Designation: E2775 – 16

# Standard Practice for Guided Wave Testing of Above Ground Steel Pipework Using Piezoelectric Effect Transduction[1]

This standard is issued under the fixed designation E2775; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice provides a procedure for the use of guided wave testing (GWT), also previously known as long range ultrasonic testing (LRUT) or guided wave ultrasonic testing (GWUT).

1.2 GWT utilizes ultrasonic guided waves, sent in the axial direction of the pipe, to non-destructively test pipes for defects or other features by detecting changes in the cross-section and/or stiffness of the pipe.

1.3 GWT is a screening tool. The method does not provide a direct measurement of wall thickness or the exact dimensions of defects/defected area; an estimate of the defect severity however can be provided.

1.4 This practice is intended for use with tubular carbon steel or low-alloy steel products having Nominal Pipe size (NPS) 2 to 48 corresponding to 60.3 to 1219.2 mm (2.375 to 48 in.) outer diameter, and wall thickness between 3.81 and 25.4 mm (0.15 and 1 in.).

1.5 This practice covers GWT using piezoelectric transduction technology.

1.6 This practice only applies to GWT of basic pipe configuration. This includes pipes that are straight, constructed of a single pipe size and schedules, fully accessible at the test location, jointed by girth welds, supported by simple contact supports and free of internal, or external coatings, or both; the pipe may be insulated or painted.

1.7 This practice provides a general procedure for performing the examination and identifying various aspects of particular importance to ensure valid results, but actual interpretation of the data is excluded.

1.8 This practice does not establish an acceptance criterion. Specific acceptance criteria shall be specified in the contractual agreement by the responsible system user or engineering entity.

1.9 *Units*—The values stated in SI units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.10 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1065 Practice for Evaluating Characteristics of Ultrasonic Search Units

E1316 Terminology for Nondestructive Examinations

E1324 Guide for Measuring Some Electronic Characteristics of Ultrasonic Testing Instruments

2.2 Equipment Manufacturer's User's Manual

## 3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *circumferential extent*—the length of a pipe feature in the circumferential direction, usually given as a percentage of the pipe circumference.

3.1.2 *coherent noise*—indications caused by real discontinuities causing a background noise, which exponentially decays with distance.

3.1.3 *Cross-Sectional Area Change (CSC)*—the CSC is calculated assuming that a reflection is purely caused by a change in cross-section. It is given as a percentage of the total cross-section. However it is commonly used to report the relative amplitude of any signal regardless of its source.

3.1.4 *Distance Amplitude Correction (DAC) curve*—a reference curve plotted using reference reflections (for example, weld reflections) at different distances from the test position.

[1] This practice is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.10 on Specialized NDT Methods.

Current edition approved Dec. 1, 2016. Published January 2017. Originally approved in 2011. last previous edition approved in 2011 as E2775–11. DOI:10.1520/E2775-16.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

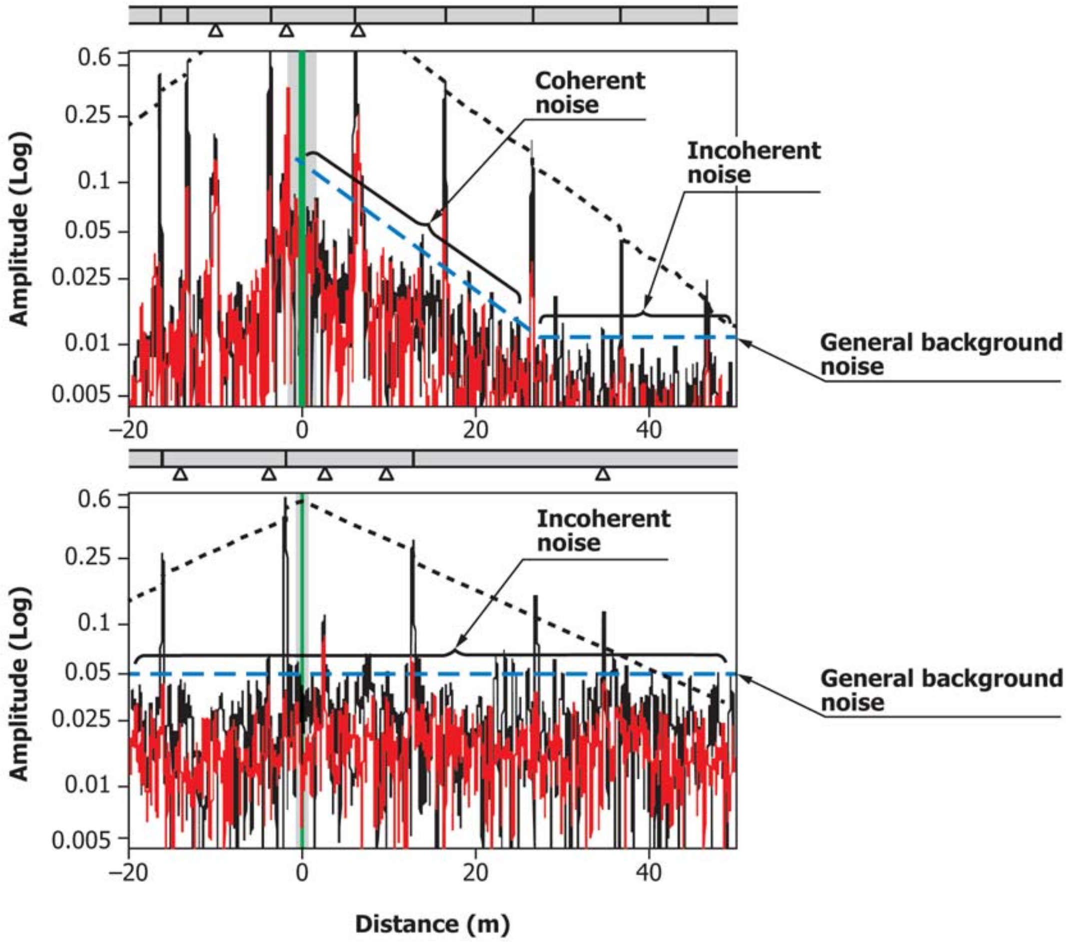


**FIG. 1 Typical GWT Results Collected in Normal Environment (Top) and in High Ambient Noise Environment (Bottom). (Both results are displayed in the logarithmic amplitude scale.)**

This curve corrects for attenuation and amplitude drops when estimating the cross-section change from a reflection at a certain distance.

3.1.5 *Estimated Cross-Sectional Loss (ECL)*—this is sometimes used instead of cross-sectional area change, where the feature is related to a flaw.

3.1.6 *flexural wave*—wave propagation mode that produces bending motion in the pipe.

3.1.7 *Guided Wave (GW)*—stress waves whose characteristics are constrained by the system material, geometry and configuration in which the waves are propagating.

3.1.8 *Guided Wave Testing (GWT)*—non-destructive test method that utilizes guided waves.

3.1.9 *longitudinal wave*—wave propagation mode that produces compressional motion in the pipe.

3.1.10 *incoherent noise*—random indications caused by electrical and ambient signal pollution, giving rise to a constant average noise floor. The terms "ambient noise" and "random noise" are also used.

3.1.11 *pipe feature*—pipe components including but not limited to weld, support, flange, bend and flaw (defect) cause reflections of a guided wave due to a change in geometry.

3.1.12 *reflection amplitude*—the amplitude of the reflection signal typically reported as CSC.

3.1.13 *reflector orientation*—the circumferential position of the feature on the pipe. This is reported as the clock position or degrees with regards to the orientation of the transducer ring.

3.1.14 *Signal-to-Noise-Ratio (SNR)*—Ratio of the amplitude of any signal of interest to the amplitude of the average background noise, which includes both coherent and non-coherent types of noise as defined in Fig. 1.

3.1.15 *torsional wave*—wave propagation mode that produces twisting motion in the pipe.

3.1.16 *transducer ring*—a ring array of transducers that is attached around the circumference of the pipe to generate GW. It is also commonly known as the ring.

3.1.17 *wave mode*—a particular form of propagating wave motion generated into a pipe, such as flexural, torsional, or longitudinal.

## 4. Summary of Practice

4.1 GWT evaluates the condition of metal pipes to primarily establish the severity classification of defects by applying GW at a typical test frequency of up to 150 kHz, which travels along the pipe. Reflections are generated by the change in cross-sectional area and/or stiffness of the pipe.

4.2 A transducer ring attached around the pipe screens the pipe in both directions simultaneously. It can evaluate long lengths of pipe, and is especially useful when access to the pipe is limited.

4.3 This examination locates areas of thickness reduction(s) and provides a severity classification as to the extent of that damage. The results are used to assess the condition of the pipe, to determine where damaged areas are located and their circumferential position on the pipe. The information can be used to program and prioritize additional inspection work and repairs.

4.4 Reflections produced by pipe features that are not associated with areas containing possible defects are considered as relevant signals. These features can be used for setting GW system DAC levels and identifying the relative position and distance of discontinuities and areas containing possible defects. Examples of these features are: circumferential welds, elbows, welded supports, vents, drainage, insulation lugs and other welded attachments.

4.5 Other sources of reflection may include changes in surface impedance of the pipe. These reflections are normally not relevant, but should be analyzed and classified in an interpretation process. Examples of these changes are the presence of pipe supports and clamps. In the advanced applications, which are not covered by this standard, these changes may also include various types of external/internal coatings or entrance of the pipe to ground or concrete wall.

4.6 Inspection of the pipe section immediately connecting to branch connections, bends or flanges are considered advance applications which are not covered by this standard.

4.7 False echoes are produced by phenomena such as reverberations, incomplete control of direction, distortion at elbows and others. These signals should be analyzed and classified as false echoes in the interpretation process.

## 5. Significance and Use

5.1 The purpose of this practice is to outline a procedure for using GWT to locate areas in metal pipes in which wall loss has occurred due to corrosion or erosion.

5.2 GWT does not provide a direct measurement of wall thickness, but is sensitive to a combination of the CSC and circumferential extent and axial extent of any metal loss. Based on this information, a classification of the severity can be assigned.

5.3 The GWT method provides a screening tool to quickly identify any discontinuity along the pipe. Where a possible defect is found, follow-up inspection of suspected areas with ultrasonic testing or other NDT methods is normally required to obtain detailed thickness information, nature, and extent of damage.

5.4 GWT also provides some information on the axial length of a discontinuity, provided that the axial length is longer than roughly a quarter of the wavelength of the excitation signal.

5.5 The identification and severity assessment of any possible defects is qualitative only. An interpretation process to differentiate between relevant and non-relevant signals is necessary.

5.6 This practice only covers the application specified in the scope. The GWT method has the capability and can be used for applications where the pipe is insulated, buried, in road crossings, and where access is limited.

5.7 GWT shall be performed by qualified and certified personnel, as specified in the contract or purchase order. Qualifications shall include training specific to the use of the equipment employed, interpretation of the test results and guided wave technology.

5.8 A documented program that includes training, examination and experience for the GWT personnel certification shall be maintained by the supplying party.

## 6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this standard.

6.2 *Personnel Qualifications*—Unless otherwise specified in the contractual agreement, personnel performing examinations to this practice shall be qualified in accordance with one of the following:

6.2.1 Personnel performing examinations to this standard shall be qualified in accordance with SNT-TC-1A and certified by the employer or certifying agency, as applicable. Other equivalent qualification documents may be used when specified in the contract or purchase order. The applicable revision shall be the latest unless otherwise specified in the contractual agreement between parties.

6.2.2 Personnel qualification accredited by the GWT manufacturers.

6.3 The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.4 *Qualifications of Non-destructive Testing Agencies*—Unless otherwise specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in E543, the applicable edition of E543 shall be specified in the contractual agreement.

6.5 *Procedure and Techniques*—The procedures and techniques to be utilized shall be specified in the contractual agreement. It should include the scope of the inspection, that is, the overall NDT examination intended to identify and estimate the size of any indications detected by the examination, or simply locate and provide a relative severity classification.

6.6 *Surface Preparation*—The pre-examination site preparation criteria shall be in accordance with 8.3 unless otherwise specified.

6.7 *Required Interval of Examination*—The required interval or the system time in service of the examination shall be specified in the contractual agreement.

6.8 *Extent of the Examination*—The extent of the examination shall be in accordance with 6.5 above unless otherwise specified. The extent should include but is not limited to:

6.8.1 The sizes and length(s) of pipes to be inspected.

6.8.2 Limitations of the method in the areas of application.

6.8.3 Drawings of pipe circuits, pipe nomenclature, and identification of examination locations.

6.8.4 Pipe access method(s).

6.8.5 Safety requirements.

6.9 *Reporting Criteria*—The test results of the examination shall be documented in accordance with the contractual agreement. This may include requirements for permanent records of the collected data and test reports. The report documentation should include:

6.9.1 Equipment inspector and test results reviewed by (if applicable).

6.9.2 Date and time of the examination performed.

6.9.3 Equipment used.

6.9.4 Test procedure/specification used.

6.9.5 Acceptance criteria.

6.9.6 Inspection location.

6.9.7 Identification of areas inspected.

6.9.8 Identification of the inspection range.

6.9.9 Any other information deemed necessary to reproduce or duplicate test results.

6.10 *Re-examination of Repairs/Rework Items*—Examination of repaired/reworked items is not addressed in this standard and if required shall be specified in the contractual agreement.

## 7. Apparatus

7.1 The GWT apparatus shall include the following:

7.1.1 *Transducer Ring Transmitter*—A transduction system using piezoelectric effect for the generation of guided wave modes with axial propagation on cylindrical pipes.

7.1.2 *Transducer Ring Receiver*—A system for the detection of the signal reflected by the geometric features on the pipe, which can be the same as the transmitter or an analogous transduction system.

7.1.3 *Instrumentation*—The GWT instrumentation shall be capable of generating, receiving, and amplifying electrical pulses within the frequency range used by GWT. Additionally, it shall be capable of communicating with a computer so that collected data can be processed and recorded.

7.1.4 *Processing System*—This is a software interface for processing and analyzing the signal, capable of distinguishing at least one guided wave mode for the specific detection system.

## 8. Examination Procedure

8.1 It is important to ensure that the proposed inspection falls within the capabilities of the technology and equipment and that the using party or parties understand the capabilities and limitations as it applies to their inspection.

8.2 *Pre-examination Preparation:*

8.2.1 All test equipment shall have current and valid calibration certificates.

8.2.2 Follow the equipment manufacturer's recommendations with regard to equipment pre-test verification and check list. As a minimum this check list should include but is not limited to:

8.2.2.1 Electronics fully operational.

8.2.2.2 Proper charging of batteries.

8.2.2.3 Verification that interconnection cables are in good condition and functioning correctly.

8.2.2.4 Correct transducer ring size for the intended pipes.

8.2.2.5 Sufficient transducer modules (including spares) are available to test the largest diameter pipe in the work scope.

8.2.2.6 The transducer ring, modules, and transducers are functioning correctly.

8.2.2.7 Any computer used with the system is functioning correctly and has sufficient storage capacity for the intended work scope.

8.2.2.8 Supplementary equipment, such as an ultrasonic flaw detector or specialized pit gauges are available and functioning correctly.

8.2.2.9 All necessary accessories, such as tape-measure markers, are available.

8.2.3 Ensure all site safety requirements and procedures are reviewed and understood prior to starting any field work.

8.2.4 The test equipment shall be calibrated in accordance to the equipment manufacturer's procedure at regular intervals.

8.3 *Examination Site Preparation:*

8.3.1 *Pipe Surface Condition*—To obtain best coupling condition, any loose material such as mud, flaking paint and loose corrosion must be removed from the surface of the pipe where the transducer ring is attached. However well-bonded paint layers of up to 1 mm (0.04 in.) can stay in place. Wire brushing or sanding, or both, are usually sufficient to prepare the surface if it is safe and permitted to do so.

8.3.2 *Insulation*—If the pipe is insulated, carefully remove an approximately 1 m (3 ft) band of insulation for attaching the transducer ring. Prior to removing the insulating material ensure it is safe and permissible to do so.

8.3.3 GWT is most effective for testing long lengths of pipe. However, tight radius elbows distort GWT signals, making interpretation of signal beyond them difficult. Where possible, it is good practice to exclude from evaluation sections of pipe immediately after elbows. In any case, no signals after two elbows should be analyzed. It is sometimes better to take additional data at different locations than to interpret a signal beyond multiple features or those with complicated geometries. Consider taking a second reading 1 m (3 ft) apart for confirmation of features and false echo identification.

8.3.4 *Visual Inspection*—Visually inspect the pipe where possible for potential damage areas or corrosion, such as the support areas if possible defect indications are found in the GWT result.

8.3.5 *Surface Temperature*—Verify that the surface temperature of the pipe to be tested is within the manufacturer's specifications for the equipment. Testing at elevated temperatures does not in general affect the performance of the GWT, however caution must be exercised to avoid injuries to personnel. When testing low temperature pipes, ensure that no ice forms between the sensor face and the surface of the pipe.

8.3.6 *Thickness Check*—Before mounting the transducer ring, verify that there is no degradation in the pipe wall thickness at the test location. As a minimum requirement, thickness measurements at no less than four equally spaced positions around the pipe should be made using an appropriate thickness measuring instrument and procedure. Some agencies also require thickness measurement of the entire dead zone and near field. It is important to note that attaching the transducer ring at locations with very severe corrosion may cause further damage to the pipe.

8.4 *Transducer Ring*—The type of ring, the transducer orientation and their spacing can vary depending on the type of collection protocol. Refer to 8.13 when selecting the transducer ring assembly for the type of examination to be performed.

8.5 *Couplant*—Couplant is generally not required for this method. GWT utilizes relatively low frequency compared to those used in conventional UT, typically in the regions of tens of kilohertz (kHz) as opposed to megahertz (MHz). At these frequencies, good coupling is obtained by simply applying sufficient mechanical force on the transducer ring.

8.6 *Choosing Test Location*—After completing the examination site preparation outlined in 8.3, attach the transducer ring to the pipe. The test location should be chosen so as to minimize false echoes. Avoid placing the ring near a feature as the corresponding signal may appear within the near field or the dead zone. In the dead zone, no echoes are received, and in the near field, the amplitude of the echoes is typically lower than normal. As a practice, a minimum of 1.5 m (5 ft) should be used to the first area of inspection. Features such as welds, which are used for the DAC curves fitting, should be outside the near field to ensure valid amplitude. Additionally, transducer rings should not be positioned equidistant between two features to avoid masking of the mirror echoes if any.

8.7 *Attaching the Transducer Ring*—When attaching the transducer ring it is important to ensure that all transducers are in good contact with the pipe and that the ring is mounted parallel to the circumference of the pipe. Apply the appropriate air pressure or clamp torque settings as specified in the manufacturer's operating manual for proper installation of the transducer ring. Any pressure gauge or torque meter used shall be checked regularly for correct functionality.

8.8 *Directionality and Orientation*—The reported directionality and orientation of the features depend on the way the transducer ring is installed. It is good practice to keep the direction between different test positions the same, and in the direction of product flow if known. To ensure the correct orientation is reported, the transducer ring should be attached with the correct ring attachment configurations.

8.9 *Reproducibility*—The examination pipe should be marked with a paint marker indicating the transducer ring position, direction, and date of examination. This can assist in the future, should it be necessary to reproduce the examination. This information should also be included in the examination documentation.

8.10 *Test Location Information*—As the data collections of most GWT equipments are fully recorded electronically, a minimum amount of information about the test location is needed in the processing software to ensure the exact location can be identified. This information shall include the following:

8.10.1 *Site Name*—The name of the site, which may include the plant name, plant unit number, approximate mile marker or any relevant reference if available.

8.10.2 *Pipe*—The pipe identification if available; if not, the pipe diameter should be recorded.

8.10.3 *Datum*—The reference feature from which the test location is measured. Typical reference features used are welds and flanges.

8.10.4 *Distance*—The distance between the datum and the center of the transducer ring shall be recorded. It is also important to include both positive and negative signs in front of the distance value for positive and negative direction of the ring respectively.

8.11 *Coupling Check*—It is important that all transducers are well coupled to the pipe. Prior to collecting any test data, perform a coupling test in accordance with the manufacturer's guidelines. As a minimum, this shall include a way of simulating "signals" on the pipe and verifying that all transducers detect it with a similar magnitude and sensitivity.

8.12 *Examination Precautions*—There are several precautions that need to be addressed when analyzing the collected data. These include:

8.12.1 *Dead Zone*—This is an area that can be up to 1 m (3 ft) long on either side of the transducer ring that is not inspected during the testing. The area of the dead zone is a function of the excitation frequency and the number of cycles transmitted. The area is inversely related to frequency and directly related to the number of cycles. In order to get a 100 % coverage of the pipe there are two options:

8.12.1.1 Inspect the dead zone with an alternative NDT method such as ultrasonic testing.

8.12.1.2 Locate the next shot so that there is overlap of the previous transducer ring position. Some agencies require a 20% overlap on all shots where possible.

8.12.2 *Near Field*—This is an area that could extend to as far as 3 m (10 ft) on either side of the transducer ring. In this area, the amplitudes are artificially lower than normal, and mirrors (see Section 8.20.4.1) can appear, making analysis of reflections in this area difficult. While this area is inspectable, extreme care must be taken when reviewing signals in this area. The length of this area depends on the length of excitation signal. It is possible to reduce the extent of the near field effect by employing special collection protocols.

8.12.3 *Expected Examination Range*—There are several physical test conditions on or around the pipe which affect the maximum examination range that can be achieved (see Appendix X1 for more detail). There are also equipment parameters such as frequency and gain settings, which can be varied so as to optimize the test parameters for specific test conditions on or around the pipe. The maximum inspection range is defined in 8.18.

8.12.4 *False Echo (False signals)*—Signals other than from a real feature. Care should be taken to minimize the potential for false signals to interfere with the interpretation of the data. The most common sources of false echoes are:

8.12.4.1 *Reverberations*—Multiple reflections either between two large features along the pipe, or between the two ends of a long feature. Echoes caused by reverberations typically have small amplitudes.

8.12.4.2 *Mirrors*—Occurs normally in the near field due to insufficient control of the propagation direction of the guided wave. The mirror echo appears at the same distance from transducer ring, but the opposite direction, as the real reflection.

8.12.4.3 *Modal Noise*—Occurs when the transducer ring is unable to control all the wave modes propagating in the pipe.

8.13 *Collection Protocol*—The collection protocol varies certain collection parameters to optimize the data quality based on the pipe diameter and the expected mechanism(s) on and around the pipe. Most manufacturers include a procedure for determining the optimum collection parameters automatically for a specific test condition. These collection parameters include:

8.13.1 *Frequency*—GWT is typically performed at frequencies between 10 and 150 kHz. When performing a test, data should be collected with enough different frequencies so as to be able to categorize each indication. Ideally, frequency can be changed quasi-continuously to observe frequency dependence. If this is not available in the instrument, multiple different frequencies including the optimum frequency should be collected. It is worth noting that the exact frequencies used vary depending on the pipe geometry.

8.13.2 *Bandwidth*—Changing the signal bandwidth can assist in resolving the attributes of a signal. A narrow bandwidth enhances the frequency dependency of a signal while a wider frequency bandwidth can improve the axial resolution of signals such as closely spaced reflections.

8.13.3 *Wave Mode*—The GWT uses an axi-symmetric wave mode excitation which can either be a torsional or longitudinal wave mode. Both wave modes provide valid inspection results. However in practice, torsional mode is commonly used as it is sensitive to most flaw types. Nevertheless it is sometimes advantageous to use longitudinal mode over torsional mode if certain special flaw types, such as corrosion at the axially welded supports, areknown to be present on the pipe.

8.14 *Data Collection*—After installing the transducer ring and performing the coupling check, the next step of the examination procedure is data collection. It is important that the data recorded is sufficient and comprehensive to evaluate and interpret any signals which may be present on the pipes. Choose the most appropriate collection protocol (see 8.13) and collection range to perform the initial data collection as per the equipment manufacturer's guidelines. Immediately after the data collection, it is important to review the collected data to ensure proper operation of the equipment during the test and that the quality meets the required standard. The data review should include an evaluation of the SNR and the transducer balance. Poor SNR is usually caused by high incoherent noise, low transducer coupling, or low transducer output. Should there be any significant problems observed in the data, it should be discarded and the problem addressed.

8.15 *Distance Amplitude Correction (DAC)*—As the excitation signal travels away from the transducer ring, its signal amplitude decreases. There are several reasons for the energy loss, including material damping, reflections at features, energy leakage, and surface conditions. The DAC provides the ability to determine the signal amplitude at a point away from the transducer ring. This allows for determining the relative amplitude of an echo, expressed in either CSC or ECL, at a given distance. If the DAC curves are set too low, the size of possible defects may be overestimated, and vice versa. Therefore it is vital that the DAC levels are set correctly before interpreting the data as they provide reference CSC levels to all other signals for comparison. There are four DAC curves that can be used in evaluating GWT reflections. Most systems provide inspectors the means of manually adjusting these curves.

8.15.1 *Flange DAC*—This is a DAC curve that represents the expected amplitude of a reflection from a large feature that reflects approximately 100 % (that is, 0 dB) of the amplitude of the excitation signal and no energy can therefore pass through.

8.15.2 *Weld DAC*—Pipe girth welds typically present 20 % to 25 % CSC. The amount of energy reflected at the weld is the reason why the maximum number of pipe joints that can be inspected is limited.

8.15.3 *Call DAC*—This is the typical threshold level that is used to determine the severity of a defect if found. Most systems set the call DAC level to roughly 6 % CSC by default, but also allow this level to be modified in accordance with the detection sensitivity requirement of the industry.

8.16 *Ambient Noise*—Ambient noise causes an increase in the overall incoherent noise level. In Fig. 1, the effect of an increased ambient noise is demonstrated, as both the detection sensitivity and the maximum inspection range are reduced as a result. Special precautions should be taken when ambient noise is higher than normal. Most equipment manufacturers offer special protocols to test in high ambient noise areas.

8.17 *Detection Threshold (DT)*—The DT of an examination is equivalent to the sensitivity, and it is typically set to 6 dB above the background noise but it can also be manually set by the inspectors.

8.18 *Inspection Range*—The section of pipe between the transducer ring and the end of test in one direction where the sensitivity is greater than the Call level (see 8.15.3). Depending on the coverage requirements, this inspection range is often used to determine the subsequent test locations. As the attenuation varies with frequency; the inspection range is normally specified for a particular frequency. The inspection range is also limited to a flange, or any feature that is not within the scope of the standard. (See also Fig. 2.)

8.19 *Distance Standardization*—The acoustic properties of different grades of steel varies slightly, causing an offset in the reported distance of the features. The software typically uses the acoustic properties of carbon steel. In most cases, the distance offset is very small and therefore it is not necessary to perform distance standardization. However, where the pipe material is not carbon steel, it is good practice to standardize distance in the software against a physical measurement prior to analyzing the data.

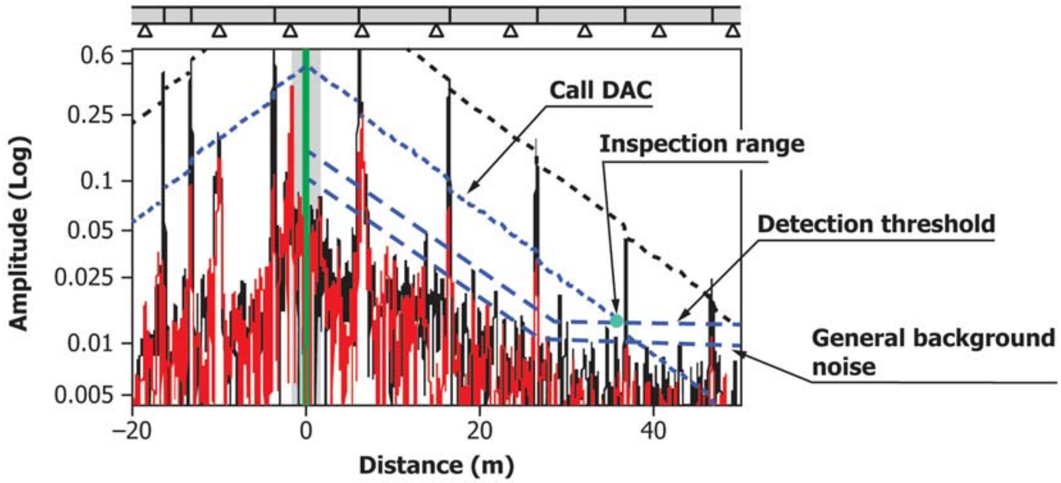


FIG. 2 Example of the GWT Result Showing How the Inspection Range is Defined

8.20 *Data Review*—The initial review of the data is to separate data into relevant, non-relevant signals and indications.

8.20.1 *Signal interpretation*—Interpretation of GWT signals is the difficult part of this method. A number of tools is available to help analyzing and distinguishing signals between various features, and these tools include:

8.20.1.1 *Shape of Reflected Signal*—The shape provides information on the axial length of a feature. An irregular reflection is typically associated with a feature that extends along the pipe such as a corrosion patch, whereas a short uniform reflection would indicate a short reflector such as a weld.

8.20.1.2 *Amplitude*—The signal amplitude is indicated by the relative signal amplitude of the axi-symmetric wave mode (that is, torsional or longitudinal mode), in terms of CSC. The shape of the signal also affect the amplitude to some extent because of the interference of reflections and scattering within the discontinuity boundaries. For a defect, the amplitude correlates to the percentage of cross-section loss of the defect at that particular position.

8.20.1.3 *Axi-Symmetry*—As the axi-symmetric wave mode reflects from a non-axially symmetric feature, such as a contact support, some of the energy is converted to the non-axi-symmetric wave modes (that is, various orders of the flexural mode). Using the ratio of the reflection magnitudes between the axi-symmetric and non-axi-symmetric modes, it is possible to determine how the feature is distributed around the circumference of the pipe.

8.20.1.4 *Behavior at Different Frequencies*—Additional information can be obtained by observing the signal response of certain features at different frequencies. The amplitude and the shape of the signal for an axially short feature, such as welds, remain unchanged as the frequency is changed. However, if the axial length is long, such as a corrosion patch, multiple signals are generated within the feature, causing interference that changes with frequencies; therefore both amplitude and shape typically change with frequencies for axially long features. Additionally, the amplitude of features causing a change in stiffness, such as contact supports, is also generally frequency dependent.

8.20.1.5 *Phase*—As the signal amplitude can be caused by either an increase or a decrease in CSC, the phase information provides a way to determine the difference between them. For example, a weld which is an increase in CSC would have a different phase to that of a flaw, which is a decrease in CSC. When evaluating the change in phase with respect to other reflectors, the intent is not to determine the actual phase of each reflection signal but instead determine which of the reflectors can be grouped into similar responses. The phase information is only accurate when the SNR is good, therefore this tool is not normally used alone.

8.20.1.6 *Circumferential Orientation*—Most systems provide basic information on the circumferential orientation of a feature by evaluating the response of the transducers in each of the segments of the transducer rings; while some advanced systems also offer focusing capabilities or other special views in the processing software such as C-Scan display (see example in Appendix X2).

8.20.1.7 *Attenuation Changes*—When there is a change on the expected attenuation pattern, it indicates there is a change in the pipe condition. Be it caused by general corrosion or internal deposit, further investigation is usually required to determine the source.

8.20.2 *DAC Fitting*—The fitting of DAC is an important part of GWT data interpretations for reasons explained in 8.15. There are a number of methods to fit the DAC levels which are summarized below in the order of increasing accuracy. The method with the highest accuracy, if available, shall be used as default.

8.20.2.1 *Standard Method*—The DAC curves are set typically using at least two reference reflectors, commonly welds or features with a known CSC value. For this reason, it is imperative to be able to identify the signals corresponding to the reference reflectors either by the signal characteristics or visually. For the majority of piping with nominal wall thickness of 7 mm to 13 mm (0.28 in. to 0.5 in), the weld cap may be approximated to be a 20% CSC. However, for piping with nominal wall thickness outside 7 mm to 13 mm (0.28 in. to 0.5 in), approximating a weld cap to be a 20% CSC can often cause significant error in defect sizing. Therefore, where equipment and pipe conditions allow, the other methods are

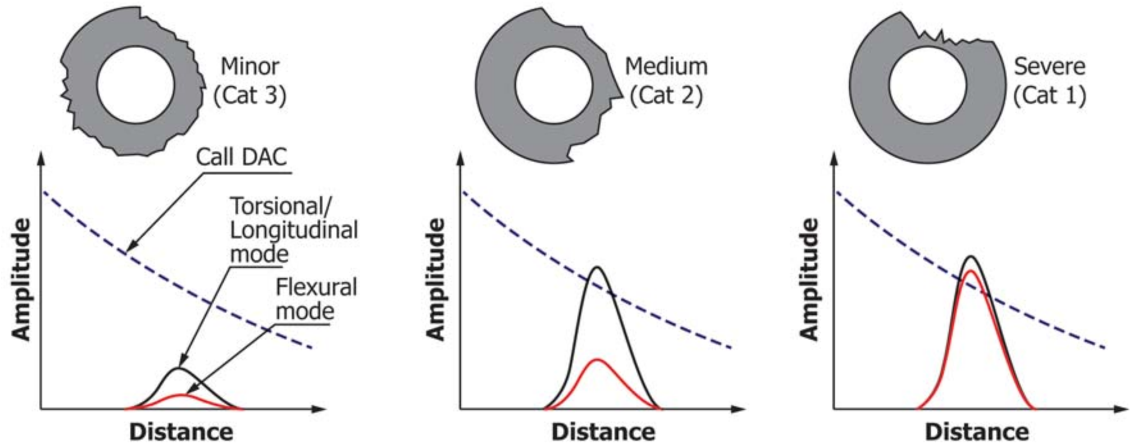


**FIG. 3 Illustrations of the Signals in Each Severity Classification**

preferred. Note that attenuation in GWT is heavily frequency dependent; therefore DAC curves are usually set at all collected frequencies in the data. An illustration of the DAC fitting can be found in Appendix X2.

8.20.2.2 *Weld Dimensions Method*—This method accurately determines the weld DAC level by correlating the actual weld dimensions to the CSC of a specific weld. The weld cap dimensions (axial width and weld cap height) shall be measured from an accessible weld, while the pipe wall thickness shall be measured from the pipe immediately adjacent to the weld.

8.20.2.3 *Absolute Calibration Method*—This method calculates the DAC levels using an algorithm of signal reflections and their multiple reflections from reflectors such as welds, within the normal test range. Any signal used must be outside the near field/dead zone. The calculation produced has the advantage of being frequency independent. However, the DAC attenuation should still be adjusted using common techniques such as using welds or coherent noise level.

8.20.3 *Relevant Signals*—Relevant signals are generated by physical fittings of the pipe, which include, but not limited to, features such as welds, flanges, valves, elbows, T-pieces, supports, diameter changes. These features are identified both by the signal characteristics and visually, when possible, as to their positions on the pipe. It is important to correlate the guided wave indications with the visual observations of the pipe. These indications should be noted in the software of the GWT test equipment. See Annex A1 for guidelines in determining reflector characteristics.

8.20.4 *Non-Relevant Indications*—Non-relevant signals are those associated with noise, false echoes and other non-useable information. The following may be used to help identifying the non-relevant indications:

8.20.4.1 *Mirrors*—If the system displays a large feature in one direction and a small feature at the equal distance in the opposite direction from the test location, there is a high possibility that the smaller indication is a mirror echo. The most effective way to deal with mirror echoes is to move the transducer ring approximately 0.6 m (2 ft) and repeat the test. This causes the mirror echoes to move or disappear as the test position changes.

8.20.4.2 *Reverberations*—This usually occurs when the transducer ring is between two larger reflectors. The reverberation echo typically appears as a small indication past the first feature. If reverberation is suspected, move the transducer ring to a location outside of the two reverberating features and perform additional examinations.

8.20.4.3 *Modal Noise*—The modal noise signals typically appear close to the test location in the result, and their amplitude decays rapidly over distance. Modal noise signals are both frequency and bandwidth dependent; therefore adjusting either of the two parameters can usually eliminate them.

8.20.5 *Indications*—All other indications should be considered unclassified and further analysis should be performed on each one to determine their source and orientation.

8.20.6 *Classification of Data*—After completing the review of the other indications, those identified to be possible defects may be further classified as Minor, Intermediate and Severe. The classification is determined based on the CSC, the circumferential extent of the signal and their relationships with the call DAC level. If the call level is set too low, inspectors are likely to overcall; while if the Call level is set too high, inspectors are likely to under-call. It is important that the call level set reflects the detection requirements which should be agreed between parties beforehand. In general, each classification can be summarized as follow:

8.20.6.1 *Minor (Cat 3)*—These are considered to be indications which are shallow and/or extend around the circumference. They are not highly concentrated. Both the symmetric (that is, torsional mode) and non-symmetric (Flexural mode) modes are below the call DAC level.

8.20.6.2 *Medium (Cat 2)*—These are areas where there is more depth than the Minor indications but still are not highly concentrated. The symmetric mode is above, while the non-symmetric mode is below the call DAC level.

8.20.6.3 *Severe (Cat 1)*—These are areas that have deep indications, or are highly concentrated, or both, in an area of the pipe. They are considered very likely to produce a penetration of the pipe wall. Both the symmetric and non-symmetric modes are above the call DAC level. Signal examples of each classification based on the defect profile around the circumference that is axially short, are shown in Fig. 3.

8.20.7 *Severity Classification Use and Significance*—Assigning a severity classification should be used for reference, classification of indications and setting priorities for follow-up inspection. The categories are assigned based on the amplitudes of the axi-symmetric and non-axi-symmetric reflections, and their relations to the Call DAC level. It is, therefore, important that the call DAC level percentage or similar detection sensitivity requirement is specified in the contractual agreement which reflects the requirements of the industry. The GWT does not provide information regarding the remaining wall thickness or nature of the damage. This information can only be obtained as a result of follow-up inspection with other NDE methods on the areas where relevant indications associated with defects have been identified. GWT is a method for detection and classification of damage, and their result shall be treated as qualitative only.

## 9. Report

9.1 The test report shall document the results of the inspection. It must have all information to be able to reproduce the test at a future date if desired. Most, if not all, the items detailed in 8.10 should be included. Additionally all observations obtained from visual inspection, thickness measurements with UT and other pertinent information that is deemed as having an effect on the quality, or characteristics, or both, of the data or results should be recorded and included in the final report. All relevant and non-relevant indications identified during the examination should be included with a classification provided those reflections deemed to be associated with defects. All results from follow-up inspection with other NDE methods shall be included in the report if available.

## 10. Keywords

10.1 guided waves; Guided Wave Testing; NDT of pipes; pipeline inspection

# ANNEX

**(Mandatory Information)**

## A1. REFLECTOR CHARACTERISTICS

A1.1 See Table A1.1.

**TABLE A1.1 Reflector Characteristics**

| FEATURE | VISUAL | AMPLITUDE | SHAPE | FREQUENCY | SYMMETRY | PHASE | ORIENTATION |
|---|---|---|---|---|---|---|---|
| Flange | Likely visible | Typically the highest | Irregular | Inconsistent | Symmetric | N/A | Fully circumferential |
| Weld | May be visible if not insulated | Medium | Clean, uniform, single echo | Consistent across wide range | Symmetric | Same as all welds | Fully circumferential |
| Elbow | Likely visible | Medium | 1st Weld: Clean, uniform<br>2nd Weld: Mostly uniform | 1st Weld: Consistent<br>2nd Weld: Inconsistent | 1st Weld: Symmetric<br>2nd Weld: Non-symmetric | N/A | 1st Weld: Fully circumferential<br>2nd Weld: Depending on elbow direction |
| Valve/Drain | Likely visible | Medium | Small size: Uniform<br>Large size: Irregular | Small size: Consistent<br>Large size: Inconsistent | Non-symmetric | N/A | Either top or bottom of the pipe |
| T-piece | Likely visible | Medium | Irregular | Inconsistent | Non-symmetric | N/A | Partial circumferential |
| Reducer | May be visible if not insulated | Medium | Irregular | Inconsistent | Symmetric | N/A | Fully circumferential |
| Short contact | Support likely visible | Low | Clean, uniform, single echo | Inconsistent | Non-symmetric | N/A | Bottom |
| Long contact | Support likely visible | Low | Irregular | Inconsistent | Non-symmetric | N/A | Bottom |
| Short Clamp support | Likely visible | Medium | Clean, uniform, single echo | Inconsistent | Symmetric | N/A | Fully circumferential |
| Axial support (welded) | Likely visible | Medium | Irregular | Inconsistent | Non-symmetric | N/A | Bottom |
| Saddle support | Likely visible | Medium | Irregular | Inconsistent | Non-symmetric | N/A | Bottom |

**TABLE X1.1 Typical Attenuation Rates and Average Test Range in Each Direction for Different Test Pipe Configurations**

| Test Condition | Typical Attenuation | Typical Range of Test |
|---|---|---|
| Clean, Straight Pipe | -0.15 to -0.5dB/m<br>(-0.046 to -0.17dB/ft) | 50–200 m<br>(164–656 ft) |
| Clean, Wool Insulated | -0.17 to -0.75dB/m<br>(-0.052 to -0.23 dB/ft) | 40–175 m<br>(131–574 ft) |
| Insignificant/Minor Corrosion | -0.5 to -1.5 dB/m<br>(-0.152 to -0.457dB/ft) | 20–50 m<br>(65.6–164 ft) |
| Significant Corrosion | -1 to -2 dB/m<br>(-0.305 to -0.61dB/ft) | 15–30 m<br>(49.2–98.4 ft) |
| Kevlar Wrapped | -0.15 to -1 dB/m<br>(-0.046 to -0.305dB/ft) | 30–200 m<br>(98.4–656 ft) |
| Spun Epoxy Coating | -0.75 to -1 dB/m<br>(-0.23 to -0.305dB/ft) | 30–50 m<br>(98.4–164 ft) |
| Well Packed Earth | -1 to -2 dB/m<br>(-0.305 to -0.61dB/ft) | 15–30 m<br>(49.2–98.4 ft) |
| Thin (<2.5mm), Hard Bitumen Tape | -1.25 to -6 dB/m<br>(-0.381 to -1.83dB/ft) | 5–25 m<br>(16.4–82 ft) |
| Thick (>2.5mm), Soft Bitumen Tape | -4 to -16 dB/m<br>(-1.22 to -4.88dB/ft) | 2–8 m<br>(6.56–26.24 ft) |
| Well Bonded Concrete Wall | -16 to -32 dB/m<br>(-4.88 to 9.76dB/ft) | 1–2 m<br>(3.28–6.56 ft) |
| Grout Lined Pipe | -1 to -3 dB/m<br>(-0.305 to 0.91dB/ft) | 10–30 m<br>(32.8–98.4 ft) |
| Loosely Bonded Concrete Wall | -4 to -16 dB/m<br>(-1.22 to -4.88dB/ft) | 2–8 m<br>(6.56–26.24 ft) |

## APPENDIXES

**(Nonmandatory Information)**

### X1. ATTENUATION

X1.1 Attenuation is the signal loss as it propagates along a structure. The loss can be caused by a combination of factors – dissipation, mode conversion, scattering due to surface roughness, absorption into other mediums and others. The rate of signal decay is the factor which determines the maximum test range for any given set up.

X1.2 *Attenuation Rate*—Attenuate rate is typically specified in loss per rate of distance traveled. This would be expressed as dB/m. occasionally, if different frequencies have a significantly different attenuation rate it may be expressed as either dB/kHz or dB/kHz-m.

X1.3 Typical attenuation rates and average test range in each direction for different test pipe configurations are found in Table X1.1.

### X2. TYPICAL LINEAR AMPLITUDE VERSUS DISTANCE GWUT DISPLAY

X2.1 See Fig. X2.1.

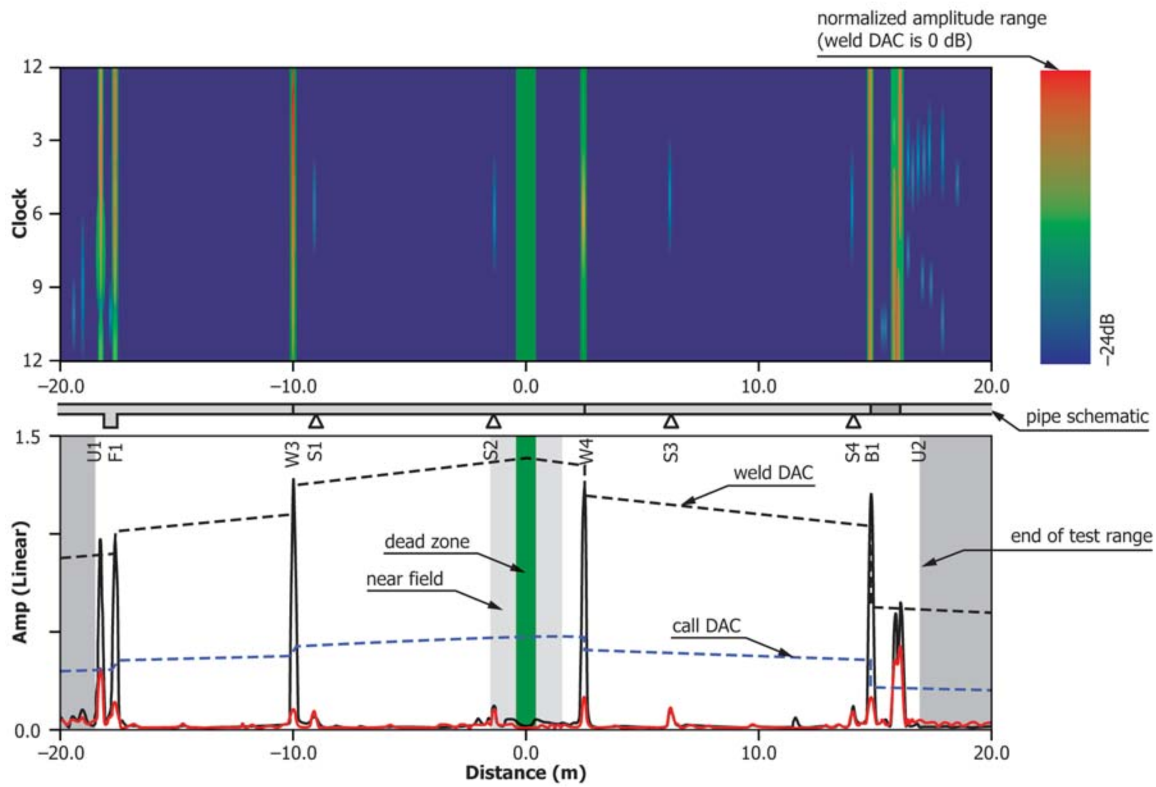


FIG. X2.1 An Example of the A-Scan Type (Bottom) and C-Scan Type (Top) Results from GWT (The C-scan plot provides the circumferential orientation, displayed as the clock position, for the corresponding A-scan signal at the bottom.)