A DETAILED ASSESSMENT OF THE INNOVATIVE METHOD FOR LARGE DIAMETER SEWER INSPECTION TO DETERMINE STRUCTURAL INTEGRITY

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Abstract

The article focuses on the technology available in the UK for carrying out investigation and assessment of large diameter conduits. The non-destructive innovative method of tunnel survey have been described to provide an assessment of the efficiency and reliability of the technique. The test is Mechanical Assessment of Conduits (MAC) for structural integrity.

The MAC system provides the capability of carrying out sophisticated analysis of pipes structure and the surrounding geology. The main application of MAC system it to identify zones of defects or any weakness in the supporting system, consisting of the pipe and the surrounding soil. The second application is based on the calculation of the soil and structure modulus. The objective is to qualify the nature and the quality of the material; such as alteration within the structure or voids/decompression in the surrounding soil.

Using information from a study carried out by Wessex Water, a detailed analysis of the Application, Performance, Limitation and Effectiveness of the testing device was accomplished. From the study, it can be concluded that the survey has delivered what it claimed to and the results have enabled Wessex Water to effectively design rehabilitation works for the areas affected.

Introduction

The UK has one of the oldest and most complete sewerage systems in the world. A vast part of the current sewerage infrastructure was built between 1945 and 1975, making the average age of the sewer system more than 50 years old. Sewer deterioration has required one of the biggest capital expenditures because of the risk of major infrastructure failure, and the costs to repair these assets in the event of failure are likely to be very high and characterise a large problem for Water Companies in the UK.

In order to tackle this problem, various inspections techniques can be implemented. Proactive management for sewer maintenance and rehabilitation is becoming more and more popular among the water industry. This article describes an innovative method for assessment of large diameter conduits - considered critical sewers - by utilizing non-destructive Mechanical Assessment of Conduits (MAC).

MAC System Survey

The need for structure-analytical evaluation in large diameter conduits, was generally omitted in practice, and was the reason The Institute of Underground Technology (IKT), a research institution, based in Germany, spent three years re-developing a non-destructive test procedure, known as the "MAC", and several months building the equipment. The concept was brought to fruition by Dr. Olivier Thépot of Eau de Paris.

The MAC System comprises a powerful hydraulic pressure cylinder, which presses two bearing plates simultaneously against opposite walls of the pipe via an automatic control of the pressure cylinder, with forces ranging from 10 to 100 kN.

Fine sensors (extensometer) measure the deformation arising directly in the area of the pressure plates and at a distance of approximately one metre in front and behind these points to record the three-dimensional deformation. Despite the high forces applied, the automatic control of the pressure cylinder prevents any overloading and damage to the pipe. The actual deformations measured are, at the most 0.5 mm (Figure 1).

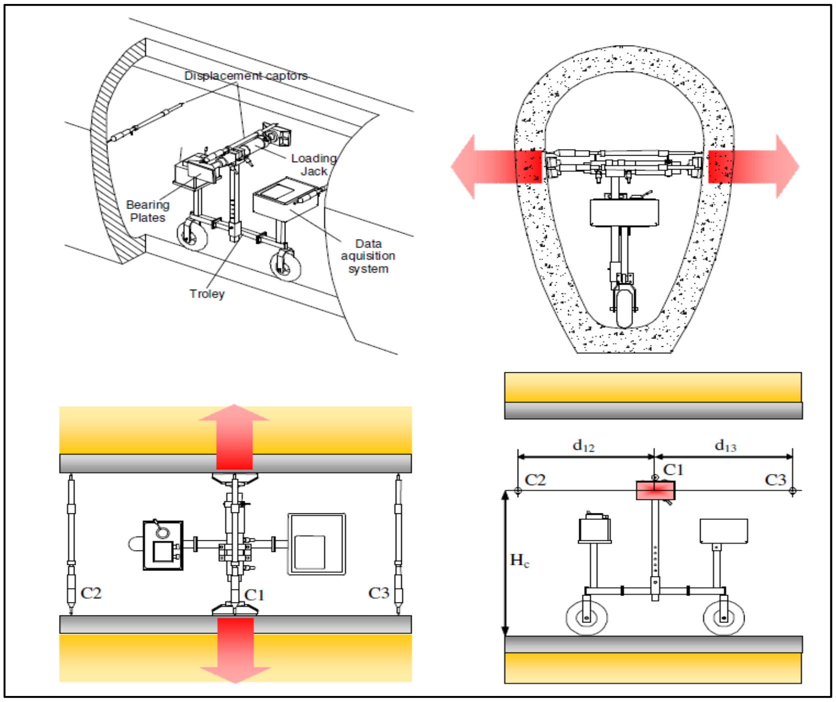

Figure 1. The MAC testing device and measuring points.

The test includes two cycles of loading/unloading, lasting on average 5 minutes including installation. The rate of loading is approximately 5 kN/s. The deformation of the horizontal diameter is limited to a minimum of 0.025 % or 500 µm, and the entire system is of variable geometry and can be adapted to all shapes of sewers.

Testing in situ

During the test, the internal jacking force causes a three-dimensional deformation as mentioned earlier, and three measurements are obtained - the force pushing on the bearing plates, the displacement measured by the main rod and the displacement measured by the 3-dimensional rod.

This data is collected and analysed, instantaneously displaying a graph on the data logger showing the force–displacement curve across the pipe and the damping of the displacement in the longitudinal direction. The information then instantly available to the operator to adjust the applied forces in order to obtain the best results.

From these two curves, it is possible to calculate two parameters: the Global Stiffness (equal to the ratio between the force and the main displacement) and the damping factor (equal to the ratio between the 3-dimentional displacement and the main displacement).

Zones are then identified where the structure behaves in a homogeneous way. This delimitation effectively limits the number of strategic cores to be taken from the structure, to determine the mechanical properties of the structure and the surrounding ground. These cores are crushed in the lab and triaxial tests are carried out for the compressive strength. Density and the geometric properties of the cores are also analysed and compered along with the survey results. Furthermore, the cores make it possible to verify the thickness and the quality of the structure and the condition of the soil-structure interface.

The spatial retrieval of cores will be dependent upon given circumstances and the potential for change in external lateral support offered by the geology, or the level of backfill grouting beyond the extrados of the conduit lining.

Results provided by the Test

When the geometry of the pipe (shape and thickness) is known, it is possible to back calculate the Young's modulus of the soil (E_{Soil}) and the Young's modulus of the structure ($E_{Material}$).

The "Institut Für Geotechnik (IGtH) der Universität Hannover" in Germany, uses a Finite-Element-Method (FEM) to curve fit expressions for the Young's modulus of the both, structure and soil as function of the global stiffness and the dumping ratio. Once the Young's modulus specific to the material of the structure is known, it can be compared to the corresponding modulus of the material in good condition (unaltered and without cracks). Finally, the Quality Index is determined using the back-calculated modulus of the material and the expected modulus of the material in good condition.

Background: Braidley Rd tunnel

As part of The Strategic Tunnel Inspection programme developed by Wessex Water, one length of the Braidley Road tunnel, located in Bournemouth on the south coast of England, was identified as being in an imminent state of collapse, due to its location in a weakly cemented sand geology, subject to high ground water pressures and phreatic flow.

The Braidley Rd tunnel has an internal diameter of 1200 mm, with depths varying from 4m to 19m. The tunnel was built using the Flexilok-Tunnel-Lining-System in 1970, which utilised concrete segments and back grouting of the annular space. This segmental system had no mechanical restraints by way of bolting, between any of the segments. The sections are held in place only by the 20-30 mm tongue on each segment and the pressure of the back grouting during construction. The gaps between the elements are continuous in axial and circumferential directions.

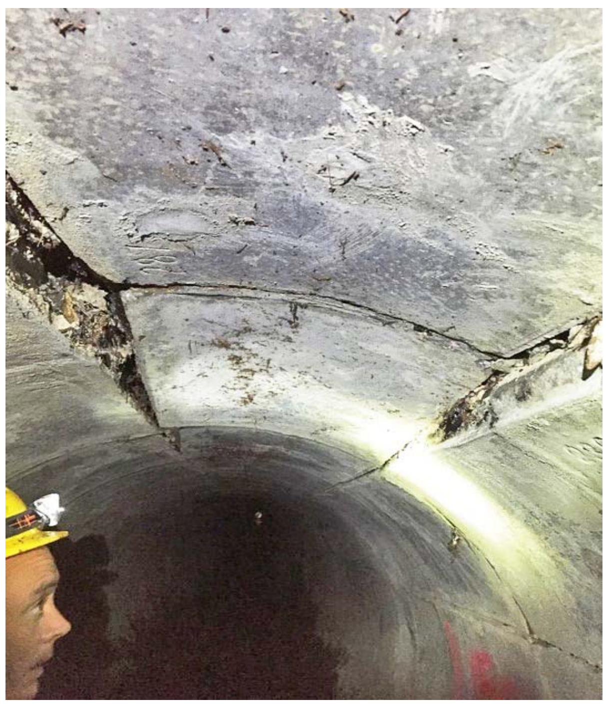

Figure 2. Defects found along the tunnel during person-entry survey.

At some point over the last few years, the Braidley Rd tunnel has been hydraulically surcharged and the water pressure has forced the segments out, over a 40m length, mid-way along the tunnel (Fig 2 &3). For the first time the MAC extensometer has given us the ability to understand the structural capability of the tunnel lining, which we assumed would vary along it 220m length, between shafts. By iteratively analysing the tunnel in discrete lengths, we were able to understand the potential longevity of the tunnel.

Figure 3. Inspection of open joints by endoscope, confirmed poor original back grouting.

Survey

The test was undertaken in April 2016 during a dry period, resulting in low flows within the system. The survey was delivered under an NC4 confined space classification with a specialist rescue team in attendance at all times, and flows were constantly monitored.

During the survey, the measuring plates were placed at a height of 600 mm from the bottom of the tunnel and measuring points were located at every five meters along the sewer length, resulting in twenty-one measuring points.

Figure 4. MAC test being carried out in the Braidley Tunnel.

At every point, 60 kN force was applied and readings were obtained of the deformation caused in the inner wall and a graph instantaneously produced the force–displacement curve across the pipe and the damping of the displacement in the longitudinal direction.

One core sample was taken on the same day of the survey, as part of the test to determine the mechanical properties of the structure and the surrounding ground. As expected, the surrounding ground is comprised of very soft wind blown running sand. For this reason, the remaining cores were strategically taken at the position of 3 and 9 o'clock to minimise sand entering the tunnel and causing voids in the surrounding ground. A total of nine core samples (diameter of 100 mm) were retrieved by Wessex Water contractors and sent to the laboratory in Germany.

Results

The 100m section of tunnel surveyed was divided into three zones based on the structure's behaviour (homogeneous Pipe-Soil Stiffness – K_G and the Damping-Ratio – Ω) as showed in Figure 5 and 6. Points highlighted in green represent the core samples location.

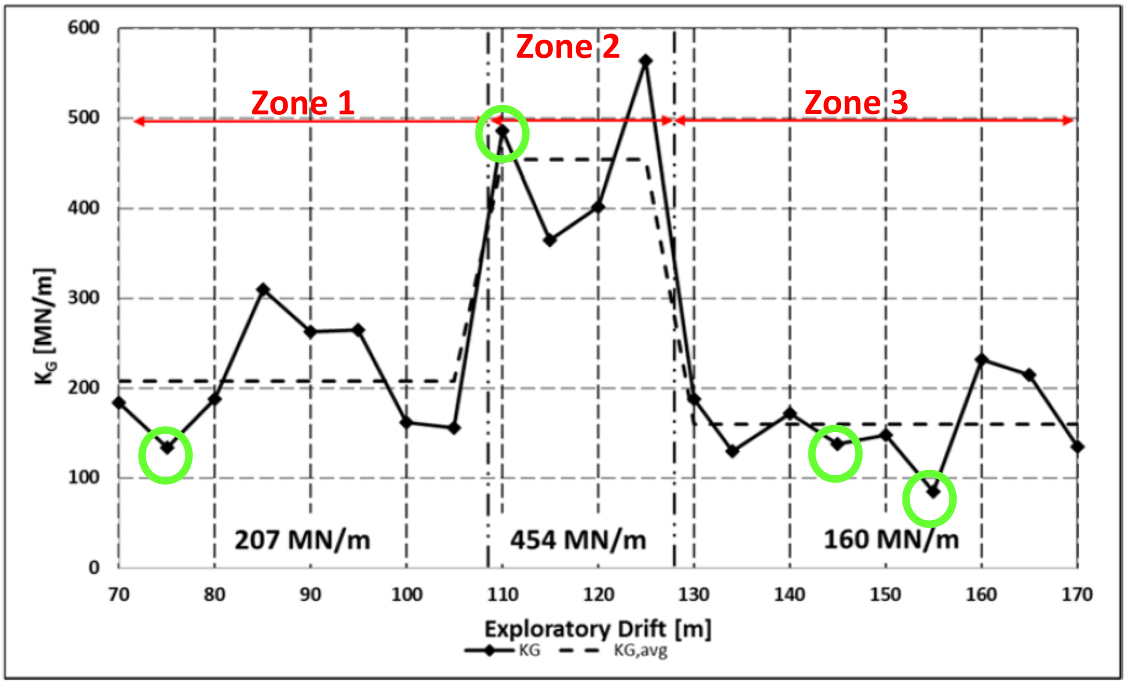

Figure 5. MAC graphical output.

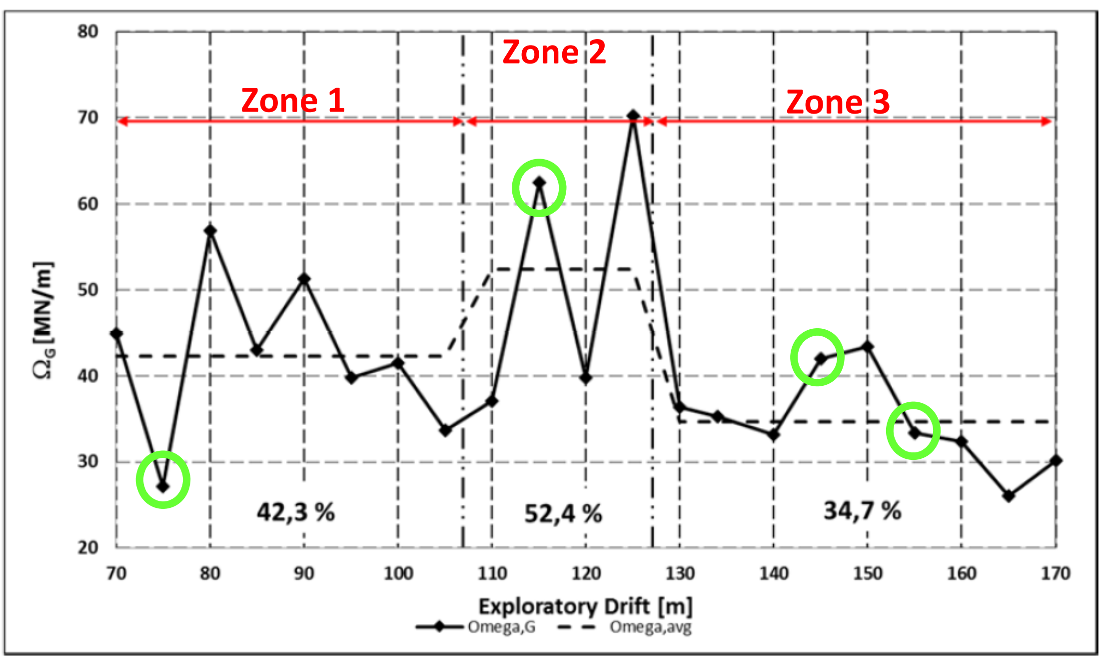

Figure 6. Damping ratio.

It was identified that in the second zone, stiffness was higher than in the first and third zone, whilst the subsequent core tests proved an average UCS value of 67 N/mm^2, which is considered high; as structural concretes are normally around 40 N/mm^2.

The stiffness of soil and sewer were divided into zones and static calculations were undertaken. The numerical FEM calculations are represented graphically in Figures 7 & 8. The points highlighted in pink in the graphs correspond to the most critical areas of the sewer due to the low stiffness calculated.

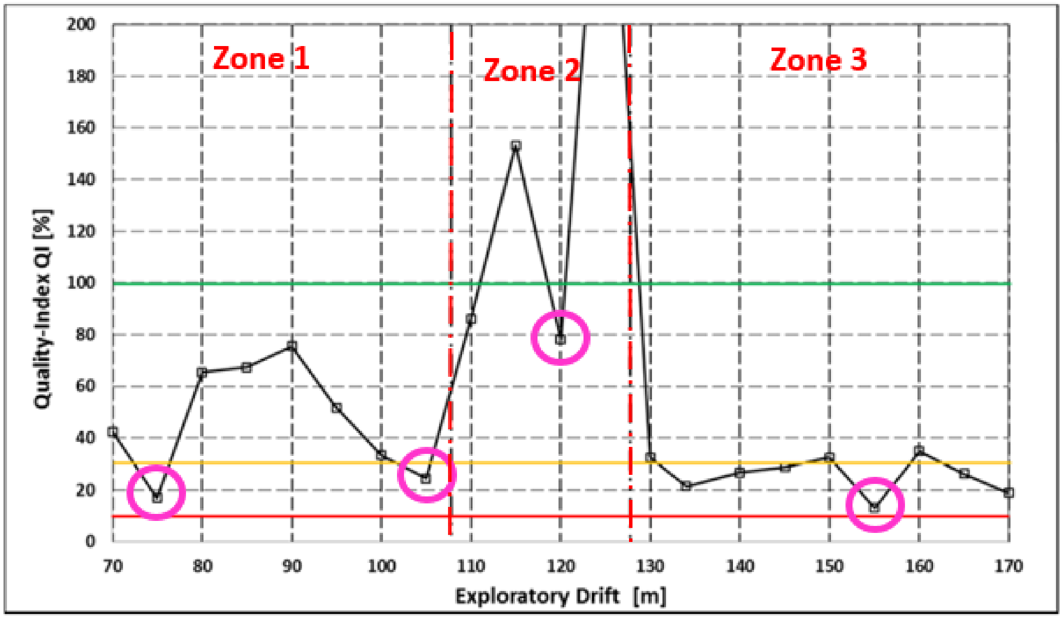

Figure 7. Quality index.

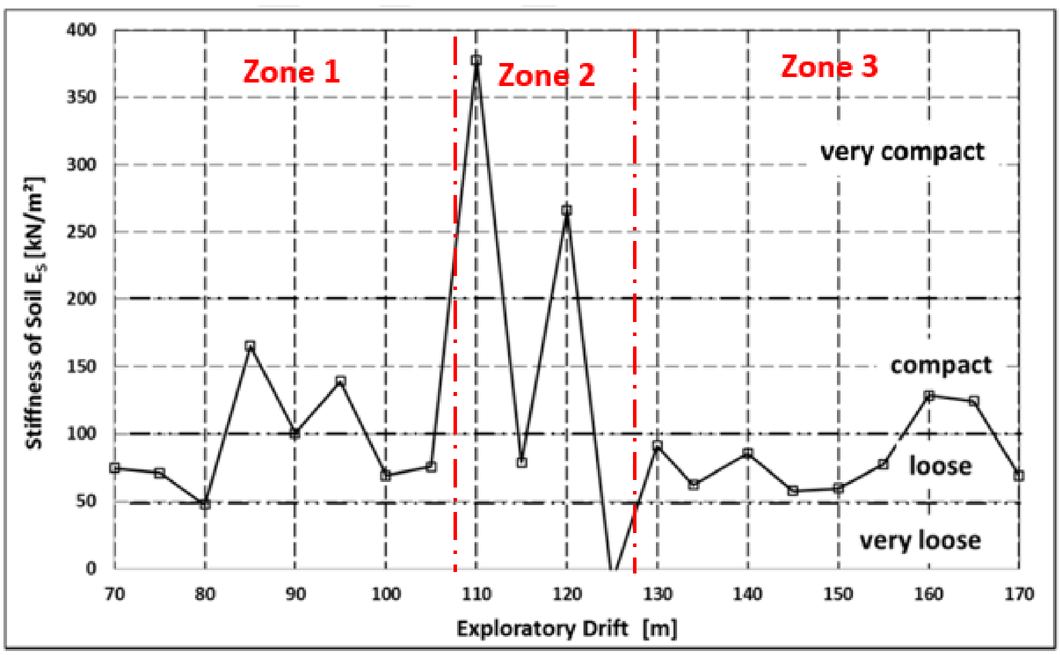

Figure 8. Stiffness of Soil.

Predominantly the stiffness values in zones 1 and 3 were low, yet the lining was intact and looked visually competent, whilst zone 2, the known defective length, had a higher stiffness, with the exception of one measuring point, where soil stiffness is nearly zero.

One reason for this result can be related to the grouting outside the segments during construction. It may be that in this area more grouting material was needed to fill the annulus at or below the horizontal mid-level as confirmed by the use of the endoscope, which acted as very hard/stiff ground, therefore the stiffness of the pipe is influenced by the concrete elements and the grouting outside. Yet this was not evident in the crown of tunnel, as deformation is evident. Soil stiffness could not be calculated due to very different boundary conditions.

From the results obtained it was suggested to reline the entire length in order to protect against internal hydraulic surcharge.

Figure 9. Amiantit SRM TYPE1 GRP linings imported from Poland.

Conclusion

The MAC system provides the capability of carrying out sophisticated analysis of pipes structure and the surrounding geology. The equipment is straightforward to operate and of very low environmental impact - the only risk identified at this stage was the risk of flooding if the sewer was blocked by abandoned equipment or other materials in the case of sudden and unexpected increased flows.

From the MAC test results it was concluded the middle section was at critical condition and imminent state of collapse, with major defects by a broken segments uplifted at the crown of the tunnel. The rest of the tunnel length was also found in a critical condition, but seemed stable. The doubt of whether the remaining tunnel length would be at risk of further distress due to future hydraulic pressure surge was confirmed by the static calculation also provided by the test. Therefore, the results from the MAC system test allowed Wessex Water to make the decision on the rehabilitation method based on the accurate and compressive data.

The decision to pro-actively survey the large tunnel assets of Wessex Water has had a significant positive impact on customers across the region. The challenge for the future is to keep developing technologies and moving to a truly proactive basis from the traditional historic reactive past.

Overall, this study strengthens the reliability of the survey technique thus suggesting its wider application in inspection practice.

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