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The detection of abandoned mineshafts by railway track bed using transmitted seismic waves using broadside shot gathers

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HIGHLIGHTS

- A new technique to locate buried vertical mineshafts has been developed.
- The technique has been validated using a numerical model followed by a full scale field trial.
- The technique was less effective where a shallow superficial deposit overlays bedrock.
- A higher frequency source (greater than 25 Hz) would be needed to identify mineshafts smaller than 2 m in diameter.

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ABSTRACT

The practical challenges of mineshaft detection under railway embankments are discussed, together with typical mineshaft properties over the centuries. The paper focuses on the broadside shot seismic transmission method to detect abandoned mineshafts, with the potential to be used in the vicinity of embankments. A numerical model was developed, using a new type of absorbing boundary condition, which is referred to as the Recursive Integration Perfectly Matched Layer. From a series of simulations using this model, a series of practical outcomes were identified regarding the feasibility of the broadside seismic transmission method. These include the layout of the geophones, the frequency of the shot source together with ways of improving the signal to noise ratio. The results from a field trail in East Lothian, Scotland are compared with the output from the numerical model and good agreement was identified.
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1. Introduction

Buried mineshafts that were abandoned over a century ago pose a present day threat to the stability of the ground above. For obvious safety reasons these mineshafts need to be accommodated for. To remediate a mineshaft its exact location has to known. Unfortunately documentation on mine workings before 1872, the year when it became compulsory to keep detailed plans, are unreliable and sometimes non-existent.

It is estimated that there are still 30,000 out of 100,000 workings in the United Kingdom which are unrecorded [3]. The issue is of course an international problem, with abandoned mine workings widespread across the USA, for example. The detection of abandoned mine workings, whilst not easy, has been well documented.

In the UK context, mine shafts can be found widely spread throughout the country, but the vast majority are located between Edinburgh and Glasgow, the Midlands, Wales and around Newcastle (Fig. 1). It is reasonable to assume that numerous shafts are present in the vicinity of both highways and railways. These workings date from the prehistoric times to late 19th century, but the majority were excavated during the last three centuries.

This is especially true for concealed mineshafts in urban areas and near infrastructure such as highways and railways. In order to diminish the risk, it is essential that the abandoned shafts are located and stabilised.

This paper will make reference to the challenges of detecting abandoned mine shafts beneath embankments.

2. Mineshafts

2.1. Development of mineshafts

The early mining operations in the United Kingdom consisted of quarrying the materials from exposed outcrops and from shallow seams [2]. Often adits were driven from the outcrops into the seam permitting the extraction of the ore or coal. Another common

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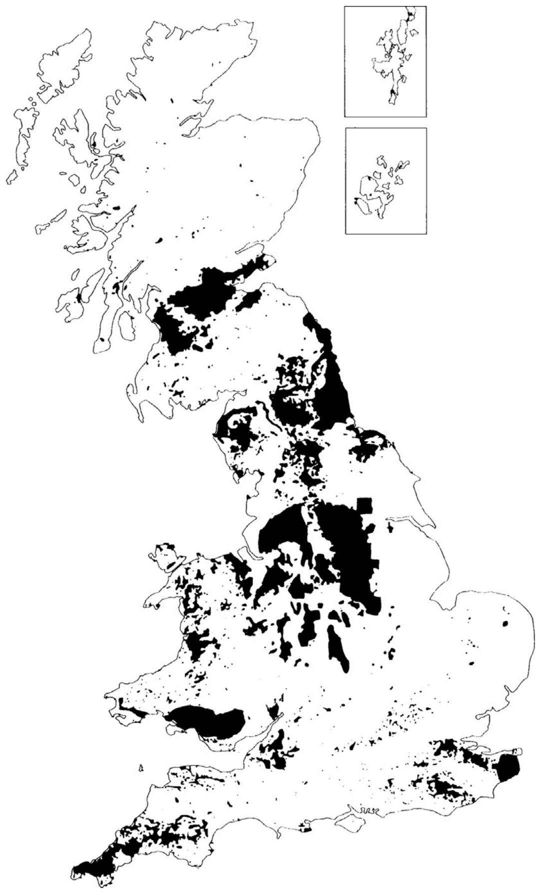

Fig. 1. Mining map of the United Kingdom [14].

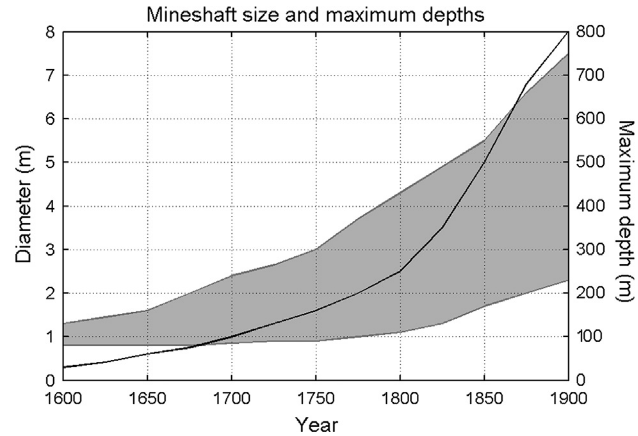

Fig. 2. The development of the diameter (grey area) and the maximum depth (black line) of the last centuries (after [4]).

method used in the early days of mining is by means of bell pits. Bell pits were mainly used for flint mining and mining iron stones; although some bell pits have been found in shallow coal fields. A bell pit is a single vertical shaft sunk to the bottom of the seam which is worked to a limited extent around the shaft till there were signs of the roof collapsing. Generally, bell pits were no more than 12 m deep, although bell pits of up to 30 m deep were constructed. The diameter of mined area around the central shaft spanned from 8 m to a maximum 20 m. Bell pits were used until the 17th century [10].

In the 15th century new techniques to extract the seam came into existence such as room-and-pillar mining and shortwall mining and longwall mining. In the beginning these mine workings were accessed by one single mineshaft. Although sometimes a connection with another colliery was established allowing air ventilation. During the 17th and 18th centuries it became more common to have two or more mineshafts. The separation between these mineshafts can be merely 3 m apart to being opposite ends of the mine workings. For deeper mine workings it was still common to use one single mineshaft, but due to frequent accidents it became compulsorily in 1852 to have at least two mineshafts per mine working.

The invention of steam-driven pumps in 1712 improved the draining of the mine workings and greater depths could easily be achieved. At the end of the 18th century mineshafts of 250 m deep were constructed. The trend of increasing maximum depths continued until modern times. Fig. 2 illustrates the general trend of maximum depths of mineshafts for the last four centuries. Similar to maximum depth of the mineshaft, the width of mineshafts increased over the last centuries. During the 1600s the average diameter of a mineshaft was merely 1 m. The average diameter rose to 2 m around 1750, although mineshafts with 1 m diameter were still constructed. The diameters of mineshafts around the 1900s were between 2.5 and 7.5 m. An overview of the development of the diameter of the mineshafts over the last centuries can be found in Fig. 2.

With increasing mineshaft depths and diameters, it became necessary to support the mineshaft to prevent it from collapsing. Mineshaft linings were used since the 17th century. In the beginning wooden linings were used and two centuries later it became common practice to use bricks for lining. During the sinking of the mineshaft, wooden and sometimes iron frames were to support the mineshaft initially and thereafter brickwork was constructed within the frame. The use of metal linings became common through the 19th and 20th century. At the close of the 20th century concrete lining was introduced.

2.2. Closure of mineshaft

After closure of the mine working, the mineshaft had to be sealed for safety reasons. There were various methods to secure an abandoned mineshaft and today abandoned mineshafts can be encountered in various conditions. The most common conditions are represented in Fig. 3. The chosen practice to secure a mineshaft depends mainly on the size of the mineshaft. Deep mineshafts were very unlikely to be completely backfilled and the most common practice was to backfill the abandoned mineshafts partially. This method consisted of building a scaffold just below ground level or near the bed rock. Sometimes the upper part of the lining was removed and the scaffold was built on the remaining lining. In 1871 the Mines Inspectorate recommended the use of large wooden logs for the scaffolding. These logs were fixed together and laid across the mineshaft.

However regardless of the recommendation, it was more common to dump mine tubs, trees or even colliery steam engines into the mineshaft, which formed an obstruction. Hereafter the mineshaft was backfilled till ground level. The material used for backfilling consisted of almost anything that was available at the site. Generally it consisted of colliery and building waste such as wood, ropes, ashes from the engines, some lining material, and remnants of rock through which the mineshaft was sunk. The backfilling might be mixed with superficial deposits.

Abandoned mineshafts that were not partially or completely backfilled were secured by either fencing the area off or by capping. There was little consistency in the methods of capping. Although these mineshafts are dangerous, they do not constitute

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