NON-INTRUSIVE ASSESSMENT OF STEEL TOWER FOUNDATIONS

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ABSTRACT

For many years non-intrusive assessment of steel tower foundations was undertaken by measuring polarisation current to assess below ground corrosion. This method was used to identify towers at highest risk of corrosion, with excavations then being undertaken at those towers to gain a visual indication of their condition.

More recently, Transient Dynamic Response (TDR) equipment has been developed to measure the characteristics of concrete foundations in the construction industry. The use of both techniques have been found to compliment each other in highlighting the tower foundations posing the most serious problems.

INTRODUCTION

For many years the UK electricity industry has supported research and development activities dedicated to the application of technology to assist with the cost-efficient management of distribution and transmission systems.

One major area of work for EA Technology has been the development and application of condition assessment techniques. With the greater emphasis on structured asset management programs within electrical utilities, the application of such techniques has begun producing practical benefits.

One such condition assessment area is the non intrusive assessment of steel tower foundations. Two differing techniques have been brought together to ensure that accurate and reliable information is gathered.

POLARISATION RESISTANCE

Measurement of Polarisation Resistance is a simple, electro-chemical measurement that is an established and proven technique for monitoring the corrosion rate non intrusively.

In controlled circumstances, it can give an absolute value of corrosion rate and therefore metal loss. However, when applied to steel tower foundations, results must be interpreted cautiously. Many unknowns exist, namely the area of steelwork involved in the corrosion, details of the environment, soil types and moisture levels. Nevertheless , the technique can indicate active corrosion situations and can quickly and relatively inexpensively give an indicative measurement. The field survey measurement procedure is illustrated in Figure 1.

Figure 1: Polarisation resistance measurement

The key to obtaining useful information for the measurement is the interpretation of the results. After many years of experience it has been concluded that the most appropriate interpretation is obtained by using the corrosion current (I_{corr}) measurements for all tower legs on a transmission circuit and considering them as a population. The values of I_{corr} can then be plotted as a histogram, the spread of results indicating the likelihood of corrosion problems. If all the values are on the low side, no corrosion problems are anticipated. A wide spread of values indicates that some tower legs are experiencing corrosion. In view of the uncertainties associated with the absolute values measured, it is recommended that in such circumstances, limited excavation is performed on a number of the tower legs with the highest values. These excavations should include some of the worst cases likely to occur on that line. Subsequent decisions can be based on this information.

Interpretation of polarisation resistance results, and, therefore, the value of the results to the electric utility, are enhanced if information on the type, age and maintenance records of the tower are available.

Following measurements on a line in which all values of Icorr are low, electricity utilities often wish to carry out limited excavations to confirm that the foundations are in a satisfactory condition. If the excavations confirm the results of the polarization resistance survey, no further action is needed. However, if some of the Icorr values measured are very high and subsequent excavation of these towers reveals serious corrosion that threatens the integrity of the structure, then the tower foundations must be repaired or replaced. In such circumstances electric utilities normally would excavate further to ensure that all seriously corroded legs have been detected and repaired.

In many cases the polarization resistance measurements and the subsequent limited excavations will indicate some active corrosion, but it is usually insufficient to threaten the immediate integrity of the tower. The dilemma facing the engineer is whether to address the corrosion problem through costly excavations of all legs and repair, even though not yet necessary, or whether to leave the foundations alone, knowing that corrosion will be an ongoing problem that could become serious.

Clearly, the use of this technique alone does not give enough information to decisively conclude that there is an issue with a steel tower foundation.

POLARISATION RESISTANCE THEORY

Where iron, oxygen and moisture come together a chemical reaction occurs that we normally call corrosion.

The corrosion current is the total flow of electrons from the steel foundation into the soil (oxygen and water) and if it were possible to measure this current then calculation of the number of iron molecules converted to rust every year and thus the rate of corrosion would be simple and direct. However, there are many thousands of anodic and supporting cathodic sites at microscopically adjacent points on the metal surface and inserting an ammeter probe in these circuits is not possible.

However, any corroding electrode will have a potential, Ecorr (normally measured with respect to a Copper/Copper Sulphate half cell). Over a region either side of this potential, the potential/current response of the system is approximately linear, the slope of the line being the Polarisation Resistance, hence the name of the technique.

TRANSIENT DYNAMIC RESPONSE

The TDR method relies on the propagation and reflection of a vibration through the concrete. A hammer equipped with a load cell is used to generate the vibration by tapping the upper surface of the foundation, with the load cell measuring the impact. The vibration travels down the concrete until reflected at the bottom, or at a crack or other feature in the structure, with the reflected pulse travelling back up to be detected by a geophone on the upper surface, as shown in Figure 2.

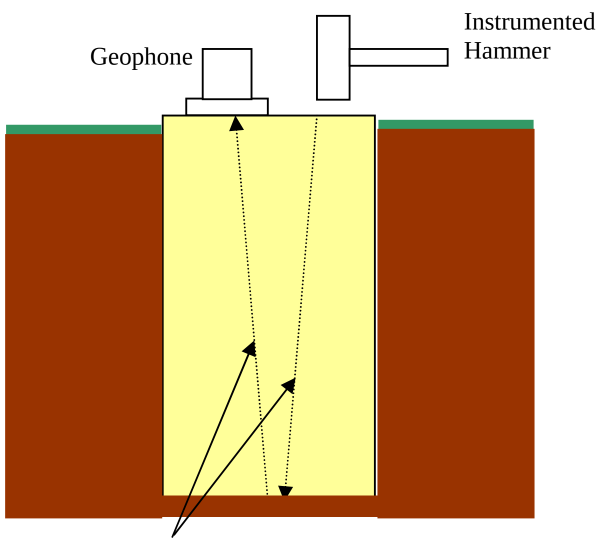

Figure 2: TDR measurement

Comparison of the load cell and geophone signals can be used to determine the time taken for the vibration pulse to travel down and be reflected back up the foundation. The speed at which the pulse travels through concrete has been found to be in the region of 4000m/s. Therefore, from the time elapsed and speed, the distance travelled by the pulse can be determined. This corresponds to twice the depth of the foundation.

With data in the frequency domain, additional analysis can be undertaken. Stiffness of the concrete can be found from the reciprocal of the slope of the initial part of the frequency/amplitude plot. A mathematical relationship between mobility (inverse of impedance to the pulse), cross sectional area, density and velocity exists. With approximate velocity having been established as 4000m/s and mean derived from the frequency vs. amplitude plot, if either the concrete density or foundation diameter is known, the other of these two parameters may be derived.

TDR SOFTWARE

Once a measurement has been taken, the software converts and shows the waveform gained. To find the depth, at least two resonating peaks are picked out by the user and clicked on to give the depth display, as shown in Figure 3.

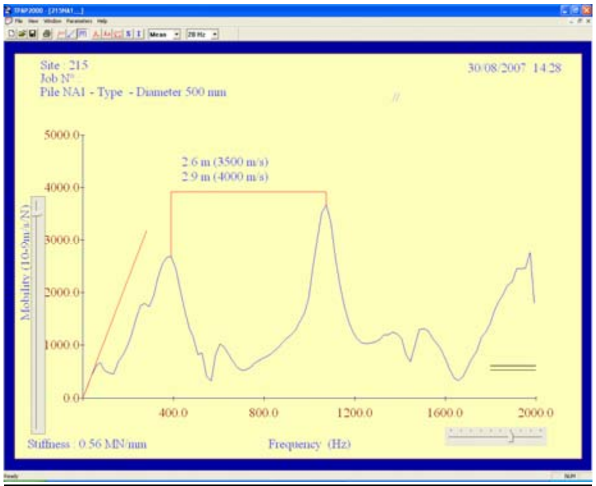

Figure 3: Typical waveform gained from a TDR measurement

A pictorial view of the foundation cross section can be obtained via the impedance profile function, which takes its name from the impedance of the pulse travelling down the foundation. The narrower the foundation cross section, the greater is the impedance of the pulse. An accurate profile requires many parameters to be input including density of the surrounding soil, nominal foundation diameter and foundation depth obtained from earlier analysis. This method can be used to highlight any reduction in foundation diameter or the integrity and shape of the foundation base.

An example of the output can be seen in Figure 4. The profile shows that the foundation nominal depth 4.1m, with a reduction in foundation diameter at around 2.5m deep. It should be stressed that the profiles generated in this way are only as good as the information that is input, requiring accurate information about the concrete and soil characteristics for meaningful analysis.

Furthermore, necking detected in this manner may not be indicative of active erosion that gives ongoing degradation of the foundation, but may be due to poor installation.

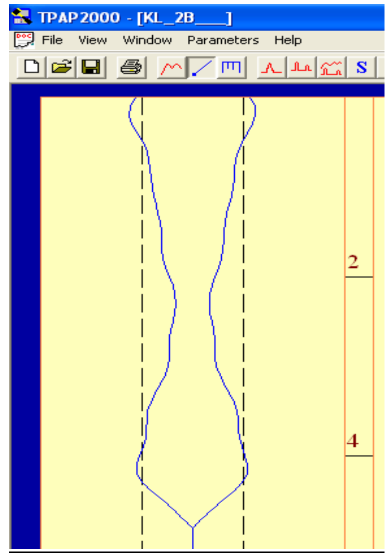

Figure 4: Profile of a foundation

CASE STUDY

When undertaking condition assessment of an overhead transmission line, TDR testing is of most value when combined with polarisation resistance measurements. A low TDR reading indicating either a shallow or cracked foundation can be obtained from either a minor discontinuity or change in density of concrete, or from the loss of a large section of concrete.

The latter situation is far more serious than the former. Loss of a large section of concrete will also give a very high corrosion current reading, even if little corrosion is present, as there is a much greater quantity of steelwork in direct contact with earth than there would be if there was only a minor crack in the concrete.

So if a large section of concrete is missing, there will be a high polarisation resistance reading and a low TDR reading. If there is only a minor crack in the concrete, there will be a lower polarisation resistance reading and a low TDR reading.

Conversely, if there is a large amount of advanced rusting on the below ground steelwork, the rust will expand and be expected to crack the concrete. This situation will give a high polarisation resistance reading and a low TDR reading. If rusting of the steelwork is not as advanced and the concrete not yet cracked, there will be a high polarisation resistance reading due to the rust, but a high TDR reading.

Thus it can be seen that the two methods complement each other in highlighting the foundations that pose the most serious problems.

A series of measurements were undertaken on a transmission line within the UK. Amongst the readings causing concern was a foundation with a high polarisation resistance reading together with a TDR reading that highlighted a fracture in the foundation at a depth of 1.2m was noted on one specific foundation.

As measurements had found significant active corrosion to the foundation steelwork and a fracture occurring at a depth of 1.2m, it was recommended that further investigations were undertaken.

Excavation works on the foundation were undertaken and it was confirmed that a fracture had occurred in the concrete foundation at a depth of 1.3m, exposing the supporting steelwork and showing that it was corroded. This is shown in Figure 5.

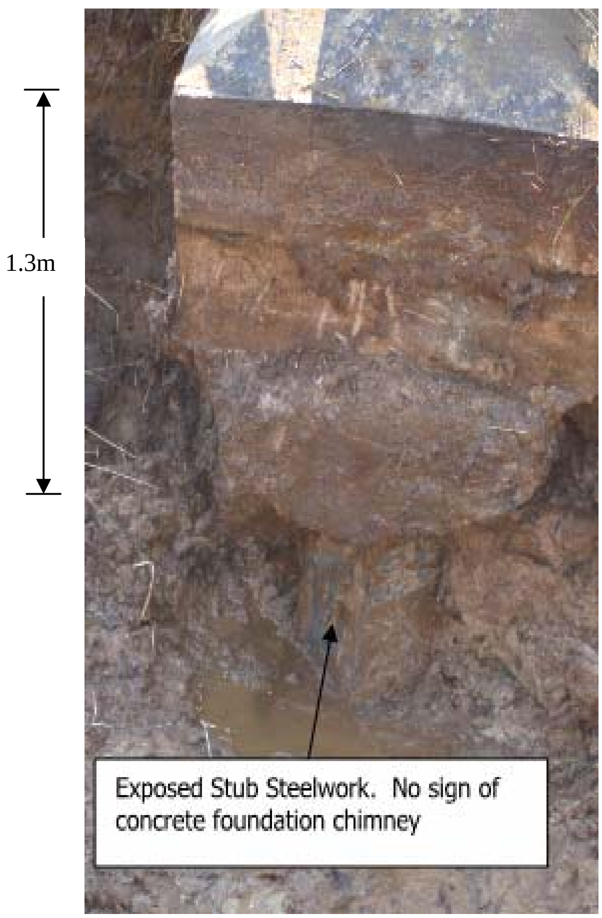

Figure 5: Excavated tower foundation showing cracked concrete and active corrosion

CONCLUSIONS

Tower foundations within the UK have been in situ for minimum of thirty years. In this time, major works have been undertaken on the above ground integrity of the tower but very little has been done with respect to the foundations.

This is mainly due to the excess cost for access and excavation together with the possible disruption to the transmission of electricity through the need for outages.

The combined use of polarisation resistance measurement and transient dynamic response has proved to be an accurate way of assessing the integrity of tower foundations in a non-intrusive manner. This allows for a more directed maintenance policy to target tower foundations where possible cracking and corrosion is occurring rather than excavating the whole tower line.