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Measuring Changes in Sewer Systems

Prof. Kirill Horoshenkov (University of Bradford) and Richard Long (Ewan Group plc)

Introduction: The Need for New Technology

In the UK the underground sewer system totals some 300,000 km in length with a replacement value of £104 billion. It is an ageing asset stock of which the system operators have little information. In England and Wales, OFWAT imposes a legal duty on the privatised utility companies to maintain the condition and serviceability of this asset and it is a statutory requirement for each water company to clearly demonstrate that services to customers can be maintained at least cost in terms of both capital maintenance and operating expenditure. Unfortunately, at present the only currently available techniques with which they can assess the condition of sewers are slow, expensive and subjective.

Water companies need enhanced information in two key areas to manage efficiently both the day-to-day performance and long-term capital maintenance of sewers, which relate strongly to the operational and structural conditions and rate of deterioration. The operational condition of sewer systems changes over time due to silting, fatting, blockages, ageing and interference. These conditions are very important and have a direct harmful effect on the performance of the system. A DEFRA review of existing private sewers and drains identified some 20000 flooding incidents from private sewers in 2002, OFWAT (2003) identified 5700 internal flooding incidents from sewers managed by water companies, with an additional 11600 properties with a 1 in 10 year risk of flooding. OFWAT has required water companies to progressively tackled identified properties at risk of flooding through capital investment, as flow capacity inadequacies are addressed, 'flooding other causes' becomes increasingly significant as a failure of service that impacts on the OPA score. It is likely that the significant majority of these types of failure are caused by operational condition. OFWAT's analysis does not include the more numerous, smaller ex section 24, or the private sewers for which the water companies are about to become responsible. Companies are now looking for new ways of reducing these incidents through means such as cluster analysis to identify hot spots, CCTV to locate developing problems, followed by pro-active sewer maintenance activities, such as jetting.

In contrast to flooding due to hydraulic overload however, 'flooding other causes' problems commonly exist on small diameter local sewers, including the ex-S24 sewers, which make up by far the largest part of the sewer network. No longer therefore will it be sufficient to focus attention on the 20% or so of 'critical' sewers as has been the case in the past. Current technologies are limited by cost and time – new technology is needed that will work quickly and economically, and provide information in a format that will permit ongoing programmes of pro-active maintenance to be carried out cost-effectively across the whole of the asset base.

Furthermore, the inspection and cleansing required is not a one-off activity. Having identified areas at risk it is important to regularly check for progressive operational deterioration and intervene again at the right time, before service deteriorates to an unacceptable level. Traditional CCTV techniques are not the ideal means of doing this, being relatively slow, expensive and subjective. As a result, a better alternative is required to provide objective measurement of current operational condition that will allow the operator to show that the condition is stable and whether a change in the on-going level of service is needed. This alternative needs to be much less expensive, objective, much more rapid and capable of being utilised in the smaller and much more numerous ex section 24 sewers.

With regard to structural condition and rate of deterioration there is increasing pressure for water companies to improve their knowledge of sewer condition, asset lives and failure modes. In January 2004 the National Audit Office carried out a review of how the 10 sewerage companies in England and Wales have fulfilled their statutory duties relating to the stewardship and performance of the sewer network and how Ofwat has fulfilled its regulatory duties in relation to the network. They concluded that "Assessments of past performance and condition … give a limited view of the future performance of networks, and how much activity properly directed each company should carry out on maintaining its sewer networks. Companies should develop a clearer understanding of the rate of deterioration of their sewerage network assets". In May 2004 The Public Accounts

Committee of the House of Commons concluded that the way in which Ofwat and the water companies manage the structural condition of sewers should be improved. Two key recommendations were: (i) "*Ofwat should require companies to include the same sewers in its regular five year asset inventory assessments*", and (ii) "*Ofwat should develop measures which provide an indication of the future condition and performance of sewer networks*". In MD161, Ofwat said that "*Each company needs to demonstrate how the flow of services to customers can be maintained at least cost in terms of both capital maintenance and operating expenditure, recognising the trade off between cost and risk*". The Common Framework is the means by which such assessments are to be made. To properly apply the Common Framework it is essential to have reliable information on asset deterioration and failure modes for each type of sewer so that the probability of failure and impact on service can be estimated with confidence. There is a dearth of suitable asset observations relating to sewers from which such information can be determined, not least because current technology is insufficiently sensitive to determine the small changes that, over time, lead to decay and eventual failure.

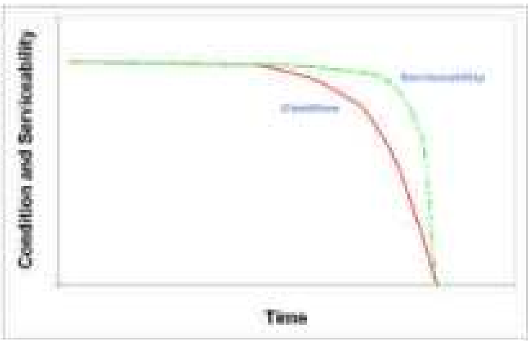

Figure 1. Conditions and serviceability of a sewer network as a function of time.

In this respect, it should be noted that the deterioration of condition and deterioration of serviceability do not occur at the same rate. Figure 1 illustrates how it is often the case that a sewer may be serviceable even when its condition has seriously decayed. The problem is that if attention is focussed on the sewer only when its serviceability has substantially decayed it is probably too late to rehabilitate the sewer in the most economic manner. Expensive and disruptive renewal is then the only solution. A system that can measure the progress of the sewer along the condition curve so that rehabilitation can be carried out in the right place at the right time will ensure that whole-life costs are minimised and so the utilisation of resources can be optimised.

Bradford University have recently obtained funding from the Engineering and Physical Sciences Research Council (EPSRC) to carry out a two year programme of research and development of these techniques. The project has been developed in conjunction with ewan Group plc and is supported by Yorkshire Water, Pennine Water Group and Birmingham University.

The aim of the project is to develop an acoustic based system that will provide a step change in technology to provide information on sewer condition, in "real time" and at a network scale. This will require new insights in acoustic signal processing, and the application of mathematical techniques to link signal responses to physical sewer condition. The potential reduction in costs required to operate an automated acoustic based sewer condition system, anticipated to be around 2 orders of magnitude, offers for the first time the potential to directly assess the majority of a sewer network from the numerous small ex section 24 sewers up to the large trunk sewers at a time scale suitable for operational and capital planning purposes.

Background

Recently, a series of acoustic experiments has been carried out by Bradford University and Ewan Group plc in which the real part of the acoustic intensity vector in a drained sewer pipe has been measured and then processed to identify the position and extent of a small blockage. Figure 2 show the spectrograms for the ~~negative amplitude of the real part of the intensity vector~~sound field measured in a clean 20m ductile iron pipe with 400mm diameter and in the same pipe with a 0.5m

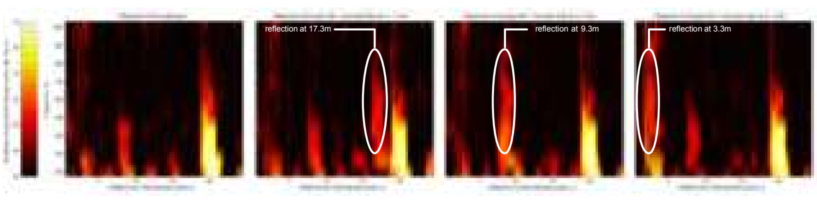

Figure 2. Spectrograms for the ~~negative amplitude of the real part of the intensity vector~~sound field in a

long, 100mm high blockage positioned in succession at 3.3m, 9.3m and 17.3m from the probe. These initial results suggest that the acoustic signature of the sewer can be used to detect the location and extent of a minor change in the cross-section of a large-diameter pipe. Although, instruments have already been developed to determine variations of the cross-section of narrow pipes using the method of acoustic reflectometry, there have been hardly any systematic studies devoted to the reconstruction of the cross-section profile from the multi-modal acoustic response of a pipe. This lack of theoretical basis and relevant experimental data is evident and can be explained by considerable mathematical challenges and by the nature of harsh, ever-changing environment that a sewer pipe represents. In this context, the obtained results are novel, challenging but highly promising and relevant to the imperative society needs.

The results indicate that small acoustic based sensors have the potential to measure pipe condition. It is our vision that in the longer term a range of acoustic based sensor can be developed, either to be deployed permanently at a single position or to advect through a system so providing real time continuous information on sewer condition. This project represents the first step of such a vision.

Objectives

The objectives of the project are as follows:

1. To develop an acoustic based system for rapid and safer "whole system" inspection of operational and structural conditions of real sewers. This will offer a step change improvement in the speed and cost efficiency to any other existing surveying method.
2. To achieve the above objective to develop a reliable theoretical method for the measurement and prediction of the 3-D variations in a sewer cross-section.
3. To develop techniques to map acoustic signatures to current descriptions of asset condition.
4. To link the new asset observations to the service received by customers and to examine the types and timings of interventions to maintain service at a pilot scale.

The proposed work aims to develop a very low cost acoustic sensor that is able to obtain an objective signature of a sewer pipe up to 1000m long in less than 60 seconds. This sensor can be operated in a stationary mode or be dropped and transported by the water flow in a pipe. It is anticipated that the technology will be able to resolve ±10% variations of the mean flow depth and to predict with similar accuracy the build-up of blockages along the sewer length. This device should be able to operate both in main trunk and in smaller Section 24 sewers. It is expected that the technology will be limited to sewers with diameter between 75mm to 900mm. The stage will mainly involve the design of sufficiently robust but cheap combination of a loudspeaker, microphone, electronic controller circuit and the development of new signal processing algorithms. The sensor will be tested in the laboratory at Bradford for a range of pipe shapes and blockages. This would demonstrate that this technology could rapidly identify blockages or changes in pipe condition that would impact on operational performance.

The completion of this project would provide the base for the development of adaptive networks of acoustic sensors that can collect and convey real time data on asset condition essential for responsive asset management.

The results of the experiments will pave the way to the development of an instrument prototype which will be tested in-situ at several representative sites to which the access will be provided with support from the industrial partners. The instrument prototype and the relevant software will be developed using the technical resources available at the University of Bradford and within Ewan Group plc. The prototype will be tested for and, if required, redesigned to satisfy the basic criteria for the intrinsic safety performance. Suitable real sewers will then be identified and a series of tests within them will be carried out and assisted with real-time CCTV data provided with the support of the relevant water company. A small number of sensors will be deployed at locations in a small sewer network with known performance problems. The aim would be to use the measured acoustic response to measure the condition of individual pipes and then try and link this with any observed deterioration in performance. The data on the hydraulic performance and any previously observed deterioration of this sewer network will be provided by the water companies.

Management of sewerage assets over the last 20 years has been based largely on the Sewerage Rehabilitation Manual. Application of the Common Framework requires a methodology that links asset observations (eg changes in sewer condition) to the service received by customers and a means of predicting the types and timings of interventions that will maintain service at least whole life cost. It is the intention to deploy the developed sensor to rapidly measure the condition of every sewer within a test catchment and then to link this to operational records of the managing sewer service provider. This will allow us to develop techniques to link acoustic data to asset condition and then to the recorded asset performance.

It is intended to provide a digital 'fingerprint' of a sewer length that is representative of the condition (and hence performance) without necessarily containing full details of every defect. By repeating the measurements at intervals and comparing the 'fingerprints' it will become apparent whether or not significant change has occurred. Digital processing means that comparison will be both quick and objective and can be carried out at a network scale. Fingerprints may be compared some time after the test, or immediately by accessing the results of previous tests, which are either stored on portable equipment on site connected by cable or wireless, or at a remote location using wireless connection. The accurate estimation of sewer conditions is crucial to managing flooding and pollution. Hence the beneficiaries will be those managing sewer systems, and the modellers, each of who will have less uncertainty in their performance analysis. Operators will also be able to obtain information about sewer deterioration with time by carrying out repeat surveys, thus having for the first time sufficient data to assess the whole life costs of interventions.

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