection, or inverted major pulse reflection (see Figure A2 for examples), it shall not be used as a calibration soil nail and a different soil nail shall be selected for calibration. The one that has atypical waveform shall be treated as a test soil nail and its length be deduced in accordance with Section 3.2 below.

3.1.4 Separate calibration soil nails shall be selected for soil nails with different types of copper wire or grout mix.

3.1.5 With the clips of the test lead unconnected as in Figure A3(a), move line '1' on the display panel of the TDR equipment to the position where the reflected pulse corresponding to the clips starts to rise. The correctness of the position of line '1' can be confirmed by connecting the clips. When the clips are connected, the polarity of the pulse at line '1' would be reversed as indicated in Figure A3(b).

3.1.6 Connect the clips to the calibration nail as shown in Figure A3(c); one to the steel reinforcement and the other to the copper wire.

3.1.7 Identify the pulse reflected from the end of the test soil nail, and move line '2' to the position where the pulse starts to rise. The recorded waveform usually shows a number of reflected pulses with small amplitude followed by one with considerably larger amplitude. Move line '2' to the one with the largest amplitude (see Figure A3(c)).

3.1.8 Record the time of travel between line '1' and line '2', and the waveform.

3.1.9 Repeat procedures in Sections 3.1.5 to 3.1.8 using a different pulse width as specified in Section 1.2.

3.1.10 Among the measurements taken with pulses of different widths, select those with a clear and distinct reflection for calculating the travel time of pulse in copper wire, t_c.

3.1.11 Determine the pulse propagation velocity, ν_p, of a calibration nail using Equation (1a).

$$\nu_p = \frac{2 L_d}{t_c} \qquad (1a)$$

where L_d is design length of the soil nail, t_c is the time of travel between line '1' and line '2', which corresponds to the time for the pulse to travel from the head of soil nail reinforcement to its end and back to the head, i.e. 2 times the nail length.

Some TDR instruments make allowance for the travel time of the pulse and the time shown on the display panel actually corresponds to one soil nail length. In such case, Equation (1b) should be used to determine the pulse propagation velocity. Users should refer to the specification of their TDR instrument to check which equation is to be used.

$$\nu_p = \frac{L_d}{t_c} \qquad (1b)$$

3.1.12 Repeat the procedures in Sections 3.1.5 to 3.1.11 to obtain the pulse propagation velocity of all three calibration soil nails selected. The Reference Pulse Propagation Velocity, ν_r, shall be taken as the average pulse propagation velocity measured in the three calibration soil nails.

3.2 Determination of the Length of Soil Nails

3.2.1 The average travel time of the pulse along the soil nail, t, shall be determined for all soil nails to be tested by TDR based on the procedures given in Sections 3.1.5 to 3.1.10.

3.2.2 Deduce the length of each soil nail, L_i, using either Equation (2a) or (2b) as appropriate.

$$L_i = \frac{\nu_r t}{2} \qquad (2a)$$

or

$$L_i = \nu_r t \qquad (2b)$$

3.2.3 The presence of small amplitude reflections may obscure the identification of the pulse reflected from the end of soil nail. Procedures to identify the rise of the largest reflected pulse in these cases are shown in Figure A4.

4. Worked Example

4.1 Determination of Pulse Propagation Velocity in Calibration Soil Nail

Three calibration soil nails were selected for the determination of the Reference Pulse Propagation Velocity. One of the calibration soil nails was 15 m long. Measurements were taken with two different pulse widths, and the results are shown in Figure A5. The pulse propagation velocity for this calibration nail, v_{p1}, is given by:

$$t_c = \frac{291.9 + 297.2}{2} = 294.6\ ns$$

$$v_{p1} = \frac{2\,L_d}{t_c} = \frac{2 \times 15}{294.6} = 0.1018\ \text{m}/ns$$

The pulse propagation velocities for the other two calibration nails, v_{p2} and v_{p3} are determined similarly. Assuming $v_{p1} = v_{p2} = v_{p3}$ in this example, v_r is determined as:

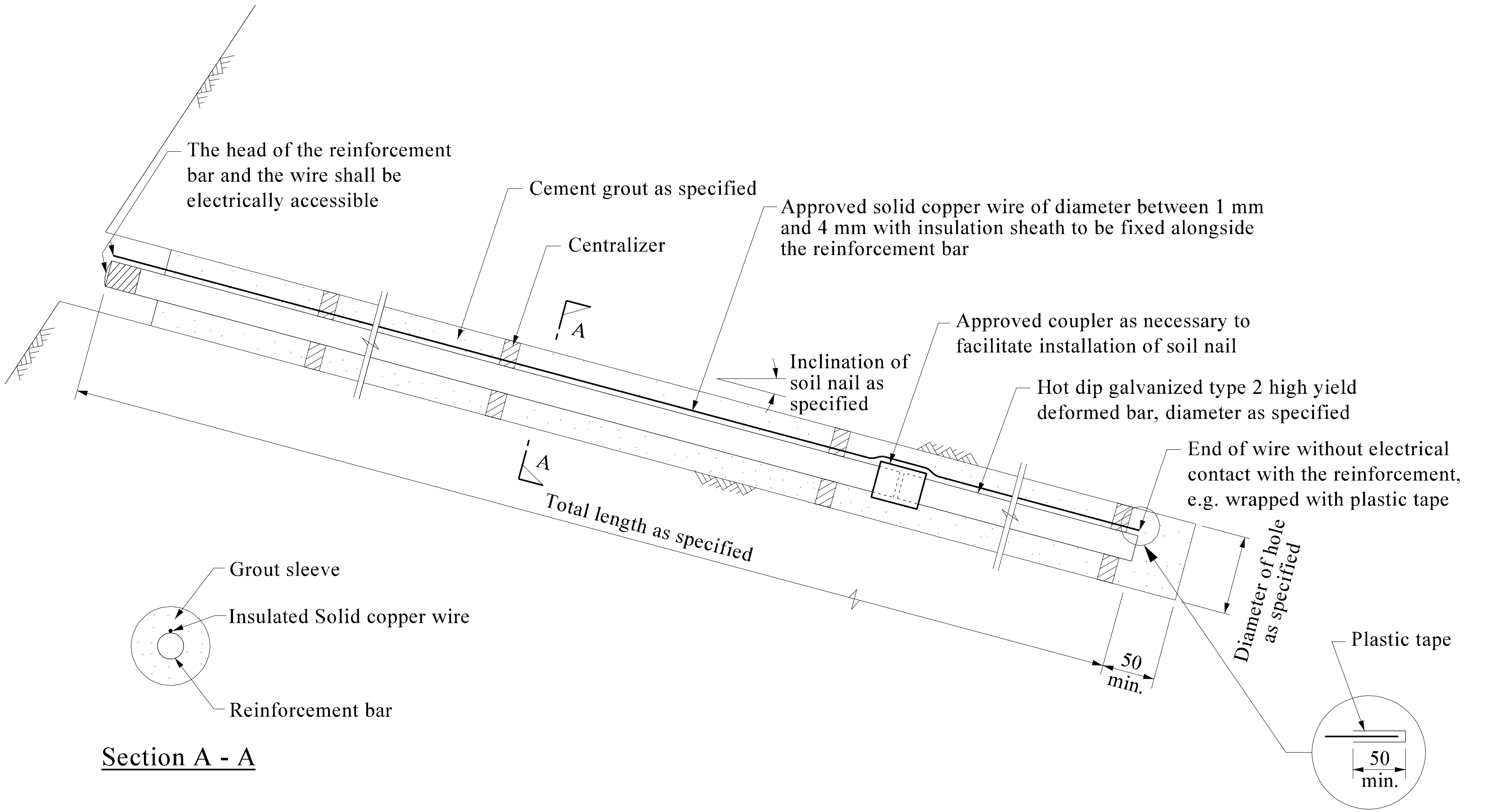
$$v_r = \frac{v_{p1} + v_{p2} + v_{p3}}{3} = 0.1018\ \text{m}/ns$$

4.2 Determination of the Length of Soil Nail

A soil nail of unknown length was tested using two different pulse widths. The results are shown in Figure A6. Based on the v_r obtained from the calibration tests, the length of the soil nail, L_i, is estimated to be:

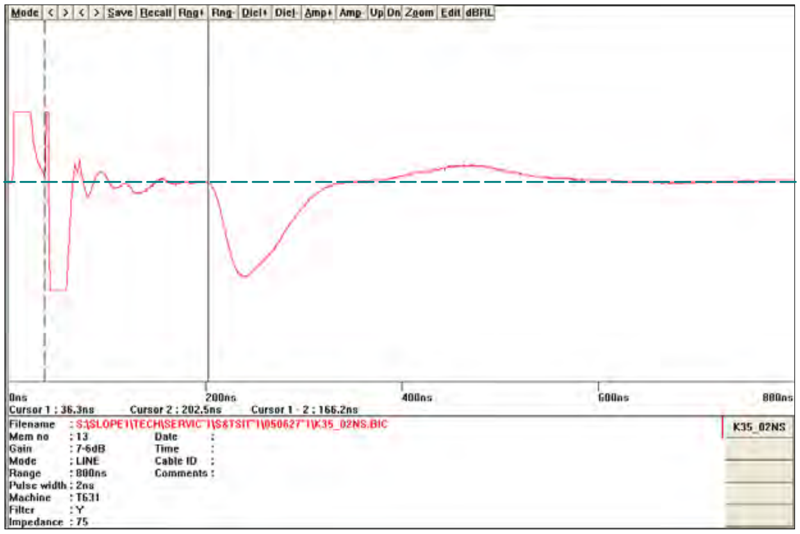
$$t = \frac{216.9 + 220.7}{2} = 218.8\ ns$$

$$L_i = \frac{v_r\, t}{2} = \frac{0.1018 \text{ x } 218.8}{2} = 11.1 \text{ m}$$

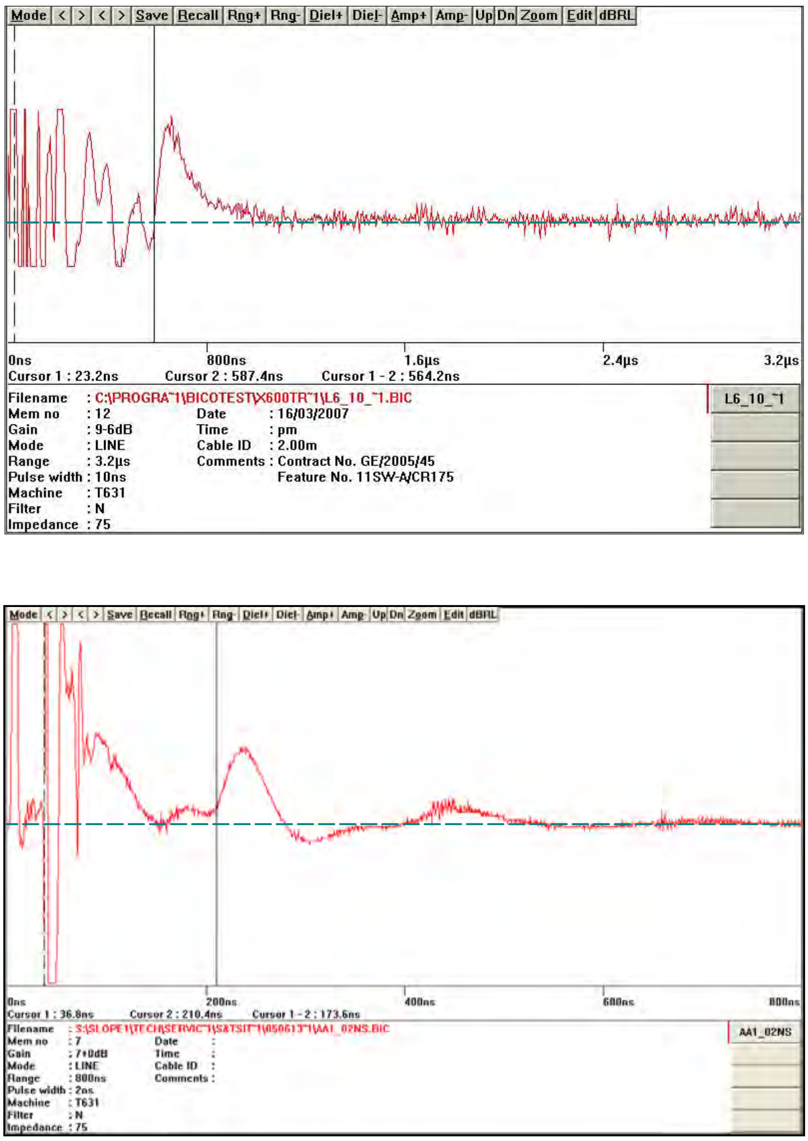


Note: All dimensions are in millimetres.

Figure A1 - Details of Provision of a Wire for Determination of Length of Soil Nail Reinforcement Using Time Domain Reflectometry



(a) Inverted Major Reflection



(b) Significant Ripples before Major Reflections

Figure A2 – Examples of Atypical TDR Waveforms

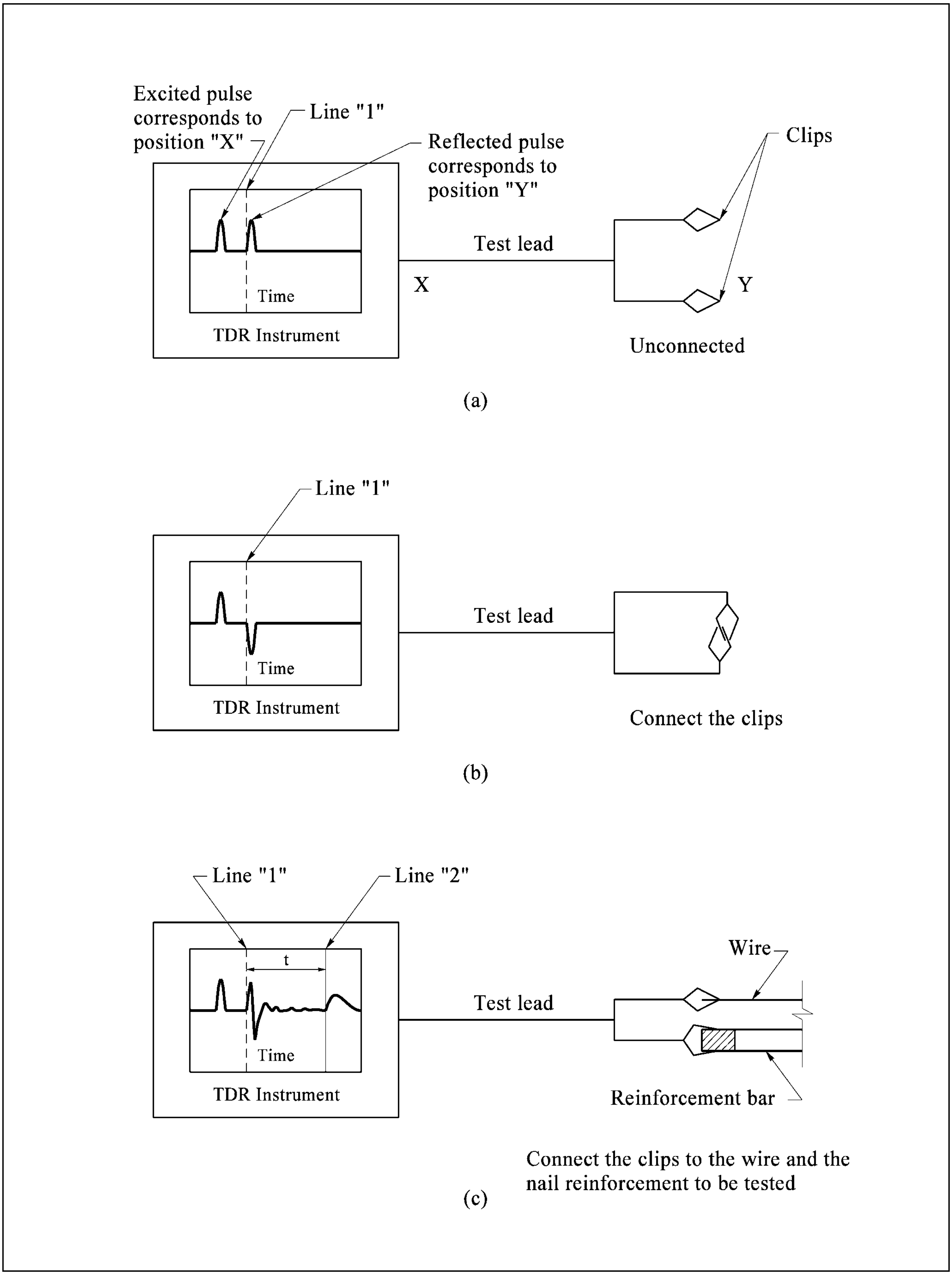
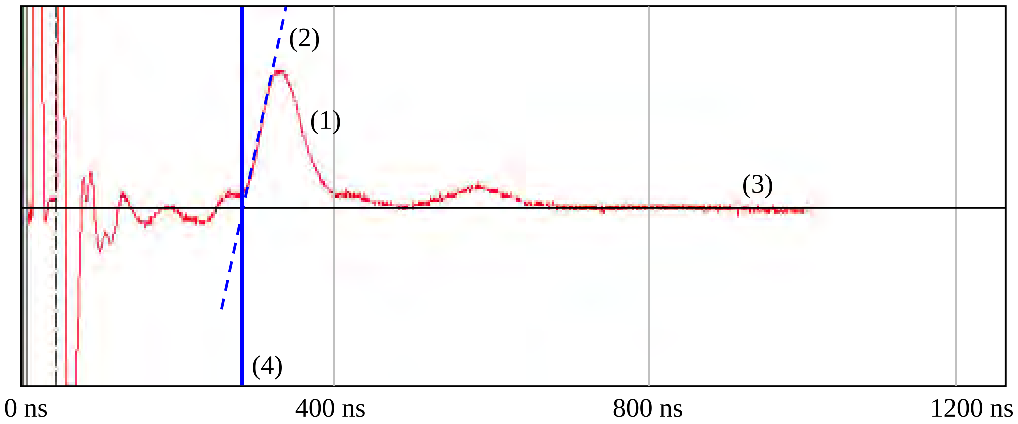


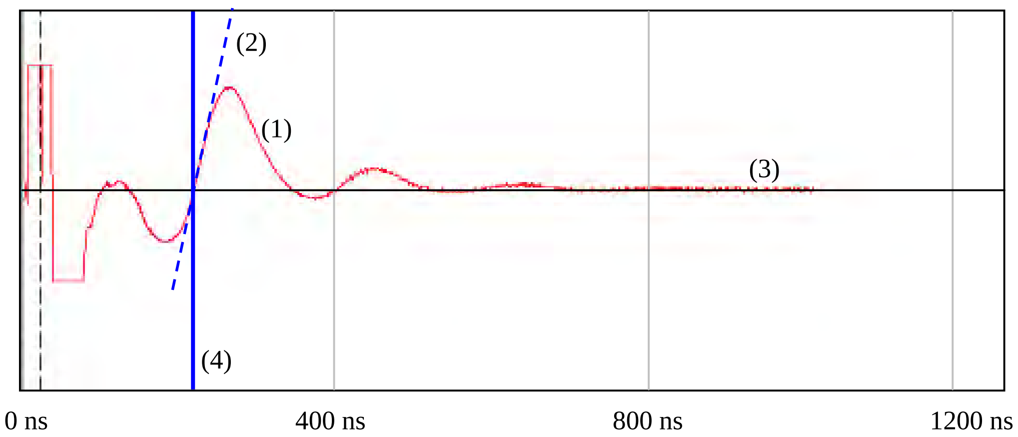
Figure A3 – Schematic Diagram Showing the Procedure of Using Time Domain Reflectometry for Determination of Length of Soil Nail Reinforcement

Procedures

(1) Identify the largest reflected pulse
(2) Extend the left sloping side of the largest reflected pulse
(3) Extend the leveled tail part of the waveform
(4) Take the time of travel as the interception point of (2) and (3)

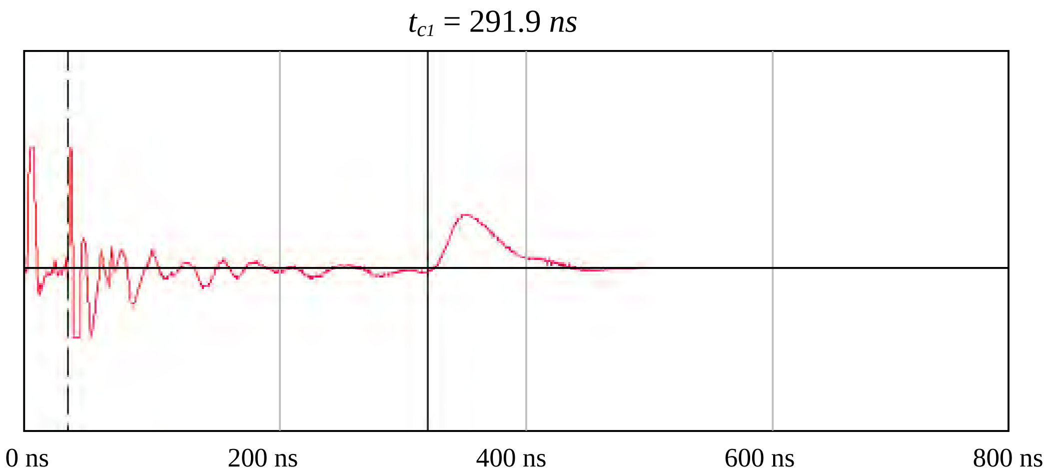


Example 1

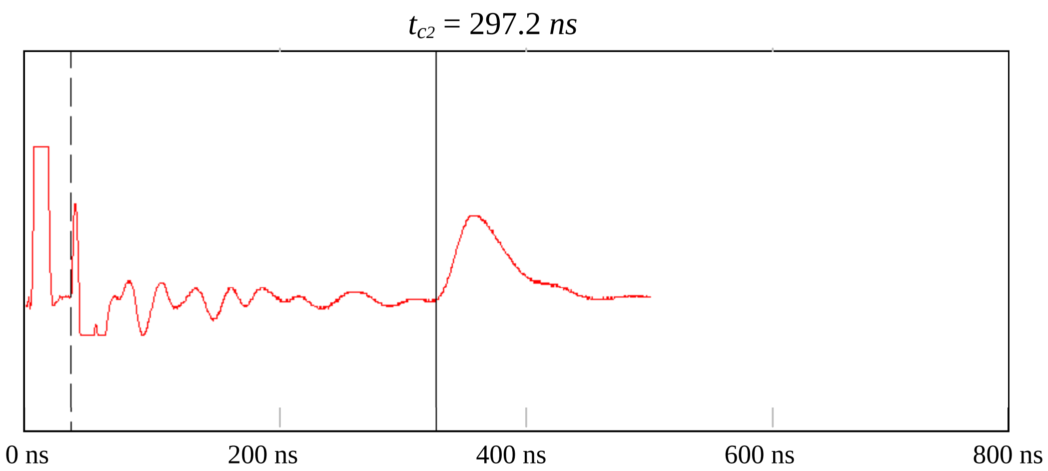


Example 2

Figure A4 – Procedures to Identify the Rise of the Largest Reflected Pulse



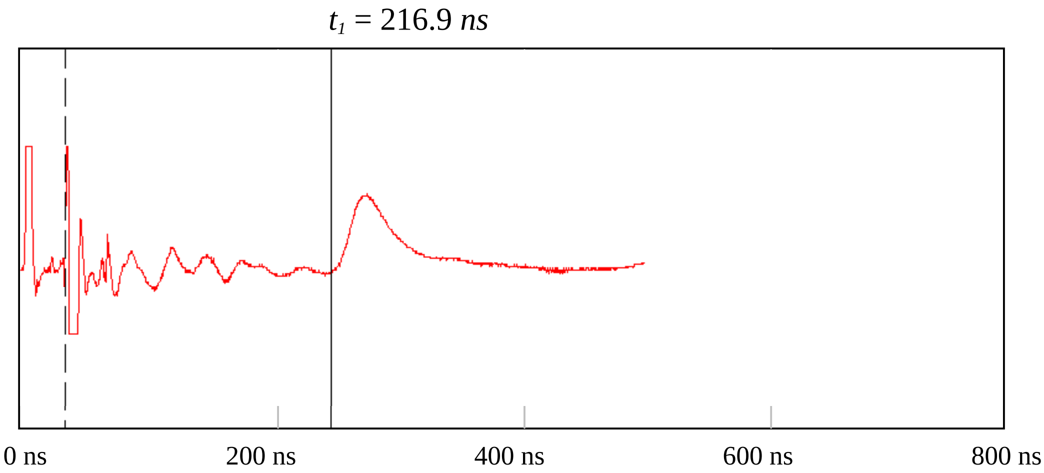
(a) Pulse width < 5 *ns*



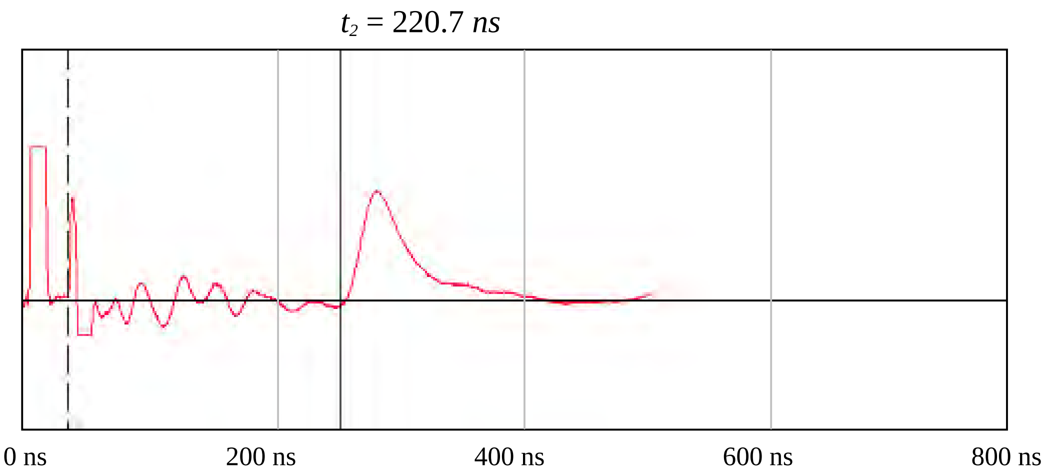
(b) Pulse width ≥ 5 *ns*

$$t_c = \frac{291.9 + 297.2}{2} = 294.6\ ns$$

Figure A 5 – Determination of Pulse Propagation Velocity from a Calibrated Soil Nail



(a) Pulse width < 5 *ns*



(b) Pulse width ≥ 5 *ns*

$$t = \frac{216.9 + 220.7}{2} = 218.8\ ns$$

Figure A6 – Results of a Test Soil Nail