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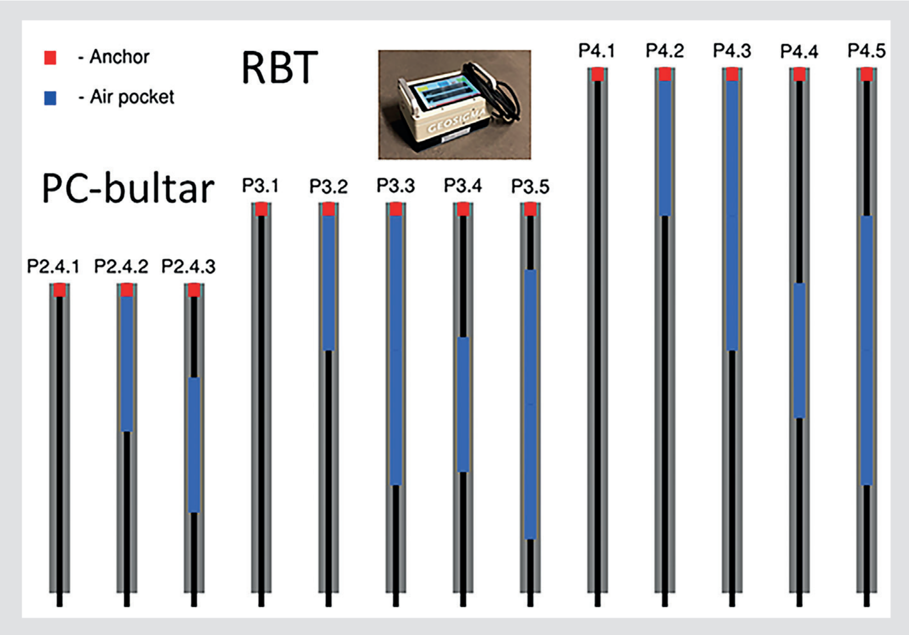

DEVELOPMENT OF THE INSTRUMENT RBT WITH RESPECT TO ROCK BOLT TYPES PC- AND CT-BOLT AND SIMILAR COMBINATION BOLTS

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BeFo Report 215

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DEVELOPMENT OF THE INSTRUMENT RBT WITH RESPECT TO ROCK BOLT TYPES PC- AND CT-BOLT AND SIMILAR COMBINATION BOLTS

Vidareutveckling av instrumentet RBT med avseende på bulttyperna PC- och CT-bult och motsvarande kombinationsbultar

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PREFACE

Building in rock is a highly important activity in today's society. Densification of large cities and expanding industries place higher demands on underground rock construction. Requirements regarding environmental impact, safety, implementation and installation, and long-term sustainability influences daily decisions in rock construction. There is a need of new and stricter methods for verifying compliance with safety, quality and durability requirements. Control methods can range from administrative checks related to the execution to destructive testing of installed elements. Destructive testing implies that the element being checked is destroyed or to some extent damaged during the testing process. This makes destructive testing a less desirable and more expensive method compared to others. Unlike destructive testing, in Non-Destructive Testing (NDT), the elements tested remain unchanged and functional. Non-destructive testing can be performed using several different methods, including ultrasound, which is one of the most commonly used NDT methods in industry.

For quality assurance of fully grouted bolts, the ultrasonic instruments RBT (Rock Bolt Tester) and Boltometer are widely used in Sweden today. These instruments are primarily designed for non-destructive inspection of the grouting of fully grouted rebar bolts. The rock construction industry today has a great interest in going from the traditional rebar bolts to different types of combination bolts (e.g. end-anchored, fully grouted and sometimes pre-tensioned bolts), due to production advantages thanks to automation but also due to work environment reasons thanks to the immediate bearing capacity that these bolts can achieve.

The instruments RBT and Boltometer are developed to check fully grouted rebar bolts. This implies a limitation of the bolt types that can be used in the industry when quality testing of rock bolt grouting is required.

The purpose of the current project is to further develop the instrument RBT to make it possible to use it to control the grouting of additional bolt types other than steel rebar bolts. The goal is to obtain an instrument that can reliably be used for quality control of the grouting of bolt types PC and CT bolt, and similar combination bolts, installed during the construction of tunnels and rock slopes.

The input from the project reference group during the project is also Appreciated. The following have participated: Per-Erik Söder (Swedish Transport Administration), Tommy Ellison (Besab), Diego Lope Alvarez (SKB), Björn Stille (Aecom), Mattias Roslin (Theta Engineering AB, previously the Swedish Transport Administration) and Per Tengborg (BeFo). The financial support came mainly from the Rock Engineering Foundation – BeFo, but also from Pre Cast Technology AB – Pretec and in-kind from Geosigma.

Stockholm, 2021

Per Tengborg

FÖRORD

Byggande i berg är ett högaktuellt ämne i dagens samhälle. Förtätning av storstäder och expanderande industrier ställer idag högre krav på bergbyggandet. Krav gällande omgivningspåverkan, säkerhet, utförande och långsiktig hållbarhet är något som dagligen påverkar beslutsfattandet inom bergbyggandet. Dessa krav innebär nya och strängare metoder för att verifiera kravuppfyllnad ur en säkerhets-, kvalitets- och beständighetssynpunkt. Metoderna kan vara allt från administrativa kontroller till förstörande provning av element som knyter till utförandet. Förstörande provning innebär att elementet som kontrolleras förstörs eller till viss del tar skada vid provningsprocessen. Detta gör förstörande provning till en mindre önskvärd provningsmetod. Till skillnad från förstörande provning, icke-förstörande provning (på engelska NDT, Non Destructive Testing) bevarar de element som testas oförändrade och funktionella. Icke-förstörande provning kan utföras med flertalet olika metoder, däribland ultraljud. Denna är ett av de vanligaste verktygen för icke-förstörande provning inom konstruktions- och bergbranschen.

För kvalitetssäkring av helingjutna bultar används idag i Sverige ultraljudsinstrumenten RBT (Rock Bolt Tester) och Boltometer flitigt. Dessa instrument är primärt utvecklade för icke-förstörande provning av kamstålsbultarnas cementingjutning. Bergbranschen har idag ett stort intresse av att övergå från traditionella kamstålsbultar till olika varianter av kombinationsbultar (dvs bottenförankrade och helgingjutna, i vissa fall förspända bultar), både av produktionsmässiga skäl tack vore automatisering men också av arbetsmiljöskäl tack vore den omedelbara bärigheten som dessa bultar ger.

Instrumenten RBT och Boltometer är framtagna för att kontrollera ingjutningens kvalitet hos kamstålsbultar. Detta innebär en begränsning av de bultarna som kan användas inom branschen där kvalitetstestning av bergbultars ingjutning har kravställts.

Syftet med det aktuella projektet är att vidareutveckla instrumentet RBT för att göra det möjligt att använda det för kontroll av ingjutningen av ytterligare bulttyper utöver kamstålsbultar. Målet är att instrumentet ska kunna användas med tillförlitligt resultat som standardmetod för kvalitetskontroll av ingjutningen hos bulttyperna PC- och CT-bultar, och motsvarande kombinationsbultar, installerade i produktionen i tunnlar och bergslänter.

Projektets referensgrupp har lämnat värdefulla synpunkter under projektets genomförande och består av; Per-Erik Söder (Trafikverket), Tommy Ellison (Besab), Diego Lope Alvarez (SKB), Björn Stille (Aecom), Mattias Roslin (Theta Engineering AB, tidigare Trafikverket) och Per Tengborg (BeFo). Finansieringen av projektet kom huvudsakligen från BeFo, men också från Pre Cast Technology AB – Pretec samt in-kindmedel från Geosigma.

Stockholm, 2021

Per Tengborg

SUMMARY

This report summarizes results of the BeFo project No 419 concerning current developments of the RBT instrument with the aim to enable its use for the inspection of the grouting quality of special rock bolt types, such as the PC and CT bolts and similar combination bolts.

The function of the RBT on the chosen rock bolt types was investigated by installing reference bolts with artificial defects in the grouting (e.g. cavities) at a test site. By conducting testing, adjusting the software settings of the instrument as well as adjusting the outgoing signals (pulse trains), the limits of the instrument capabilities were investigated.

The project resulted in the conclusion that more research and development are required to obtain the desired function of the instrument RBT for quality controls of the grouting of the bolt types PC and CT, and similar combination bolts. On one hand, the complex geometry and material combination in the bolt should be analysed to understand if the measurements can give meaningful results, on the other hand, the instrument might need to be adjusted to operate in such complex conditions.

Keywords: rock bolts, Non-Destructive Testing, NDT, ultrasound, PC bolt,
CT bolt, combination bolt

SAMMANFATTNING

Denna rapport sammanfattar resultaten av BeFo-projektet Nr 419 som berör den aktuella utvecklingen av RBT-instrumentet i syfte med att möjliggöra dess användning för kontroll av ingjutningskvalitet för PC- och CT-bultar och motsvarande kombinationsbultar.

För att möjliggöra en kontroll och utveckling av RBTs funktion på de valda bulttyperna installerades ca 70 referensbultar med och utan artificiella defekt i bultarnas ingjutning (dvs håligheter) vid en testplats. Genom att utföra mätningar, analysera data och justera inställningar på de utgående signalerna kunde instrumentets begränsningar utredas.

Projektet resulterade i slutsatsen att mer forskning och utveckling krävs för att erhålla önskvärd funktion hos instrumentet RBT vid kvalitetskontroller av ingjutningen för bulttyperna PC- och CT-bult och motsvarande kombinationsbultar. Dels behöver den komplexa geometriska och materialuppsättnigen i bulten analyseras för att avgöra om mätningarna kan ge meningsfulla resultat, dels instrumentet eventuellt anpassas till dessa komplexa förhållanden.

Nyckelord: bergbultar, NDT, icke-förstörande provning, ultraljud, PC-bult, CT-bult, kombinationsbult

Table of contents

1. Background

1.1 Introduction

In rock constructions, rock reinforcement is often required to stabilize the rock mass. Rock reinforcement usually consists of rock bolts, steel mesh and/or shotcrete. The rock bolts are the reinforcing element with the greatest impact on the stability of the rock mass, while the use of steel mesh and shotcrete aims to prevent blocks between the bolts from falling out, and to confine the rock mass between the rock bolts.

Rock constructions are today often designed to meet a technical life of up to 120 years. To ensure that the technical life of the steel rock bolts is not affected by corrosion, it is often required the bolts to be fully grouted with cement mortar. In order to check that a rock bolt is fully grouted, a non-destructive test method can be applied. Non-destructive testing (NDT) of rock bolt grouting can be performed today with the instruments RBT and Boltometer, both based on ultrasonic technology.

The limitation of the application of the Rock Bolt Tester (RBT) and Boltometer is that both have been developed mainly for testing the grouting around traditional steel rebar bolts. This means that the designer and the contractor, if non-destructive quality control methods are to be applied, are indirectly forced to use this type of bolts because of lack of control methods for other types of bolts.

The development of the RBT instrument has been carried out by the Geosigma Company since 2010. Today, there is only one specimen of the instrument available, but Geosigma's intention is to build several instruments so that there is sufficient capacity to satisfy the demand for non-destructive testing in the rock underground industry in Sweden. The development of the instrument has taken place in close collaboration with the Swedish Transport Administration, the Norwegian Public Roads Administration and the mining companies LKAB and Boliden. These organizations took part in the Reference Group advising the RBT development project.

Several prototypes of the instrument were tested and a reference library of tests results on prepared reference bolts (a total of 85) installed at a few different locations (Dannemora Mine, Roslagsbanan Railway, Citybanan Railway Tunnels, Äspö Hard Rock Laboratory and Stockholm Road Bypass) was obtained. The reference bolt library mainly consists of steel rebar bolts, but also of a number of PC-bolts and CT-bolts. For various reasons, two of the reference sites have become difficult to access (Dannemora facility was closed and Citybanan railway tunnels are in operation).

Comparative tests in Dannemora, Äspö HRL and Stockholm Road Bypass have shown that the RBT is more sensitive to defects in the bolt grout than the Boltometer, but also that the agreement between the indications of both instruments is very good. Overcoring of three of the measured bolts showed that the defects identified by the RBT could be observed in the cores. Tests on combination bolts (PC-bolt and CT-bolt) also gave promising preliminary results, which lead to the start of the present project.

1.2 Aim

The Rock Bolt Tester (RBT) has been developed to enable non-destructive quality control of the installation of rock supports with fully grouted rebar bolts, in the interest of Clients and Contractors. The RBT is used for non-destructive testing using ultrasonic technology. The instrument is designed to check the quality of the grout of rebar bolts, which are the most common bolt types in infrastructure projects. This imposes a limitation on the rock excavation industry when it is forced to use rebar bolts because the only available non-destructive quality control method for the grout with the RBT and Boltometer instruments only works on rebar bolts. Control is usually performed on randomly selected tests bolt.

The purpose of the present project is to further develop the RBT instrument to enable its application for quality control of the grout of additional types of rock bolts, such as PC- and CT-bolts, and similar combination bolts. An additional goal of this project is to obtain the RBT instrument to be approved by the Swedish Transport Administration for quality control of combination bolts.

PC-bolts are produced by Pretec Cast Technology AB (www.Pretec.se). It should be noticed that CT-bolt is a commercial product name by Vik Ørsta AS (www.vikorsta.no). In this project, CT-bolts have been substituted with NC-bolts by Pretec Cast Technology AB (www.Pretec.se), which are equivalent in construction and performance to the CT-bolts.

1.3 Scope of the work

This project consists of the following main work packages:

1) Installation of reference bolts and bolts with pre-prepared (artificial) defects at a selected site (at Sätra, Stockholm Road Bypass)

2) Calibration of the RBT instrument on the reference bolts

3) Evaluation of the test results and comparisons with the reference bolts

4) Reporting, review and proofreading.

1.4 Constrains

This project focuses on fully grouted PC- and NC-bolts, and on the function of the RBT with regards to the instrument capability of detecting artificial cavities in the grout of these rock bolt types installed at a test site in Stockholm.

2. Measurement principles and methodology

2.1 Measurement principles

The RBT instrument operates on the principle of ultrasonic guided waves (GW) that propagate in solid media limited by hard boundaries, for instance, plates, bars and tubes. Guided ultrasonic waves have a more complex physical behavior than bulk elastic waves, i.e. longitudinal (L) and shear (S) waves, commonly used in NDT methods. Guided waves are multimodal and dispersive, which means that, during propagation, a number of wave modes can propagate simultaneously with different velocities that are frequency dependent. The basic modes encountered in bars and tubes are compressional (Comp), torsional (T) and flexural (Flex) modes. If a pulse of a guided wave propagates through a bar, the dispersion effect will cause its deformation, i.e. the pulse will be stretched in time and its envelope will become elongated. The longer the propagation length, the more pronounced the dispersion effects will be. Guided waves have an important advantage – they can travel over long distances through pipes, bars and plates.

2.2 The Rock Bolt Tester

The Rock Bolt Tester (RBT) (Fig. 2-1) is a PC based measuring instrument that contains specially designed and digitally controlled analog electronics and a Data Acquisition card (DAQ) for generating, sampling, and converting electric signals into a digital form (Stepinski and Mattsson 2014 and 2016).

Figure 2-1. Rock Bolt Tester (RBT).

The RBT's electronics, shown in Figure 2-2, consists of a signal generator and signal receiver board connected to ultrasonic probe and a DAQ board from National Instruments. The electronic boards communicate with a Windows based tablet via the DAQ card.

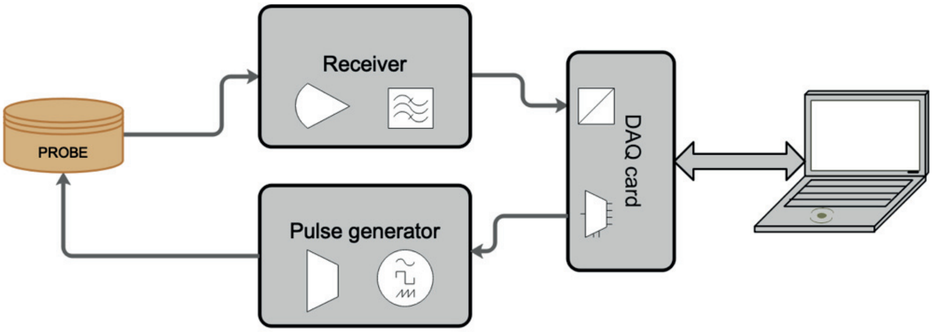


Figure 2-2. Block schema of the Rock Bolt Tester.

The specially designed ultrasonic probe contains four powerful piezo elements integrated in a 4-quadrant bottom plate. One pair of the piezo elements operates as transducers that generate elastic waves, and the second pair is used as receivers for sensing the echo signals propagating back from the bolt. The element pairs can be configured to be most sensitive for compressional (Comp) or quasi-flexural (Flex) modes. To facilitate acoustic and mechanic coupling to the bolt end, the probe has four strong magnets attracting it to the outer face of the inspected bolt.

The RBT instrument operates in a pulse-and-echo mode, which means that a strong guided wave mode is initiated first, and then, small amplitude echoes received form the bolt’s end as well as the discontinuities present in grouting are received during some time interval. The probe transmitters, which are excited by high-energy pulses from the pulse generator, produce mechanical vibrations initiating guiding waves. These propagate thorough a steel bolt embedded in a grout towards the embedded bolt’s end where they are reflected. A part of the wave energy leaks out into the grout and further into the surrounding rock if a bolt is well grouted. The resulting energy loss creates a length-dependent attenuation of the wave echo returning to the probe through the bolt. The attenuation amount depends on the acoustic properties of the grout and rock. For embedded steel rock bolts, attenuation is lower for an epoxy grout than for a cement grout, which is commonly used in Scandinavia. If discontinuities are present in the surrounding grout (e.g., due to air pockets, cracks, or steel corrosion), these can also reflect the waves and generate a stronger echo that can return to the probe before dissipating. The echo signals formed by the reflection from these discontinuities in the grout and by the bolt end are received by the sensing elements of the probe, amplified and analyzed in by the RBT.

Attenuation of guided waves propagating in grouted bolts, which is much higher than for a steel bar in air, sets a limit for the lengths of rock bolts that can be reliably tested (typically around 4 meters). To extend the length range of the battery-operated RBT, a solution commonly used in radar technique was applied. The operation principle is illustrated in Figure 2-3.

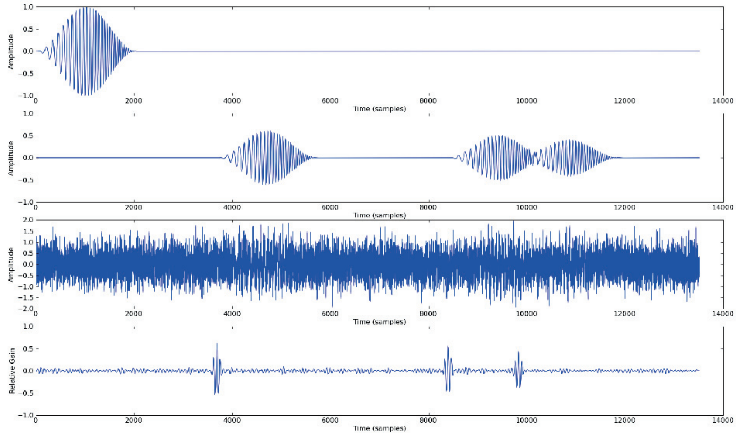


Figure 2-3. Illustration of the matched filter operation used in the RBT (simulation). Starting from the upper panel: Chirp signal emitted by the probe; Echo signals that could be received by the probe sensor if there were no noise; Echo signals corrupted by noise; Matched filter output after filtering the noisy signal.

The transmitter generates long pulse trains since high amplitude pulses are difficult to produce in a battery-operated instrument. The pulse trains take the form of a broadband sine wave with variable frequency (chirp). The energy of the generated wave depends on the length and shape of the pulse train. The received echoes are filtered in the RBT by digital filters, matched to the specific pulse train emitted by the generator, and produce at their output short pulses with high amplitude.

Two separated pulse sequences generate compressional (Comp) and quasi-flexural (Flex) waves that travel through the bolt. The receiver has two separate mode-sensitive channels capable of amplifying received small signals and presenting the Comp and Flex modes on separated graphs. Matched filtering of the received signal results in a considerable increase of the signal to noise ratio and length resolution.

The velocities of the Comp and Flex waves depend on the material type they travel through. Therefore, velocities in a bare steel rod are considerably higher than those in a grouted bolt, and velocities in a cement grout are higher than velocities in an epoxy grout. For this reason, estimation of the length of a bolt based on the wave travel time can be only approximative (precision up to ±0.05 m). Grouting type and thickness, rock type and bolt type also affect the amplitude of the echo created along the rock bolt.

The RBT is designed to detect defective grout in ordinary embedded rebar bolts with diameter Ø 20 to 25 mm and with length up to maximum 4 m.

2.3 Preparation

Before the RBT measurement can be performed, the plate and nut of the rock bolt should be removed. If this is not done, the ultrasound signal might be dispersed and weakened at the bolt end. The exposed bolt-end should be grinded perpendicularly to the bolt axis to achieve a smooth and planar surface that facilitates transmission of the ultrasound signal. Grinding also removes possible damage that the bolt has experienced during handling and installation, possible traces of epoxy coating of the bolt corrosion protection, traces of grout or shotcrete, etc. A contact agent, in the form of silicon or copper paste, is applied at the bolt end and the RBT probe is fixed onto the bolt end by permanent magnets integrated in the probe.

2.4 Methodology

A measurement with the RBT should be repeated at least three times by rotating the probe by approximative 120° around the bolt axis.

The relative RMS (root mean square) signal power is calculated for the measured signal and expressed in logarithmic scale (dB) to allow large and small values to be clearly displayed in the same graph. The RMS, commonly used as a measure of a signal power, is calculated as a square root of the sum of squared signal amplitude values within a defined time interval. For a discrete signal, it corresponds to the sum of N samples in the chosen interval, according to:

$$P_{RMS} = 1/N\sqrt{\sum_{i=0}^{N}(s_i^2)}$$

where s_i are the signal samples in the chosen length interval and N is the number of samples in this interval.

The relative signal power in the RBT is evaluated by calculating the RMS of the signal values within a preset interval, divided by the RMS of the signal measured in the same interval for a well-grouted reference bolt. The resulting relative power ratio is expressed in decibels as:

$$PdB = 10 \log \left(\frac{Ps}{Pr}\right)$$

where *Ps* is power of the measured signal and *Pr* denotes power measured on the bar used as a reference.

The RBT should be calibrated against the relative signal power obtained for a reference steel bar or against a reference value. Color strip scale indicator and the numerical PdB value between 0 (*PS* = *Pr*) and 12dB (*Ps* = 16 *Pr*) are displayed at the RBT's screen. The instrument's sampling period is 4 ms, which corresponds to approximately a bolt interval length of 16 mm for a wave velocity 4000 m/s. The length and position of the interval for the relative signal power calculation can be chosen by the operator.

2.5 The RMS classification system

The RBT automatically calculates the RMS value of the reflected compressional and flexural signal components. The RMS delivered by the instrument is used as a quality indicator of the bolt grouting quality.

The classification system developed for fully grouted rebar bolts consists of two classes, A and B. "A" implies that the grouting can be accepted, and "B" implies that the grout has flaws and the bolt should be rejected. During development of the system, it was concluded that the bolts classified as "A" are mostly included within a range of RMS-values between 0 – 11 (RMS dB) for the compressional waveform, and within a range of RMS-values between 0 – 16.2 (RMS dB) for the flexural waveform. These limits were obtained by a process of optimization of the number of bolts assigned by the classification system to the class of accepted rock bolts by the RBT and by the Boltometer, which is the instrument in use for bolt quality assessment in Sweden today. See an example of 299 rebar bolts, tested with both RBT and Boltometer, in Figure 2-4.

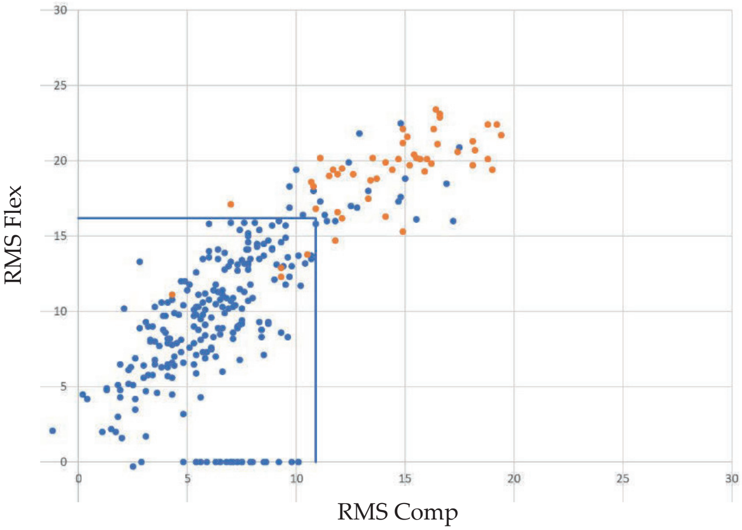


Figure 2-4. Compressional and flexural RMS for the tested rock bolts based on RMS-method. Blue color implies approved bolts, and orange color implies not approved bolts according to the Boltometer. The blue lines define the A to B limit according to the RBT and its classification system.

These ranges of values constitute the limits of the "A" class bolts for the RBT's classification system. Thus, if both the compressional and flexural wave RMS values fall within these limits, bolts are considered as accepted. Bolts with combinations RMS-values of the compressional and flexural wave that fall outside these limits should be considered by the RBT classification system as "rejected" or "B" class bolts, i.e. insufficiently or poorly grouted.

3. Test setup of the reference bolts

In the access tunnel AT215 (Sätra), a part of the Stockholm Bypass tunnel system (in Swedish, Förbifart Stockholm), 72 prepared bolts were installed as reference bolts for this project. 35 of the bolts were of the type PC-bolt and 37 NC-bolt by Pretec Cast Technology AB, which is deeply acknowledged for the sponsorship of this project. The refence bolts were installed in an area that will be accessible for many years ahead, even during the operational phase of the tunnels. A presentation of the prepared bolts is given in Table 3-1. Further details regarding the reference bolts can be found in Appendix 5.

The principles of the design and preparation of the reference bolts were developed in an earlier preparatory project under the auspices of BeFo (Andersson et al., 2020), which successfully verified the function of the RBT on fully grouted rebar bolts. The principles imply relatively large artificial cavities in the grouting, also referred to as artificial defects. The defects in the reference bolts are made by shielding a part of the space where the cement grout should be with plastic tubes and silicone.

The rock bolts were grouted with water-to-cement-ratio (WC-ratio) of 0.3. All holes were drilled into the tunnel wall with an angle of 30-50 degrees down from the horizontal plane. This was done to avoid air pockets forming in the grout. To further decrease the risk of air pockets, superplasticizer was added to the cement grout, and the bolts were vibrated after grouting.

Table 3-1. Details of the reference bolts by Pretec Cast Technology AB (www.Pretec.se).

	PC-bolts	**NC-bolts**
Diameter (thread)	R27/15	M20 x2,5
Minimum Failure load	191 kN*	186 kN*
Length	2.4, 3.0 and 4.0 m	2.4, 3.0 and 4.0 m
Combi coated	Yes	Yes
Material	40Cr	HRB500E

*According to Pretec, when fully grouted.

3.1 PC-bolts

The PC-bolt is basically a pipe bolt with a mechanical anchor at the bolt end. The "pipe" is used for the grouting process, as it leads the grout to the bottom of the borehole. The grout extrudes inside of the PC-bolt, to the bolt end and hereafter fills the borehole from bottom to top.

The defects introduced on the PC-bolts in this project are of different type and size, see Figure 3-1.

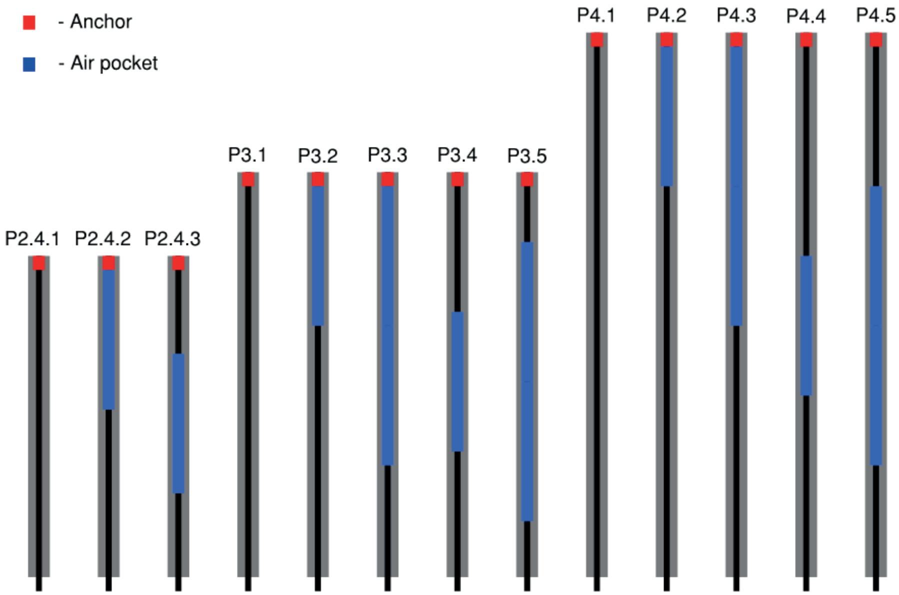


Figure 3-1. Illustration of the defect introduced during preparation of the PC-bolts. See also detailed description in Appendix 5.

3.2 NC-bolts

The NC-bolt is basically a rebar bolt with a grouting tube mounted outside. The tube is used for the grouting process, as it leads the grout to the bottom of the borehole. The grout extrudes outside the plastic tube, filling the borehole from bottom to top.

The defects introduced on the NC-bolts in this project are of different type and size, see Figure 3-2.

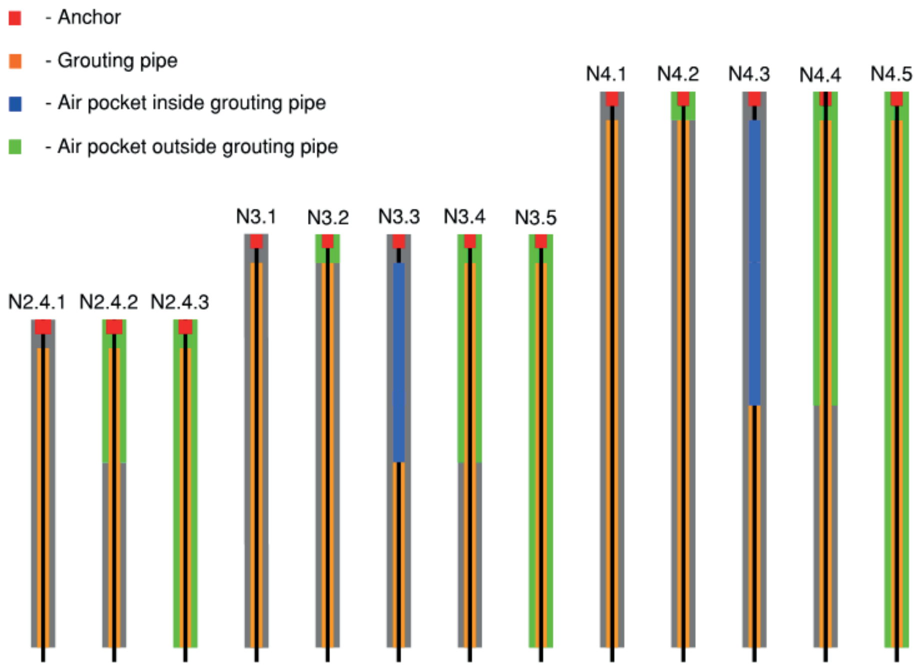


Figure 3-2. Illustration of the defect introduced during preparation of the NC-bolt. See also detailed description in Appendix 5.

4. Results

In total, 887 measurements were conducted on the 72 reference bolts. More details on the conducted work are summarized in Appendix 6.

4.1 PC-bolts

Results of the RBT measurements on PC-bolts are summarized in Figure 4-1 to Figure 4-3 for the bolts of 2.4, 3.0 and 4.0 m length (see also Appendix 1, 2 and 4). The RMS of the reflected compressional and flexural signal component are shown for each installed bolt.

For the PC-bolts of 2.4 m, it is not possible to even discern between bolts prepared with defects from those installed according to the bolt producer's instructions, and thus free from apparent defects.

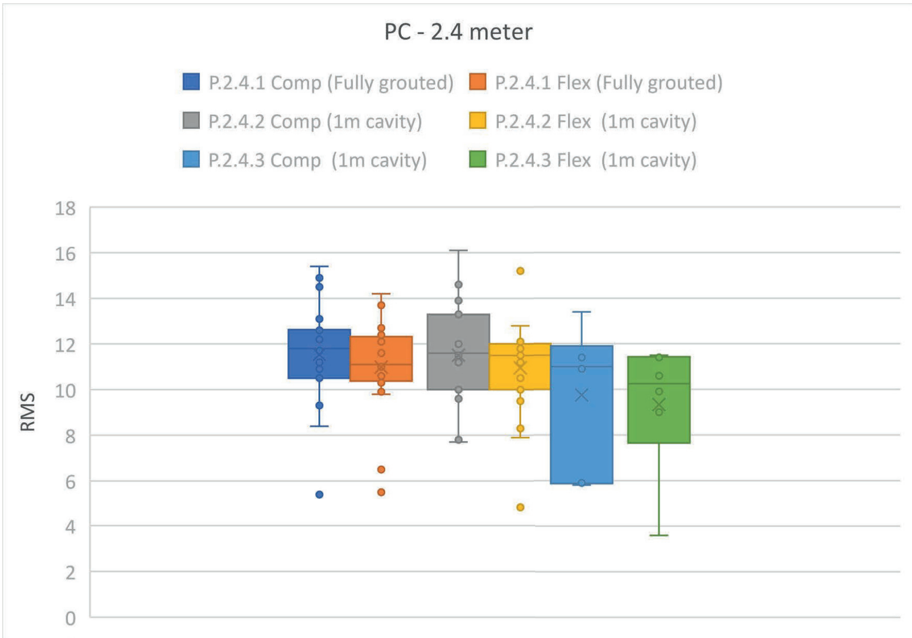


Figure 4-1. PC-bolts with length 2.4 meters. Box charts illustrating the spread of the RMS-values for each type of bolt preparation. See complete data sheets with echogram plots in the Appendices.

For the PC-bolts of 3.0 m, there is a weak but clearer difference in the power of the reflected waves between bolts prepared with defects and those installed according to the bolt producer's instructions, and thus free from apparent defects. On the other hand, it was not possible to identify any clear patterns of the relation between the artificial defects and RMS.

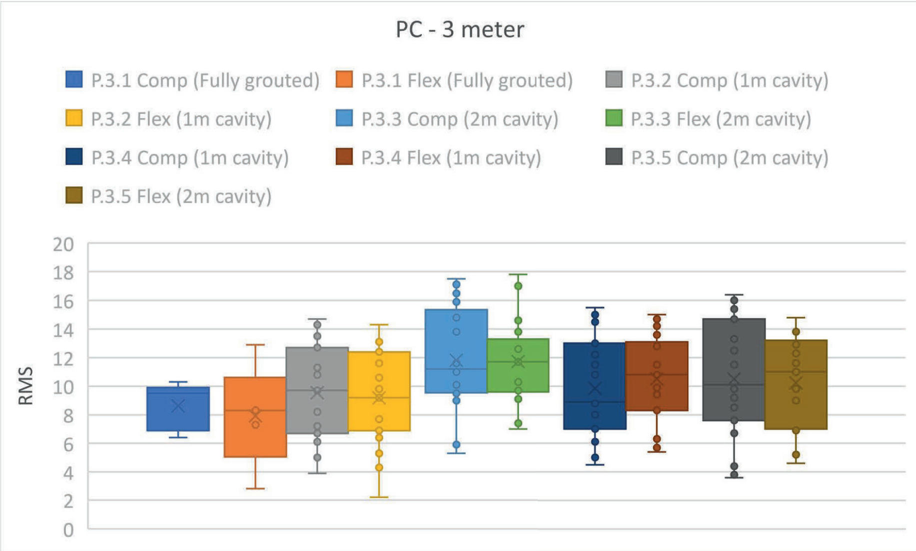


Figure 4-2. PC-bolts with length 3.0 meters. Box charts illustrating the spread of the RMS-values for each type of bolt preparation. See complete data sheets with echogram plots in the Appendices.

For the PC-bolts of 4.0 m, as for those of 2.4 m length, it is not possible to even discern between bolts prepared with defects from those installed according to the bolt producer's instructions, and thus free from apparent defects.

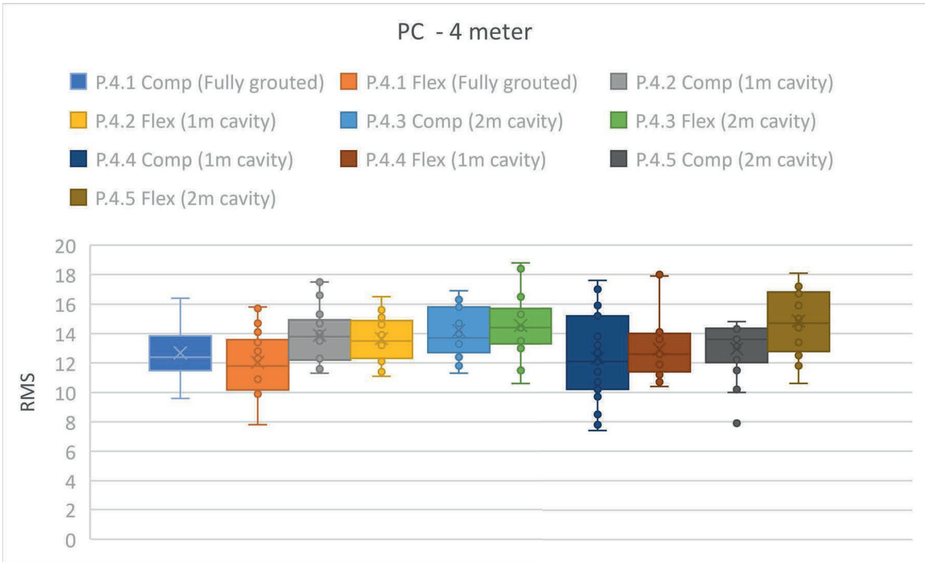


Figure 4-3. PC-bolts with length 4.0 meters. Box charts illustrating the spread of the RMS value for each type of bolt preparation. See complete data sheets with echogram plots in the Appendices.

4.2 NC-bolts

Results of RBT measurements on NC-bolts are summarized Figure 4-4 to Figure 4-6 for bolts of 2.4, 3.0 and 4.0 m length (see also Appendix 1, 3 and 4), where the RMS of the reflected compressional and flexural signal component are shown for each installed bolt.

For the NC-bolts of 2.4 m, it is not possible to even discern between bolts prepared with defects from those installed according to the bolt producer's instructions, and thus free from apparent defects.

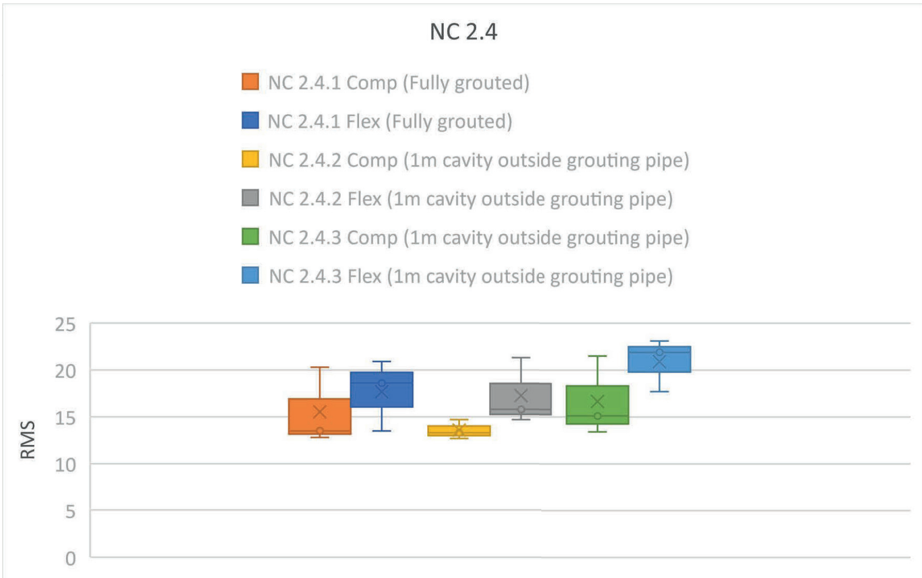


Figure 4-4. NC-bolts with length 2.4 meters. Box charts illustrate the spread of the RMS-values for each type of bolt preparation. See complete data sheets with echogram plots in the Appendices.

For The NC-bolts of 3.0 m, as for those of 2.4 m length, it is not possible to even discern between bolts prepared with defects from those installed according to the bolt producer's instructions, and thus free from apparent defects.

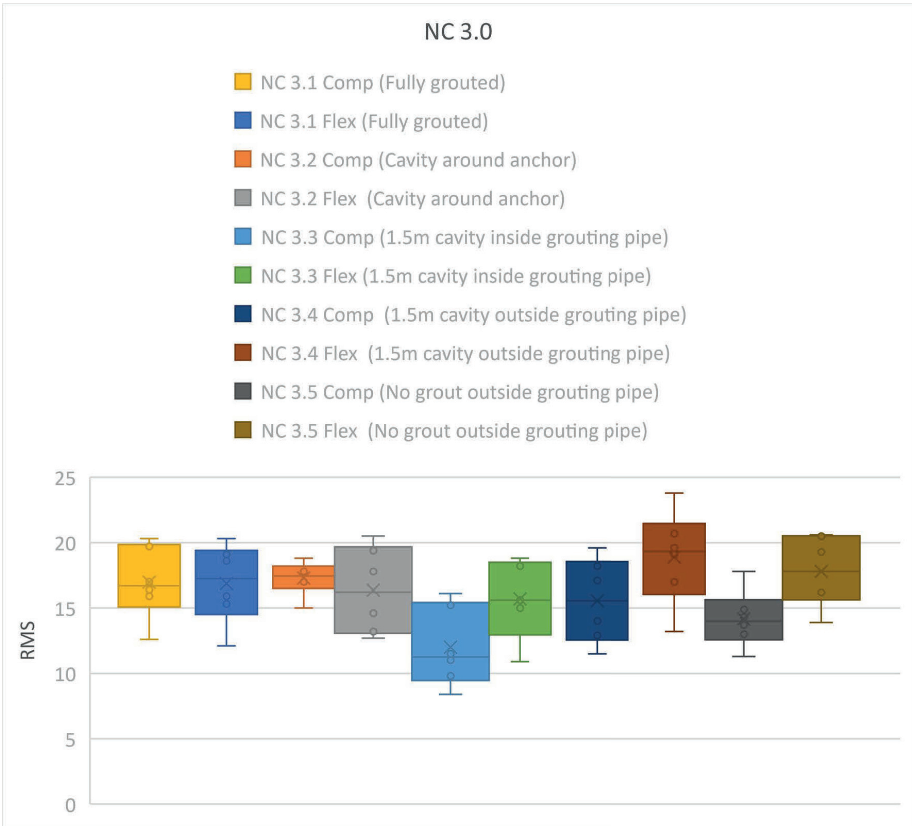


Figure 4-5. NC-bolts with length 3.0 meters. Box charts illustrating the spread of the RMS-values for each type of bolt preparation. See complete data sheets with echogram plots in the Appendices.

For the NC-bolts of 4.0 m, as for those of 2.4 and 3.0 m length, it is not possible to even discern between bolts prepared with defects from those installed according to the bolt producer's instructions, and thus free from apparent defects.

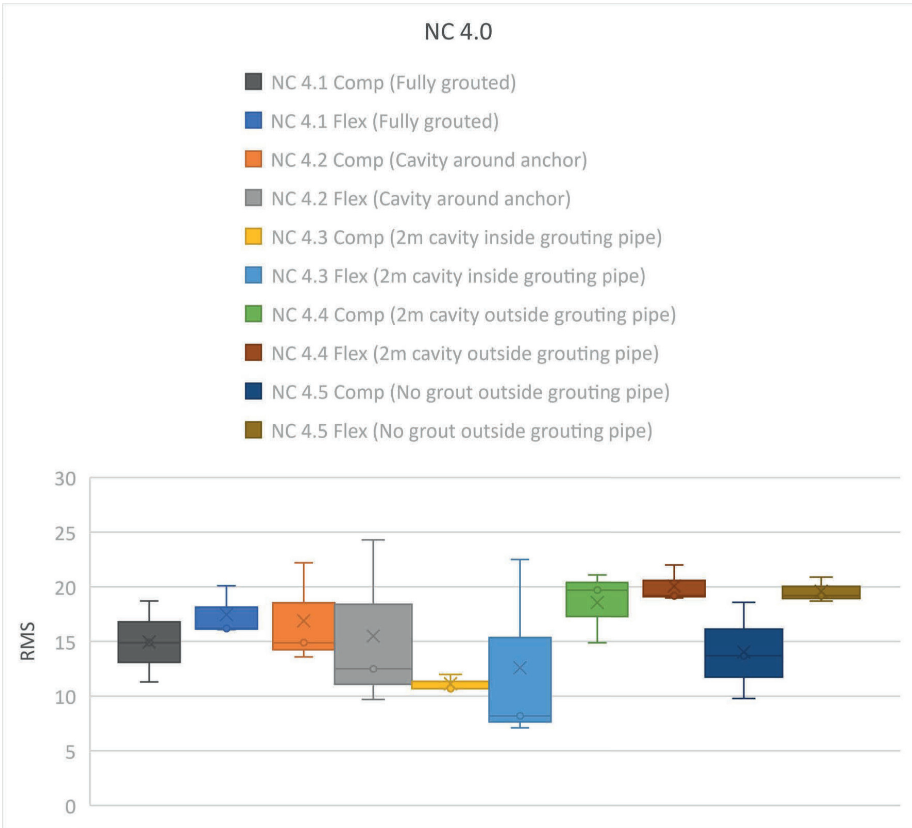


Figure 4-6. NC-bolts with length 4.0 meters. Box charts illustrate the spread of the RMS-values for each type of bolt preparation. See complete data sheets with echogram plots in the Appendices.

5. Discussion

In the following, the results of this study are discussed considering the present measurement and instrument set-up as well as possible recommended future modifications to improve the measurement outcome.

5.1 PC-bolts

The conclusion after the first test round was that it was not possible to distinguish any significant difference in RMS indices between the conducted measurements, even though some of the bolts were not grouted at a length of up to 66% of the total length. With this as a starting point, further investigations were conducted. First of all, the grinding was overseen, as a possible cause of measurement problem.

All bolts were re-grinded and afterwards new measurements were conducted. The grinding had a small impact on the measurements for some of the rock bolts that were poorly grinded from the beginning.

Furthermore, the sampling interval of the signal was overseen. The RBT's trigger delay was adjusted to 0, which is a setting that enables registration of the initial interval of the incoming signal. This was done to be sure that no important part of the signal was left out. New measurements were conducted, and the analysis method was overseen.

The full signal length, from excitation to reflection, was investigated for all reference bolts. Different length intervals for the RMS calculation were investigated, with no success in finding correlation with the prepared defects.

When analyzing the results from the PC-bolts, the conclusion was that the guided waves are possibly strongly scattered along the bolt length and most of the amplitude peaks are most likely flattened out by the scattering effect. The RMS-values were compared and, unfortunately, no correlation with the prepared defects was found, see the results in Chapter 4.

Two PC-bolts were tested in our laboratory environment. One was not grouted at all, and the other was grouted inside the hollow steel bolt pipe. This was done to investigate how the signal is affected by the fact that the core of the rock bolt consists of concrete. During this test, different lengths of the signal pulse train were used in order to find the optimal signal-setup for the bolt type (see Figure 2-3).

5.2 NC-bolts

The idea behind the setup of the reference NC-bolts with prepared defects was to investigate if it was possible to detect defects in the grouting, even if the defect is located outside of the grouting tube. Since the RBT is developed to be able to detect defects in the grouting surrounding rebar bolts, the main objective was to investigate defects occurring outside of the grouting tube of the NC-bolts.

The conclusion after the first test-round was that it was not possible to distinguish any significant difference in RMS indices between the conducted measurements, even though some of the bolts were not grouted at all outside the grouting tube. Therefore, further investigations were conducted.

The sampling interval of the signal was overseen. The RBT's trigger delay was adjusted to 0. This was done to ensure that no important part of the signal was left out. New measurements were conducted, and the analysis method was overseen.

The full signal, from excitation to reflection, was investigated for all reference bolts. For fully grouted rebars, the analysis focused on amplitude peaks and the RMS-values. Different length intervals for the RMS calculation were investigated, with no success in finding correlation to the prepared defects.

For defects where the air-steel contact occurred, an amplitude peak was observed as expected. This is the normal case for which the RBT was developed to detect. However, when the cavity was located around the grouting pipe, and therefore without any air-steel contact, it was not possible to distinguish any indication of cavity.

6. Conclusions and recommendations for future work

6.1 PC-bolts

The conducted tests resulted in the following conclusions regarding the RBT instrument ability to perform quality testing of the grouting of the PC-bolts using the RMS-index:

- The RBT with its present probe design is not capable of distinguishing defects in the grouting surrounding the PC-bolts. In order to detect voids, the following possible actions for future investigations are suggested:
    - Redesign the probe because the probe diameter needs to match the size of the bolt thread. The probe has to excite guided waves in the steel hollow bolt but it should not have contact with the bolt concrete core. See illustration of the problem in Figure 6-1.
    - Develop a method and a tool for effectively drilling out the first centimeter of the cement grout core at the bolt end to avoid wave propagation in the inner cement grout. The cement of the inner grout is most likely disturbing and causing scattering of the signal, which makes the interpretation of the test results difficult for the operator.

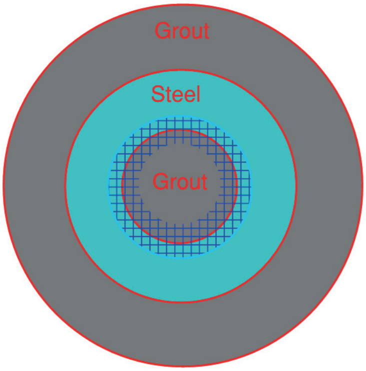


Figure 6-1. Illustration of the area of a PC-bolt where the ultrasound signal is applied with current RBT's probe design (blue hatch).

- Further research is needed to understand how the signal propagates in the complex steel-cement grout geometry of the PC-bolts. This could be done, as a first attempt, by using numerical modelling. This investigation could result in a better understanding of the most important parameters affecting the ability of the instrument of detecting defects, and provide guidance for a new probe design. Using this knowledge, a more advanced tool for the analysis and classification of the RBT signals than the present RMS-index, could be possibly developed.

6.2 NC-bolts

The conducted testing resulted also in the following conclusions regarding the RBT ability to perform quality testing of the grouting of NC-bolts:

- The RBT with its present probe design is not capable of distinguishing, using the RMS-index, defects in the grouting surrounding the NC-bolts. The geometry of these bolts is complex due to the presence of a plastic grouting tube. Further research is needed to understand the behavior of the signal in these environments. This could be carried out, as a first attempt, by using numerical modelling. The investigation could result in an understanding about which parameters are most important for detecting defects in the bolt cement grout and for providing guidance about the development of a new probe and signal design.

7. References

Buys B J, Heyns, P S, and Loveday, P W, 2009. Rock bolt condition monitoring using ultrasonic guided waves, The Journal of the Southern African Institute of Mining and Metallurgy 108, 97-105.

Beard M D, Lowe M J S, 2003. Non-destructive testing of rock bolts using guided ultrasonic waves. International Journal of Rock Mechanics & Mining Sciences 40, pp527-536.

Han S I, Lee I M, Lee Y J, and Lee, J S, 2009. Evaluation of rock bolt integrity using guided ultrasonic waves, Geotechnical Testing Journal, ASTM 32 (1), 31-38.

Li C C, Kristjansson G, Høien A H, 2016. Critical embedment length and bond strength of fully encapsulated rebar rockbolts. Tunnelling and Underground Space Technology, 59, p. 16-23.

Song G, Li W, Wang B, and Ho S, 2017. A review of rock bolt monitoring using smart sensors," Sensors 17 (4), 776.

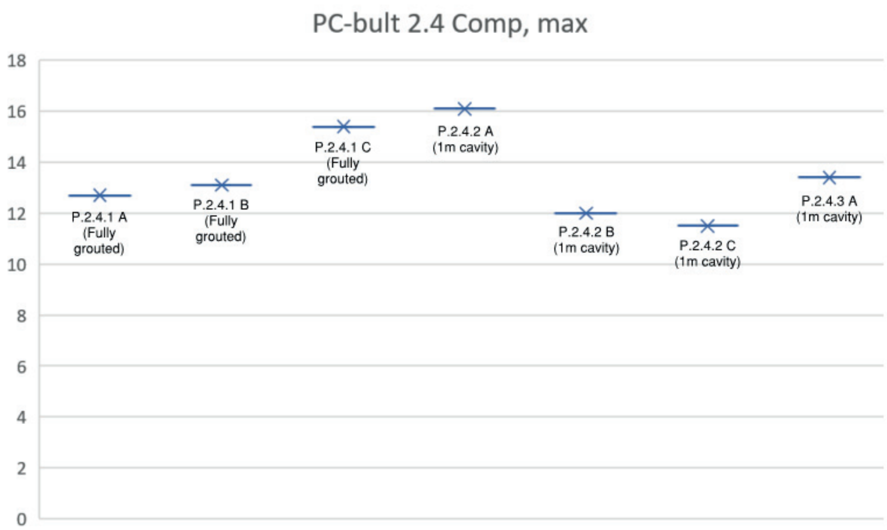
Stepinski T, Mattson, K-J, 2014. New instrument for rock bolt inspection using guided waves," in Proc. 11th World Conference on Non-Destructive Testing.

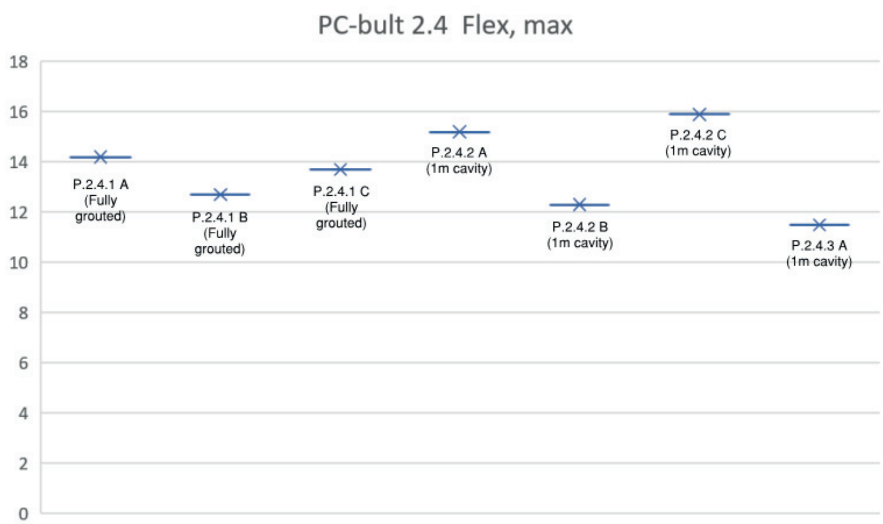
Stepinski T, Mattsson K-J, 2016. Rock bolt inspection by means of RBT instrument. In Proceedings of the 19th World Conference on Non-Destructive Testing, Munich, Germany, June 2016.

Thurner H, 1988. Boltometer-Instrument for Non-Destructive Testing of Grouted Rock Bolts. In Proceedings 2nd International Symposium on Field measurements in Geomechanics, Sakurai (ed.), Rotterdam. s. 135-143.

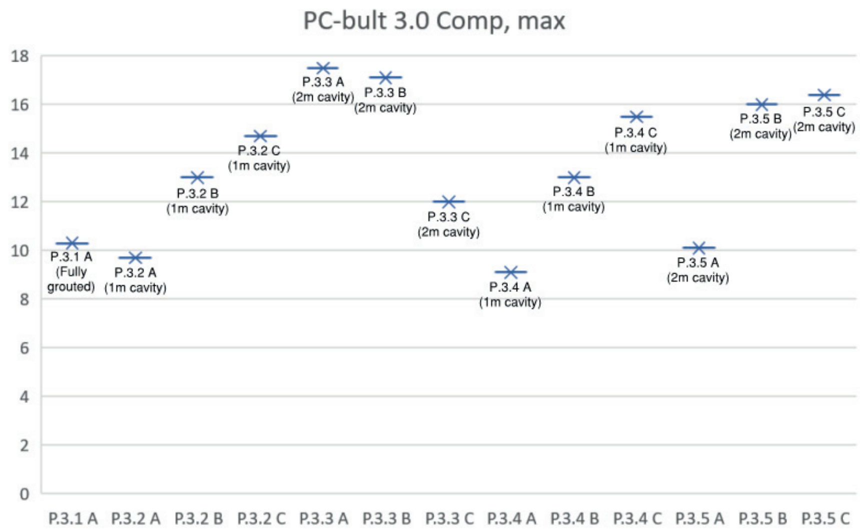
APPENDIX 1
MAXIMUM RMS PLOTS

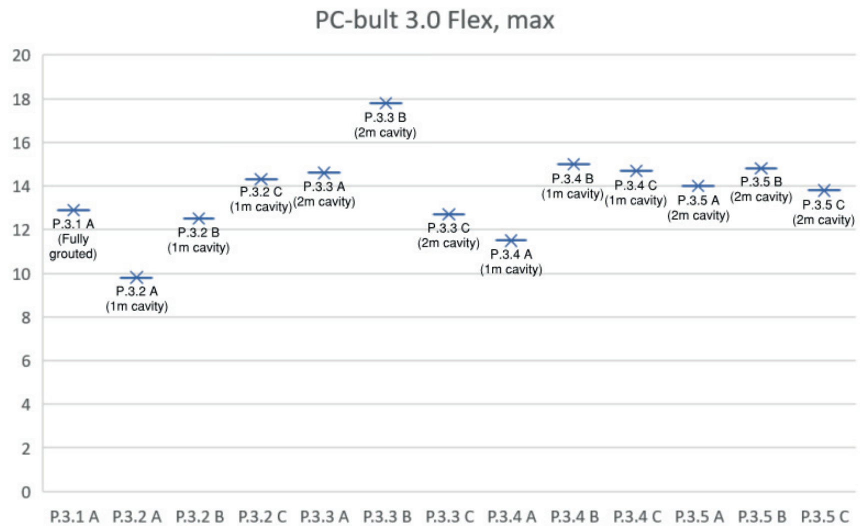
1. PC-bolts, length 2.4 m.



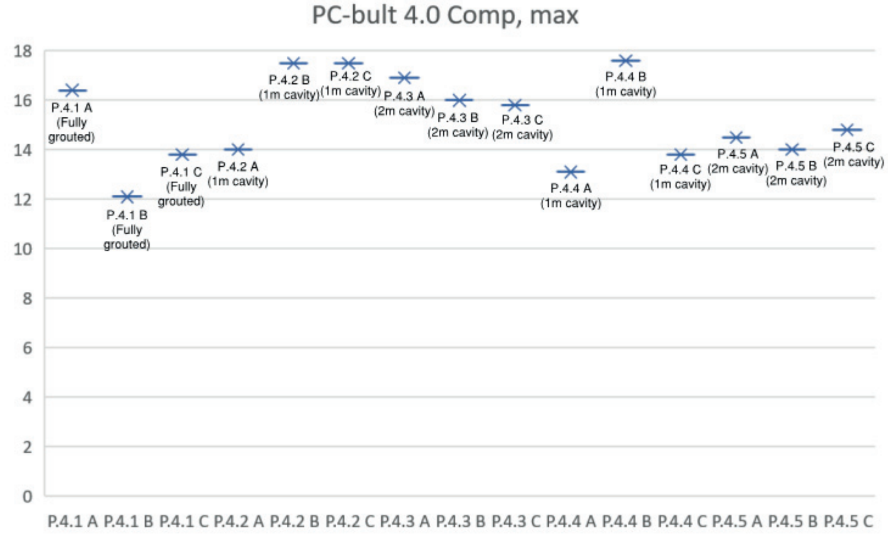


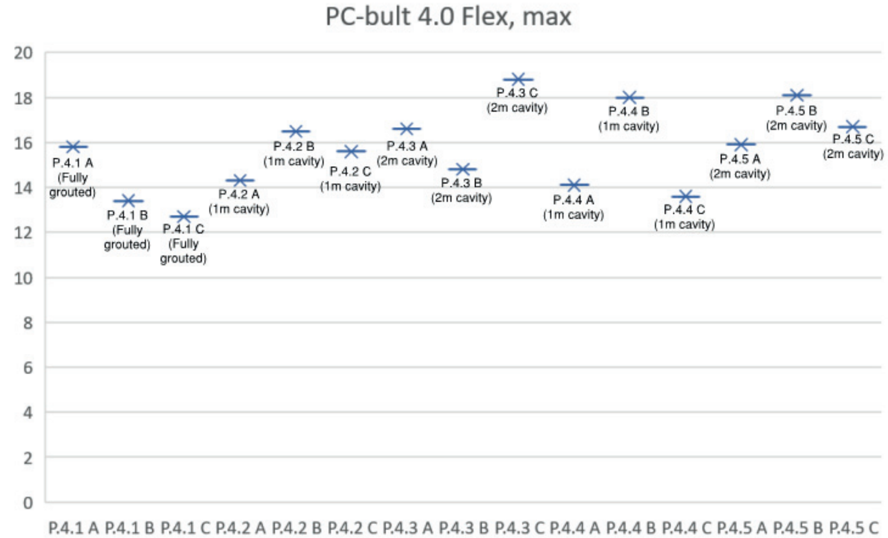
2. PC-bolts, length 3.0 m.



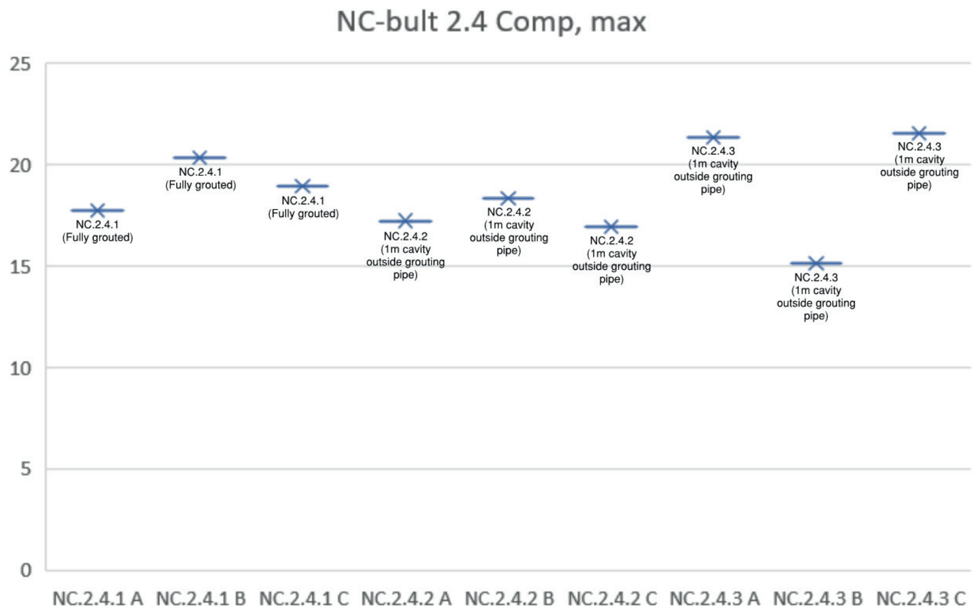


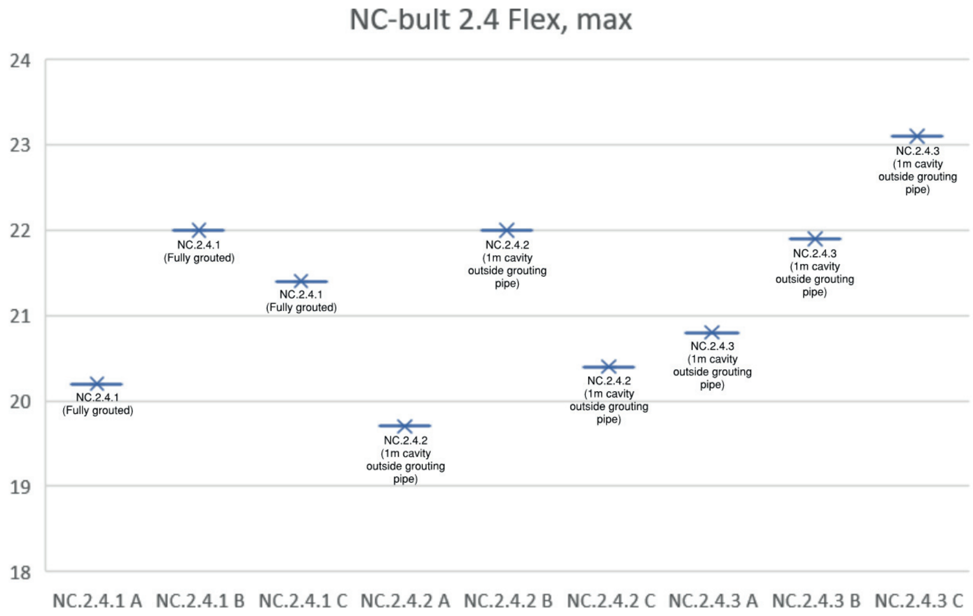
3. PC-bolts, length 4.0 m.



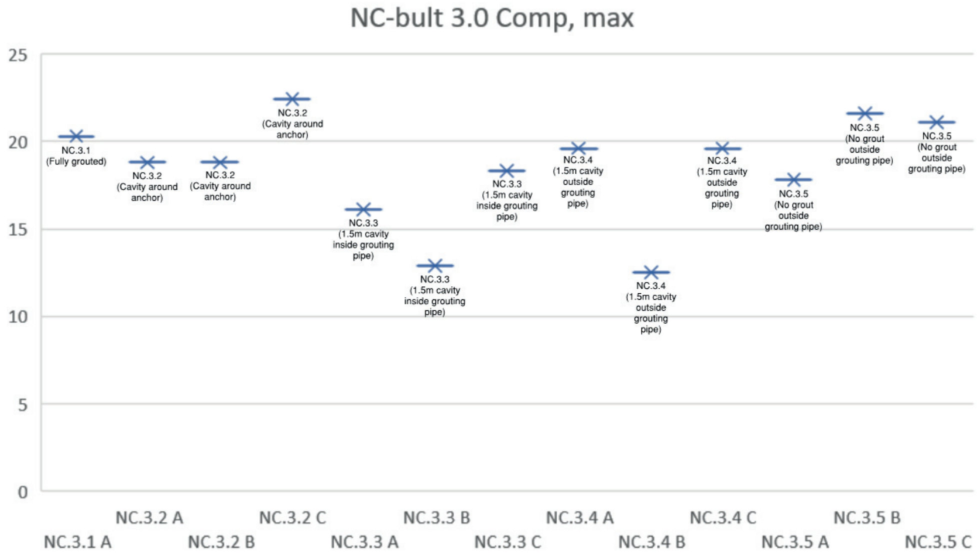


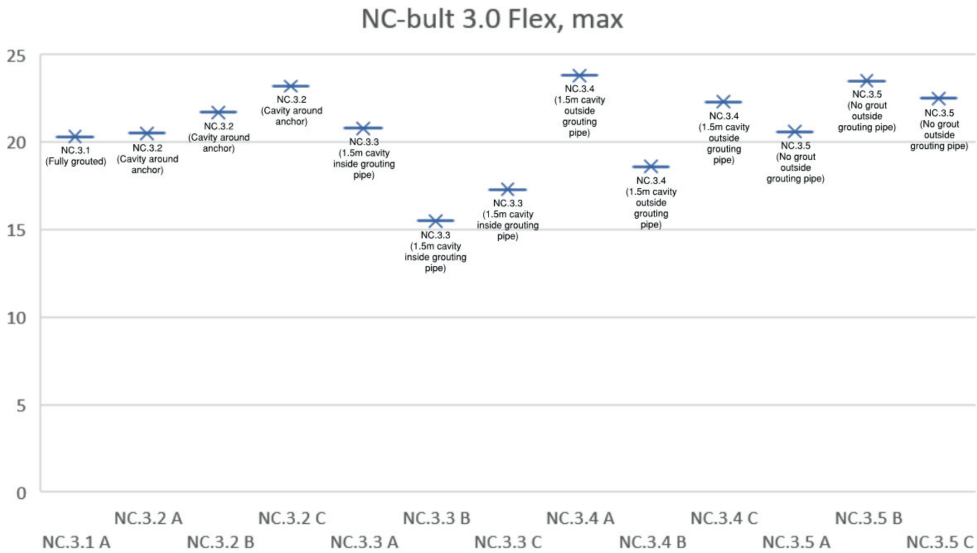
4. NC-bolts, length 2.4 m.



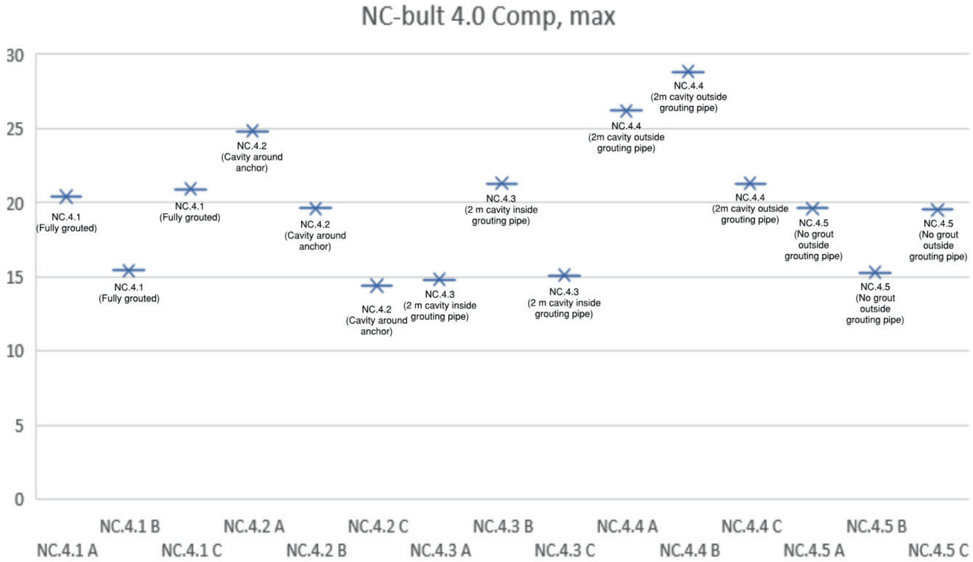


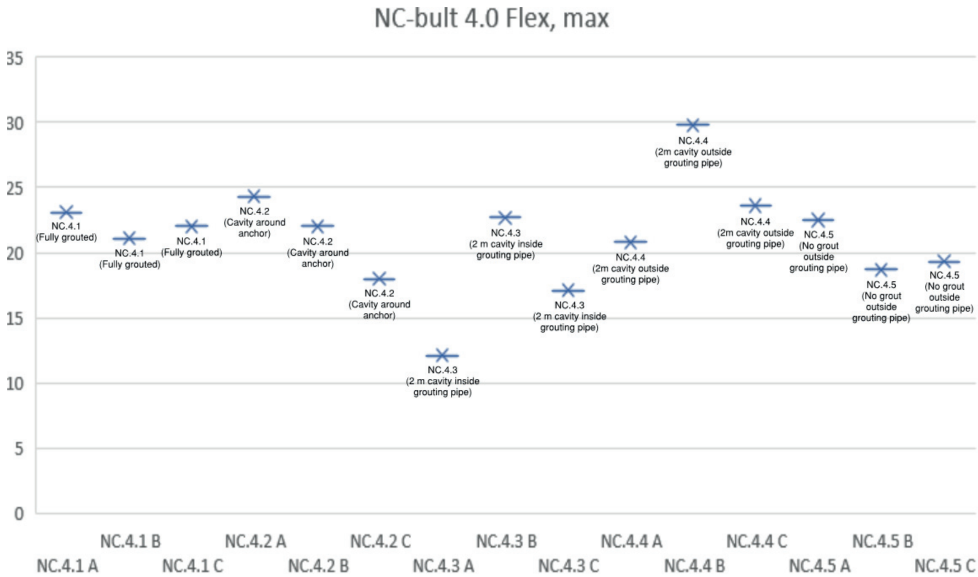
5. NC-bolts, length 3.0 m.





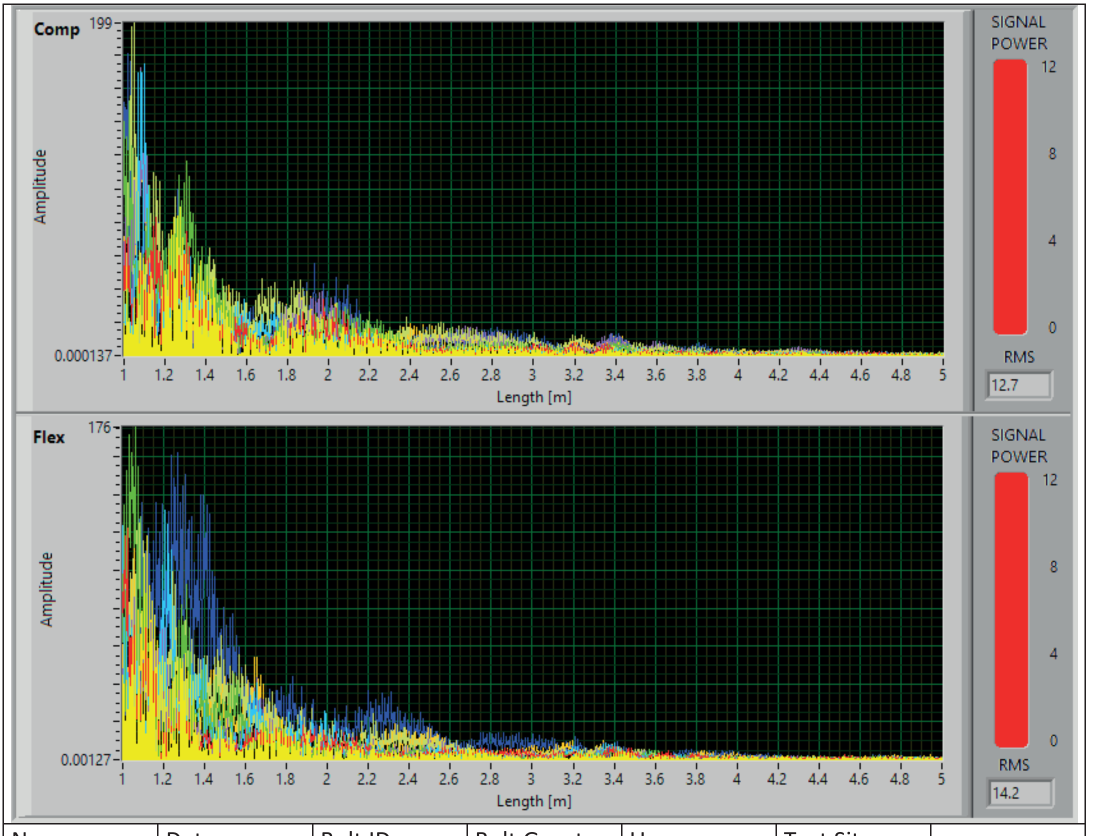
6. NC-bolts, length 4.0 m.



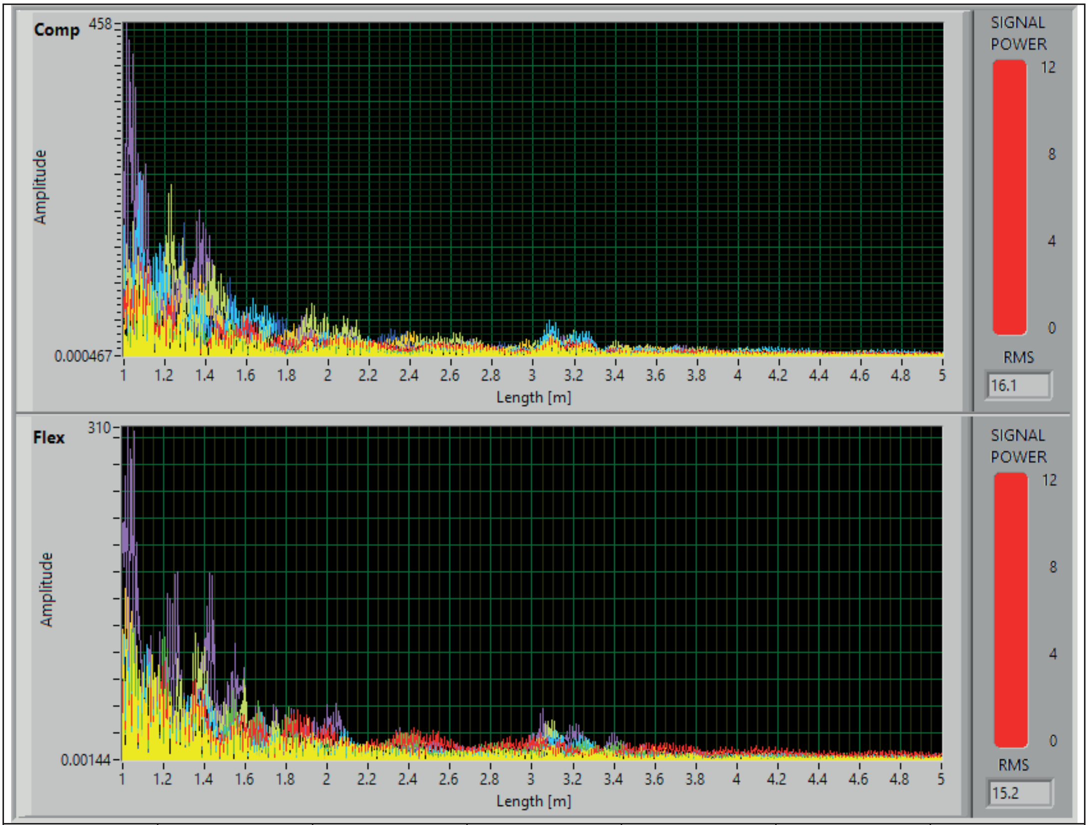


APPENDIX 2
RBT ECHOGRAM PLOTS FOR PC-BOLTS

Bolts named by the following system: Sätra *"Bolt type"_"Bolt ID"_"measurement nr on bolt".*

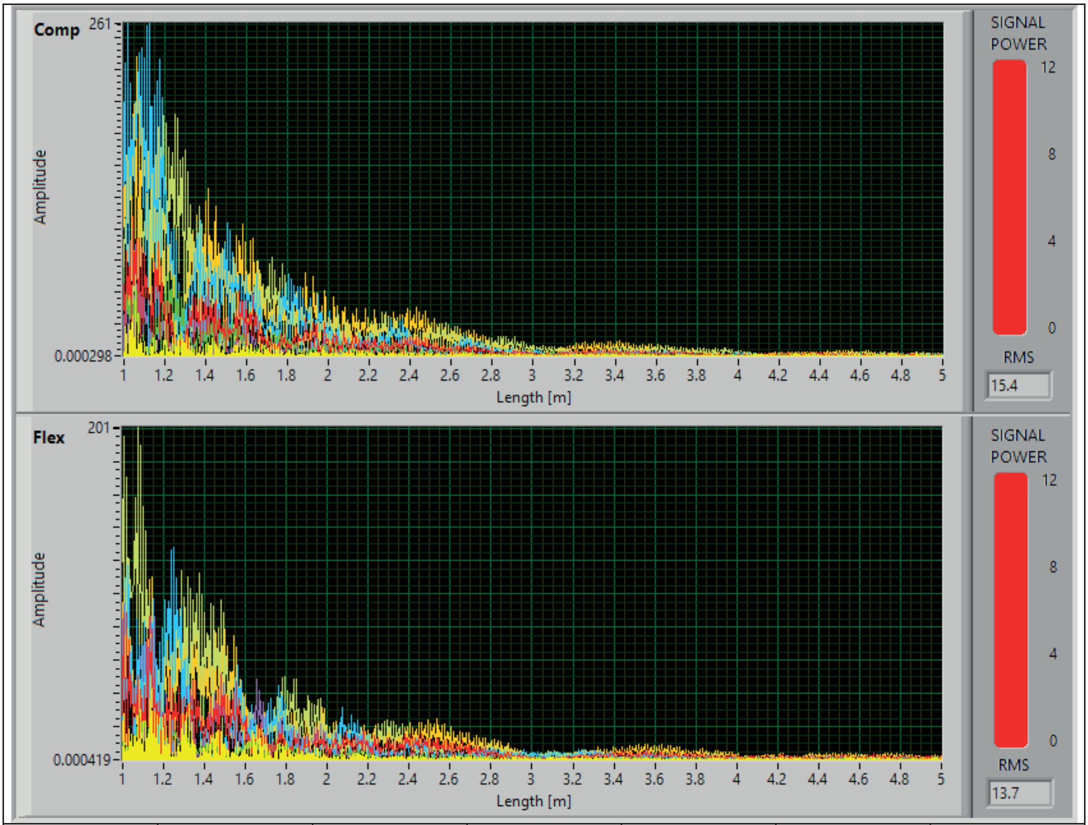


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_1_7 Sätra PC_1_4	2020/08/27		k	fra	Sätra PC	



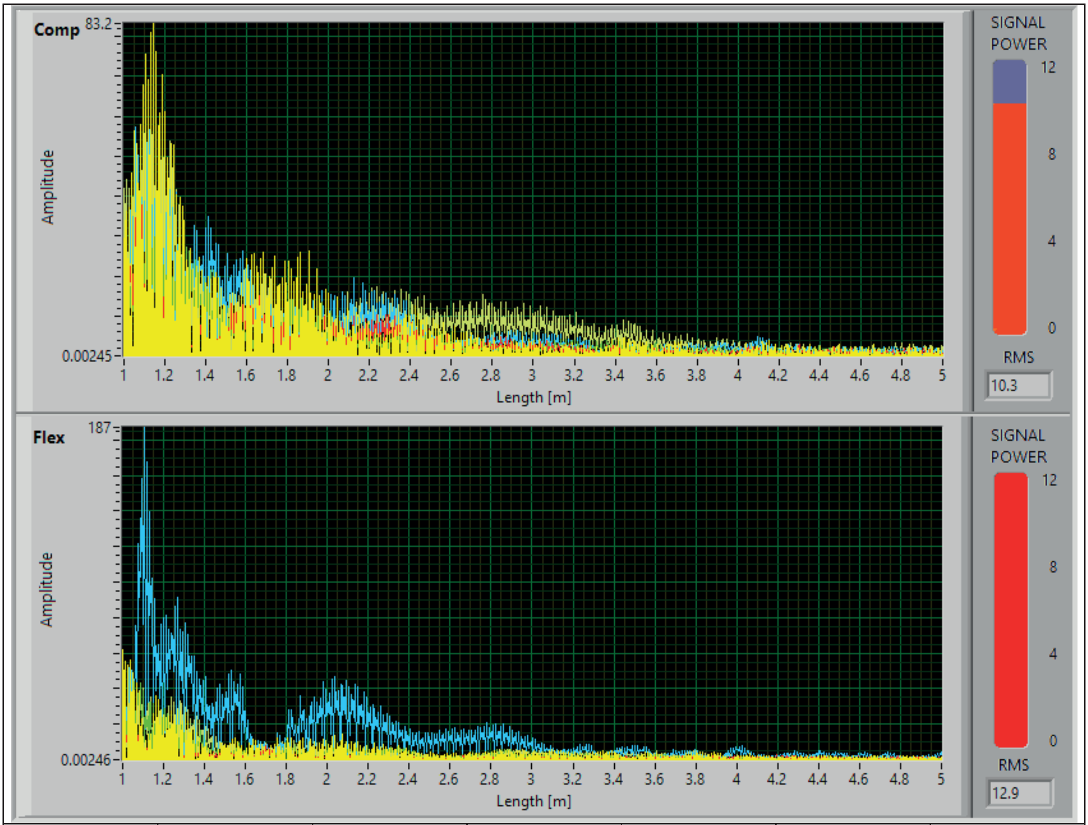
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_3_5 Sätra PC_3_5	2020/08/27		k	fra	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



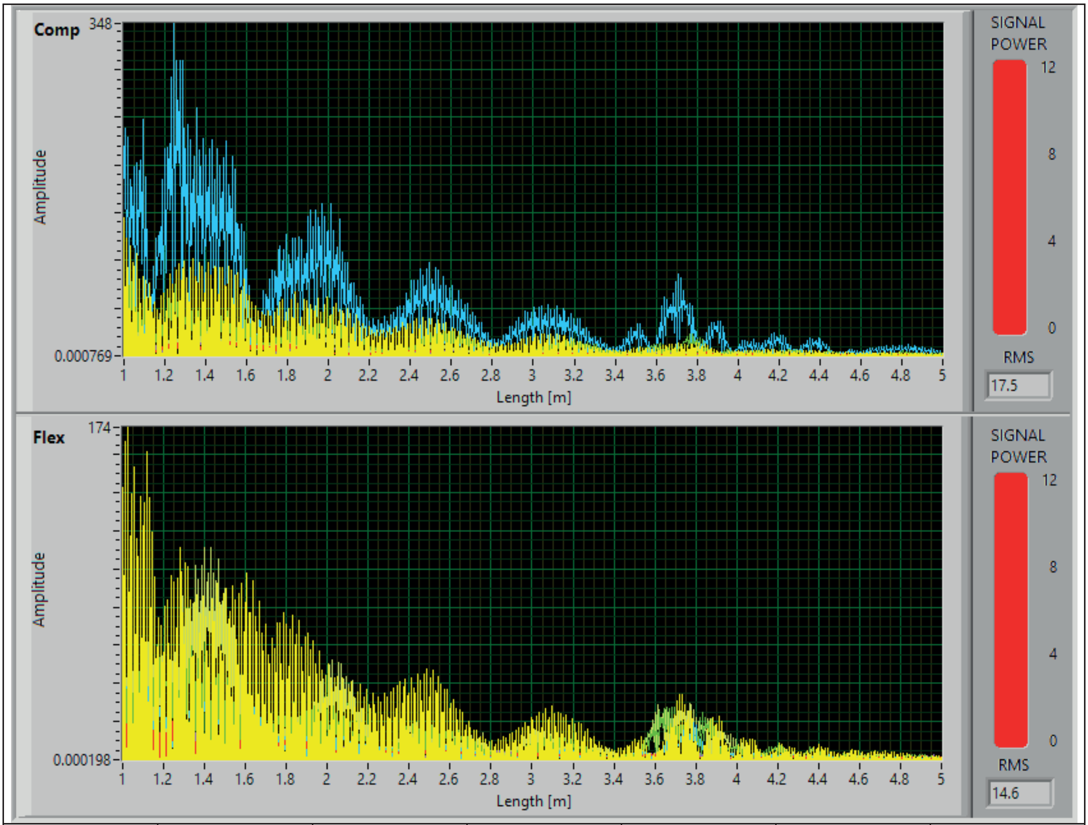
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_5_4 Sätra PC_5_3	2020/08/27		k	fra	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_6_3 Sätra PC_6_0	2020/08/27		k	fra	Sätra PC	

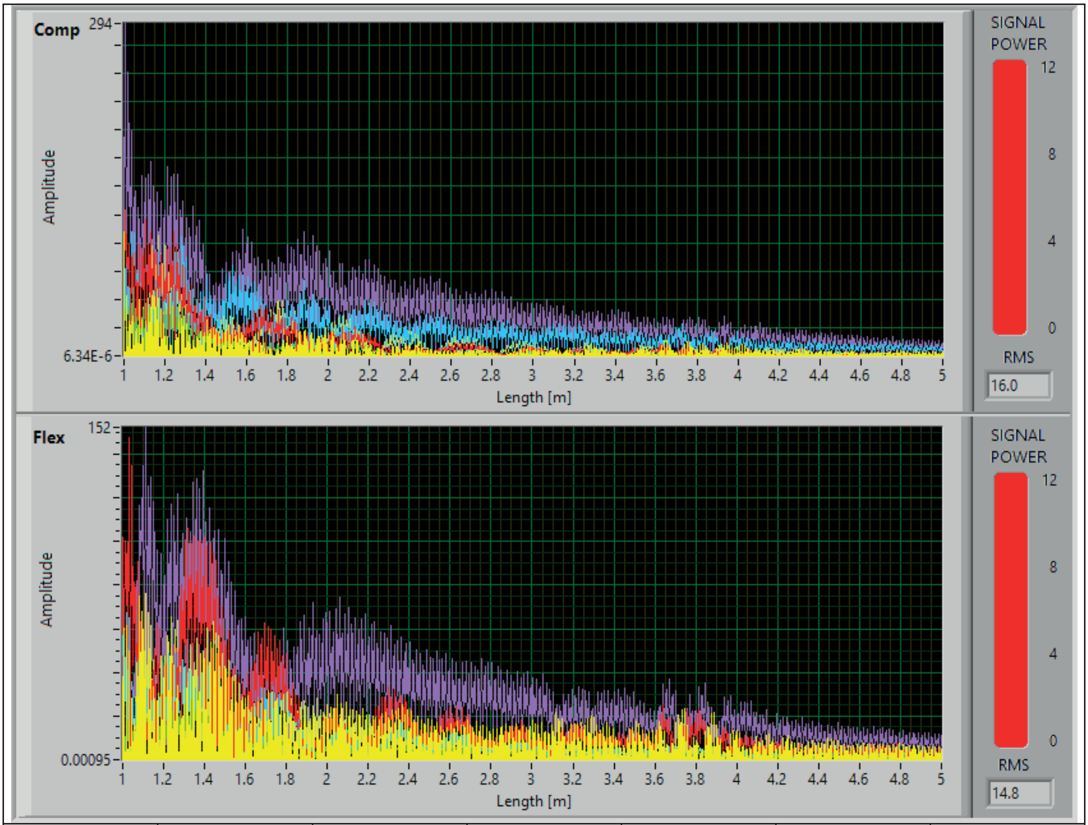
Appendix 2 – RBT echogram plots for PC-bolts



Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_7_0 Sätra PC_7_3	2020/08/27		k	fra	Sätra PC	

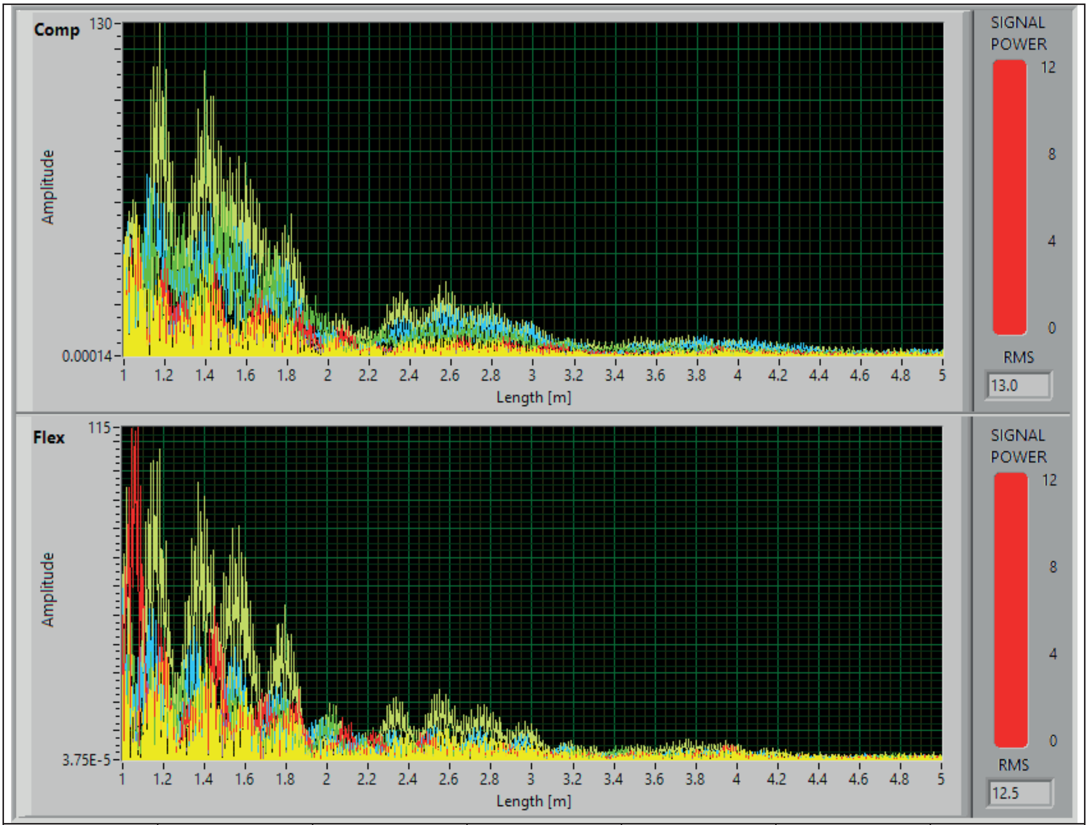
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_9_6 Sätra PC_9_4	2020/08/27		k	fra	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



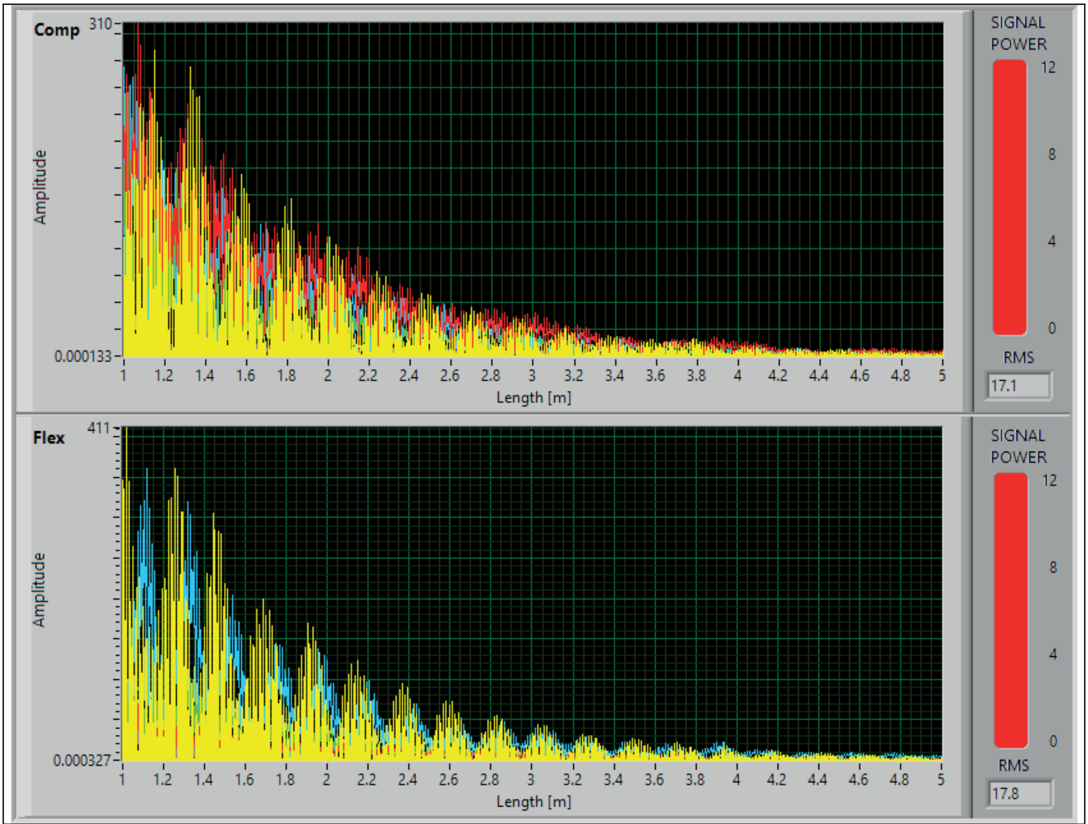
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_10_5 Sätra PC_10_5	2020/08/27		k	fra	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



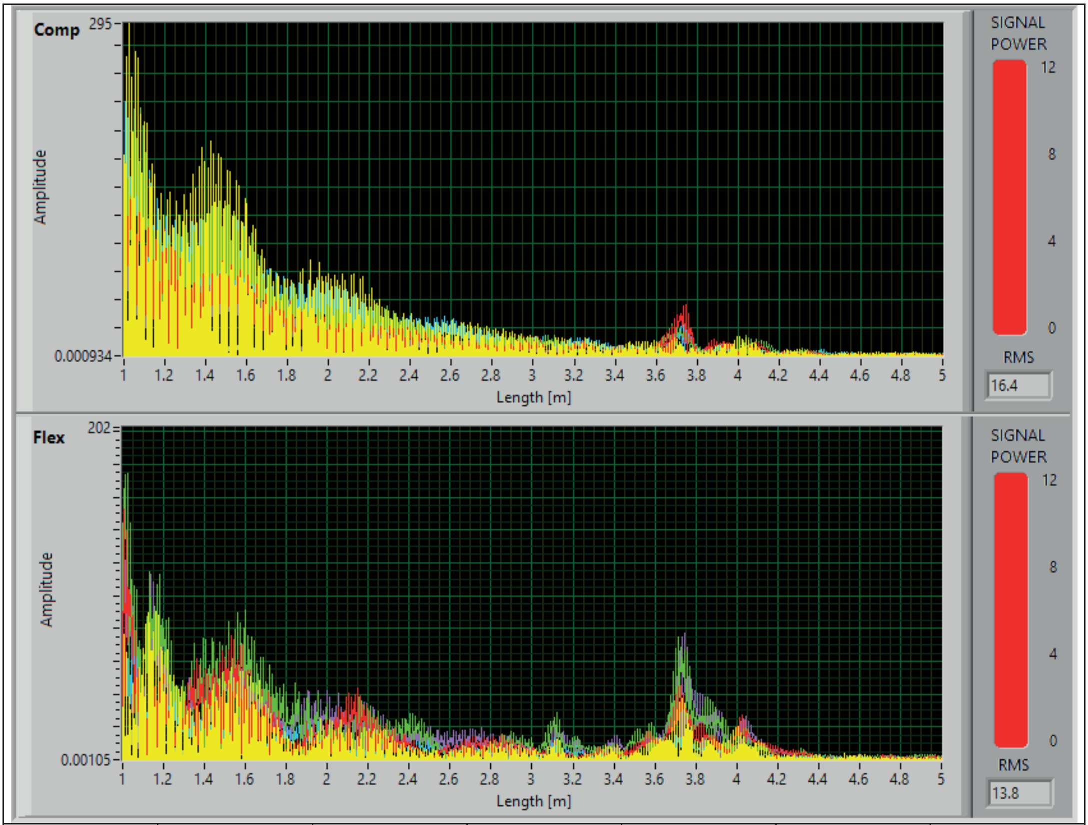
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_10_10 Sätra PC_10_10	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



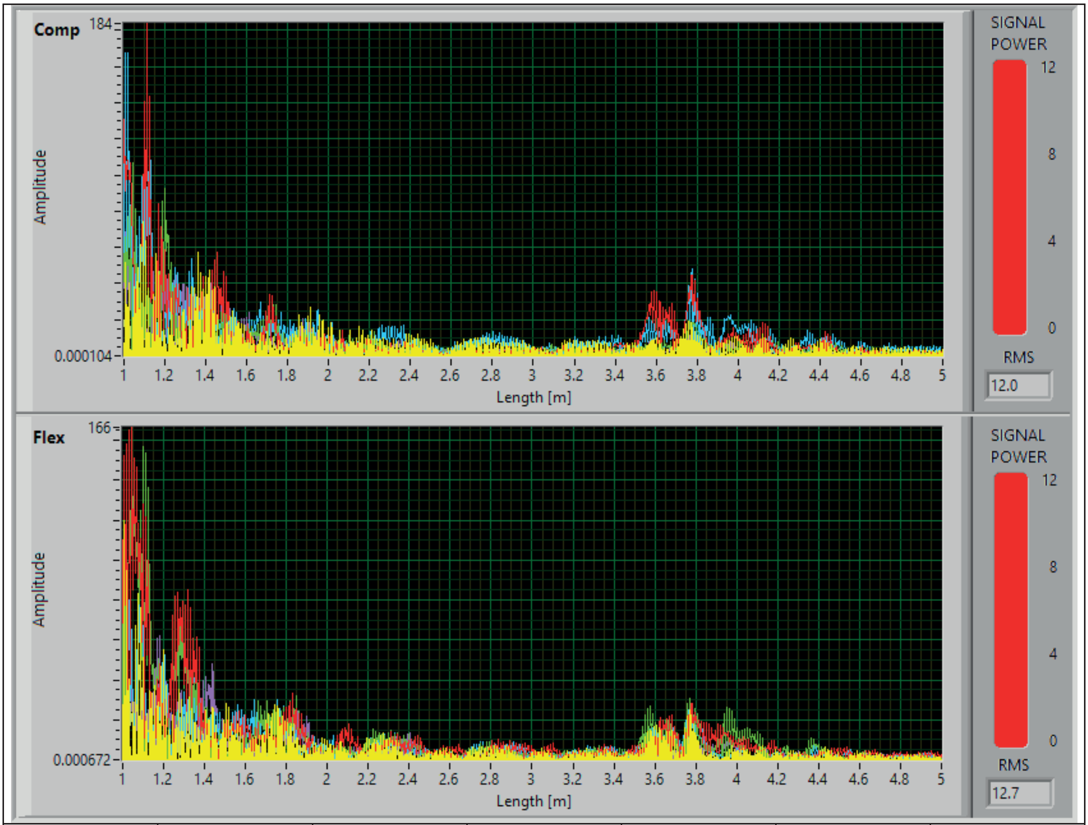
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_11_0 Sätra PC_11_1	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



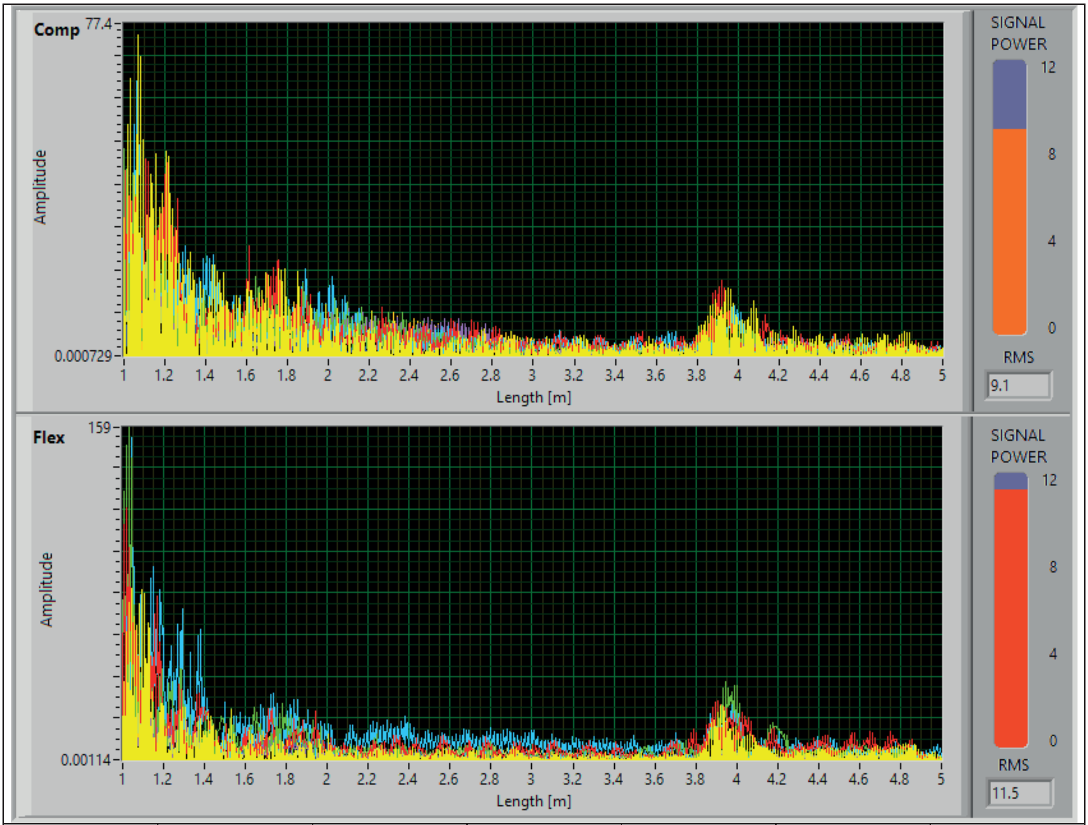
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_12_2 Sätra PC_12_0	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



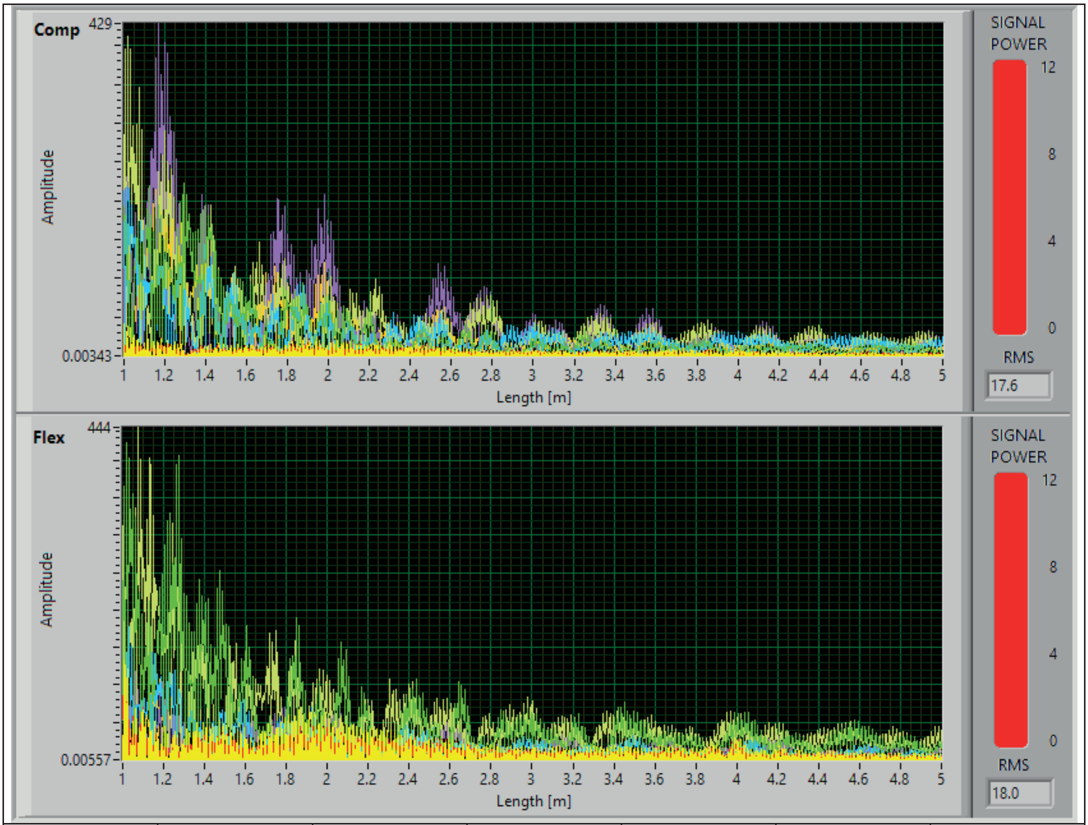
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_13_1 Sätra PC_13_1	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

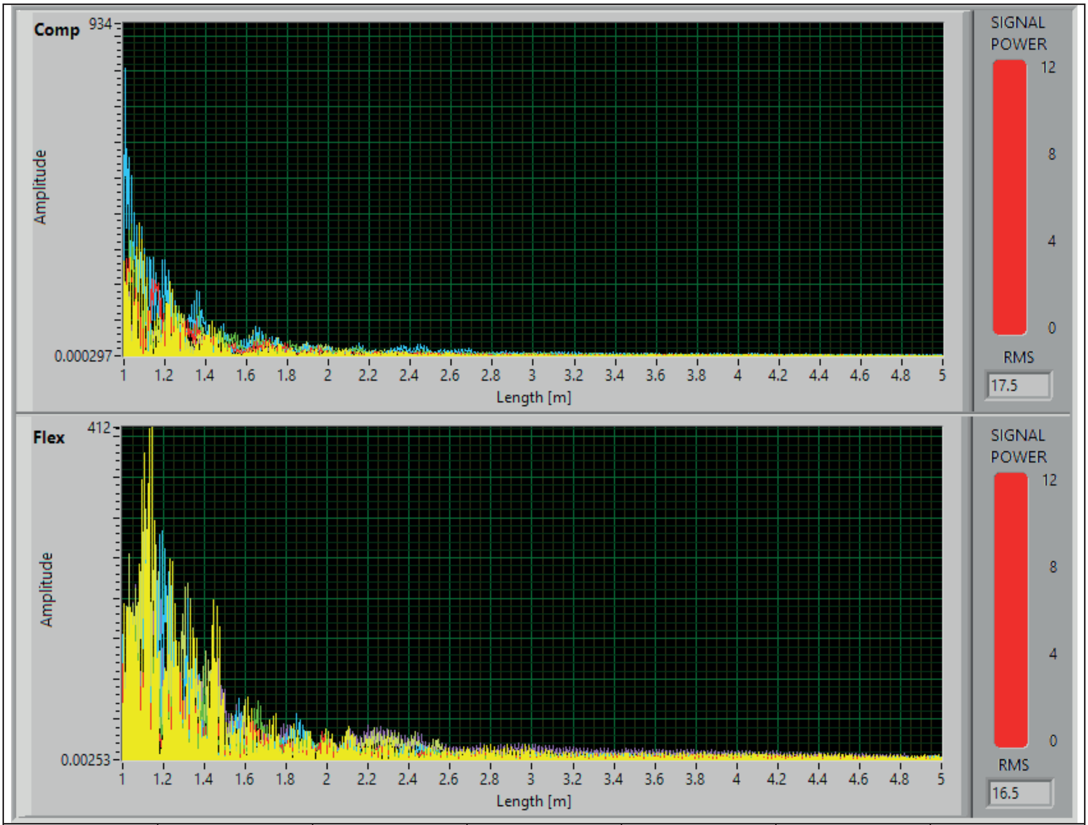


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_14_3 Sätra PC_14_0	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

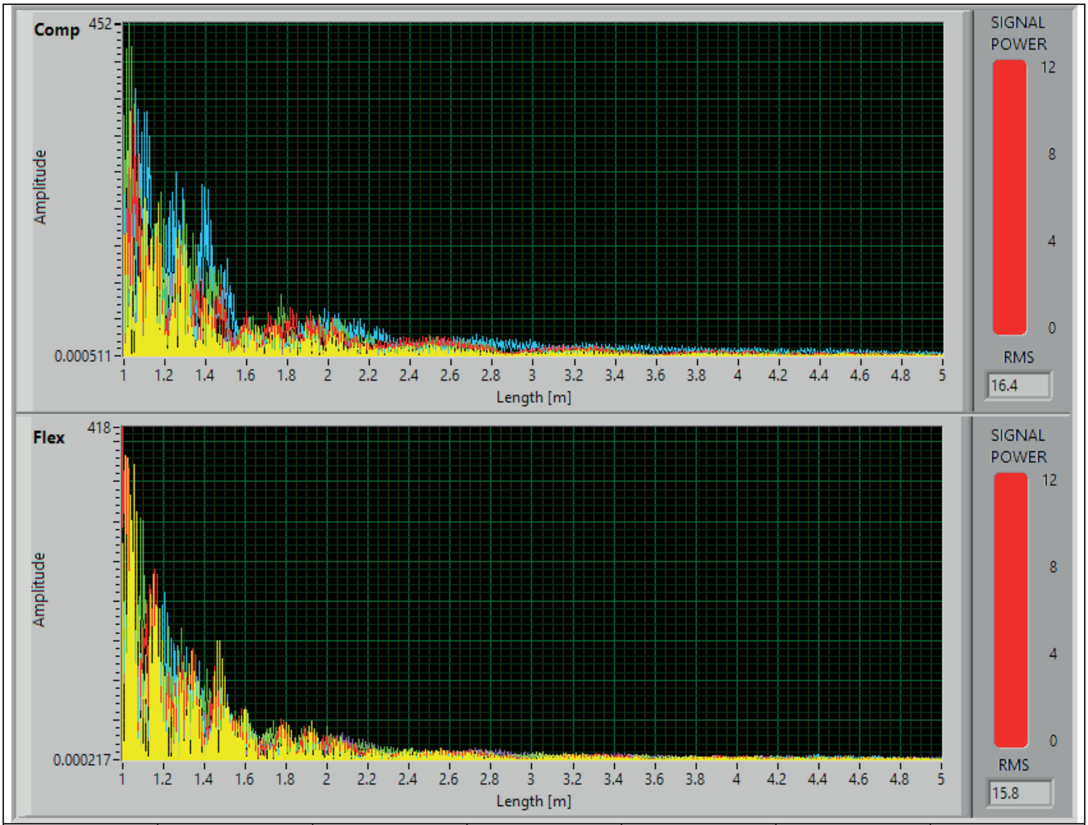


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_14_10 Sätra PC_14_13	2020/08/27		k	sk	Sätra PC	



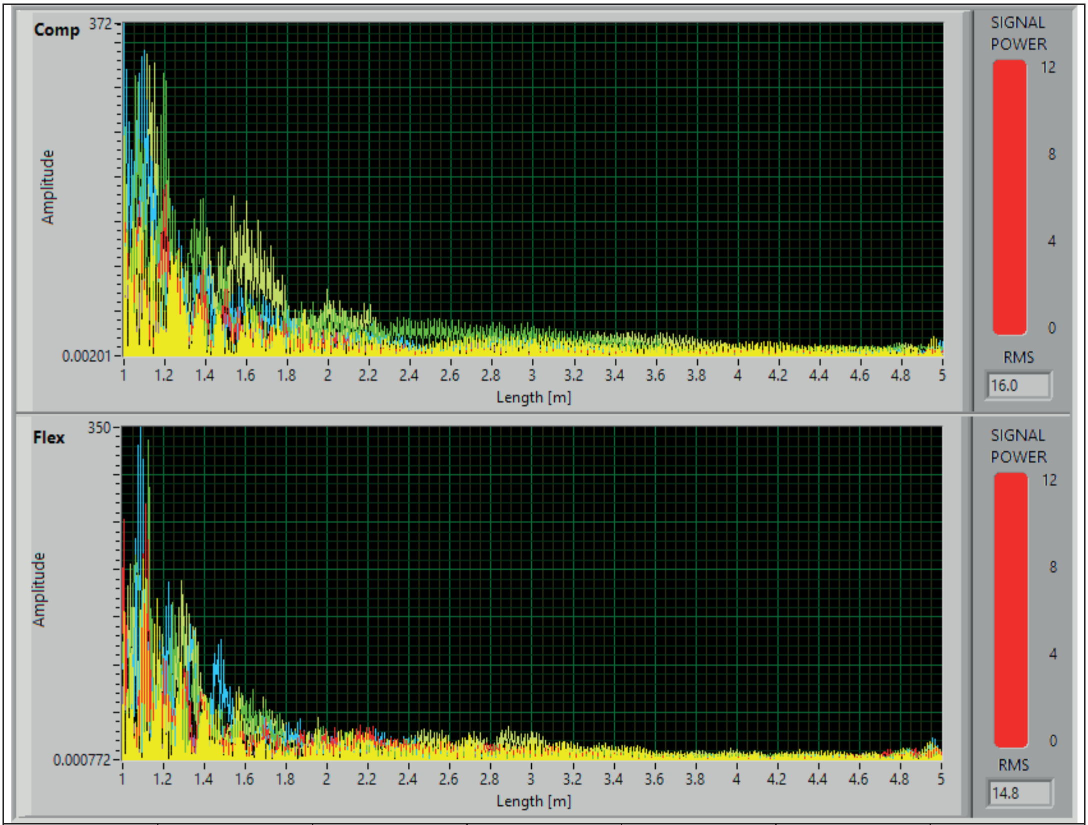
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_16_0 Sätra PC_16_3	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



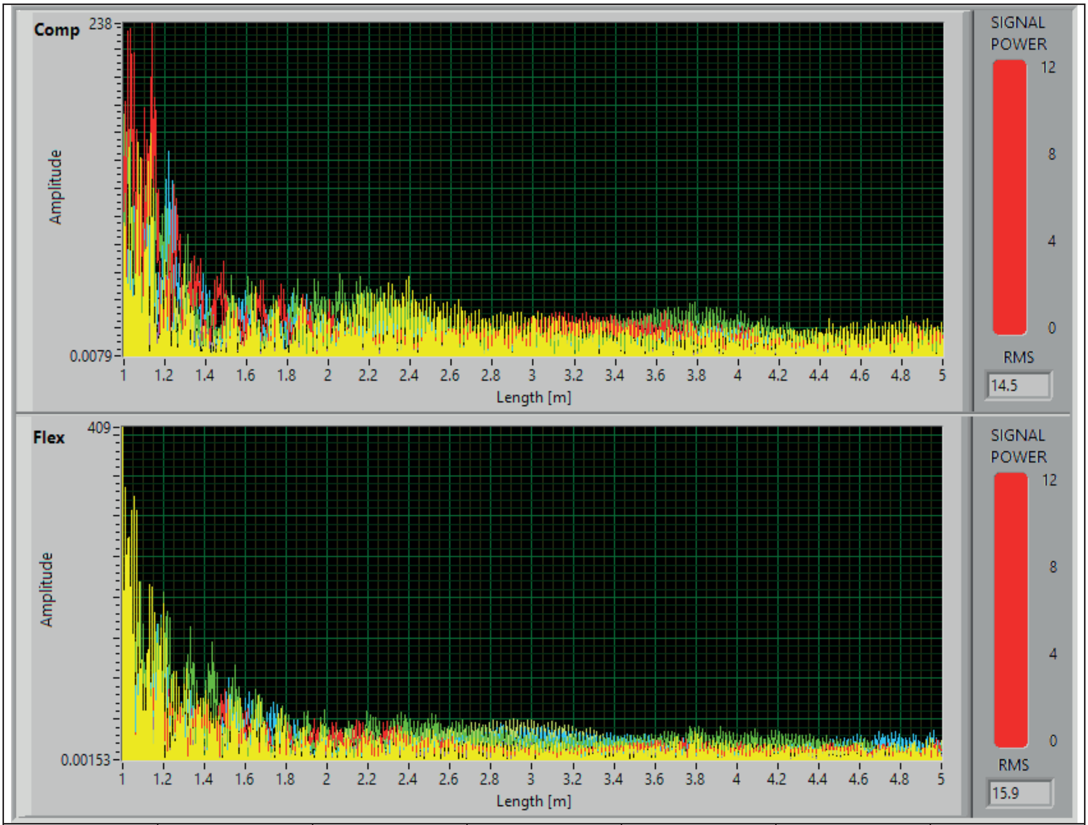
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_17_0 Sätra PC_17_3	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



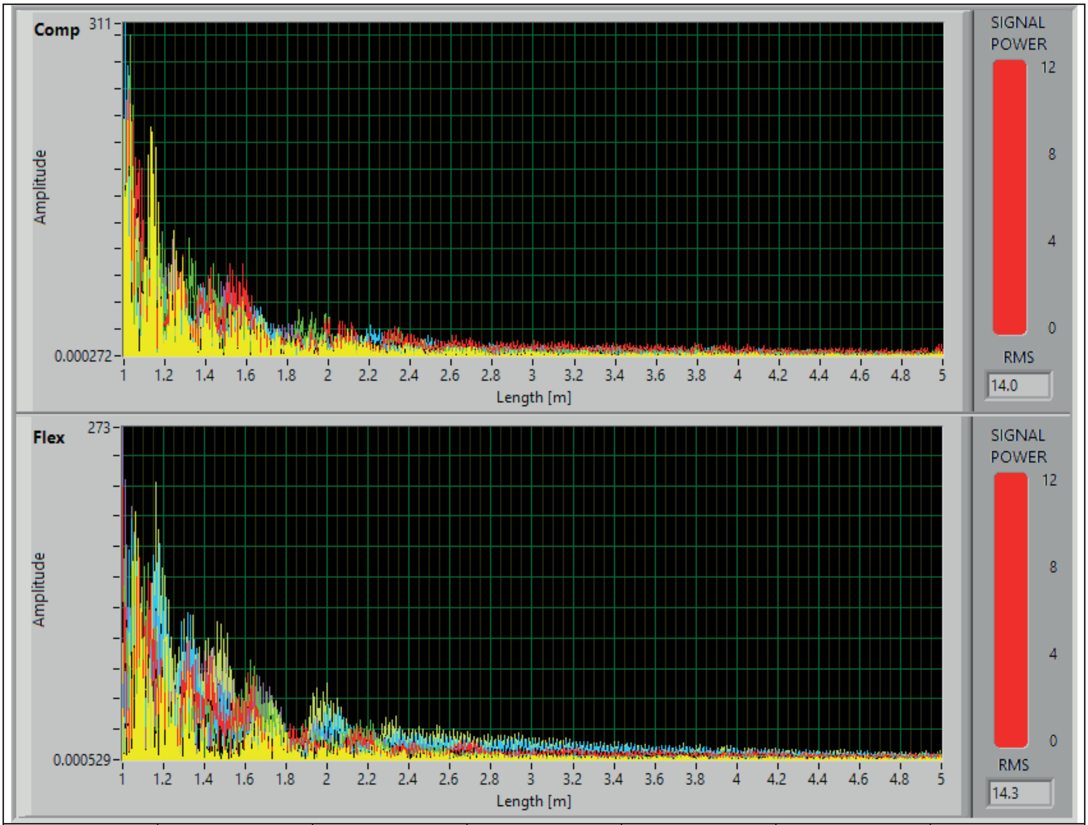
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_18_3 Sätra PC_18_4	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



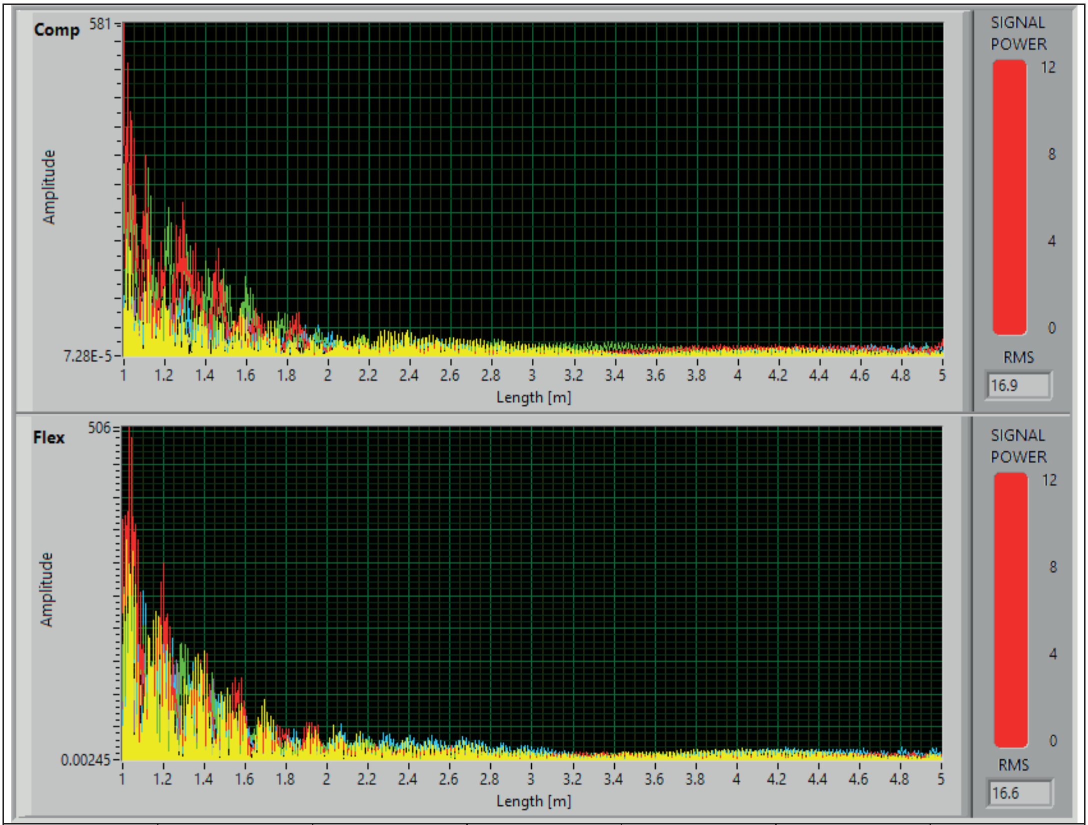
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_19_0 Sätra PC_19_1	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



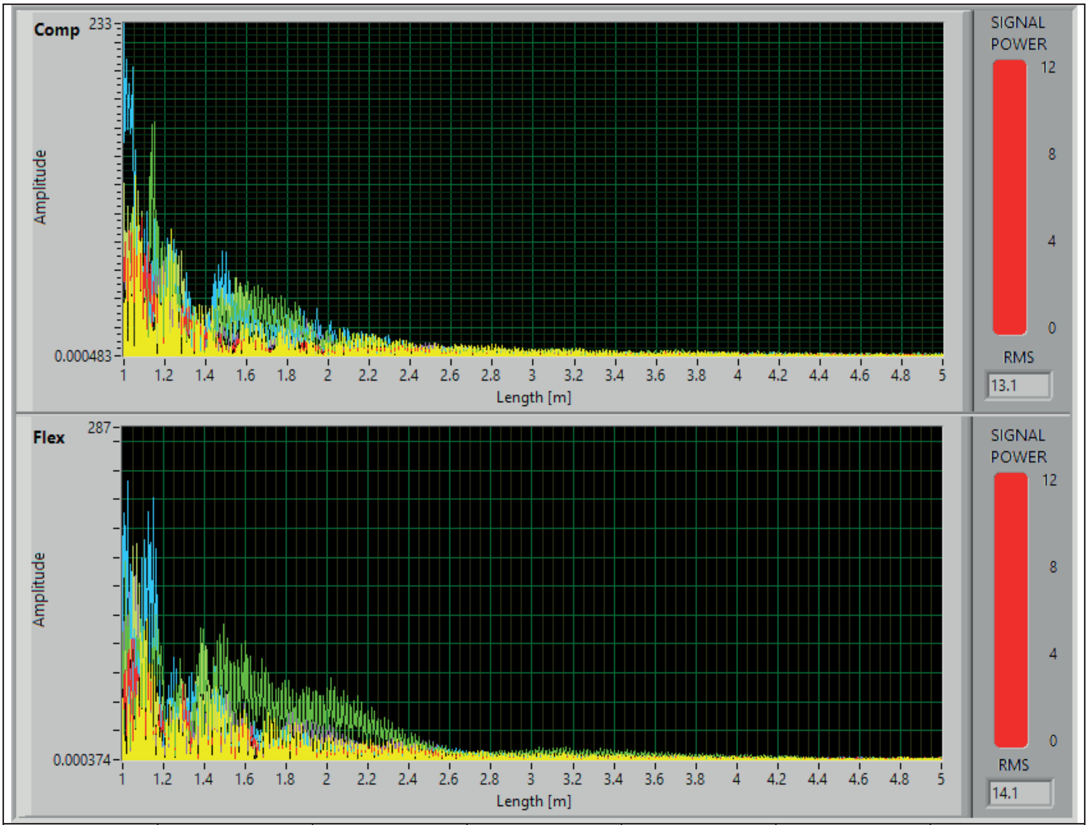
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_20_4 Sätra PC_20_2	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



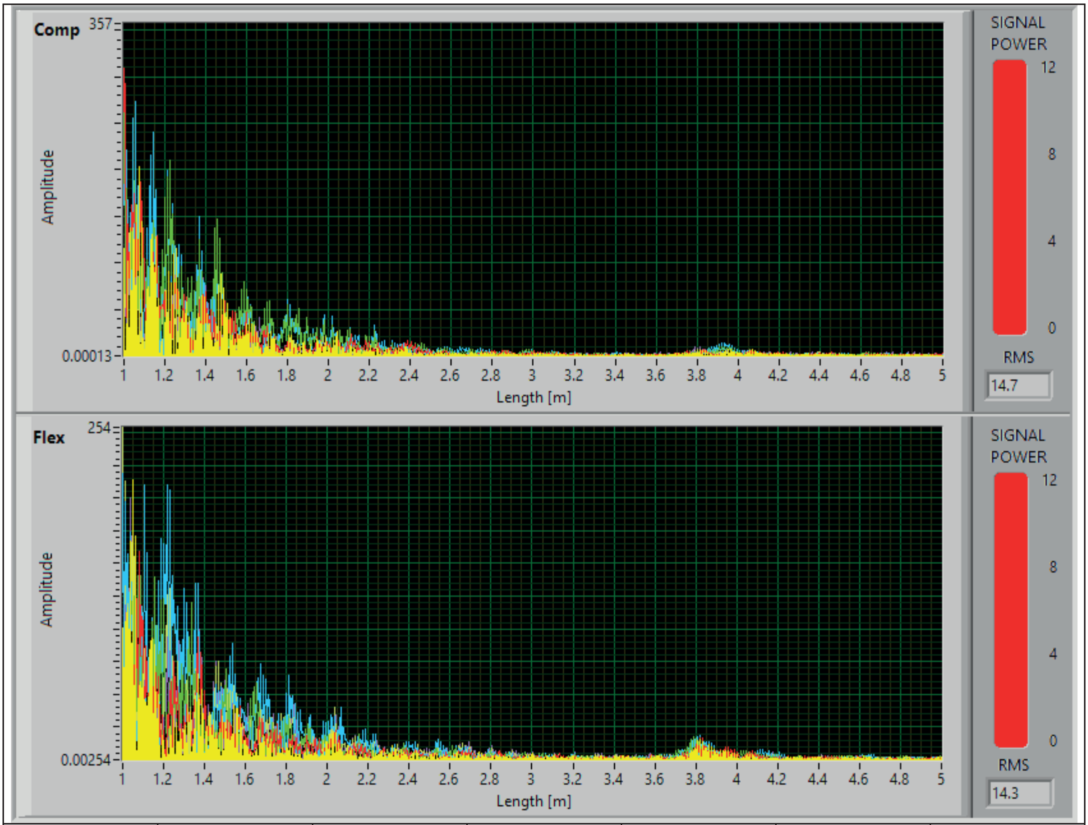
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_21_1 Sätra PC_21_1	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

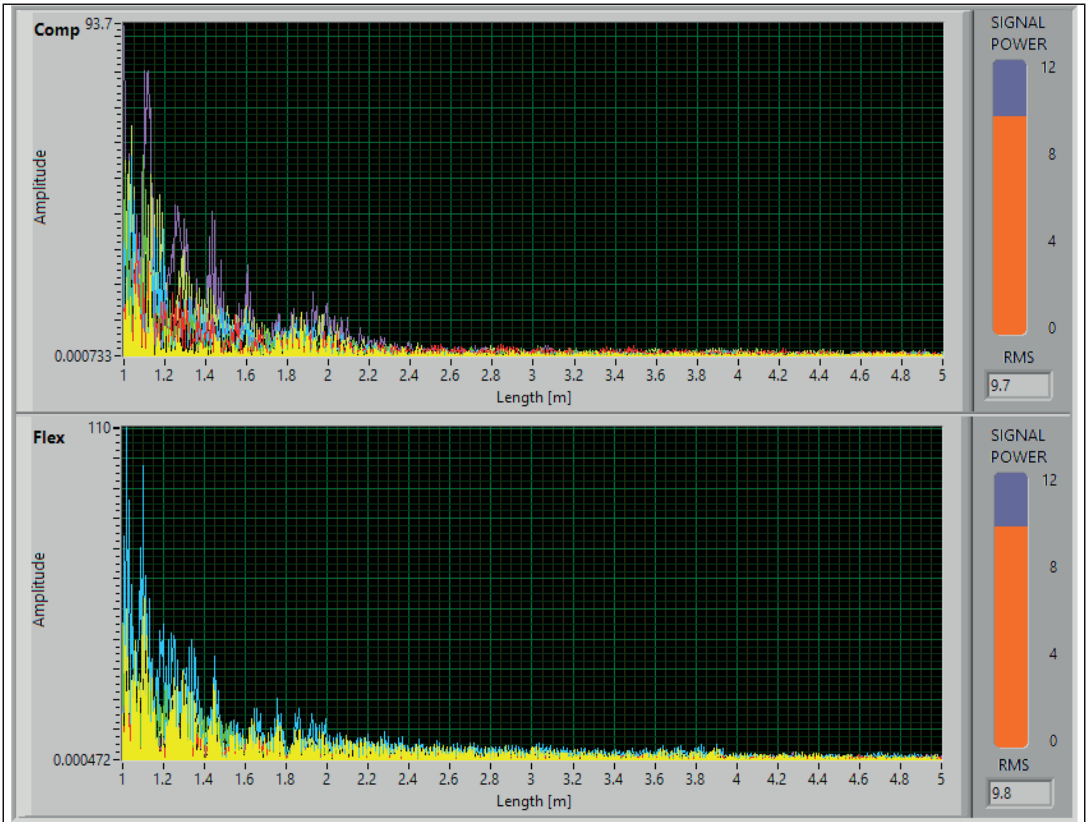


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_22_2 Sätra PC_22_3	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

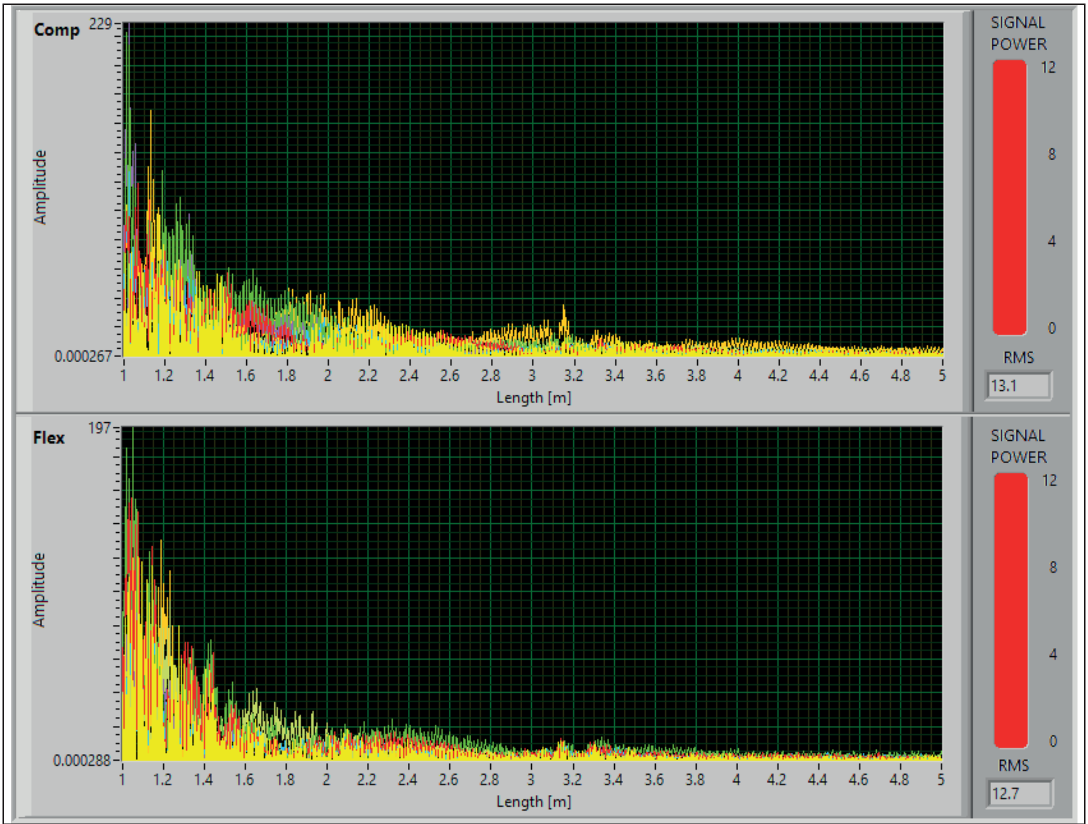


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_23_3 Sätra PC_23_3	2020/08/27		k	sk	Sätra PC	



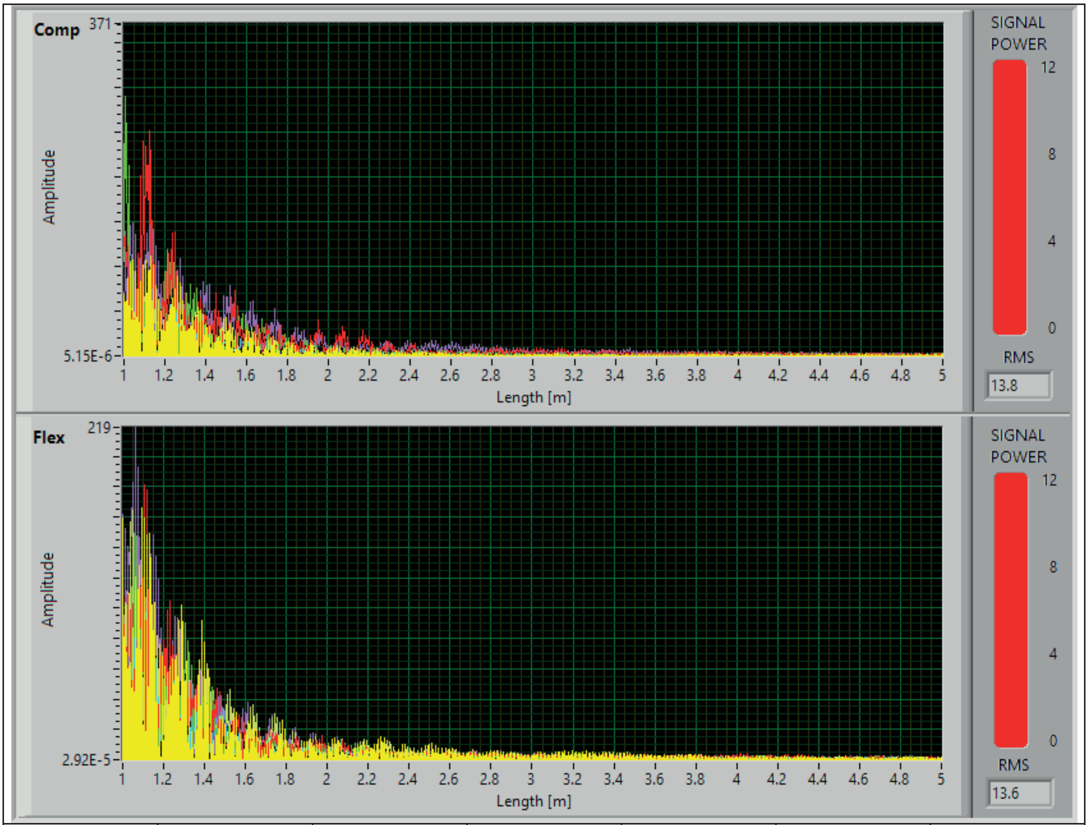
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_24_3 Sätra PC_24_5	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



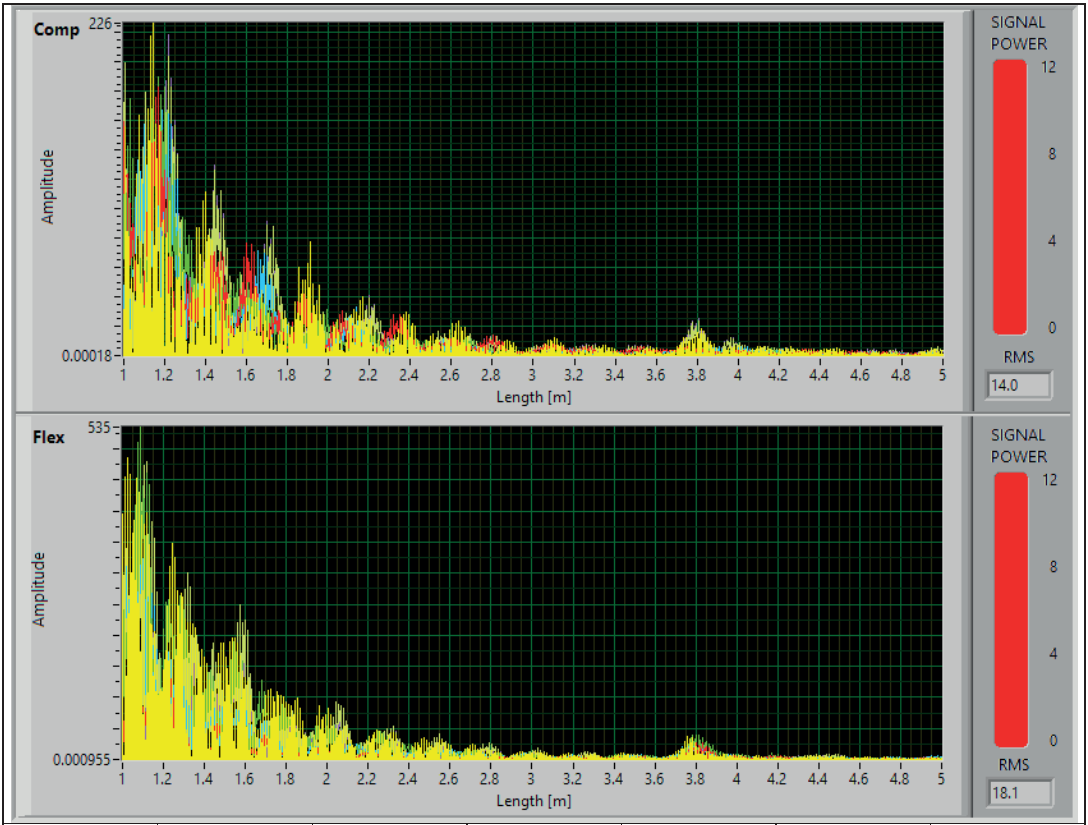
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_25_2 Sätra PC_25_2	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



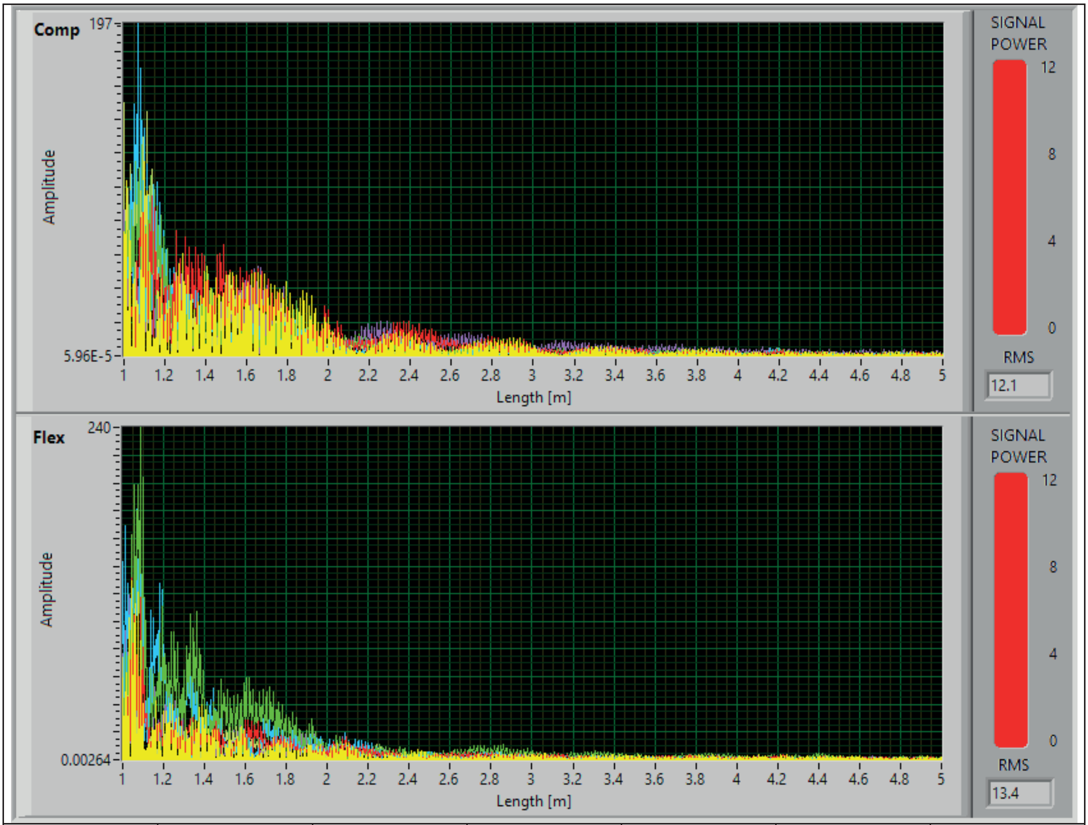
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_26_5 Sätra PC_26_1	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



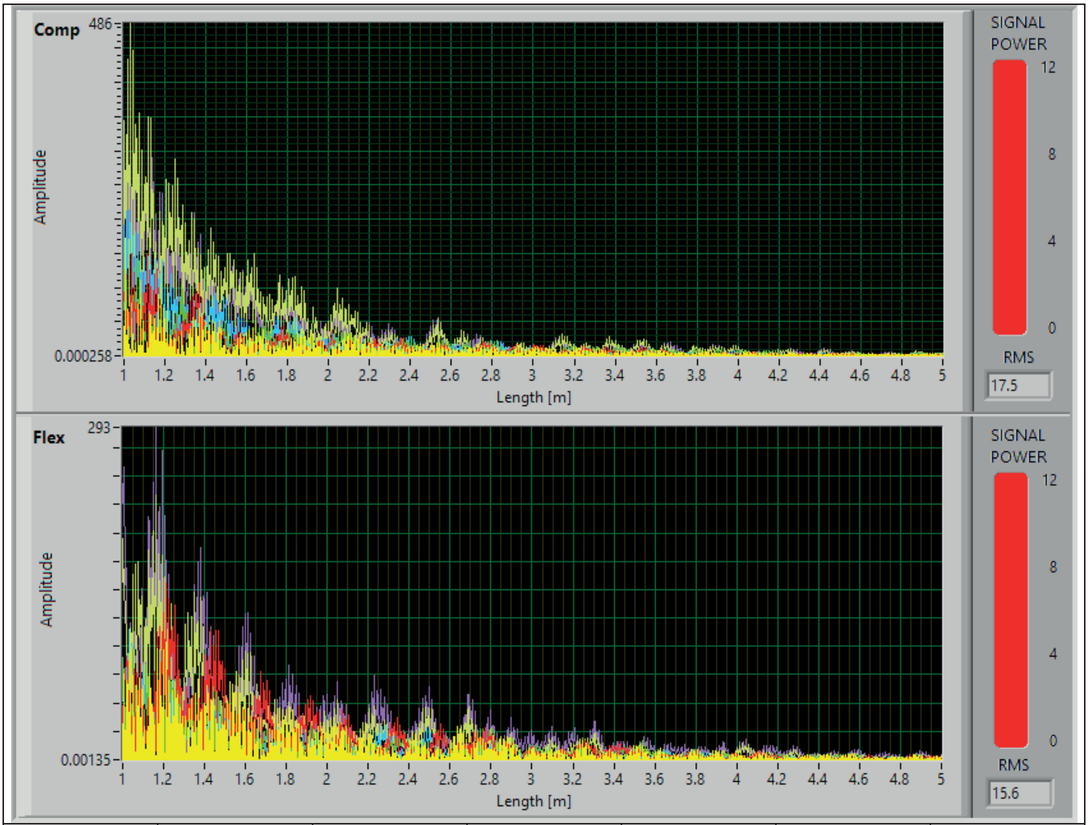
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_27_0 Sätra PC_27_5	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

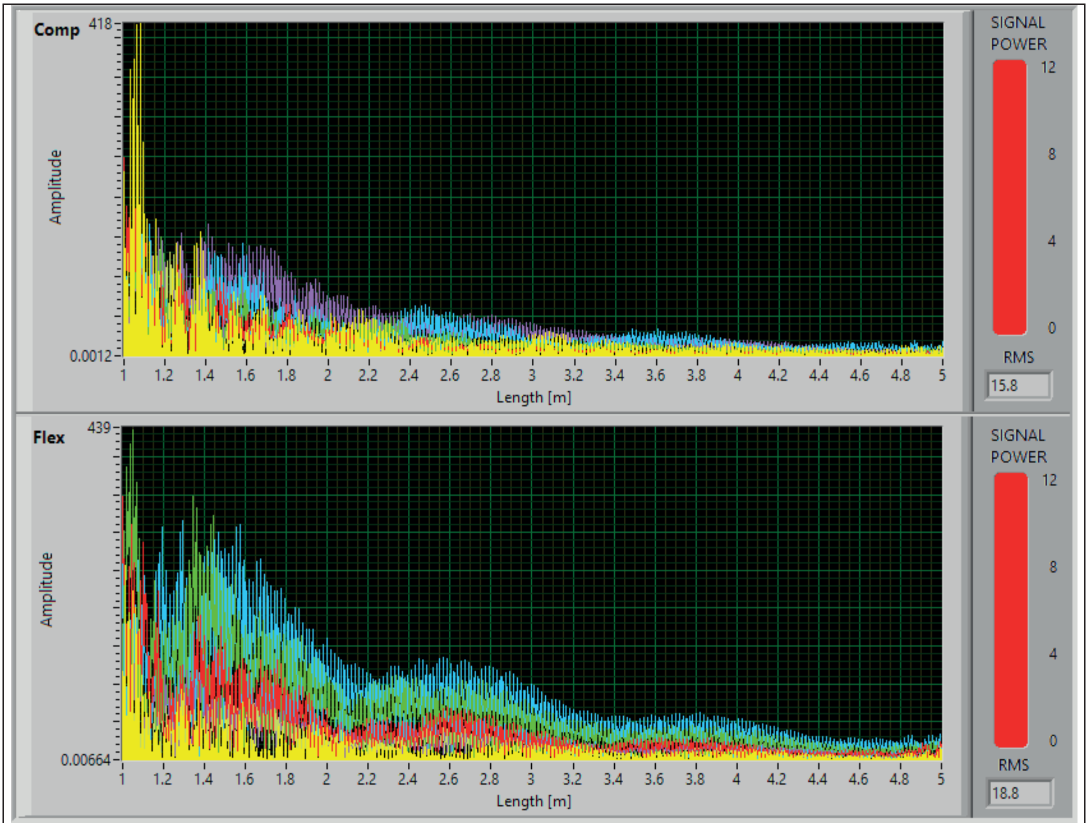


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_28_2 Sätra PC_28_3	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

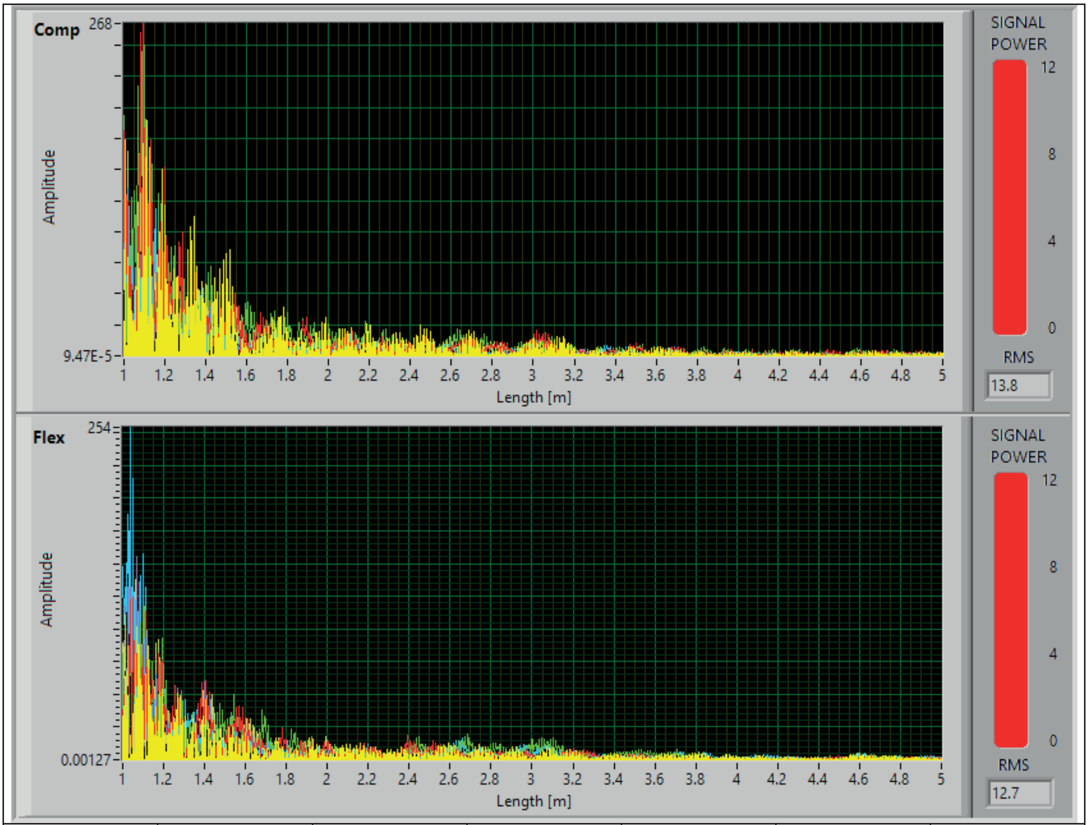


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_29_5 Sätra PC_29_4	2020/08/27		k	sk	Sätra PC	



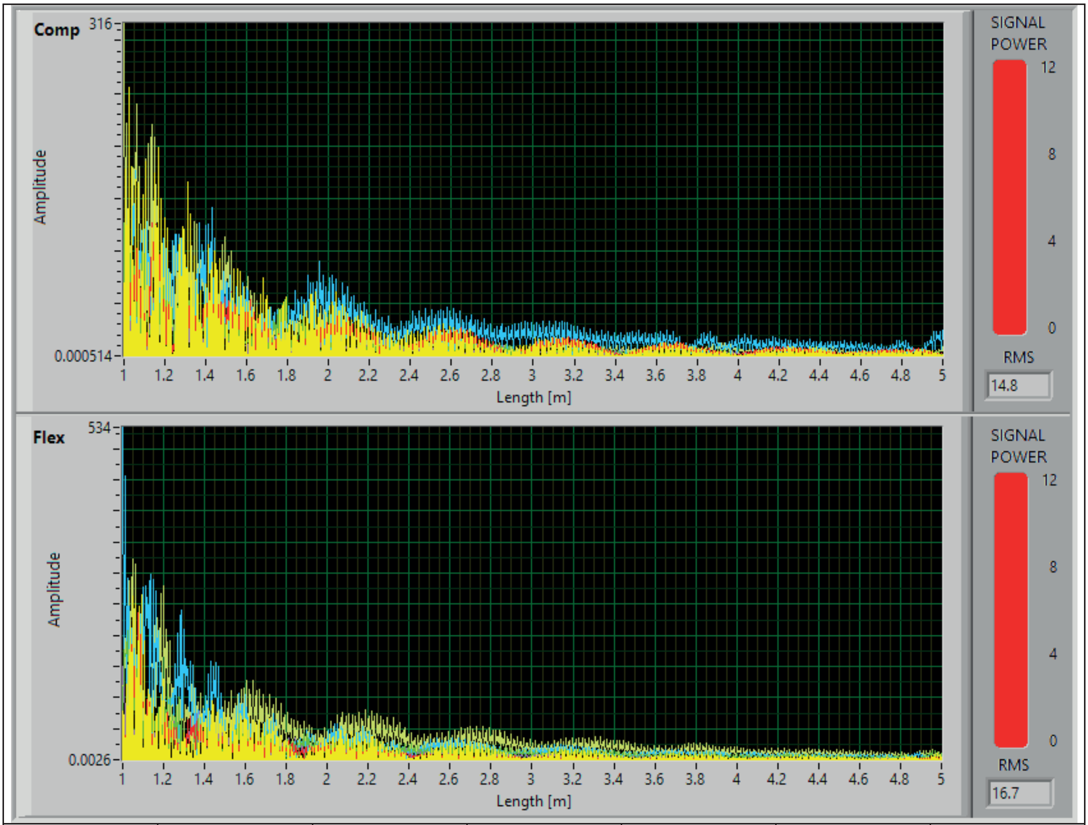
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_30_3 Sätra PC_30_0	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



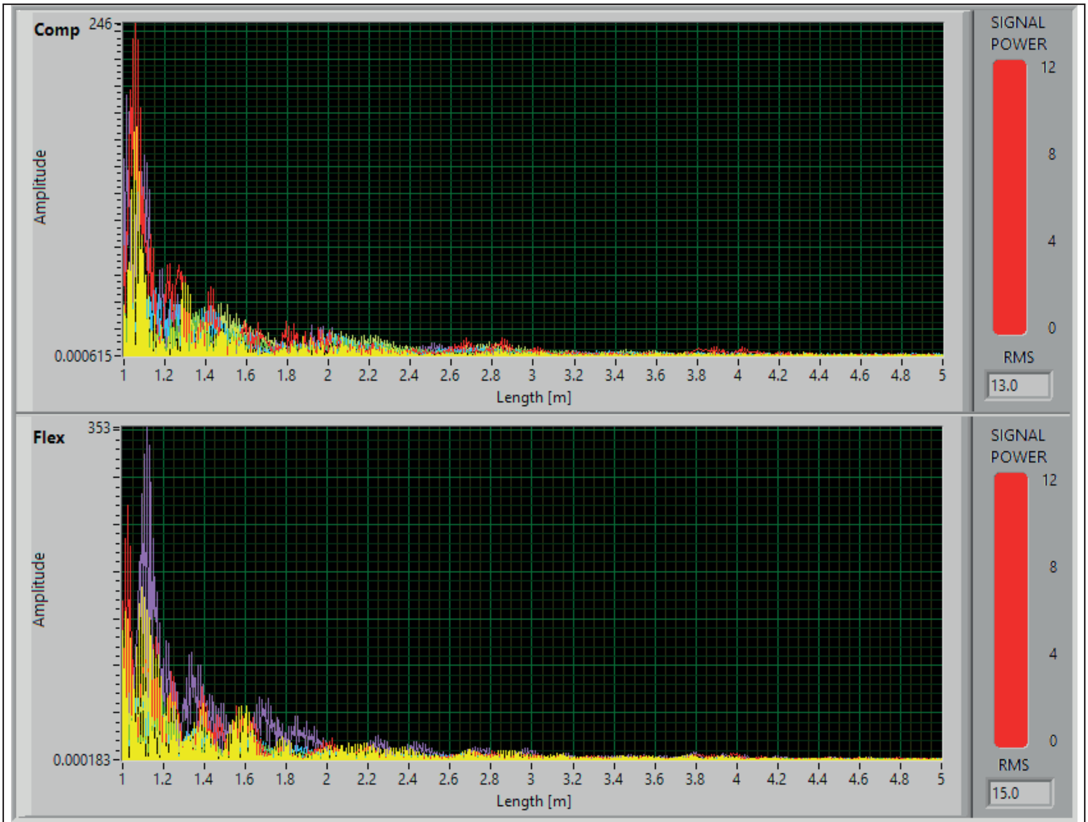
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_31_3 Sätra PC_31_2	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



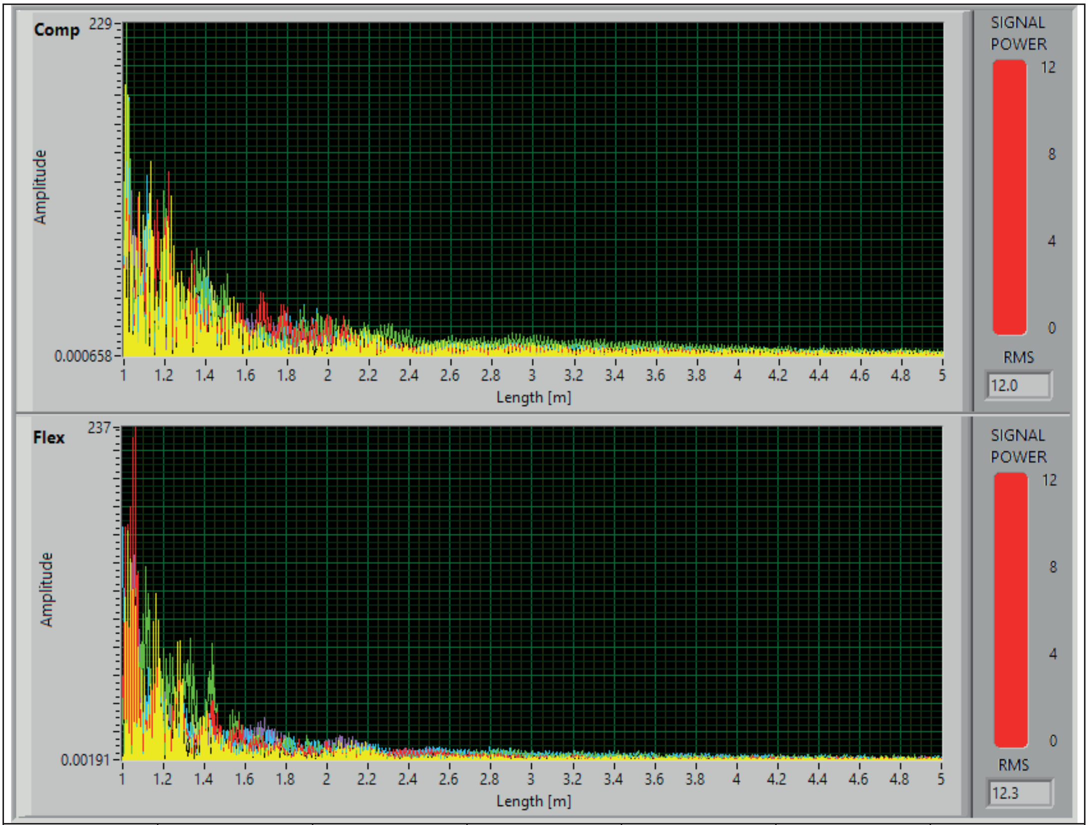
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_32_3 Sätra PC_32_4	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

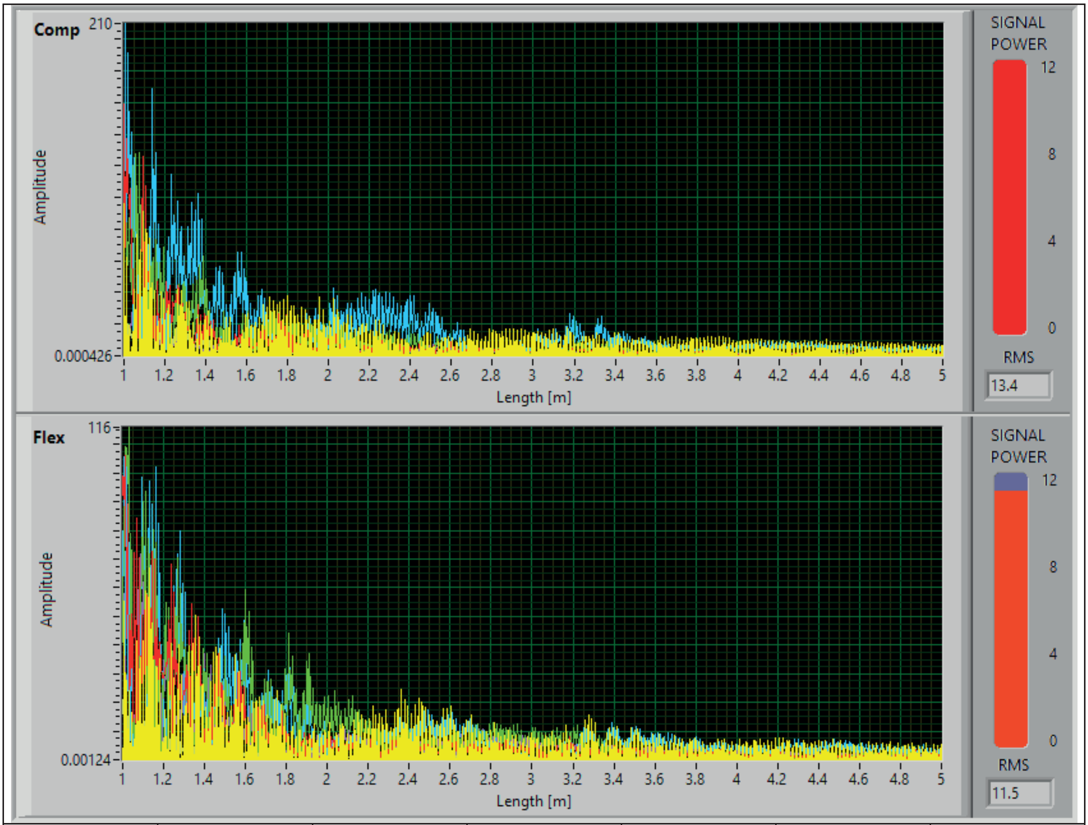


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_33_5 Sätra PC_33_1	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts

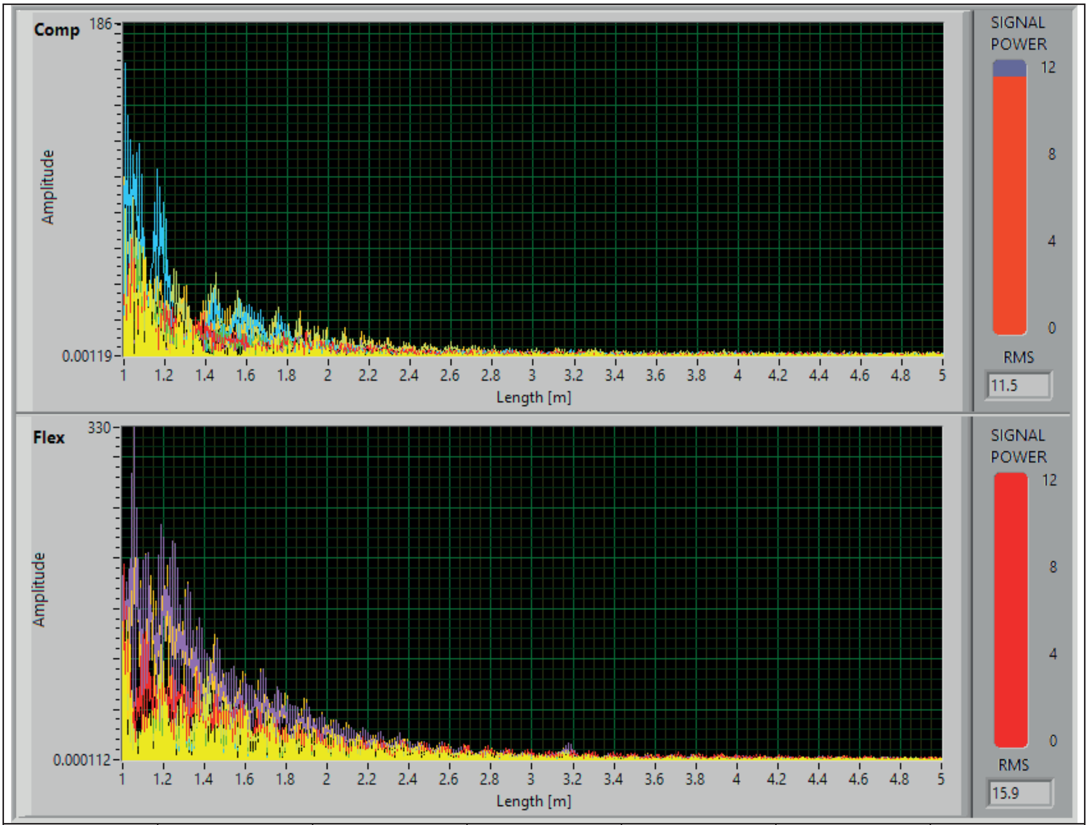


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_34_2 Sätra PC_34_0	2020/08/27		k	sk	Sätra PC	

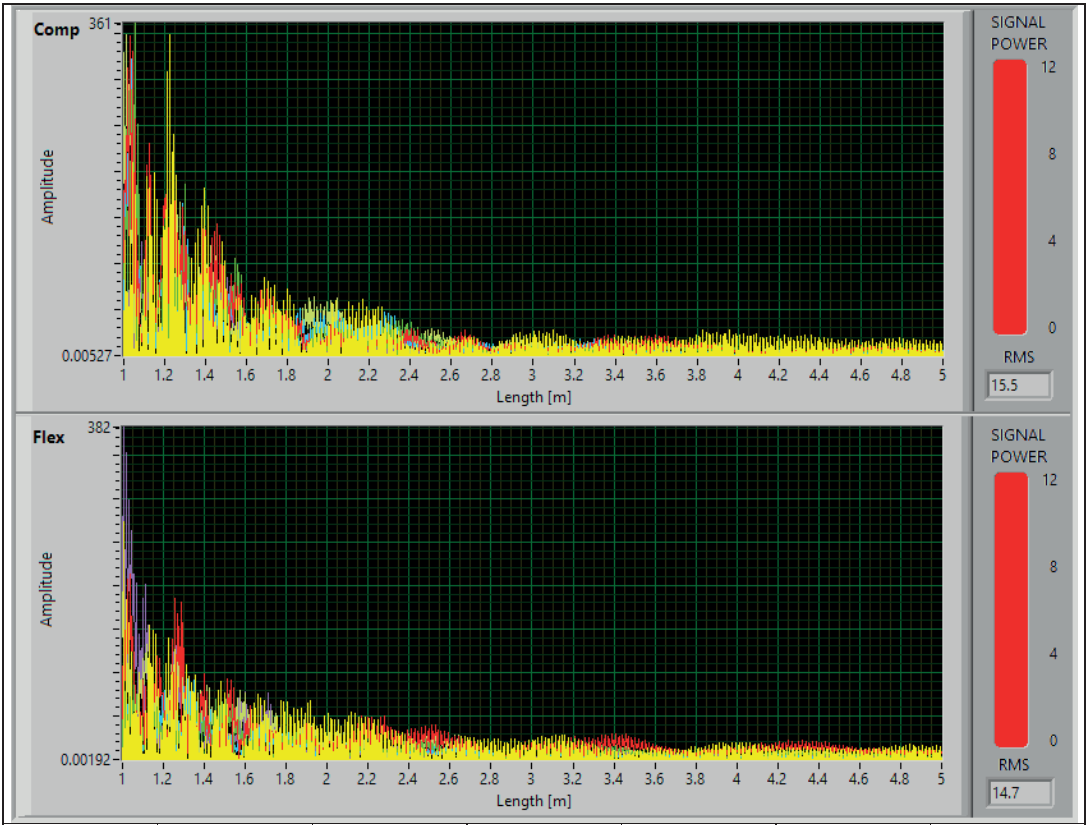


Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_35_3 Sätra PC_35_3	2020/08/27		k	sk	Sätra PC	

Appendix 2 – RBT echogram plots for PC-bolts



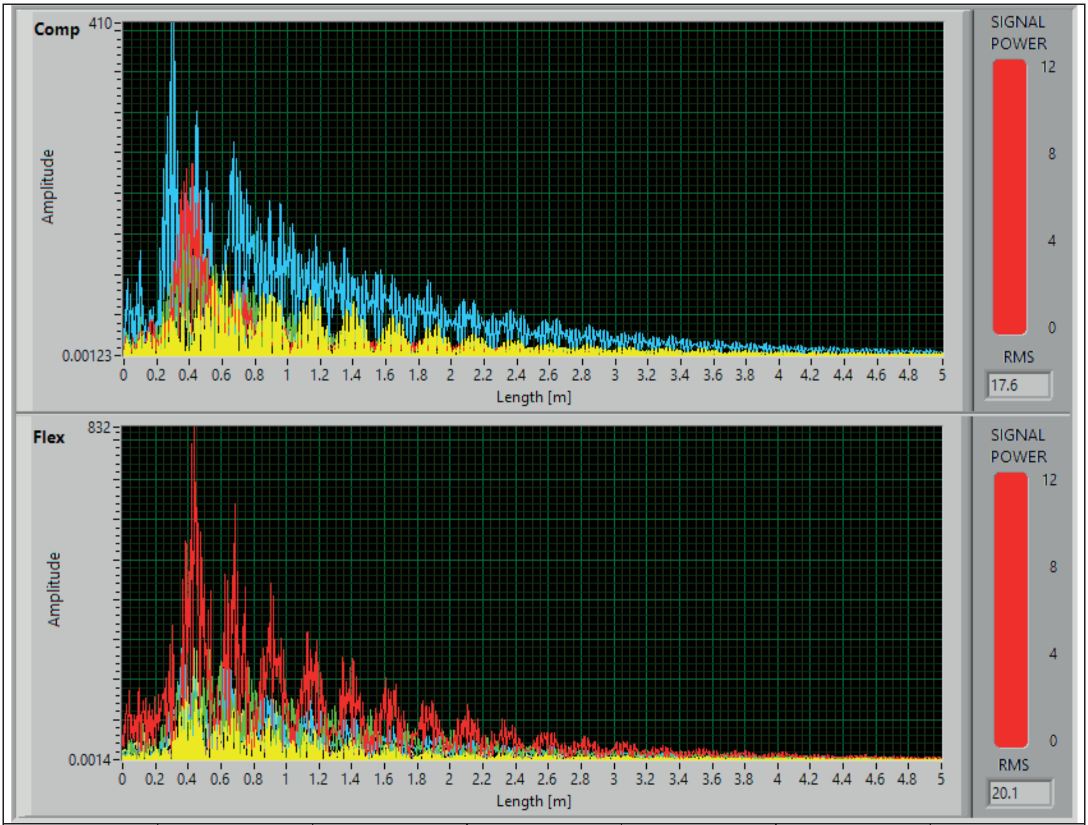
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_36_5 Sätra PC_36_3	2020/08/27		k	sk	Sätra PC	



Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra PC_37_5 Sätra PC_37_1	2020/08/27		k	sk	Sätra PC	

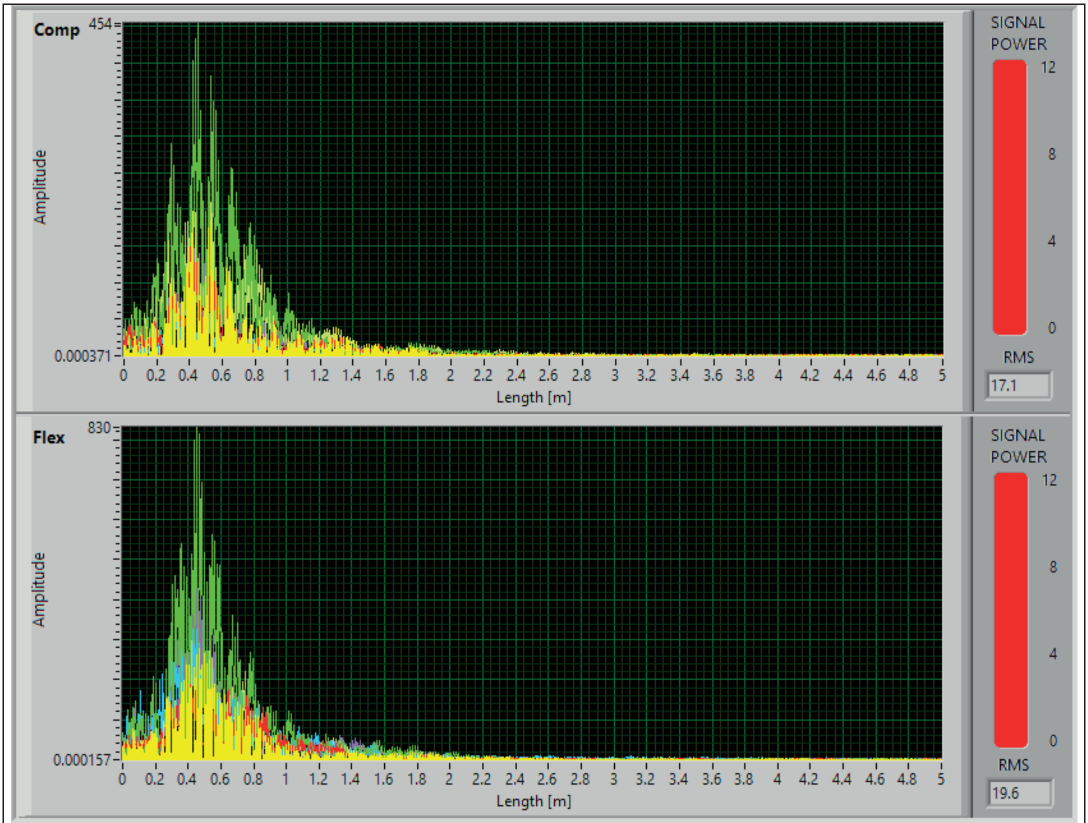
APPENDIX 3
ECHOGRAM PLOTS FOR NC-BOLT

Bolts named by the following system: Sätra *"Bolt type"_"Bolt ID"_"measurement nr on bolt".*



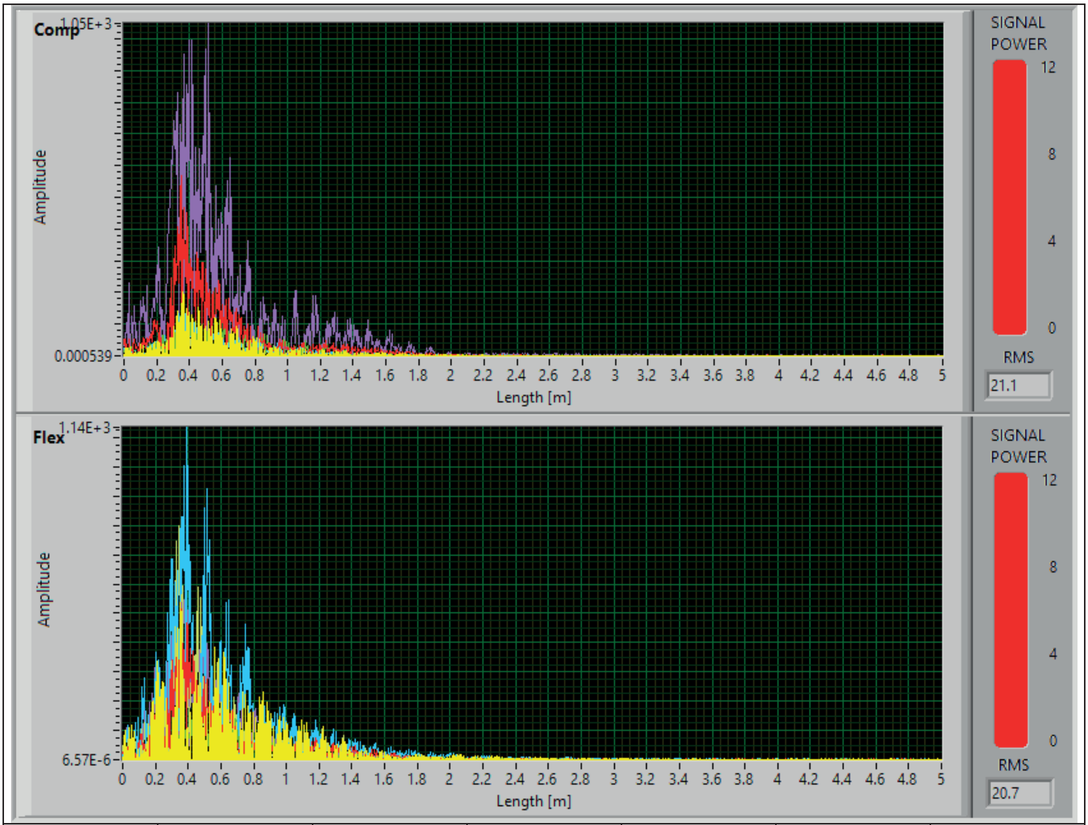
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_1_1 Sätra NC_1_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



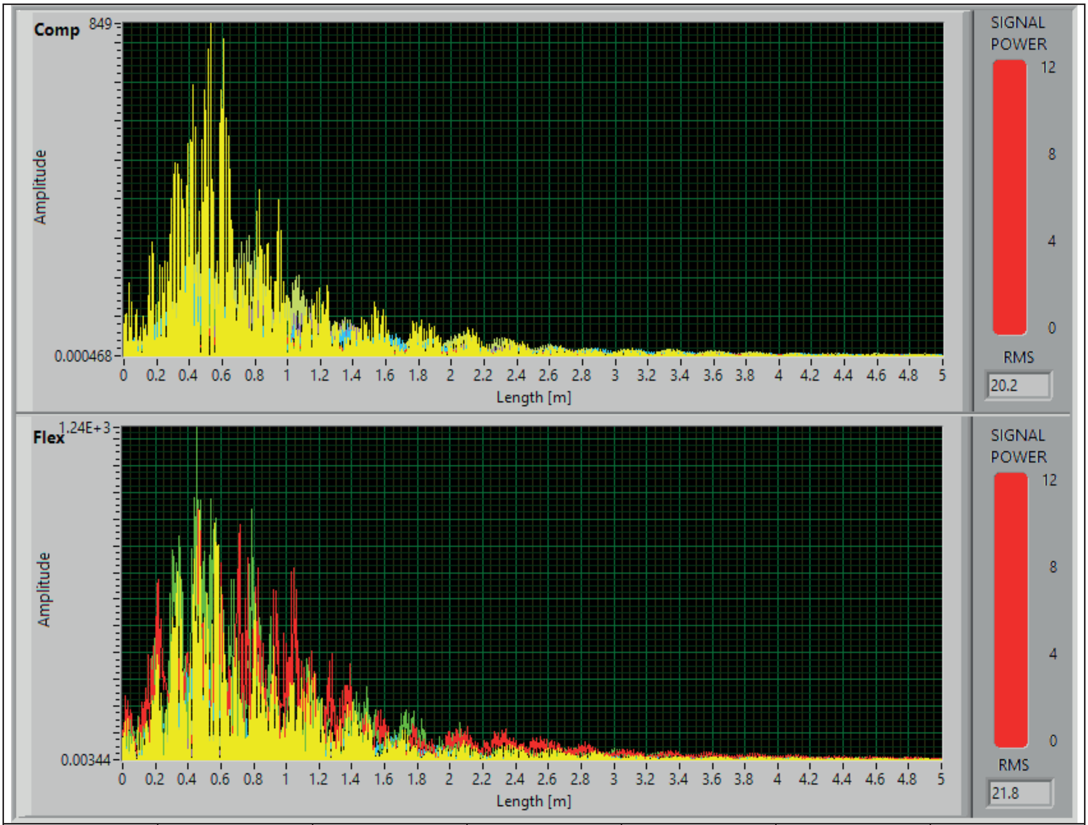
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_2_2 Sätra NC_2_2	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



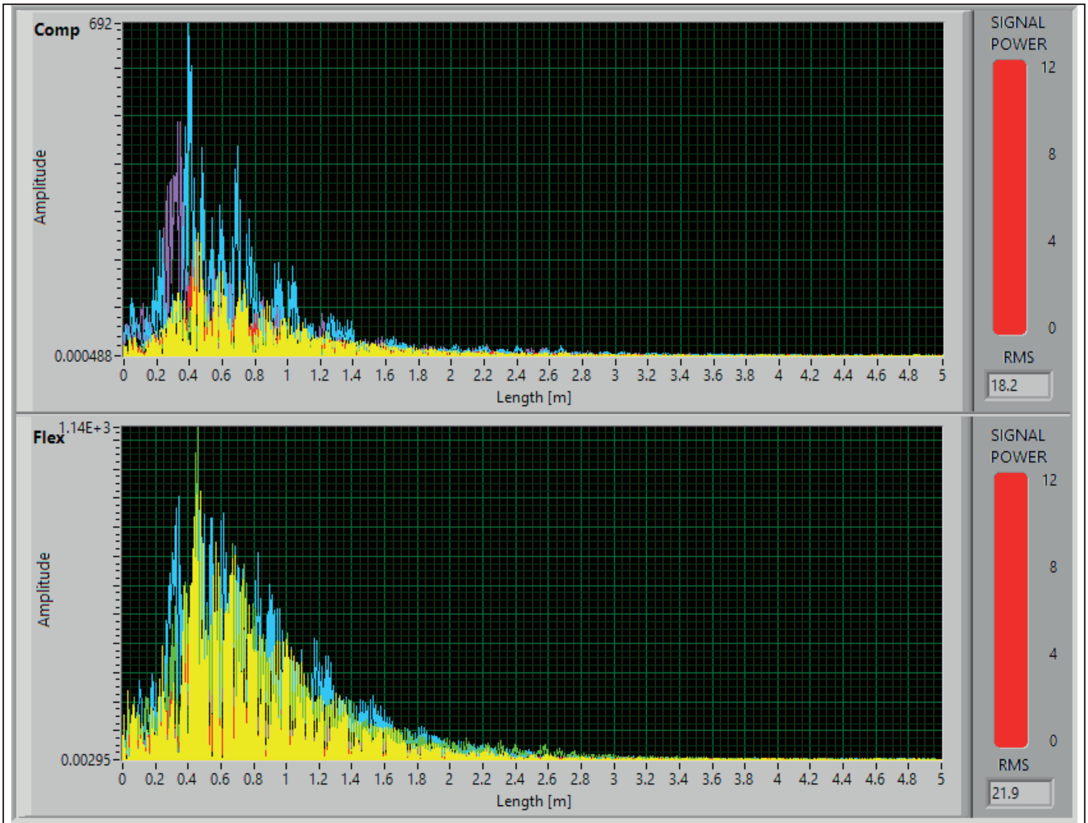
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_3_3 Sätra NC_3_5	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



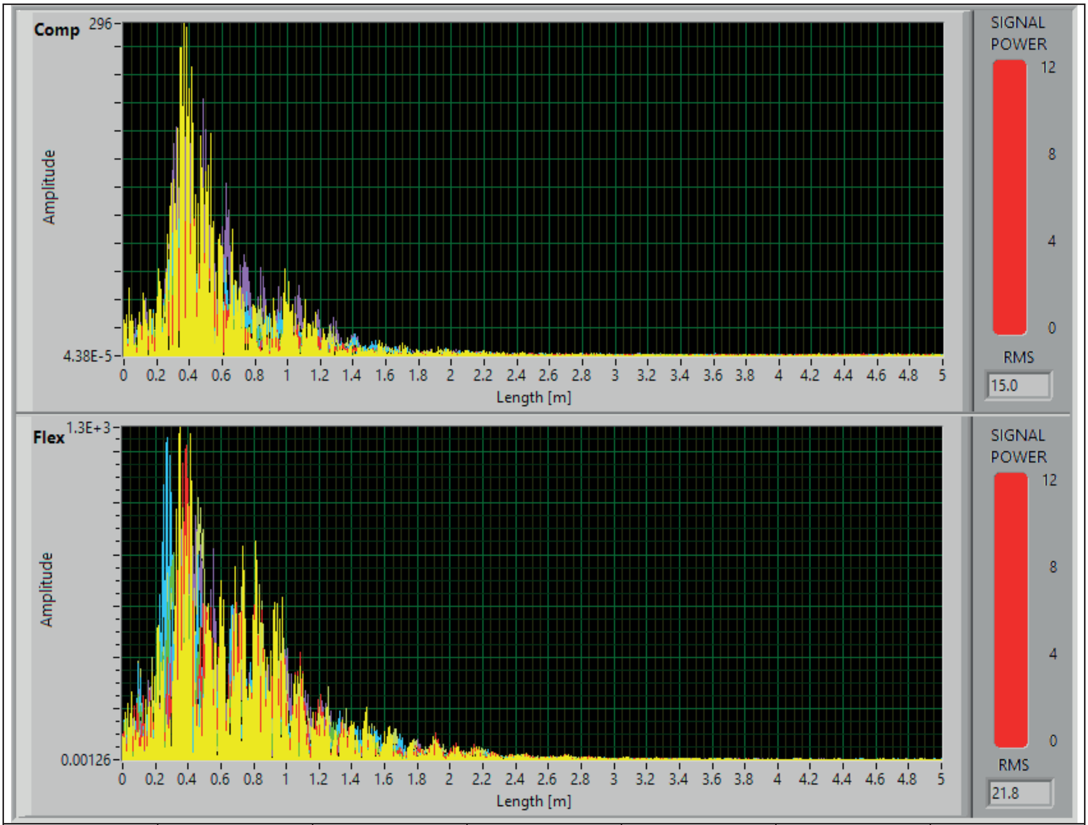
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_4_2 Sätra NC_4_0	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



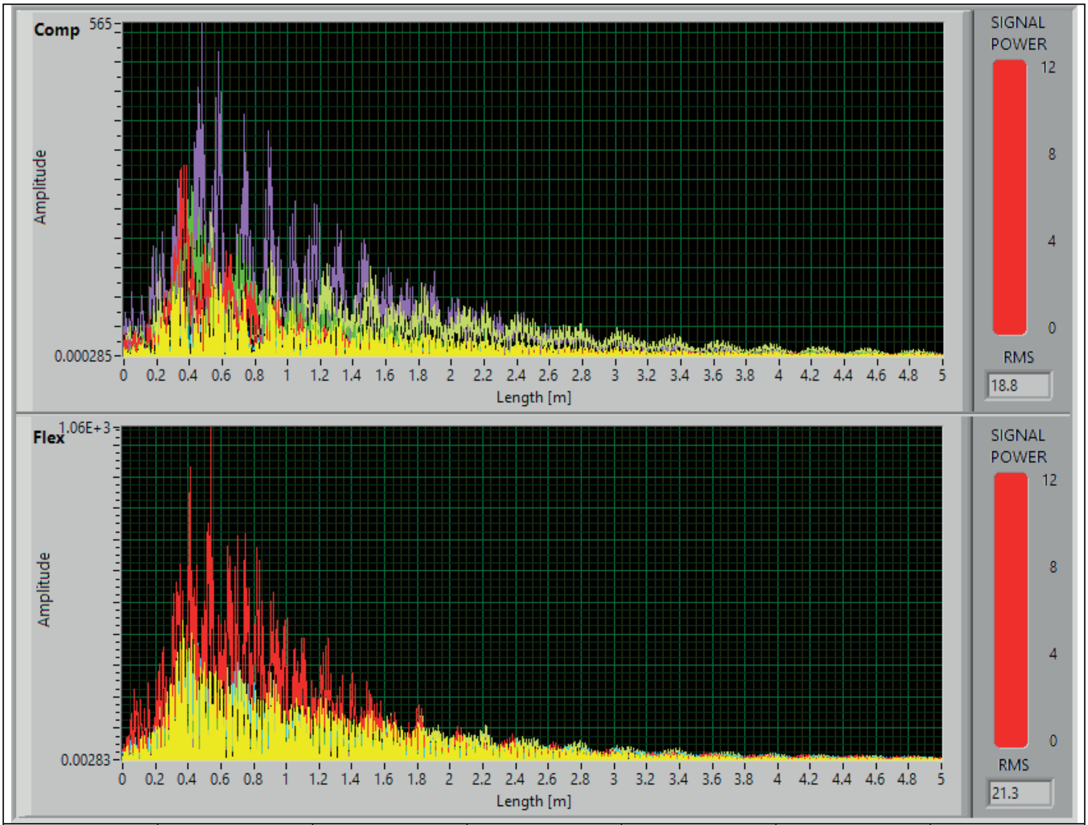
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_5_3 Sätra NC_5_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



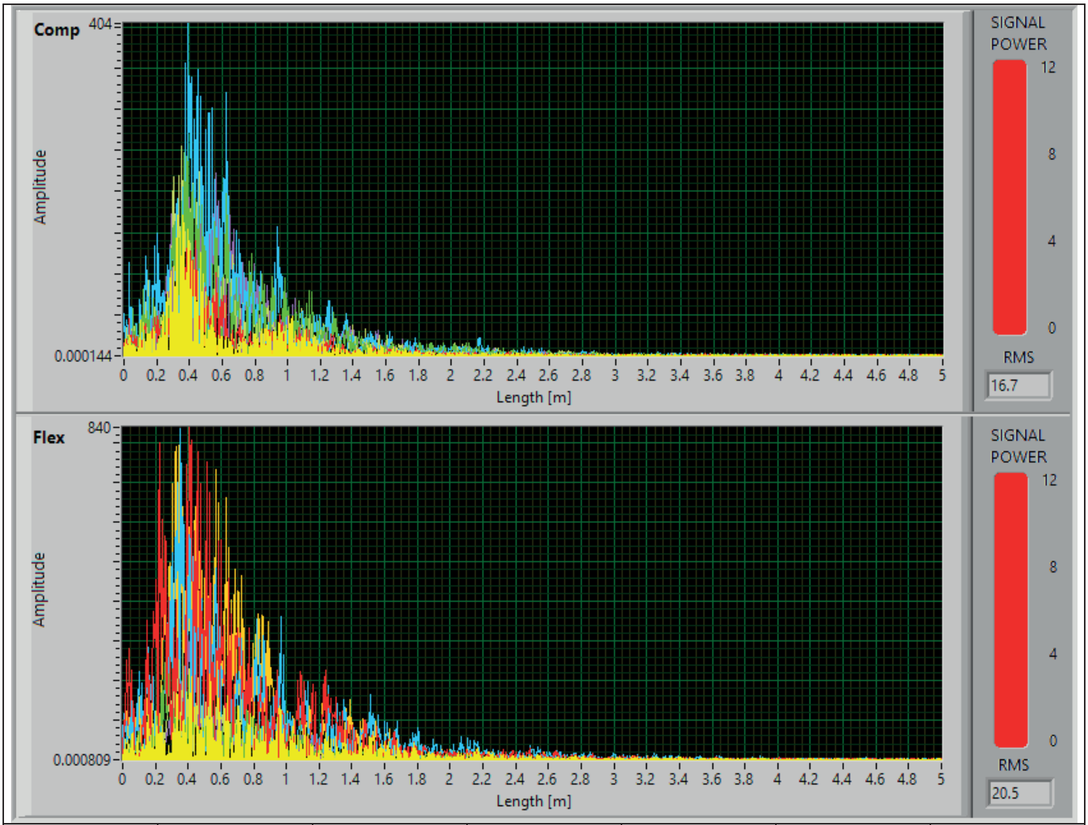
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_6_0 Sätra NC_6_0	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



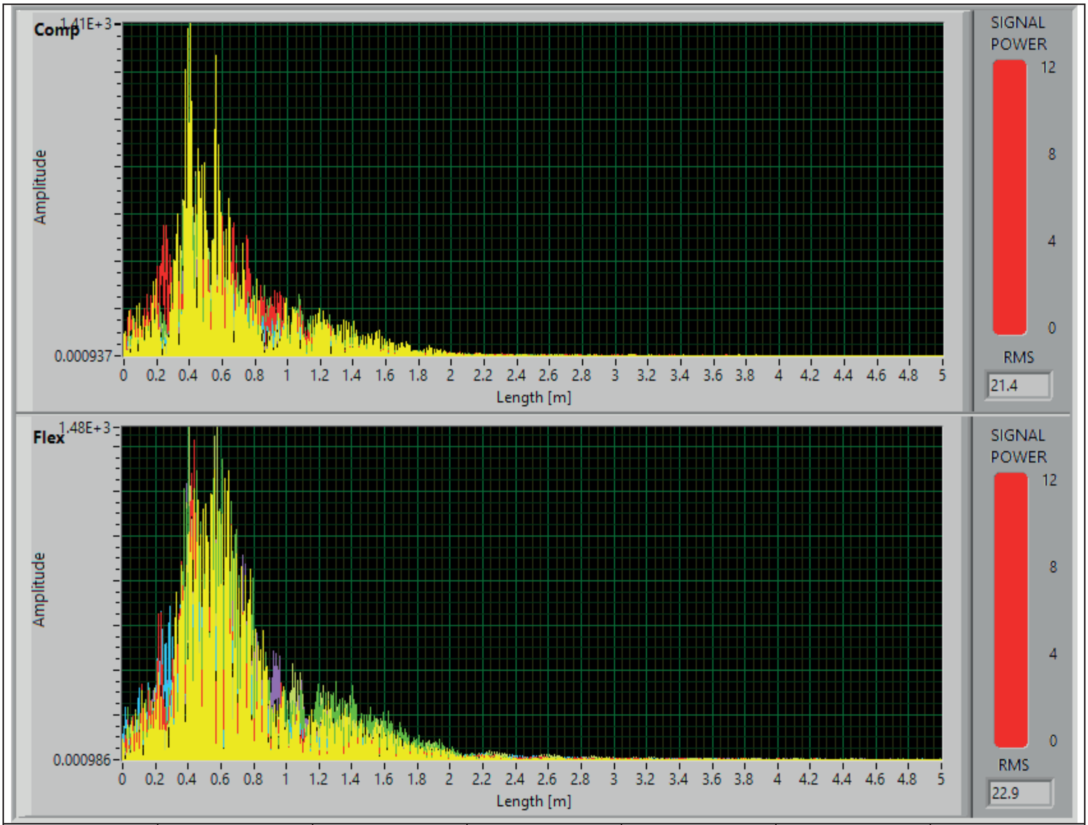
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_7_1 Sätra NC_7_5	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



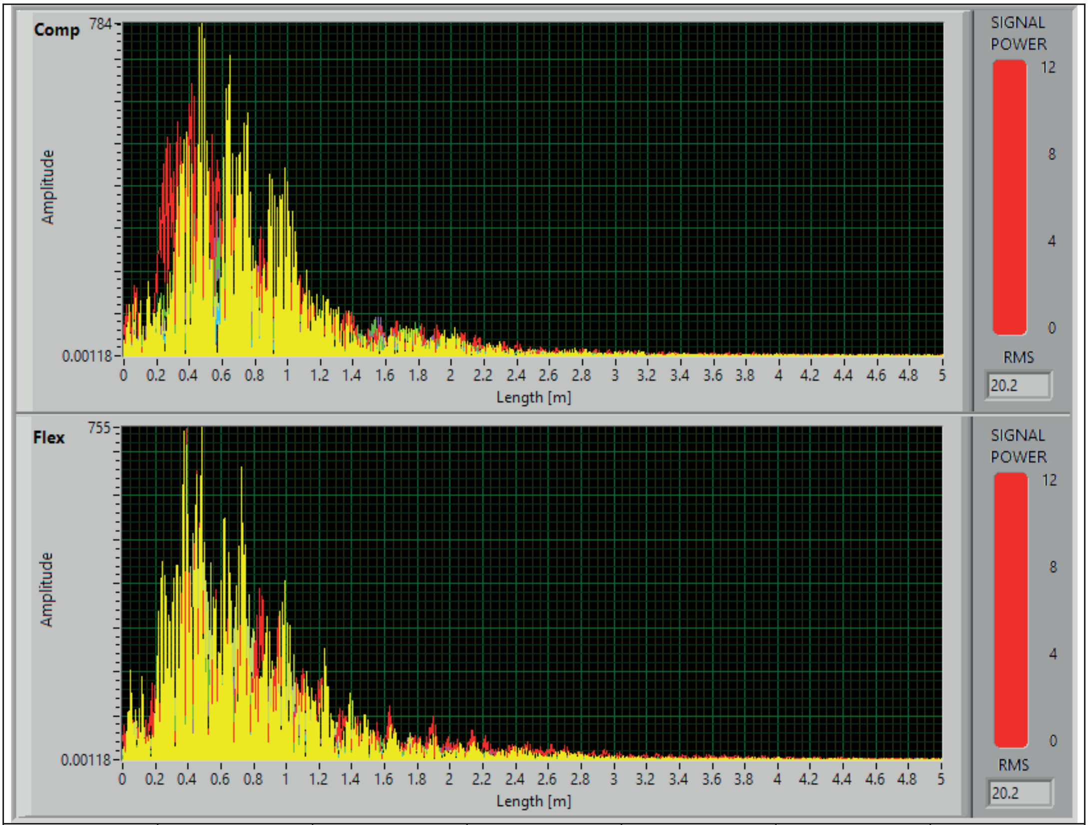
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_8_6 Sätra NC_8_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



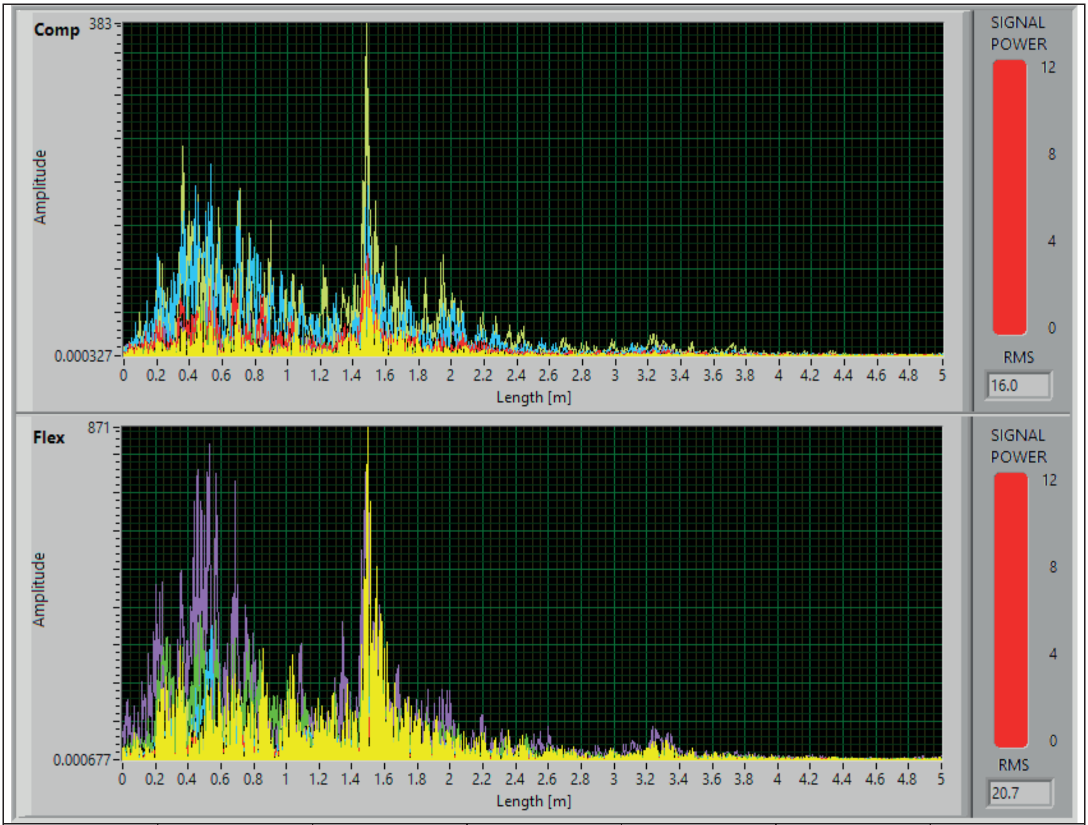
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_9_0 Sätra NC_9_0	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



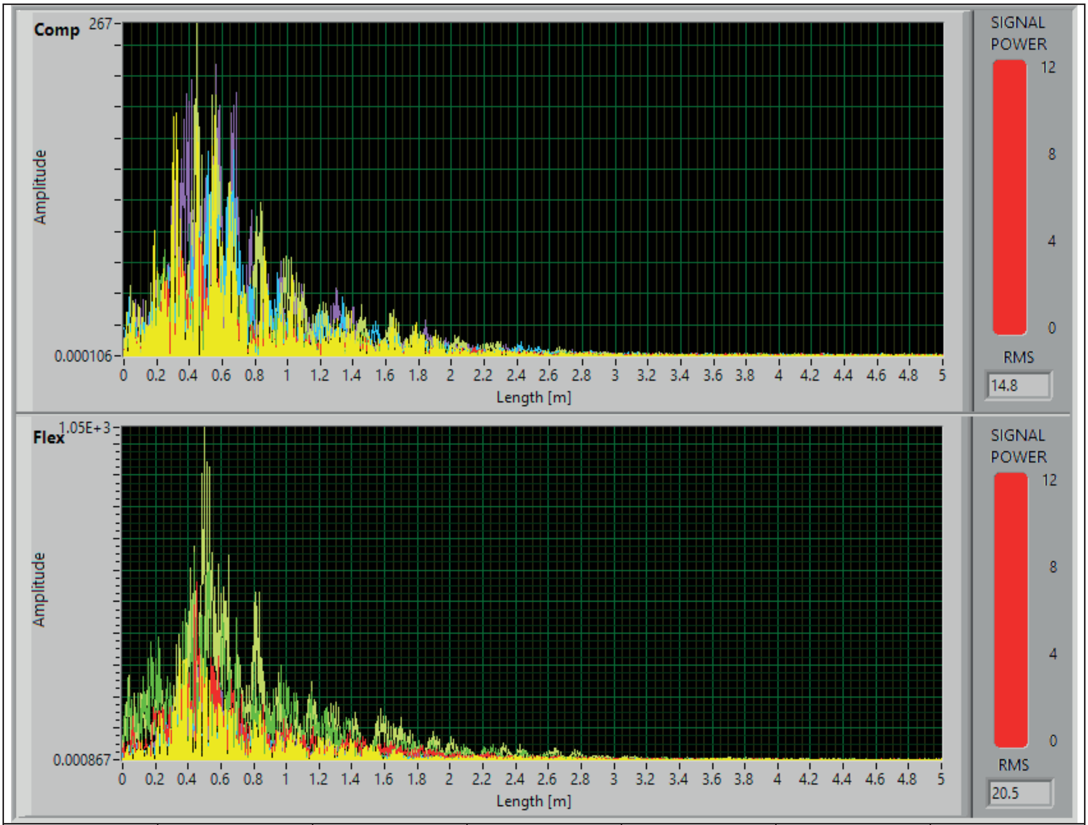
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_10_0 Sätra NC_10_0	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



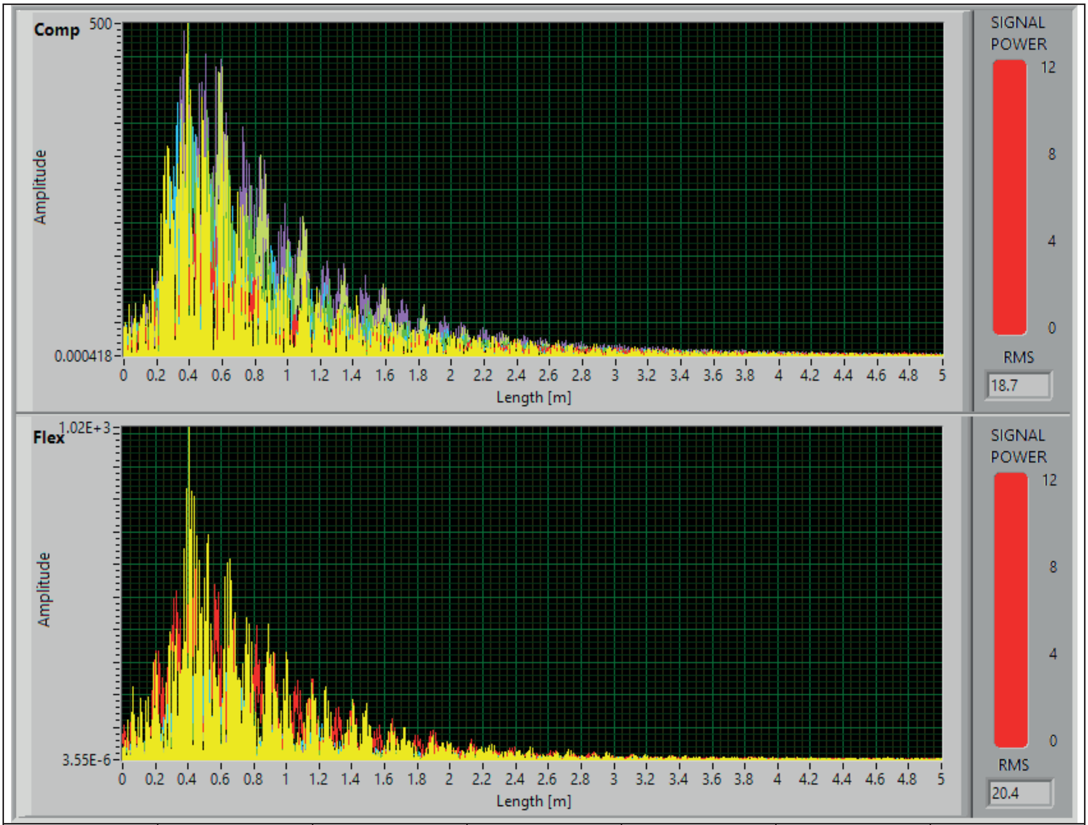
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_11_5 Sätra NC_11_4	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



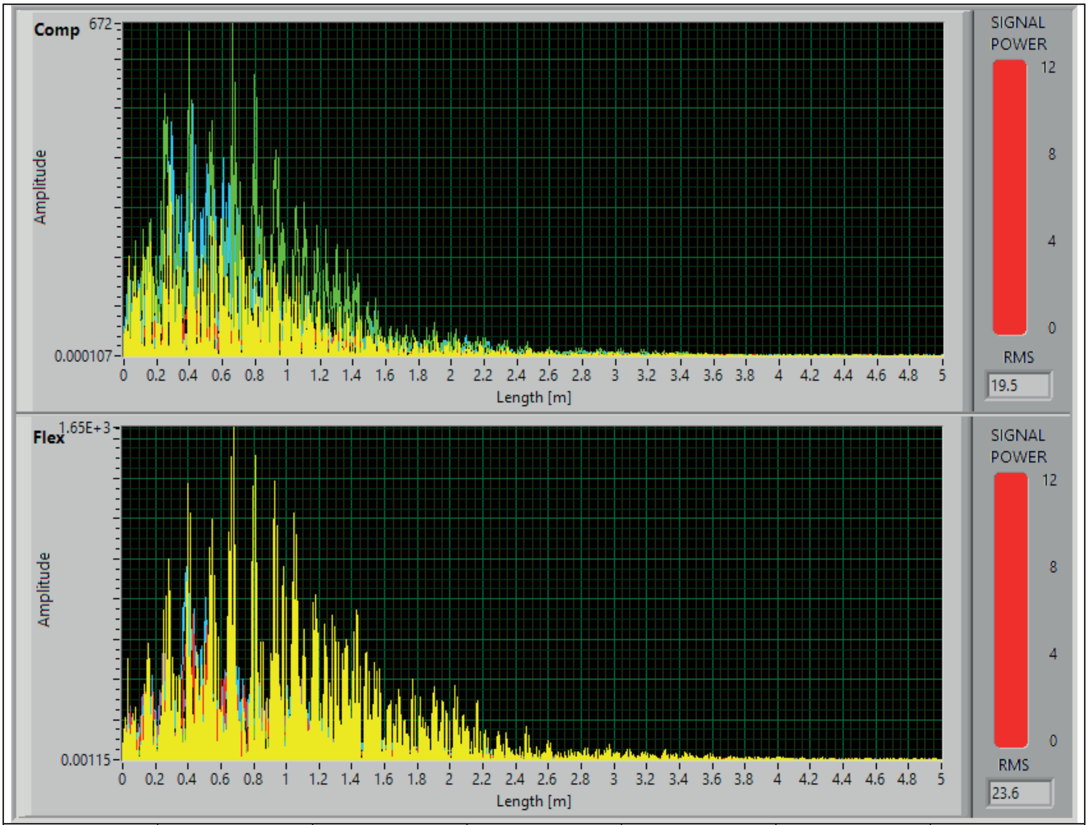
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_12_4 Sätra NC_12_5	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



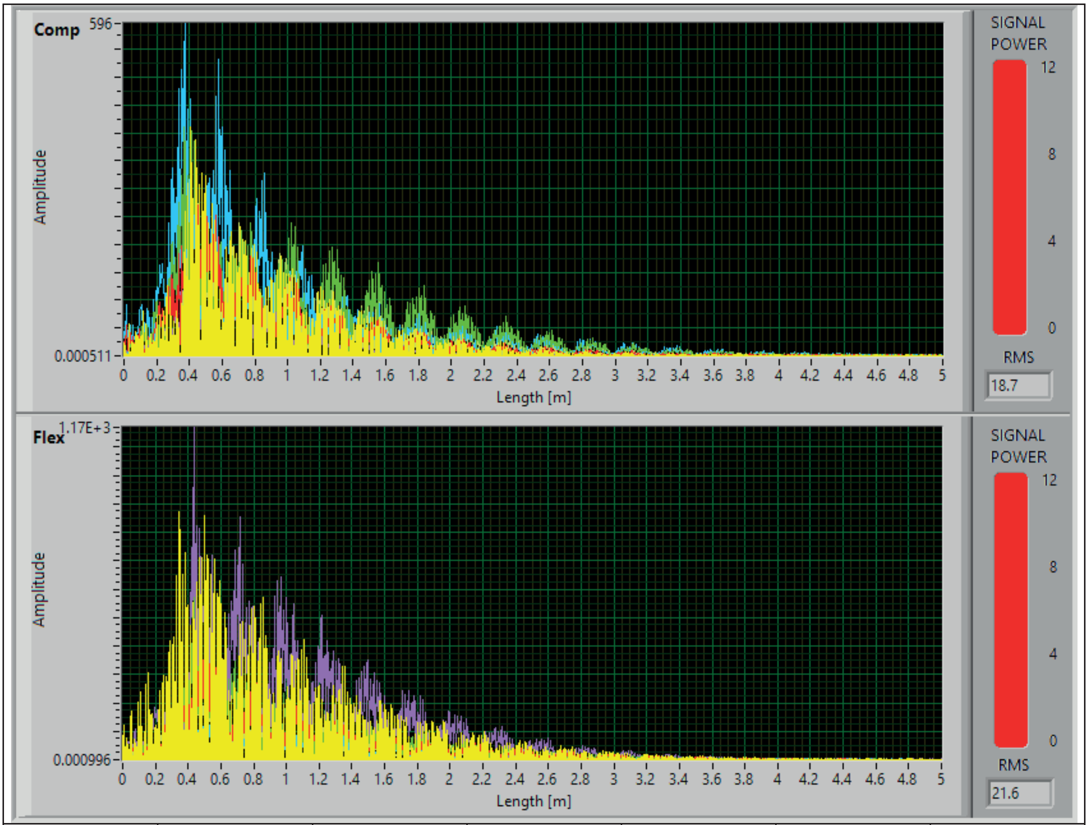
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_13_0 Sätra NC_13_5	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



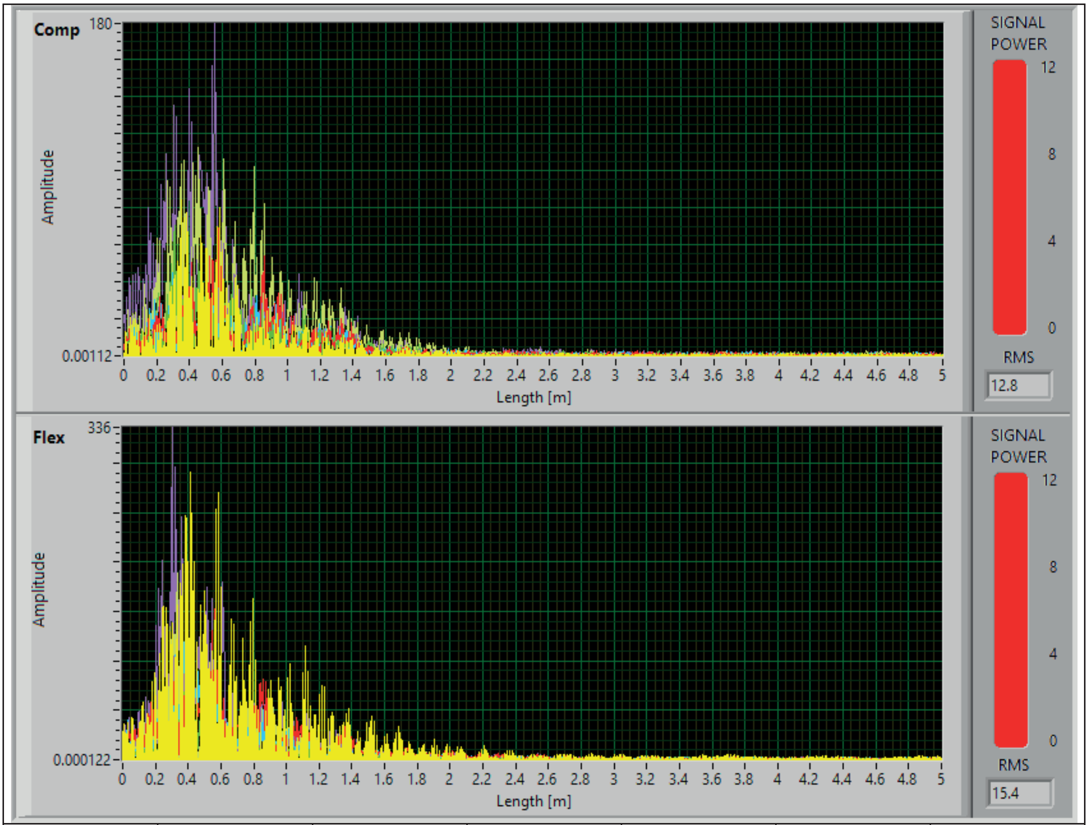
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_14_0 Sätra NC_14_2	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



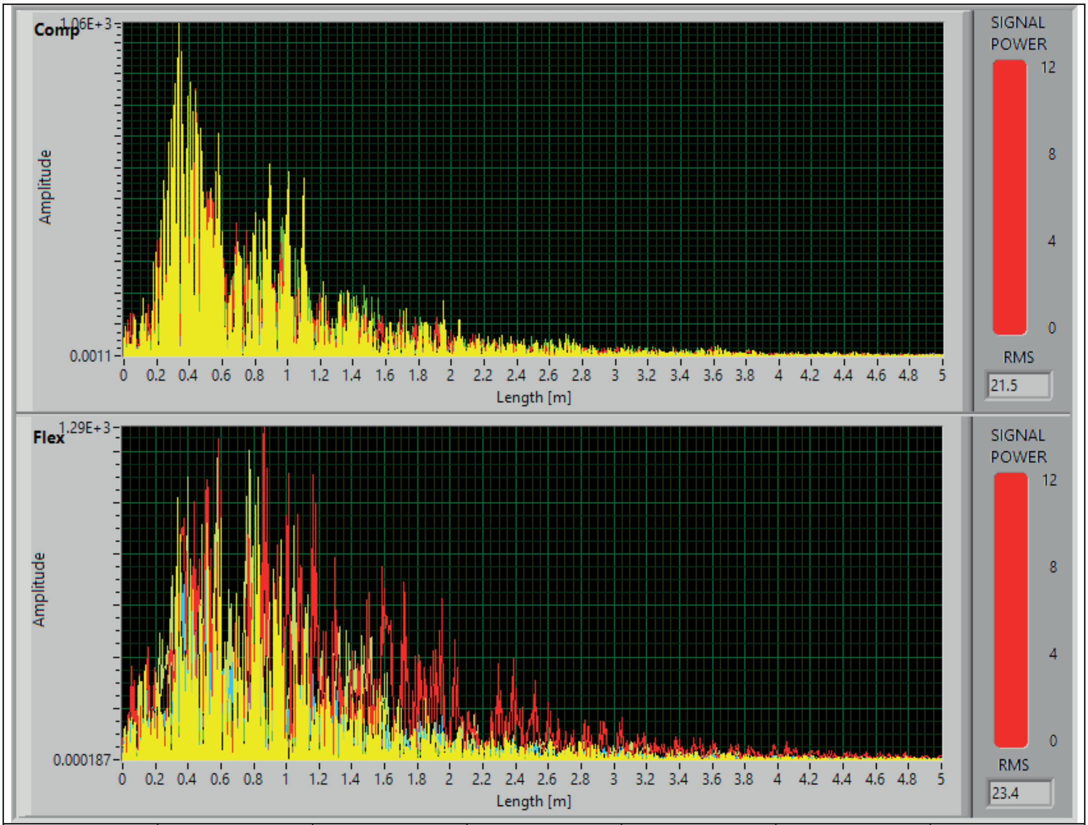
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_15_5 Sätra NC_15_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



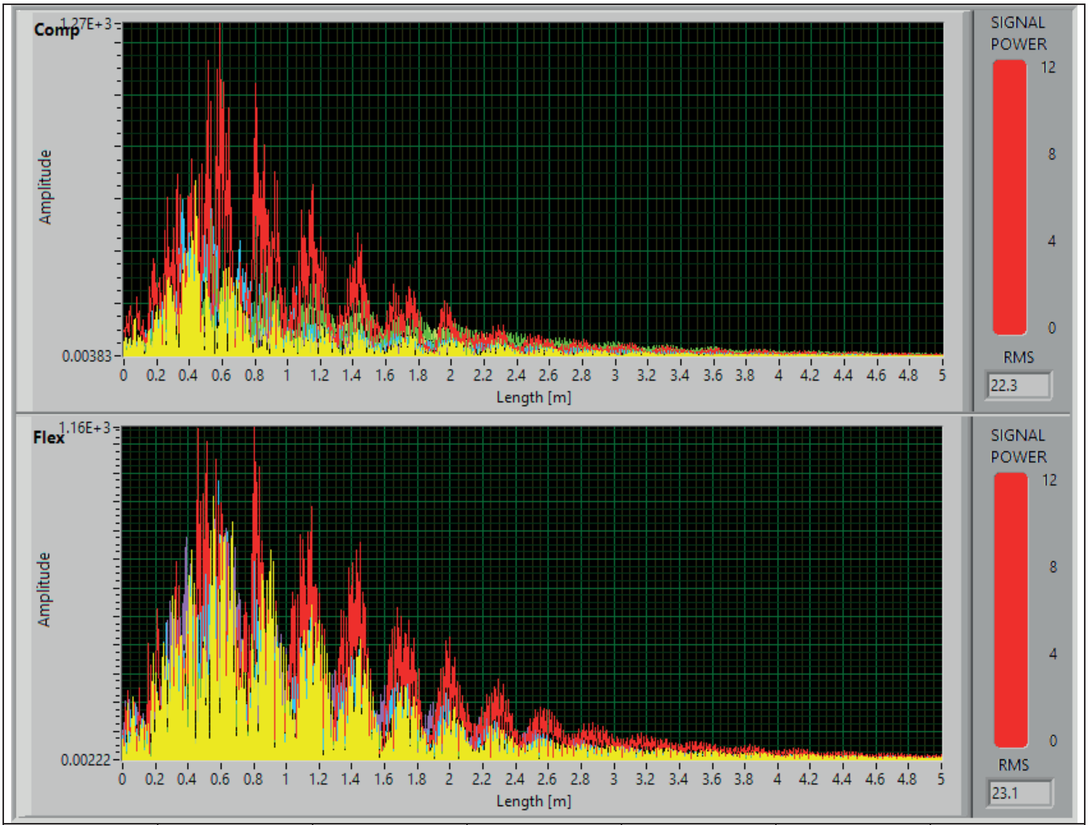
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_16_0 Sätra NC_16_5	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



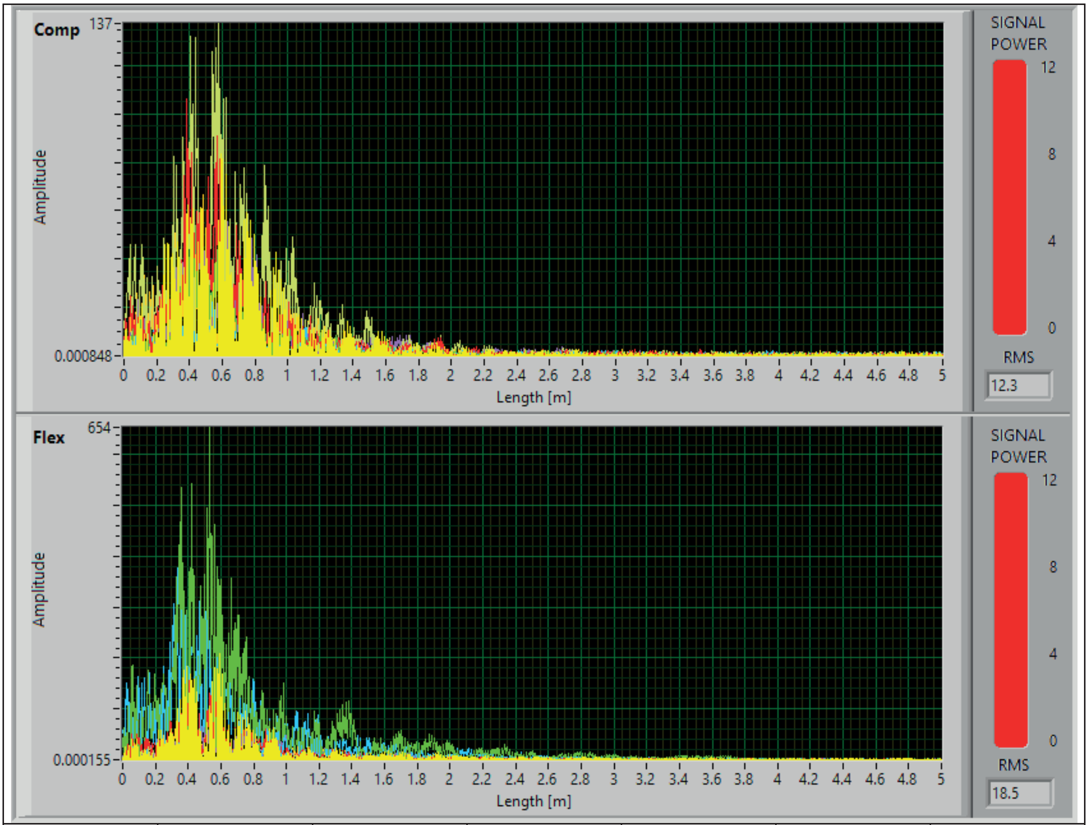
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_17_1 Sätra NC_17_0	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



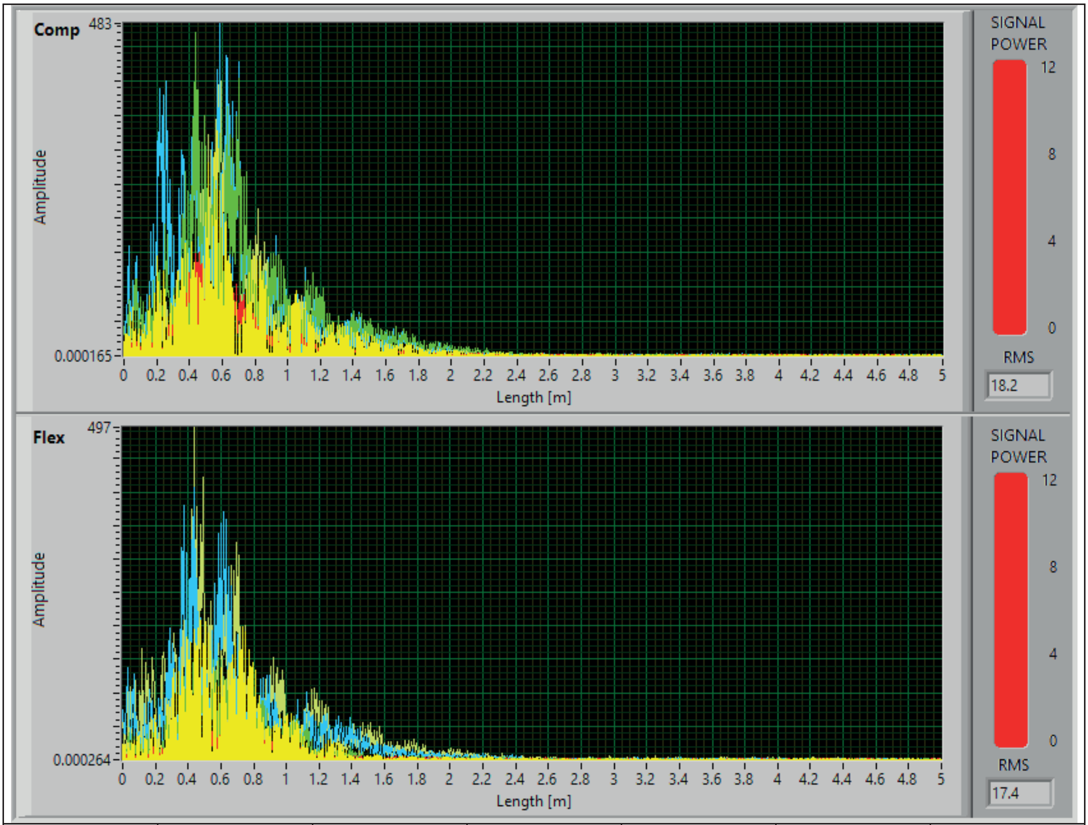
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_18_1 Sätra NC_18_1	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



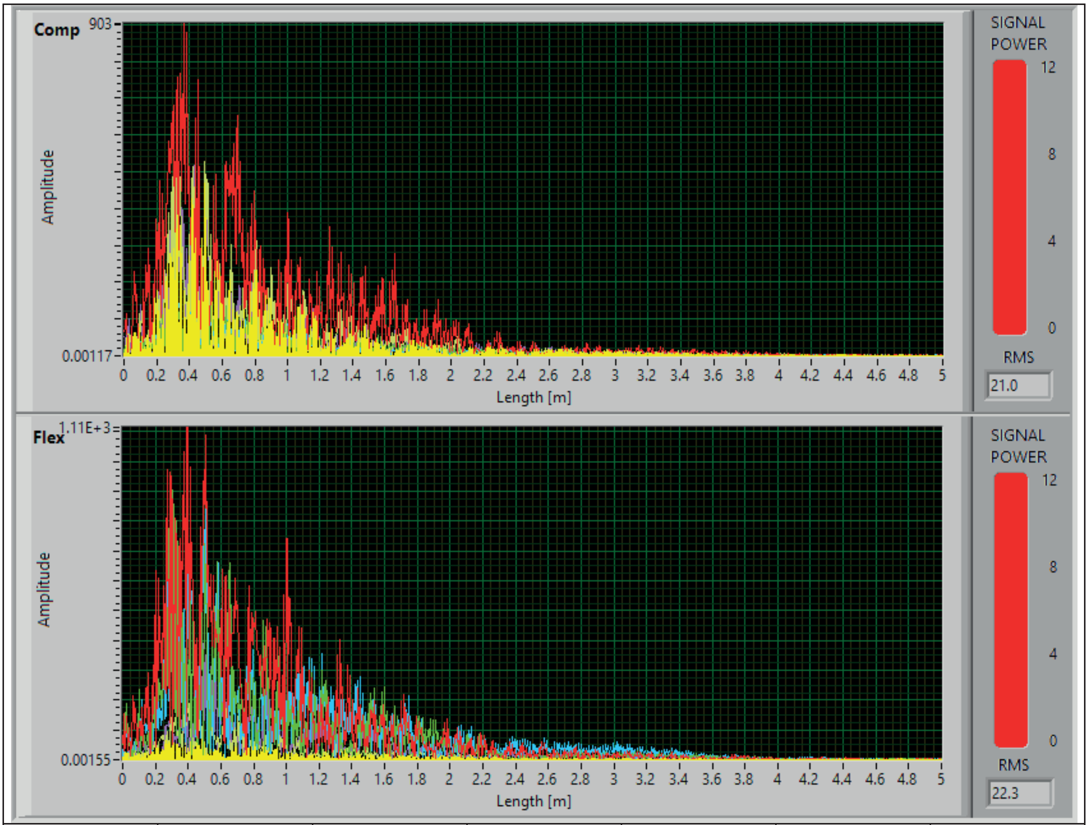
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_19_2 Sätra NC_19_4	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



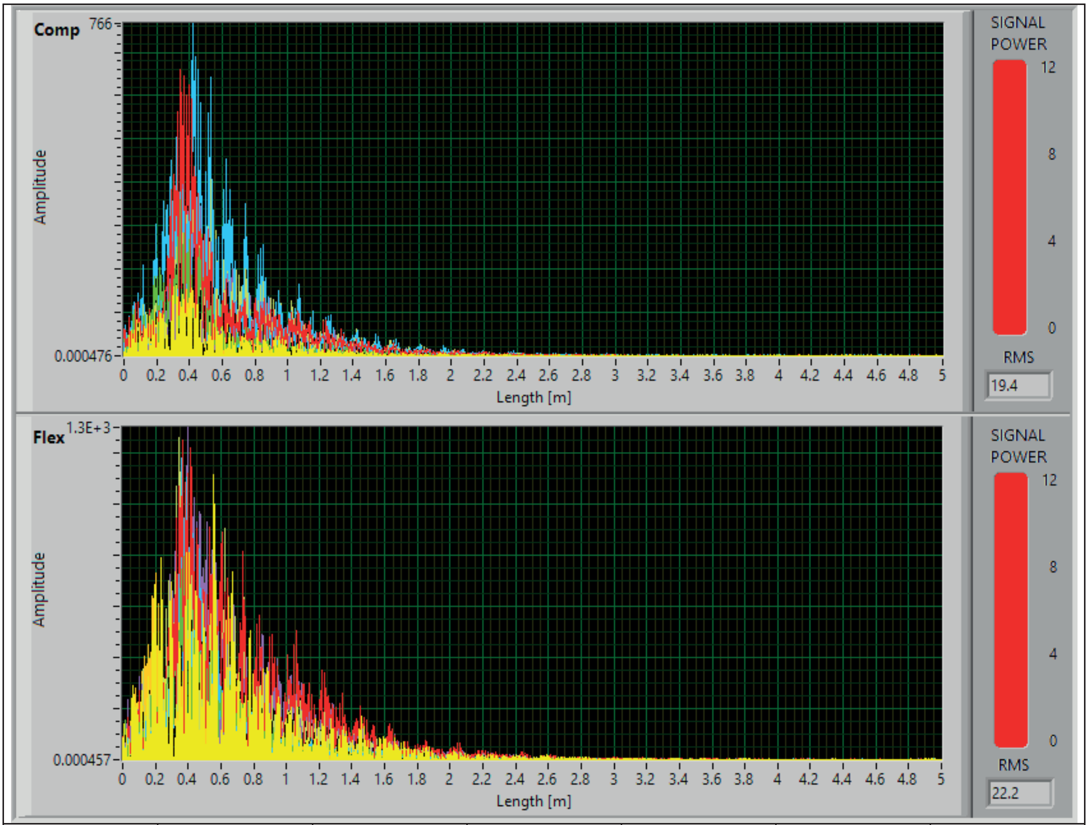
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_20_4 Sätra NC_20_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



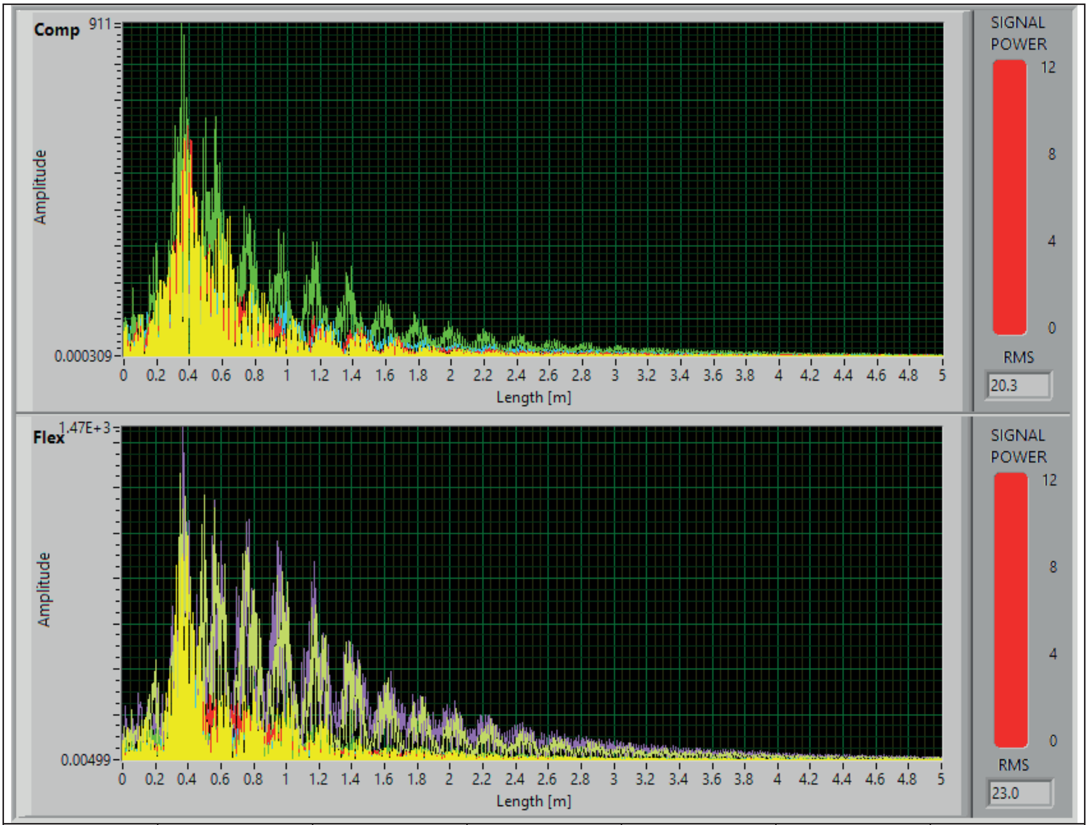
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_21_1 Sätra NC_21_1	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



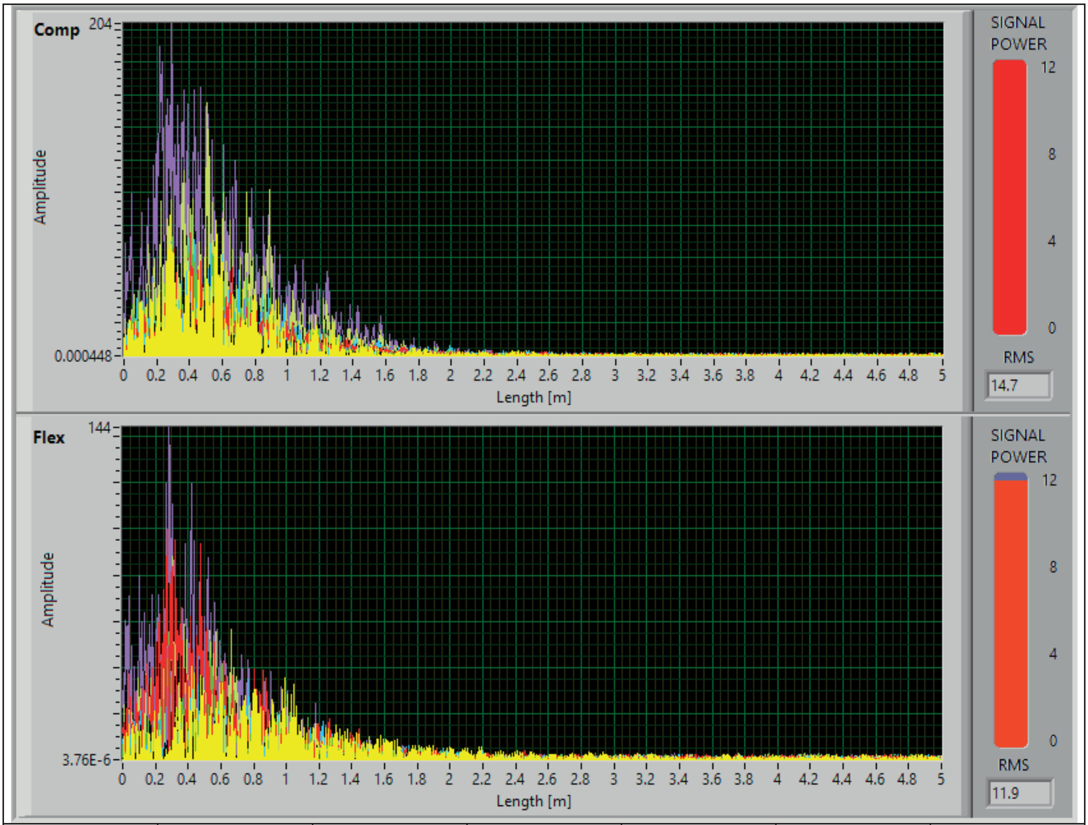
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_22_1 Sätra NC_22_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



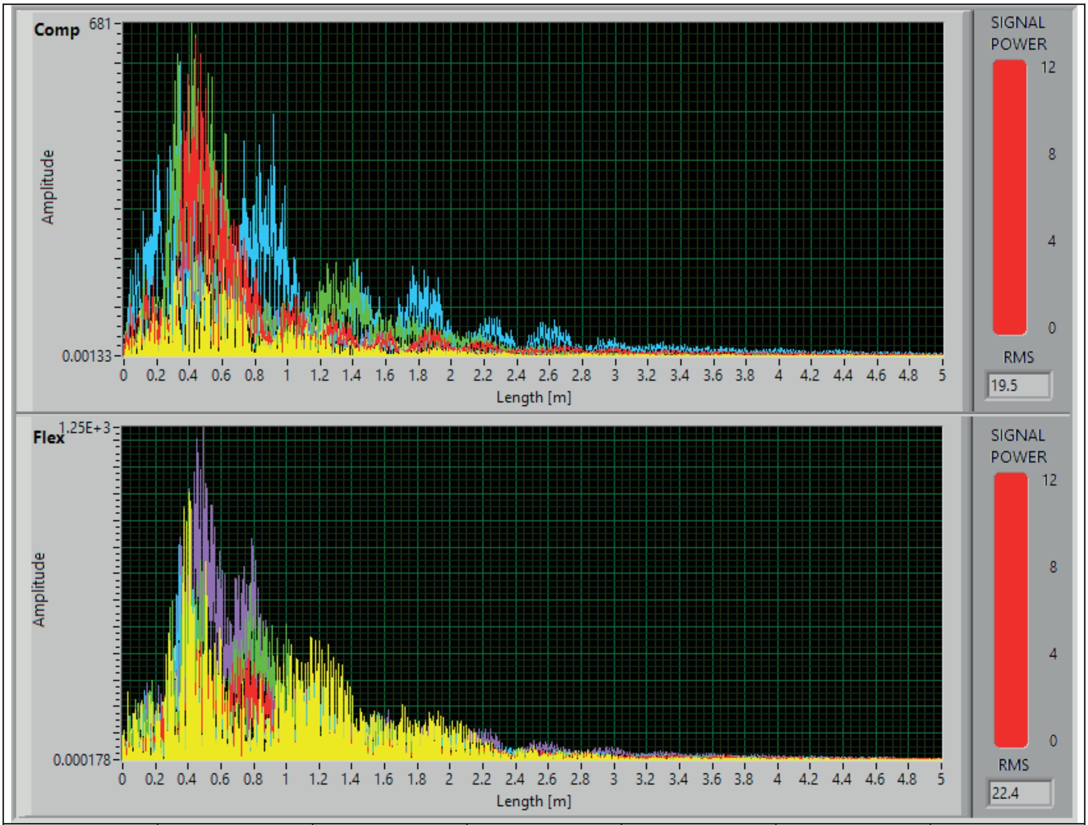
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_23_5 Sätra NC_23_2	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



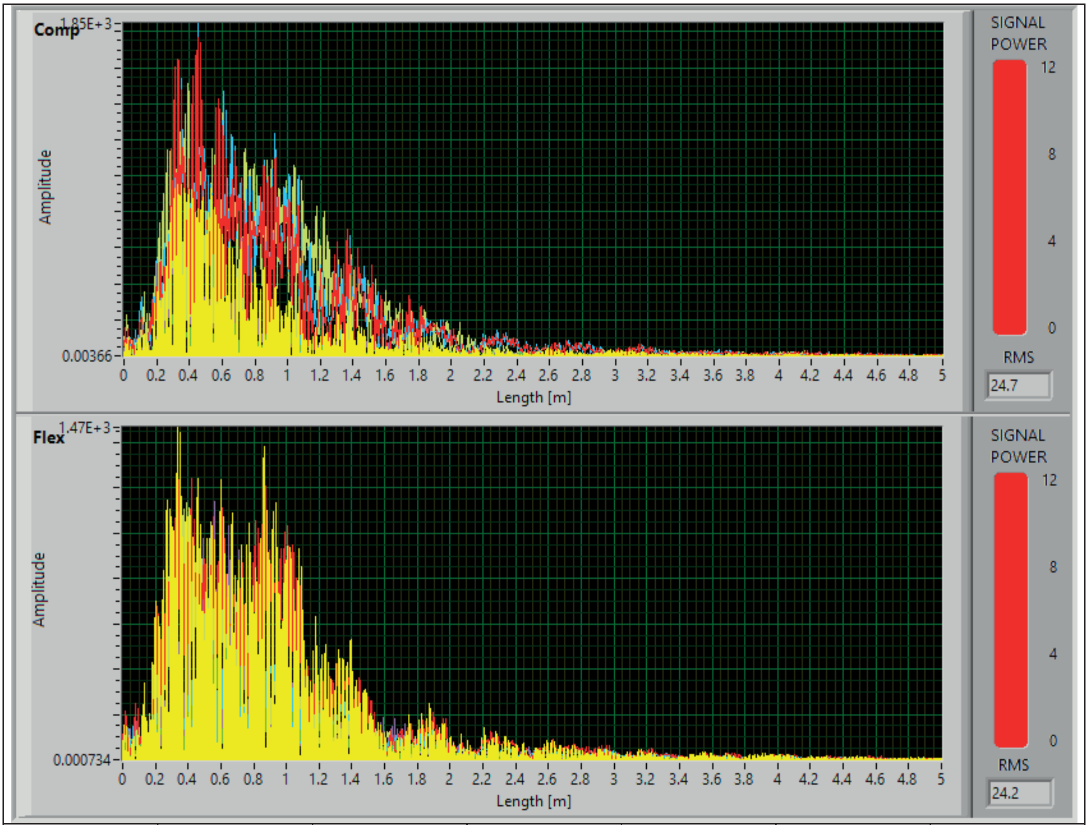
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_24_5 Sätra NC_24_5	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



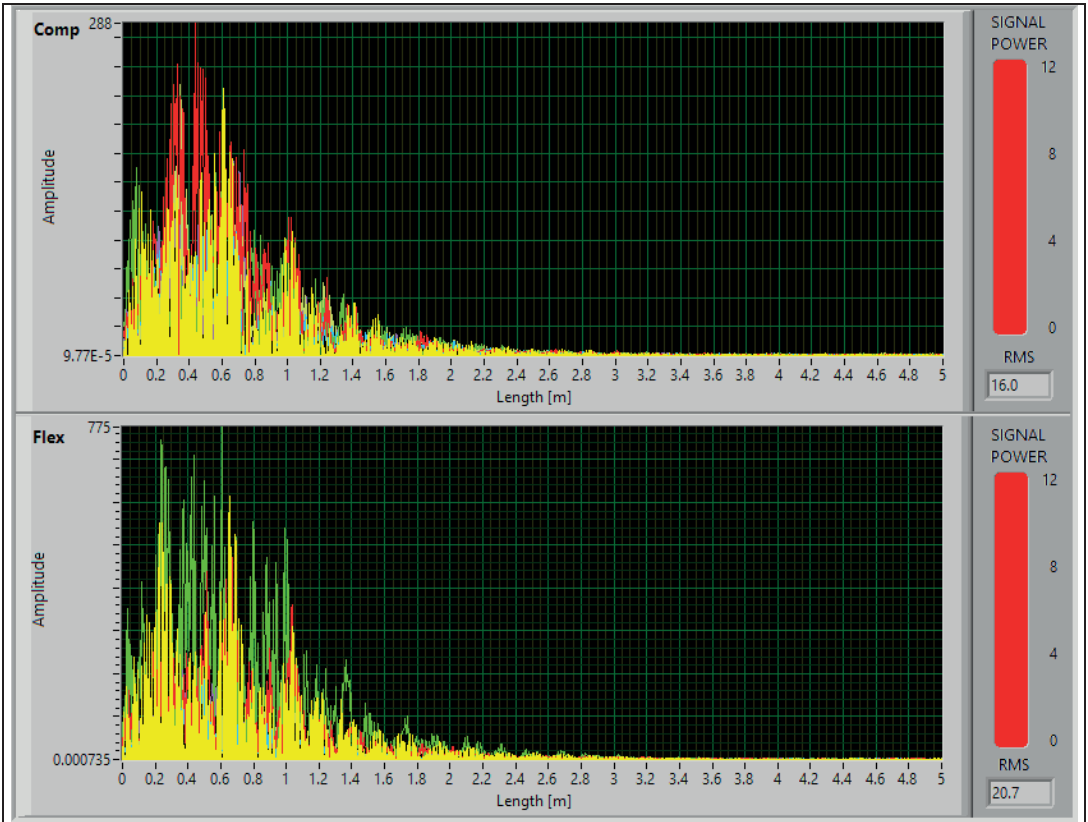
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_25_5 Sätra NC_25_2	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



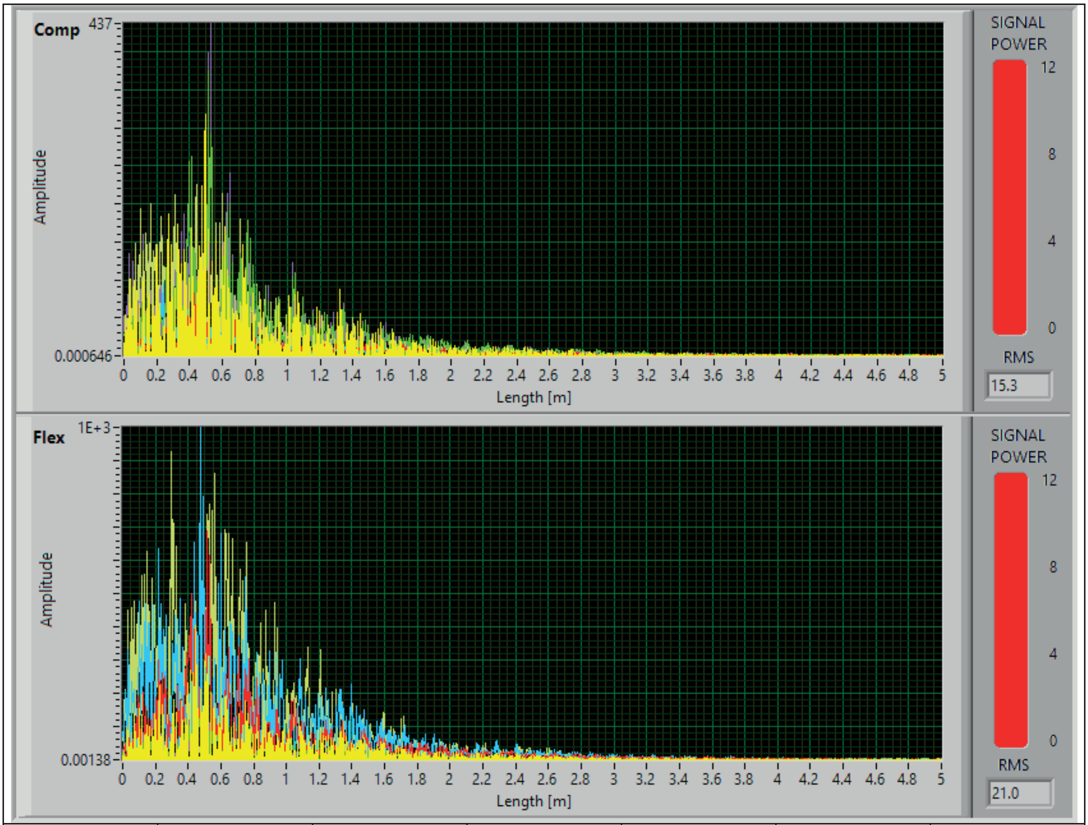
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_26_0 Sätra NC_26_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



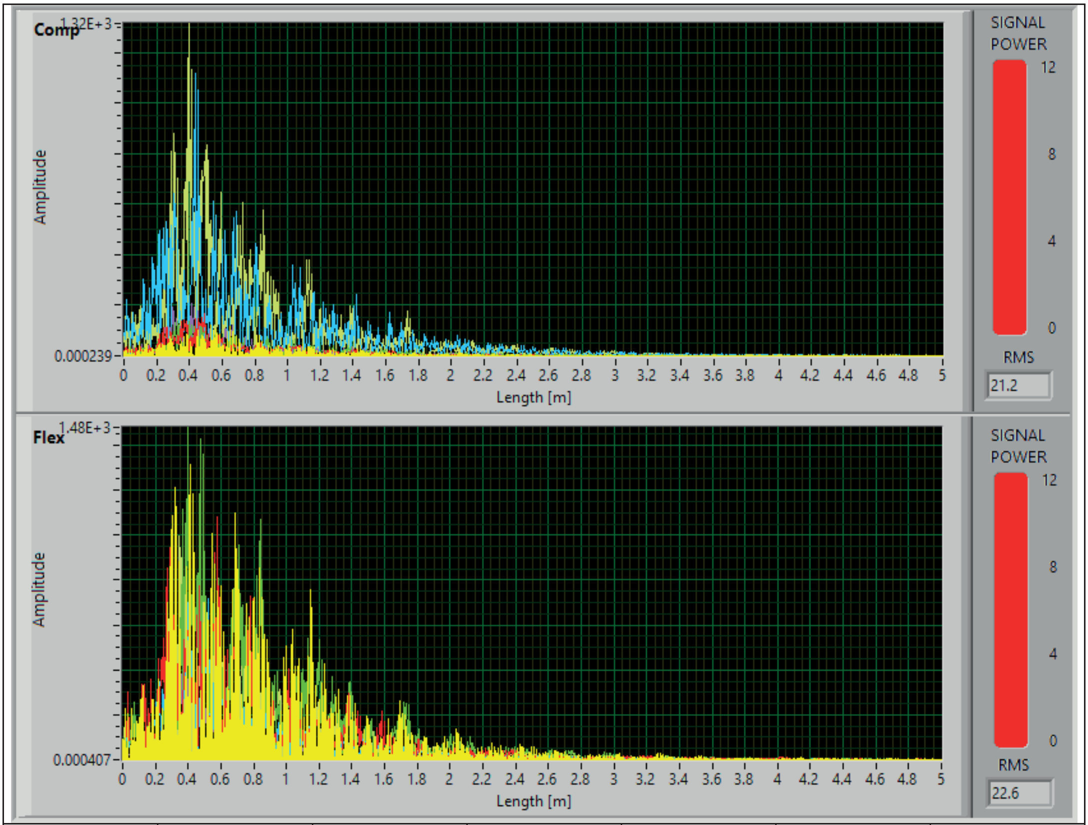
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_27_2 Sätra NC_27_1	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



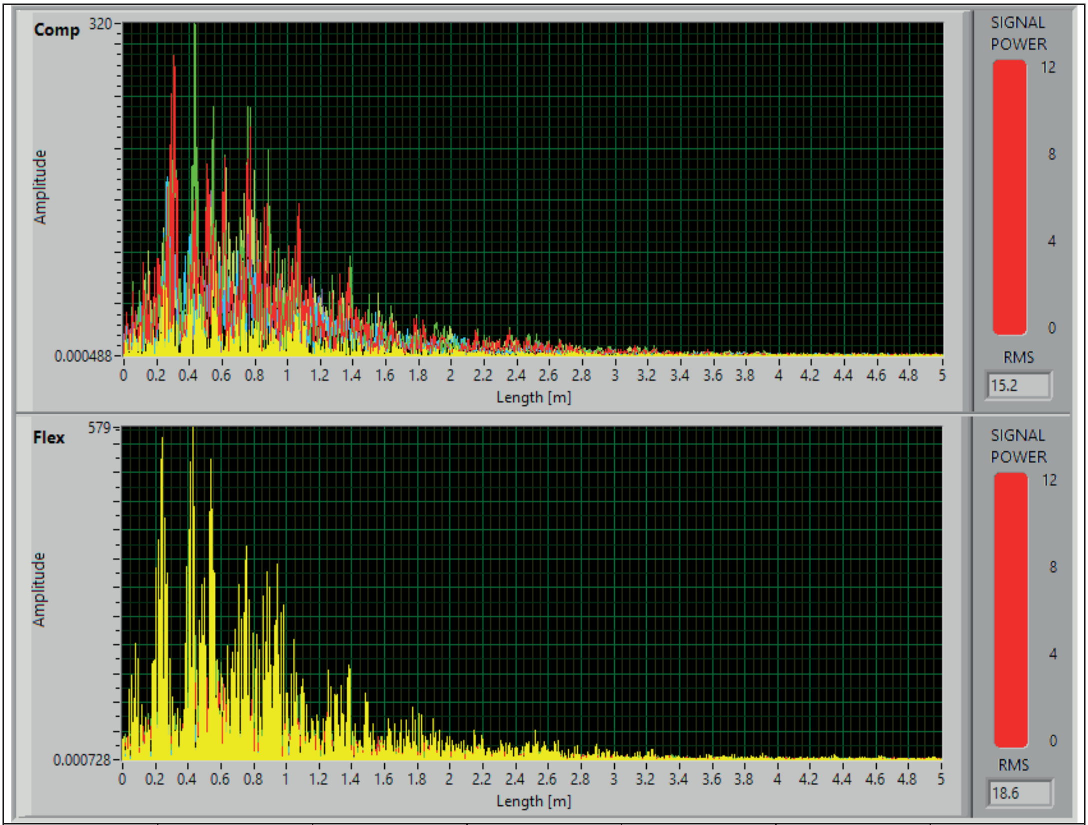
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_28_4 Sätra NC_28_5	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



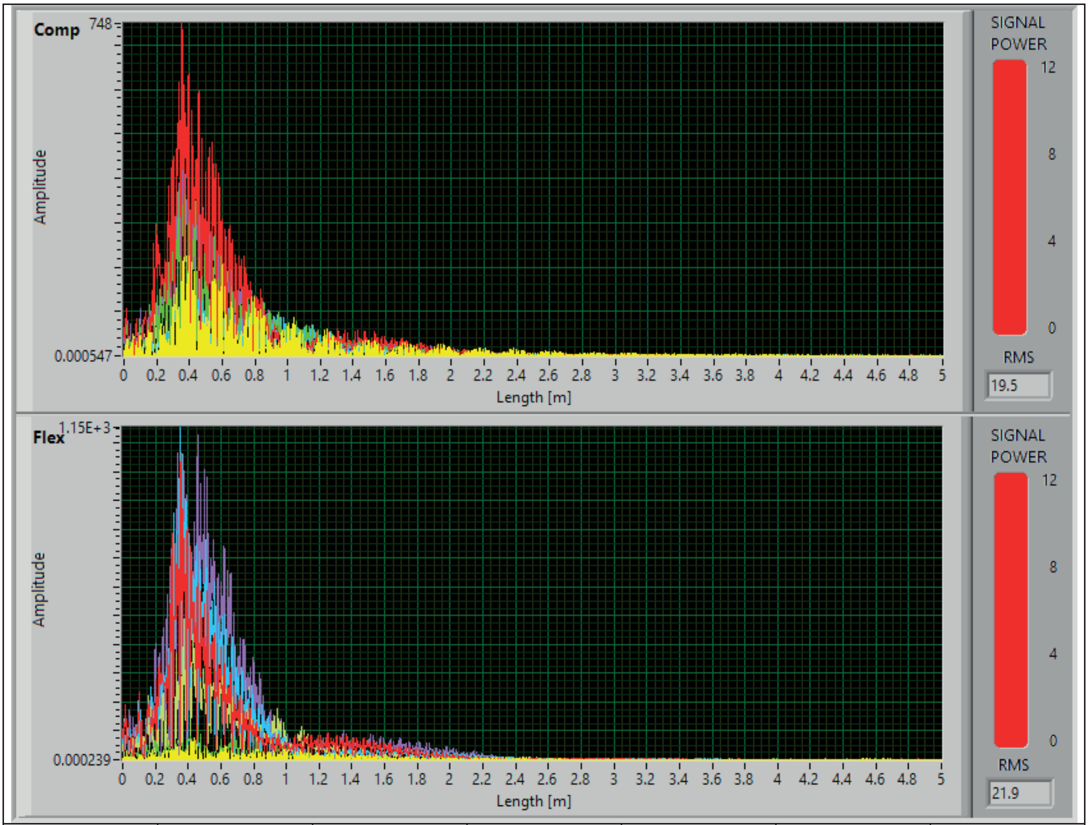
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_29_2 Sätra NC_29_4	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



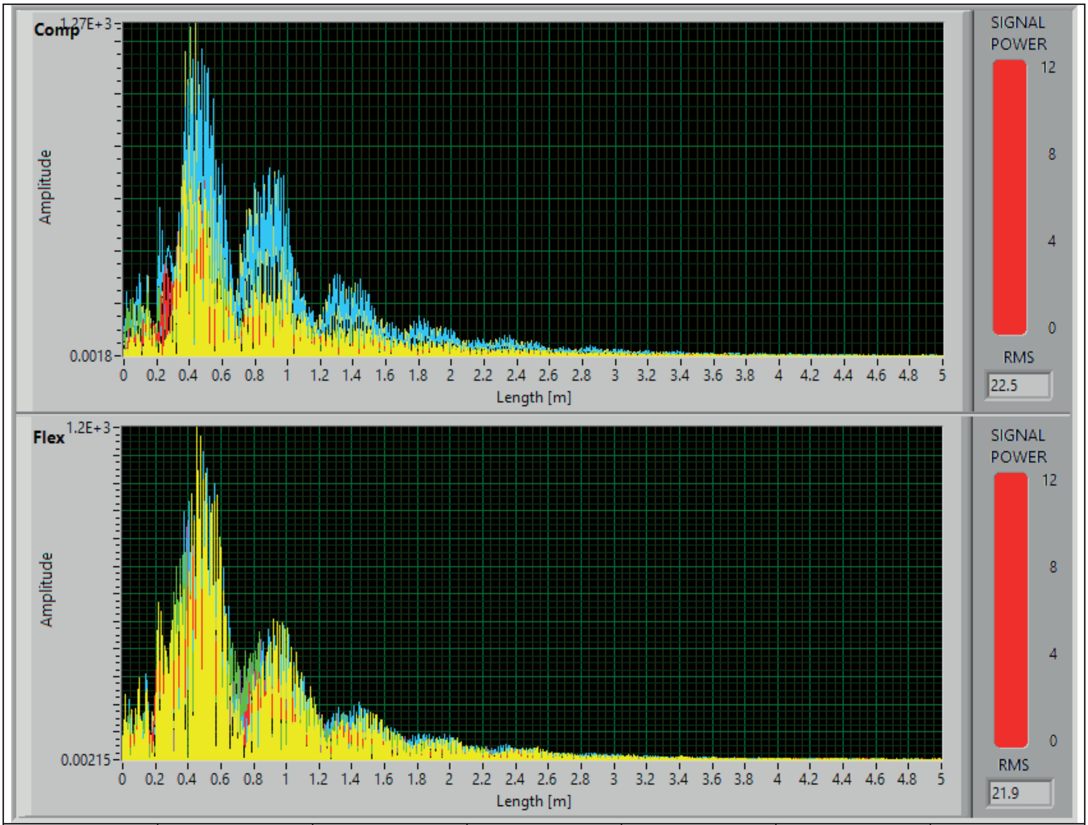
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_30_0 Sätra NC_30_2	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



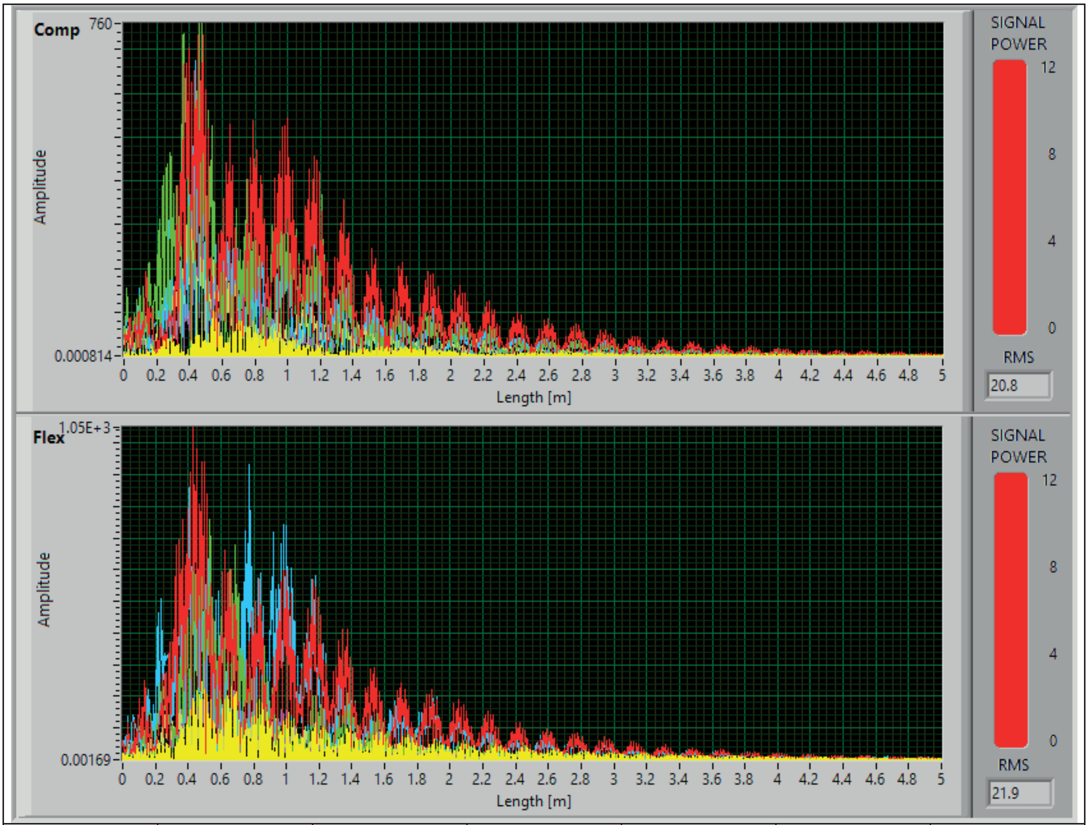
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_31_5 Sätra NC_31_1	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



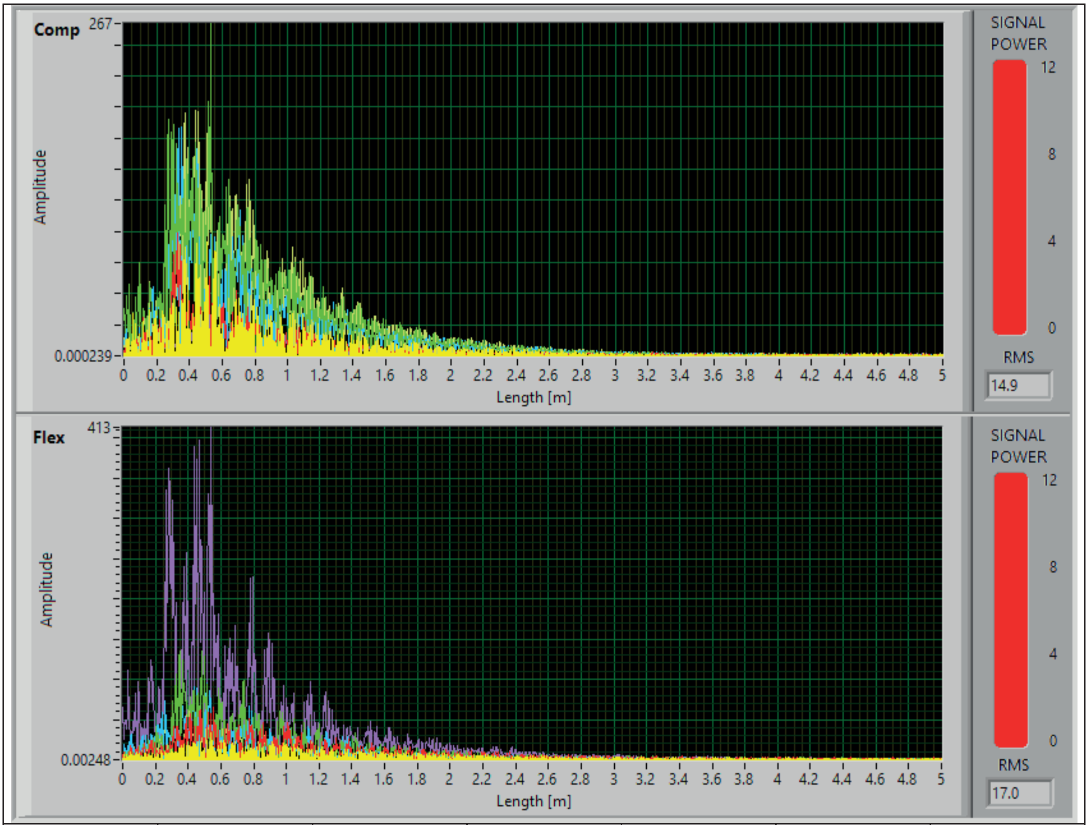
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_32_0 Sätra NC_32_3	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



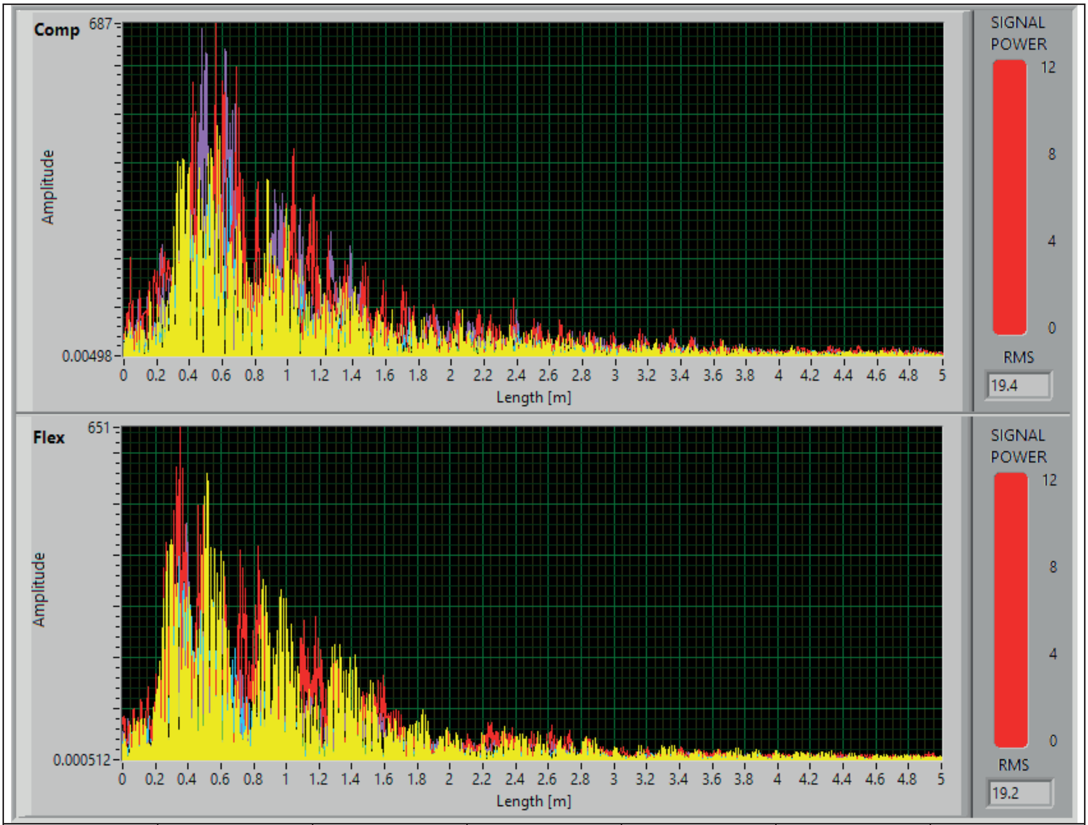
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_33_1 Sätra NC_33_1	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



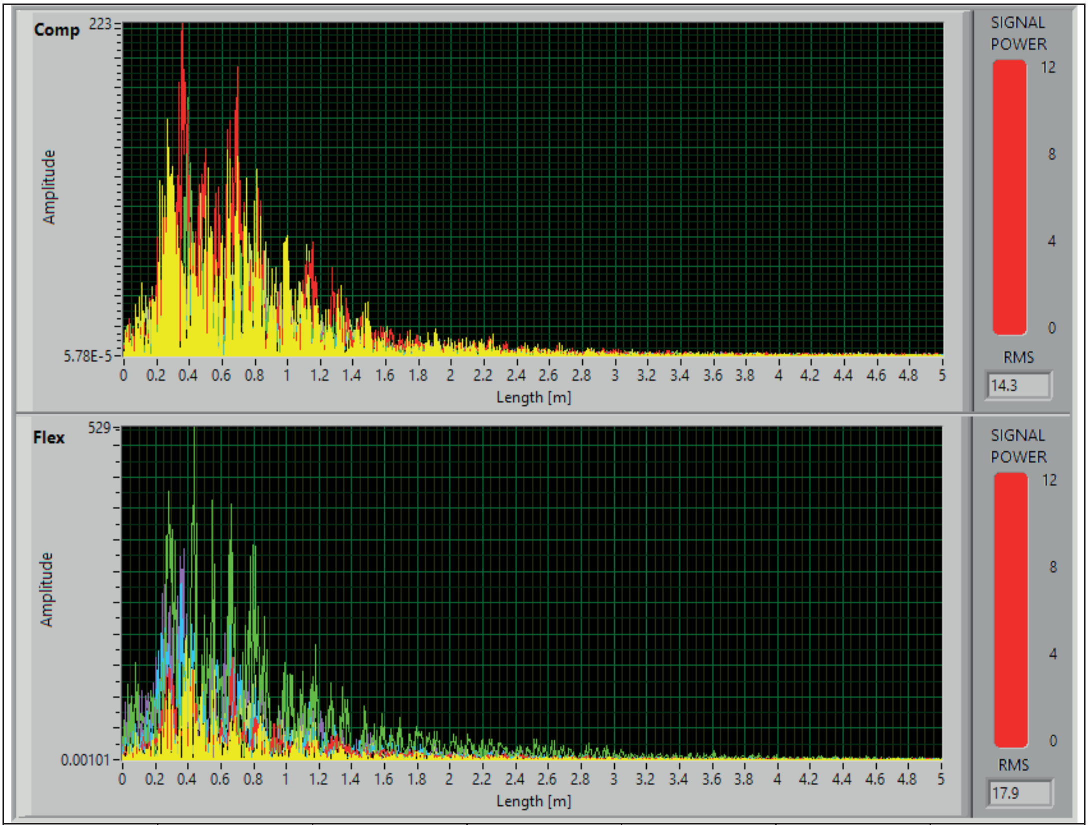
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_34_5 Sätra NC_34_2	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



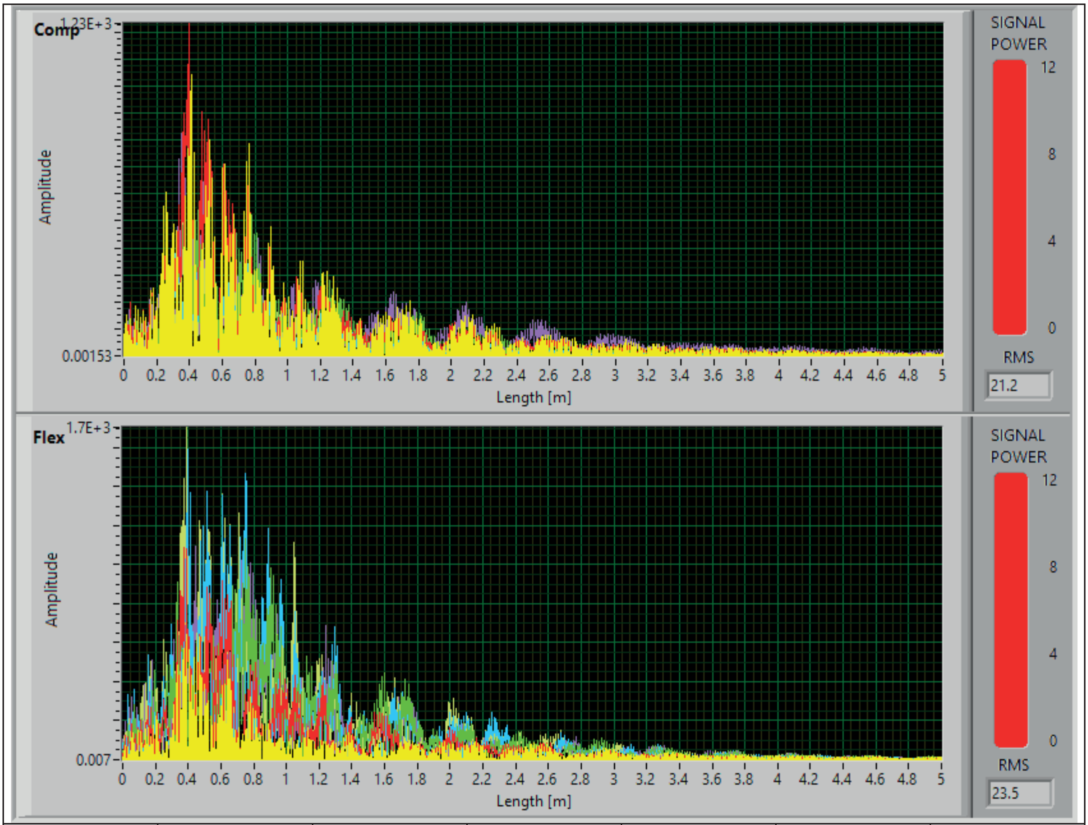
Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_35_1 Sätra NC_35_1	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_36_2 Sätra NC_36_1	2020/06/09		k	nai	Sätra NC	

Appendix 3 – RBT echograms plot for NC-bolts



Name	Date	Bolt ID	Bolt Grout	User	Test Site	
Sätra NC_37_3 Sätra NC_37_1	2020/06/09		k	nai	Sätra NC	

APPENDIX 4
RMS DATA FROM FINAL MEASUREMENT SERIES

	Bolt ID	Comp RMS per measurement nr						Flex RMS per measurement nr						Maximum RMS	
Bolt name		**0**	**1**	**2**	**3**	**4**	**5**	**0**	**1**	**2**	**3**	**4**	**5**	**Comp, max**	**Flex, max**
NC.2.4.1 A	1	12.8	14.3	13.7	17.7	11	13.6	13.5	20.2	16.5	16.3	16.6	11.6	17.7	20.2
NC.2.4.1 B	4	20.3	10.6	12.6	16.3	17.4	16	20.9	21.6	22	17.9	14.5	10.4	20.3	22
NC.2.4.1 C	7	13.5	15.6	16.2	9.6	16.1	18.9	18.6	21.4	15	17.8	17.7	15.4	18.9	21.4
NC.2.4.2 A	2	13.3	12.3	17.2	10	15	13	15.8	14.5	19.7	16.5	16.3	17.4	17.2	19.7
NC.2.4.2 B	5	14.7	12.8	11.9	18.3	13.6	17	21.3	17.6	21.1	22	14.2	17.4	18.3	22
NC.2.4.2 C	8	12.7	11.8	15	16.9	15.1	15	14.7	20.4	14.6	19.7	15.4	15.7	16.9	20.4
NC.2.4.3 A	3	13.4	17.5	12.3	12.4	10.4	21.3	17.7	17.5	13.4	20.8	18.7	18.5	21.3	20.8
NC.2.4.3 B	6	15.1	13.4	11.3	12	11.1	14.5	21.9	21.8	20.2	20.7	21.8	21.5	15.1	21.9
NC.2.4.3 C	9	21.5	19.5	20	17.4	20	18.6	23.1	22	23	21.7	22.5	22.4	21.5	23.1
NC.3.1 A	10	20.3	19.7	17	12.6	15.9	16.4	20.3	19.1	15.3	12.1	18.6	15.9	20.3	20.3
NC.3.2 A	13	17.8	15	17	17.1	18	18.8	20.5	19.4	12.7	17.8	13.2	14.6	18.8	20.5
NC.3.2 B	15	17.2	16	17.9	18.8	16.5	13.9	21.4	17.7	19	14.2	16.7	21.7	18.8	21.7
NC.3.2 C	18	18.1	22.4	18.8	19.4	17.5	16.8	21.8	23.2	17.1	21.7	18.5	21.5	22.4	23.2
NC.3.3 A	11	9.8	11.5	8.4	15.2	16.1	11.6	18.8	10.9	18.2	15.6	15	20.8	16.1	20.8
NC.3.3 B	16	9.9	9.1	9	8.1	12.3	12.9	15.5	12.2	9.5	12	12.2	14.9	12.9	15.5
NC.3.3 C	20	15.7	12.7	17.7	18.3	16.3	-	15.2	10.8	13.6	17.1	17.3	-	18.3	17.3
NC.3.4 A	14	17.1	12.9	19.6	18.2	14	11.5	23.8	19.6	17	20.7	13.2	19.1	19.6	23.8
NC.3.4 B	19	10.4	10.4	8	5	12.5	9.1	13.9	13	18.6	17	7	10.7	12.5	18.6
NC.3.4 C	22	13.1	18.5	15.8	19.6	18	17.8	21	22.3	20.1	20.7	21.4	22.3	19.6	22.3
NC.3.5 A	12	13.7	11.3	13	14.3	14.9	17.8	16.3	19.3	13.9	20.6	16.2	20.5	17.8	20.6
NC.3.5 B	17	21.6	19.6	18.9	10.8	11.4	16.6	21.9	23.5	16	20.2	22.4	18.5	21.6	23.5
NC.3.5 C	21	17.4	21.1	14.1	13.9	18.8	17.8	10.4	22.5	20.7	20.8	14.7	17.3	21.1	22.5
NC.4.1 A	23	18.7	18.1	20.4	16.4	13	14.3	20.1	16.6	18.2	16.5	23	23.1	20.4	23.1
NC.4.1 B	28	14.9	9.8	15.1	10.4	15	15.4	16.2	18	13.2	20.2	21.1	15	15.4	21.1
NC.4.1 C	33	11.3	20.9	20.3	18.6	17.1	16.5	16.1	22	20.3	21.7	15.1	16	20.9	22
NC.4.2 A	26	22.2	24.7	16.6	24.8	24.7	19.9	24.3	23.9	18.3	21.2	22.4	21.9	24.8	24.3
NC.4.2 B	31	14.9	19.6	17.3	14.4	13.9	18.2	9.7	20.6	11.6	21.2	18.3	22	19.6	22
NC.4.2 C	36	13.6	14.4	11.6	8.6	12	10.4	12.5	12.6	18	15.3	12.9	16	14.4	18
NC.4.3 A	24	10.7	9.6	10.3	10.1	12.6	14.8	8.2	10.7	8.5	8.1	9.6	12.1	14.8	12.1
NC.4.3 B	29	12	13.2	12.9	20.5	21.3	14.2	22.5	21.3	22.7	19.9	20.9	17.4	21.3	22.7
NC.4.3 C	34	10.7	10.1	15.1	13.9	14.8	7.1	7.1	10	12.5	11.3	9.3	17.1	15.1	17.1
NC.4.4 A	27	14.9	26.2	14.2	13.1	14.3	13.5	19	18.3	20.8	14.9	15.7	15.6	26.2	20.8
NC.4.4 B	32	19.7	28.8	19	22.6	22.2	17.1	22	29.8	20.4	21.8	20.6	20.3	28.8	29.8
NC.4.4 C	37	21.1	21.3	19.7	18	17.8	20.1	19.2	21.6	22.5	23.6	23.6	22.6	21.3	23.6
NC.4.5 A	25	13.7	18.9	19.6	19.4	16.1	15.4	20.9	18.5	21	19.4	18.6	22.5	19.6	22.5
NC.4.5 B	30	9.8	15.1	15.3	13.4	14.3	13.6	18.7	13.4	14	8.7	12.2	8.7	15.3	18.7
NC.4.5 C	35	18.6	19.5	14.1	16.9	16.8	19.4	19.2	19.3	12.6	17.5	13	17.5	19.5	19.3

Appendix 4 – RMS Data from final measurement series

Bolt name	Bolt ID	ID and measurement nr.	Comp RMS	Flex RMS
P.2.4.1 A	1	1_0	10.5	10.5
P.2.4.1 A	1	1_1	10.5	9.9
P.2.4.1 A	1	1_2	12.4	12.4
P.2.4.1 A	1	1_3	11.7	11.2
P.2.4.1 A	1	1_4	12.7	12.1
P.2.4.1 A	1	1_5	11.9	10.4
P.2.4.1 A	1	1_6	11.9	11.2
P.2.4.1 A	1	1_7	12.4	14.2
P.2.4.1 B	25	25_0	11.1	11.6
P.2.4.1 B	25	25_1	11.4	12.3
P.2.4.1 B	25	25_2	13.1	12.7
P.2.4.1 B	25	25_3	10.9	9.8
P.2.4.1 B	25	25_4	9.4	10.6
P.2.4.1 B	25	25_5	12.6	10.3
P.2.4.1 B	25	25_6	12.2	11
P.2.4.1 C	5	5_0	5.4	6.5
P.2.4.1 C	5	5_1	11.2	10.5
P.2.4.1 C	5	5_2	9.3	5.5
P.2.4.1 C	5	5_3	15.4	12.1
P.2.4.1 C	5	5_4	14.5	13.7
P.2.4.1 C	5	5_5	8.4	10.5
P.2.4.1 C	5	5_6	14.9	12.7
P.2.4.2 A	3	3_0	11.7	11.8
P.2.4.2 A	3	3_1	12.2	11.5
P.2.4.2 A	3	3_2	10.2	11.4
P.2.4.2 A	3	3_3	14	11.8
P.2.4.2 A	3	3_4	14.6	12
P.2.4.2 A	3	3_5	16.1	15.2
P.2.4.2 A	3	3_6	13.3	11.3
P.2.4.2 A	3	3_7	13.9	9.5
P.2.4.2 B	34	34_0	12	11.2
P.2.4.2 B	34	34_1	11.6	12.1
P.2.4.2 B	34	34_2	12	12.3
P.2.4.2 B	34	34_3	11.2	10
P.2.4.2 B	34	34_4	11.2	8.3
P.2.4.2 B	34	34_5	10	10.5
P.2.4.2 C	36	36_0	8	11.8
P.2.4.2 C	36	36_1	7.8	12.8
P.2.4.2 C	36	36_2	7.7	7.9
P.2.4.2 C	36	36_3	11.5	4.8
P.2.4.2 C	36	36_4	9.6	11.8
P.2.4.2 C	36	36_5	5.6	15.9
P.2.4.2 C	36	36_6	9.5	15.7

Appendix 4 – RMS Data from final measurement series

P.2.4.3 C	35	35_0	10.9	9.9
P.2.4.3 C	35	35_1	11.1	10.6
P.2.4.3 C	35	35_2	11.4	11.4
P.2.4.3 C	35	35_3	13.4	11.5
P.2.4.3 C	35	35_4	5.9	3.6
P.2.4.3 C	35	35_5	5.8	9

Bolt name	**Bolt ID**	**ID and measurement nr.**	**Comp RMS**	**Flex RMS**
P.3.1 A	6	6_0	10.3	8.3
P.3.1 A	6	6_1	6.4	2.8
P.3.1 A	6	6_2	7.4	7.3
P.3.1 A	6	6_3	9.5	12.9
P.3.1 A	6	6_4	9.5	8.3
P.3.2 A	24	24_0	3.9	7.3
P.3.2 A	24	24_1	5	2.2
P.3.2 A	24	24_2	6.1	5.3
P.3.2 A	24	24_3	6.7	9.8
P.3.2 A	24	24_4	8.2	6.9
P.3.2 A	24	24_5	9.7	4.3
P.3.2 B	10	10_6	8.4	7.7
P.3.2 B	10	10_7	8.2	10.6
P.3.2 B	10	10_8	10.8	8.1
P.3.2 B	10	10_9	11.1	9.2
P.3.2 B	10	10_10	13	12.5
P.3.2 B	10	10_11	5.2	6.4
P.3.2 B	10	10_12	7.2	8
P.3.2 C	23	23_0	12.7	12
P.3.2 C	23	23_1	13.5	11.6
P.3.2 C	23	23_2	14.3	12.4
P.3.2 C	23	23_3	14.7	14.3
P.3.2 C	23	23_4	11.3	13.1
P.3.2 C	23	23_5	11.4	12.8
P.3.3 A	7	7_0	13.8	14.6
P.3.3 A	7	7_1	5.9	7.4
P.3.3 A	7	7_2	11.2	11.7
P.3.3 A	7	7_3	17.5	10.3
P.3.3 A	7	7_4	9	12.8
P.3.3 B	11	11_0	16.5	17.8
P.3.3 B	11	11_1	17.1	10.5
P.3.3 B	11	11_2	14.8	12.6
P.3.3 B	11	11_3	15.9	17
P.3.3 B	11	11_4	11	13.8
P.3.3 B	11	11_5	10.2	9.5
P.3.3 C	13	13_0	9.6	9.7

Appendix 4 – RMS Data from final measurement series

P.3.3 C	13	13_1	12	12.7
P.3.3 C	13	13_2	10.1	12.6
P.3.3 C	13	13_3	11.6	10.1
P.3.3 C	13	13_4	5.3	7
P.3.3 C	13	13_5	9.5	9.1
P.3.4 A	14	14_0	9.1	9.4
P.3.4 A	14	14_1	8.1	10.3
P.3.4 A	14	14_2	7	10.8
P.3.4 A	14	14_3	8	11.5
P.3.4 A	14	14_4	5	5.7
P.3.4 A	14	14_5	6.1	5.4
P.3.4 A	14	14_6	6.3	6.1
P.3.4 A	14	14_7	4.5	6.3
P.3.4 B	33	33_0	10.8	12.8
P.3.4 B	33	33_1	13	13.1
P.3.4 B	33	33_2	8.1	8.3
P.3.4 B	33	33_3	8.9	9.9
P.3.4 B	33	33_4	8.8	9.4
P.3.4 B	33	33_5	12.2	15
P.3.4 C	37	37_1	15.5	14.2
P.3.4 C	37	37_2	15	11.7
P.3.4 C	37	37_3	14.5	11.5
P.3.4 C	37	37_4	14.9	13.6
P.3.4 C	37	37_5	11.5	14.7
P.3.5 A	8	9_0	8.5	5.2
P.3.5 A	8	9_1	4.4	9
P.3.5 A	8	9_2	6.7	7
P.3.5 A	8	9_3	9.8	14
P.3.5 A	8	9_4	10.1	5.5
P.3.5 A	8	9_5	3.6	7.1
P.3.5 A	8	9_6	7.6	14
P.3.5 B	9	10_0	9.2	11.4
P.3.5 B	9	10_1	12.5	12.9
P.3.5 B	9	10_2	8.9	6.9
P.3.5 B	9	10_3	13.3	10.1
P.3.5 B	9	10_4	11.5	11
P.3.5 B	9	10_5	16	14.8
P.3.5 C	12	12_0	16.4	11.6
P.3.5 C	12	12_1	14.7	12.3
P.3.5 C	12	12_2	15.1	13.8
P.3.5 C	12	12_3	15.4	9.8
P.3.5 C	12	12_4	3.8	4.6
P.3.5 C	12	12_5	11.9	13.2

Appendix 4 – RMS Data from final measurement series

Bolt name	Bolt ID	ID and measurement nr.	Comp RMS	Flex RMS
P.4.1 A	**17**	17_0	14	15.8
P.4.1 A	**17**	17_1	14.9	15.7
P.4.1 A	**17**	17_2	16	14.7
P.4.1 A	**17**	17_3	16.4	14.1
P.4.1 A	**17**	17_4	13.3	12.8
P.4.1 A	**17**	17_5	12.7	12.3
P.4.1 B	**28**	28_0	11.3	10.2
P.4.1 B	**28**	28_1	11.7	10.1
P.4.1 B	**28**	28_2	11.5	13.4
P.4.1 B	**28**	28_3	12.1	12.8
P.4.1 B	**28**	28_4	11.8	7.8
P.4.1 B	**28**	28_5	10.5	10.1
P.4.1 C	**31**	31_0	12.9	9.9
P.4.1 C	**31**	31_1	13.1	10.9
P.4.1 C	**31**	31_2	13.8	11
P.4.1 C	**31**	31_3	11.4	12.7
P.4.1 C	**31**	31_4	11.5	11.1
P.4.1 C	**31**	31_5	9.6	11.3
P.4.2 A	**20**	20_0	13.8	12.1
P.4.2 A	**20**	20_1	13.8	13.2
P.4.2 A	**20**	20_2	14	13.4
P.4.2 A	**20**	20_3	12.7	13.6
P.4.2 A	**20**	20_4	11.6	14.3
P.4.2 A	**20**	20_5	11.8	13.9
P.4.2 B	**16**	16_0	15.3	16.5
P.4.2 B	**16**	16_1	14.8	12.5
P.4.2 B	**16**	16_2	14.7	12.4
P.4.2 B	**16**	16_3	17.5	15.1
P.4.2 B	**16**	16_4	13.5	15.7
P.4.2 B	**16**	16_5	12.4	14.6
P.4.2 C	**29**	29_0	11.3	12.1
P.4.2 C	**29**	29_1	12.3	13.4
P.4.2 C	**29**	29_2	11.9	11.4
P.4.2 C	**29**	29_3	14.2	11.1
P.4.2 C	**29**	29_4	17.5	14.8
P.4.2 C	**29**	29_5	16.6	15.6
P.4.3 A	**21**	21_0	13.6	15.7
P.4.3 A	**21**	21_1	16.9	16.6
P.4.3 A	**21**	21_2	16.3	15.3
P.4.3 A	**21**	21_3	12.7	15.3
P.4.3 A	**21**	21_4	11.8	11.7
P.4.3 A	**21**	21_5	12.7	14.4
P.4.3 B	**18**	18_0	13.6	13

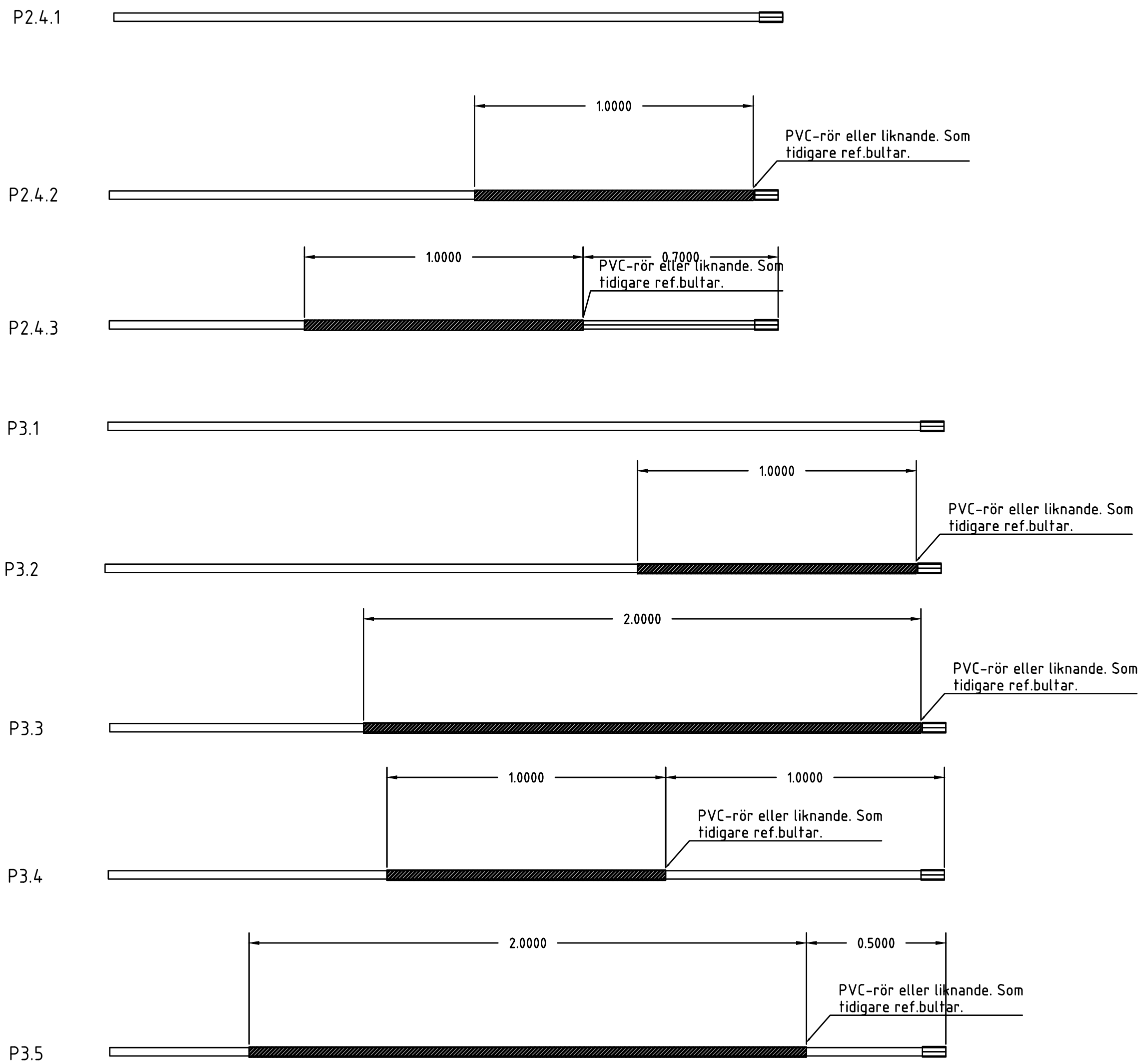
Appendix 4 – RMS Data from final measurement series

P.4.3 B	**18**	18_1	13.3	13.3
P.4.3 B	**18**	18_2	15.8	14.7
P.4.3 B	**18**	18_3	15.8	14.8
P.4.3 B	**18**	18_4	16	14.4
P.4.3 B	**18**	18_5	11.3	10.6
P.4.3 B	**18**	18_6	13.7	11.5
P.4.3 C	**30**	30_0	15.8	13.6
P.4.3 C	**30**	30_1	14	16.5
P.4.3 C	**30**	30_2	13.7	18.4
P.4.3 C	**30**	30_3	14.7	18.8
P.4.3 C	**30**	30_4	12.4	13.5
P.4.3 C	**30**	30_5	15.8	14.4
P.4.4 A	**22**	22_0	10.6	11.3
P.4.4 A	**22**	22_1	10.2	10.4
P.4.4 A	**22**	22_2	12.1	14.1
P.4.4 A	**22**	22_3	13.1	14
P.4.4 A	**22**	22_4	11.4	12.7
P.4.4 A	**22**	22_5	10.7	12.3
P.4.4 B	**15**	14_8	7.8	12.6
P.4.4 B	**15**	14_9	7.4	11.9
P.4.4 B	**15**	14_10	15.9	18
P.4.4 B	**15**	14_11	15.2	14
P.4.4 B	**15**	14_12	17	17.9
P.4.4 B	**15**	14_13	17.6	12.8
P.4.4 B	**15**	14_14	15.6	11.2
P.4.4 C	**26**	26_0	11.7	12.8
P.4.4 C	**26**	26_1	13.8	12.3
P.4.4 C	**26**	26_2	12.7	11.4
P.4.4 C	**26**	26_3	8.5	10.7
P.4.4 C	**26**	26_4	9.7	11.6
P.4.4 C	**26**	26_5	13.2	13.6
P.4.5 A	**19**	19_0	13.6	15.9
P.4.5 A	**19**	19_1	14.5	13.5
P.4.5 A	**19**	19_2	14.3	15
P.4.5 A	**19**	19_3	13.1	14.4
P.4.5 A	**19**	19_4	10	12.7
P.4.5 A	**19**	19_5	7.9	10.6
P.4.5 B	**27**	27_0	13.7	18.1
P.4.5 B	**27**	27_1	13.3	12.5
P.4.5 B	**27**	27_2	13.6	17.5
P.4.5 B	**27**	27_3	13.3	16.7
P.4.5 B	**27**	27_4	13.9	17.5
P.4.5 B	**27**	27_5	14	17.2
P.4.5 C	**32**	32_0	14.6	14.4
P.4.5 C	**32**	32_1	12.2	12.8

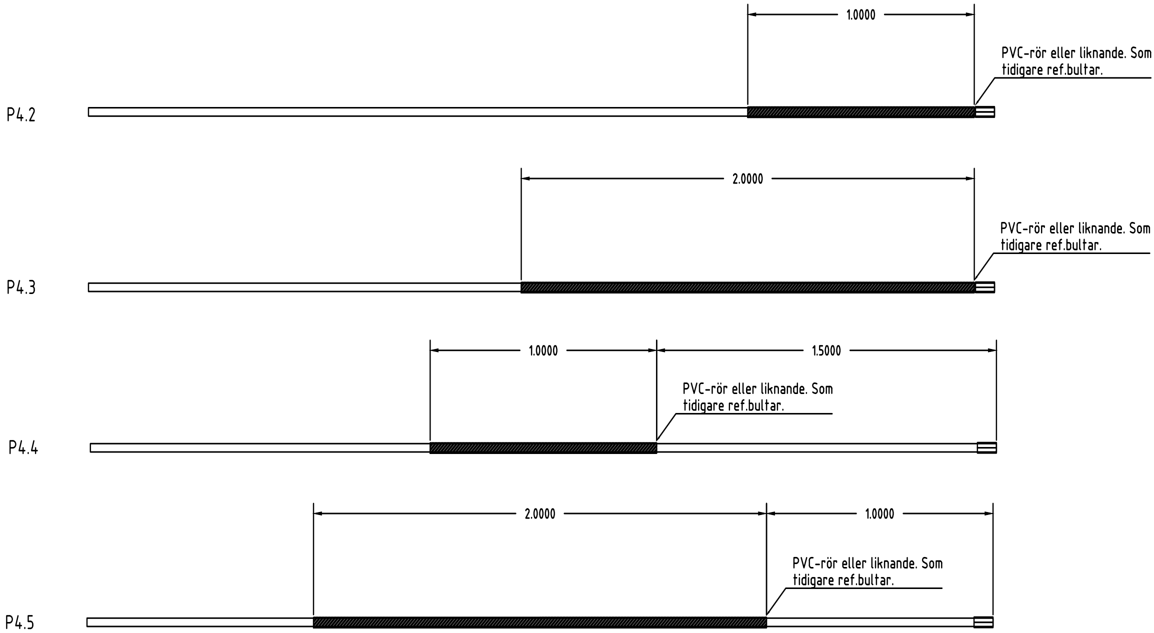
Appendix 4 – RMS Data from final measurement series

P.4.5 C	**32**	32_2	11.5	13.4
P.4.5 C	**32**	32_3	14.5	16.7
P.4.5 C	**32**	32_4	14.8	16.3
P.4.5 C	**32**	32_5	10.2	11.8

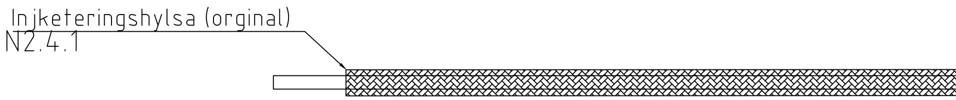
Appendix 5. Drawings of the reference bolts

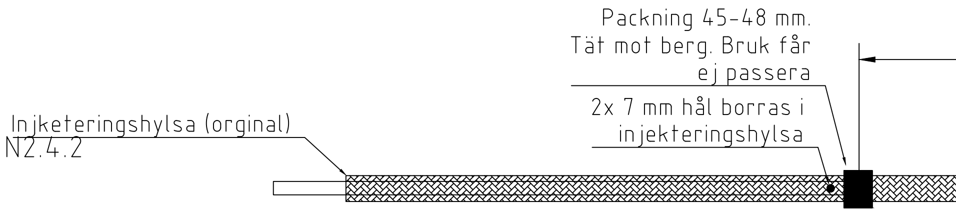


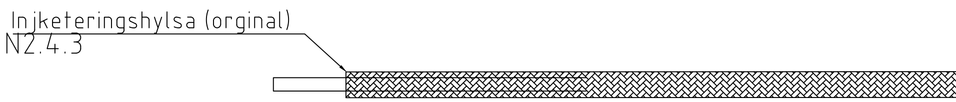
Appendix 5. Drawings of the reference bolts

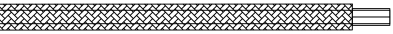


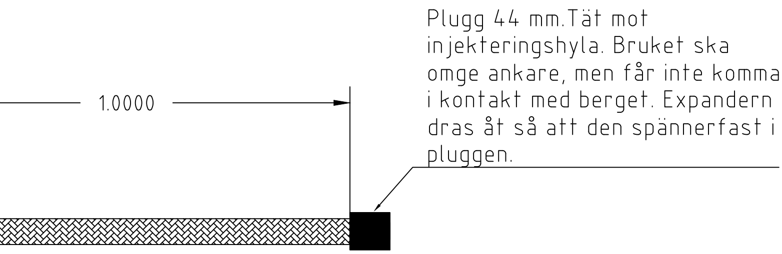
Appendix 5. Drawings of the reference bolts



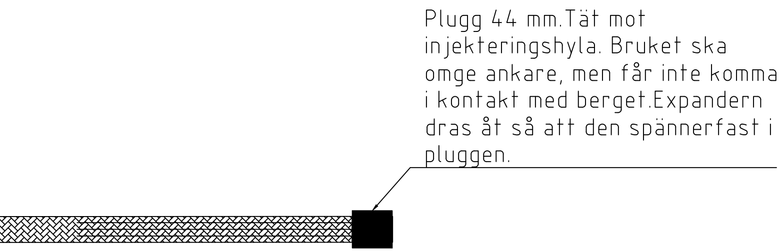








1.0000
Plugg 44 mm.Tät mot
injekteringshyla. Bruket ska
omge ankare, men får inte komma
i kontakt med berget. Expandern
dras åt så att den spännerfast i
pluggen.



Plugg 44 mm.Tät mot
injekteringshyla. Bruket ska
omge ankare, men får inte komma
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dras åt så att den spännerfast i
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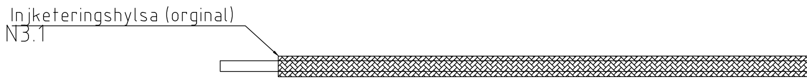
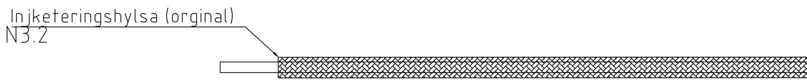
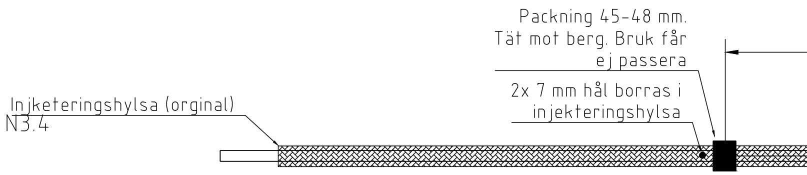
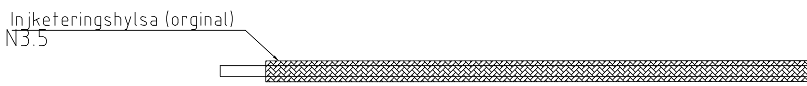
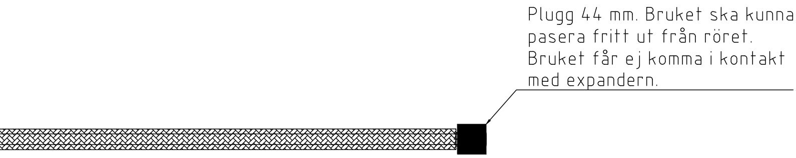
Appendix 5. Drawings of the reference bolts

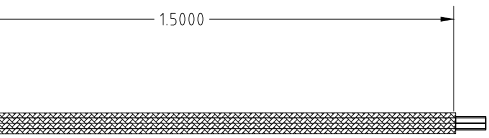


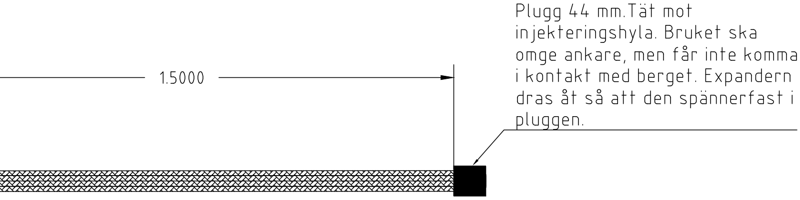


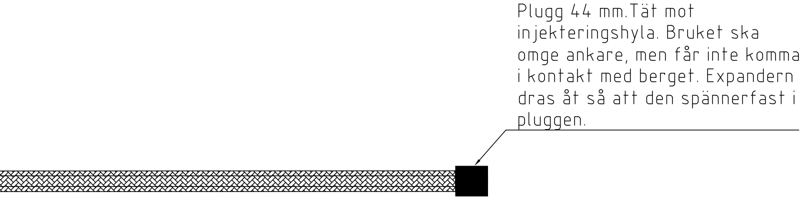




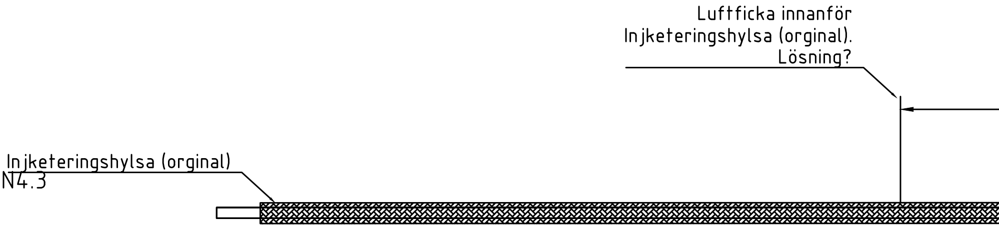

Plugg 44 mm. Bruket ska kunna pasera fritt ut från röret. Bruket får ej komma i kontakt med expandern.

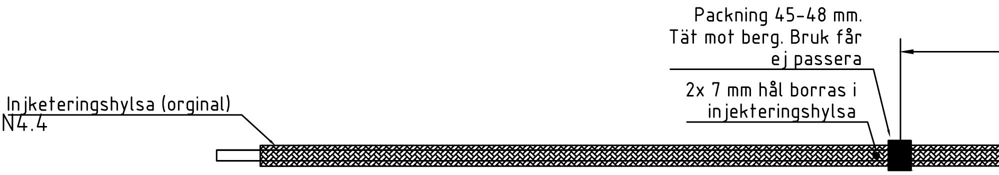

1.5000

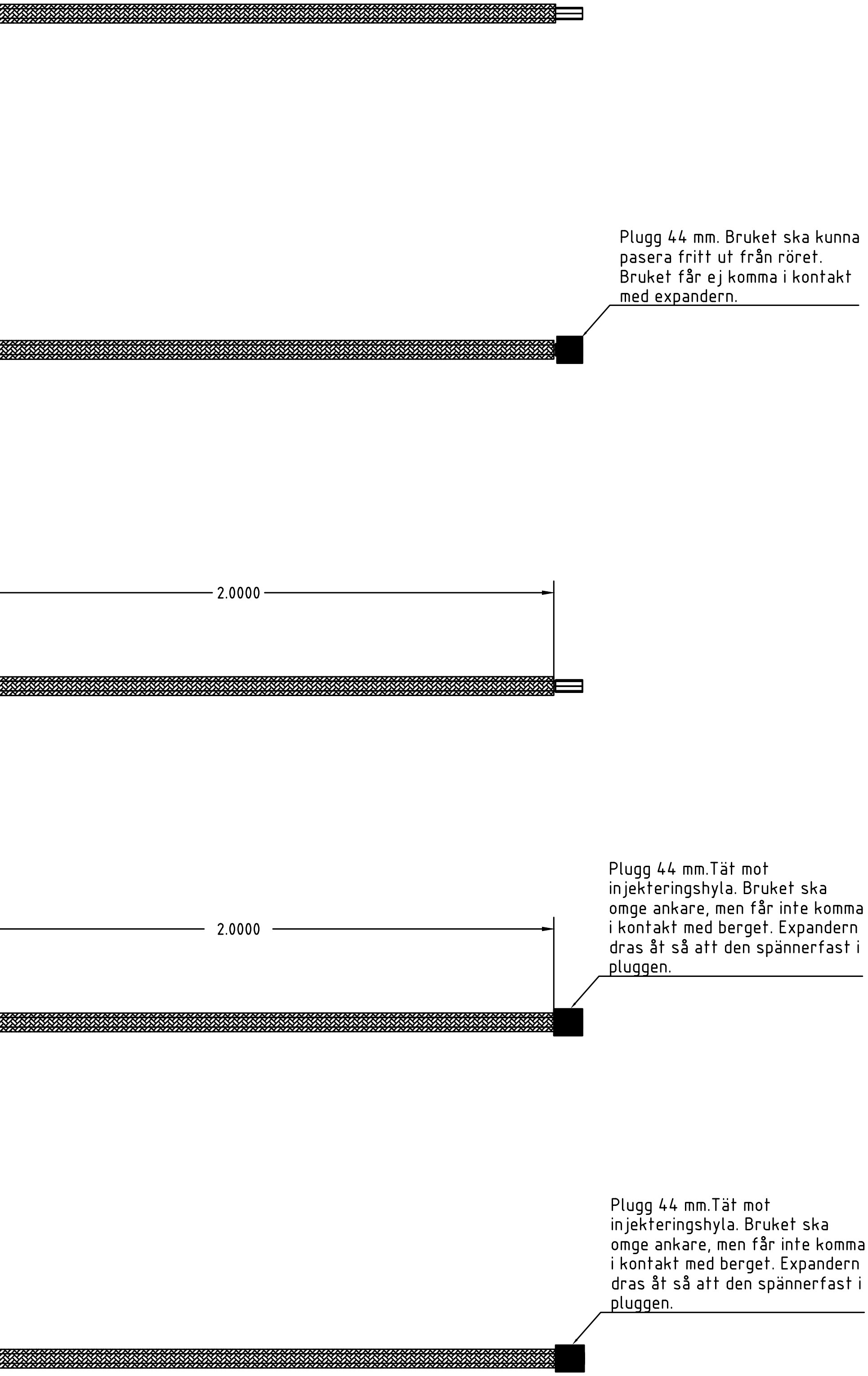

1.5000
Plugg 44 mm.Tät mot injekteringshyla. Bruket ska omge ankare, men får inte komma i kontakt med berget. Expandern dras åt så att den spännerfast i pluggen.


Plugg 44 mm.Tät mot injekteringshyla. Bruket ska omge ankare, men får inte komma i kontakt med berget. Expandern dras åt så att den spännerfast i pluggen.

Appendix 5. Drawings of the reference bolts






Plugg 44 mm. Bruket ska kunna pasera fritt ut från röret. Bruket får ej komma i kontakt med expandern.
2.0000
2.0000
Plugg 44 mm.Tät mot injekteringshyla. Bruket ska omge ankare, men får inte komma i kontakt med berget. Expandern dras åt så att den spännerfast i pluggen.
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GEOSIGMA

APPENDIX 6

Status report of the work carried out in the project

Sammanfattning av lägesrapporteringar och utfört arbete

Detta är en sammanfattning av lägesrapporteringar och utfört arbete, som gjort under projektets gång, för BeFo-projektet "Vidareutveckling av instrumentet RBT med avseende på bulttyperna PC- och CT-bult, och motsvarande kombinationsbultar" (BeFo: 419) till referensgruppen.

8:e Januari: *Startmöte i Sätra. TRV visade upp förslag på en lämplig plats för installation av referensbultar, i en av arbetstunnlarna (FSE209, AT215). Deras entreprenör Subterra kunde eventuellt utföra borrning i mån tid. Utrymmet valdes som lämplig plats för referensbultarna då det kommer att vara tillgängligt under många år framöver.*

19:e februari: *Geosigma fick beställningen på projektet av Befo, och därmed ett besked om projektstart.*

20:e februari: *Det markerades lägen för referensbultar på bergväggen i arbetstunneln i Sätra.*

24:e februari: *Bultar började referensbultar att prepareras på Geosigmas verkstad i Uppsala.*

31:a mars: *Det meddelades att borrningen var färdigställd.*

21:a april: *Då monterades och gjöts referensbultarna in i arbetstunneln i Sätra.*

28:e april: *Den första mätningen på referensbultarna utfördes.*

4:e maj: *Analys av mätdata påbörjades. Ett fel i mätdatan upptäcktes och RBT skickades till verkstan i Uppsala för kontroll.*

20:e maj: *Programmeraren som sköter kodningen av mjukvaran meddelade att han noterat ett elektroniskt fel i instrumentet. Just nu jobbar dom som byggt instrumentet med att hitta orsaken till felet.*

3:e juni: *RBT levererad åter till geosigma. Fel åtgärdade.*

7:e juni: *Mätningar utfördes i Sätra. Samtliga brickor inte avlägsnade. Dessa gick inte att lossa då muttern fastnat. Mätdata inte representativ innan alla bultar mäts utan mutter och bricka. Analys av erhållna data.*

28:e juli: *Ytterligare mätningar utfördes. Fortsatta försök att lossa muttrar. Analys av erhållna data.*

24:e augusti: *Samtliga muttrar lossades.*

27:e augusti*: Mätningar utfördes på samtliga PC-bultar. Analys av erhållna data.*

29:e september – 2:a oktober: *Förberedelser och ingjutning av cementkärna på en PC-bult i Geosigmas verkstad i Uppsala.*

5:e– 9:e oktober: *Mätningar med RBT på den lösa PC-bult med cementkärna och på en lös PC-bult utan cementkärna (lös bult direkt från leverantör). Data analyserades kontinuerligt.*

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