

# ANALYSIS OF MULTITEMPORAL AIRBORNE REMOTE SENSING DATA FOR THE LOCATION OF SOLUTION FEATURES IN THE CHALK OF SOUTHERN ENGLAND

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## ABSTRACT

The potential use of airborne remote sensing techniques for the detection of collapse and subsidence features in chalk and other limestone rocks is examined. The detection of such features in the early stages of an engineering project is of crucial importance if serious geotechnical problems to building construction and public safety are to be avoided. Particular attention is paid to the use of aerial photography and thermal infrared (IR) data as a means of detection. Some preliminary results from the analysis of multitemporal data acquired over two test sites are presented.

## 1. INTRODUCTION

Natural solution features which develop upon soluble carbonate rock terrains have morphologies controlled by geological, hydrogeological and geomorphological conditions. Chalk, which has the largest outcrop area (250,000Km<sup>2</sup>) of any limestone in Great Britain, is a weak, open textured non-crystalline carbonate rock. Such rocks have a characteristic range of solution features, some of which are metastable, and these are outlined in Section 2. The metastable forms pose a serious subsidence risk to engineering structures which can result in severe stress, or even their complete destruction.

It would clearly be advantageous to be able to detect metastable solution forms prior to the engineering development of an area. Remote sensing has been attempted for such detection, with varying degrees of success, as cost-effective precursors to land-based investigation using geophysical techniques (McCann et al, 1987) or standard ground investigation techniques (details of which can be found in BS 5930 (1981)). In general, detection methods can only successfully identify solution features in plan or vertical section. Therefore, usually two or more successful methods will have to be combined in order to achieve a three dimensional picture of the feature requiring treatment.

Airborne remote sensing should be considered primarily as a reconnaissance tool to be used during, or immediately after, the

desk study stage, rather than as a technique to be used during the main detailed ground investigation stage. The aim of a survey utilising remote sensing techniques should therefore be to delineate areas where, potentially metastable solution features may exist and to identify specific areas where more detailed local investigations should be carried out.

There are three principal methods of airborne remote sensing which have been used for the detection of potential solution features: aerial photography, thermal IR linescanning and multispectral scanning (MSS). To date the latter technique has been used to a much lesser extent than the former two methods.

The application of aerial photography to the detection of collapse features is well known; a general account of the method being presented by Norman and Watson (1975). Aerial photography can be used to detect collapse or subsidence features either by direct (often stereo) observation of the photographs or by the use of indirect evidence; for example, the presence of stressed vegetation or structural weaknesses such as faults and fractures (Littlefield et al, 1984). In the latter two cases the use of false colour IR emulsions has also provided useful.

A number of authors have also considered the use of airborne thermal IR and, to a much lesser extent, MSS for solution feature detection. The following selective list of previously published work indicates the widespread interest in these techniques. In the US work has been carried out by Coker et al (1969), Newton (1976), in South Africa by Warwick et al (1979) and Day and Wagner (1984) in Italy by Marino et al (1983) and in the United Kingdom by Cooper (1988). A more comprehensive literature review and an assessment of the comparative performance of the different techniques is given in Kennie and Edmonds (1987). In general terms the results obtained by previous workers in this field have been quite variable and further highlight the need for an investigation of the factors which influence the success of the different techniques.

Details of a current project to acquire multitemporal data over two test sites in southern England is presented in Section 4. The results of the preliminary interpretation of the imagery over these two sites, and an outline of some of the difficulties associated with the use of such data for two test sites for solution feature detection is presented in Section 5. The paper concludes by considering the benefits which may accrue from the use of a Geographical Information System (GIS) for the assessment of subsidence hazard in chalk regions.

## **2. TYPES OF SOLUTION FEATURES**

Surface and subsurface solution features develop in carbonate rocks as a result of dissolution caused by acidic surface and ground water; collectively known as karst. "Surface" karst features in a carbonate bedrock may also be reflected within any overlying superficial deposits. Thus solution-widened joints,

solution pipes, swallow holes and dolines ("sinkholes") can cause collapse features in the overburden. Subsurface karst features are developed deeper within the body of the carbonate bedrock and include both open and infilled solution pockets, cavities and cave systems.

Solution is the fundamental cause for the development of karst. However, it is subsidence, caused by the destabilisation of the infilling deposits or breakdown of a limestone roof to a cavity, which triggers the final collapse and causes damage to engineering structures.

The ambiguous and poorly defined terminology of karst provides one of the most difficult aspects of studying solution features as discussed by Edmonds (1983) and Beck (1984). In order to clarify the terminology, Figure 1 illustrates and defines schematically the range of terms used by the present authors to describe natural solution features that develop both within the carbonate bedrock and the overburden.

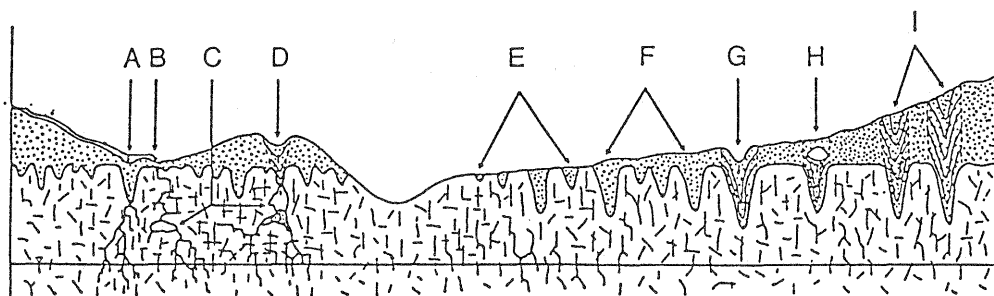


FIG.1. SCHEMATIC DIAGRAM TO ILLUSTRATE RANGE OF NATURAL SOLUTION FEATURES PRESENT ON LIMESTONE

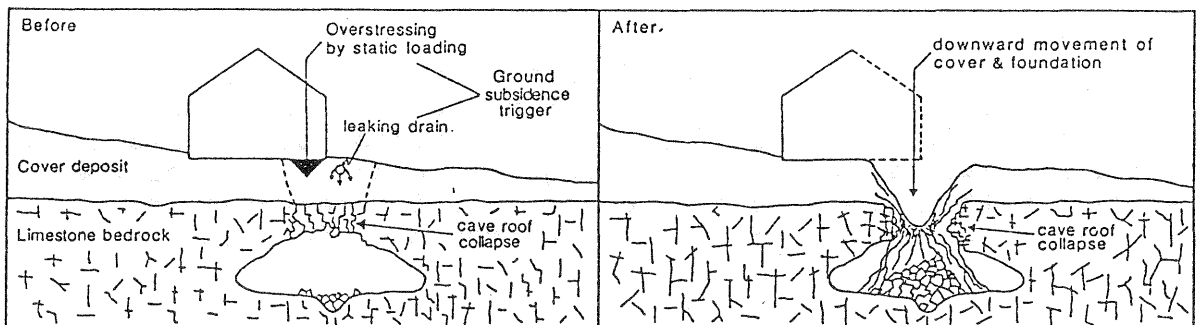
- A Swallowhole, downward percolation of ground water taking advantage of a pre-existing infilled solution pipe or solution widened joint.
- B Swallowhole, downward percolation of ground water taking advantage of solution enlarged joints in the limestone bedrock.
- C Solution cavity within the bedrock produced by phreatic and/or vadose dissolution.
- D Collapse doline, produced by collapse of a solution cavity roof and subsequent upward cavity migration to the surface.
- E Remnants of infilled solution widened joints or solution pipes just beyond the cover deposit outcrop margin.
- F Solution widened joints or solution pipes infilled with deposits that have undergone solution subsidence below a thin cover deposit.
- G Subsidence doline, produced by collapse of a metastable cavity within a cover deposit and subsequent upward cavity migration to the surface.
- H Metastable cavity formed during solution subsidence of cover deposits down into developing solution widened joints or solution pipes in the limestone rock.
- I Solution widened joints or solution pipes infilled with deposits that have undergone solution subsidence below a thick cover deposit.

### 3. GEOTECHNICAL PROBLEMS ASSOCIATED WITH SOLUTION FEATURES

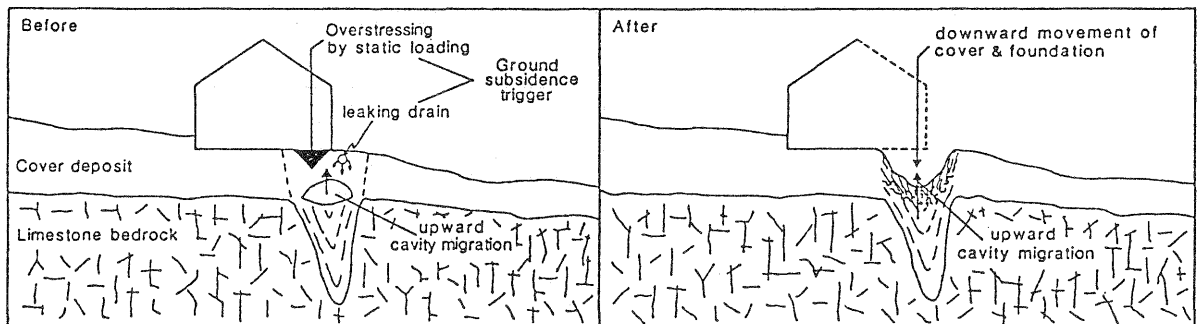
The metastable karst features caused by the dissolution of carbonate rock generally provide unreliable bearing capacity for foundations leading to partial or complete structural failure. The time dependent nature of karstic solution makes prediction of the hazard risk uncertain. Once failure has occurred, remedial measures such as grouting and underpinning can be undertaken but this can involve considerable expense. Occasionally severe or even catastrophic damage is suffered by the structure which necessitates demolition and of course there is also the inherent danger to the public because of the possibility of unexpected ground collapses. There is therefore an urgent need to more reliably assess the risk of solution feature development in carbonate areas.

FIGURE 2 Examples of foundation failure caused by induced dolines

Case 1 : induced collapse doline



Case 2 : induced subsidence doline



First, the areas that could potentially host active karstic development need to be identified. Then an assessment must be made of each of the possible trigger mechanisms. These include heavy rainstorms, water from leaking drains or pipes, artificial ground water lowering and both dynamic and static surface loading. Two examples which illustrate the potential effects of static surface loading and excessive concentrations of water drainage on the development of induced dolines are shown in Figure 2.

## 4. MULTITEMPORAL DATA ACQUISITION

### 4.1 Location of Test Sites

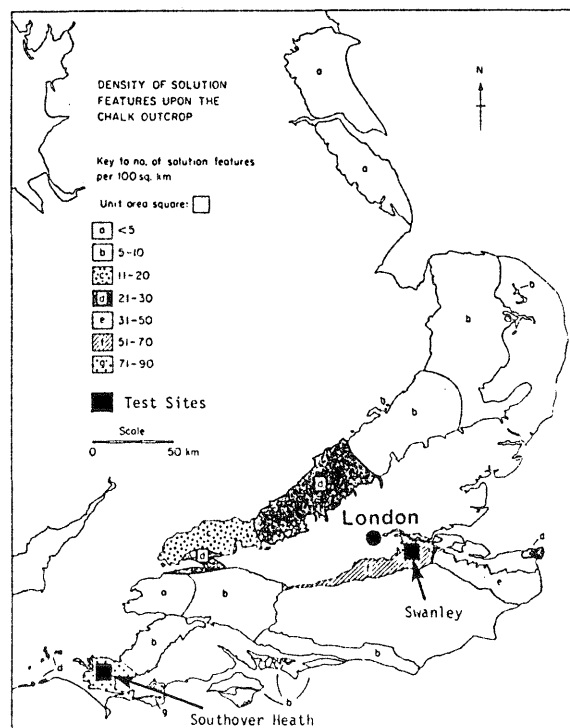
The first test site chosen for the project was located near Swanley, Kent; an area close to the highly populated and actively developing fringe around London. In this general area to the east of London, the Cretaceous Chalk limestone bedrock is overlain by a variety of Tertiary and Quaternary deposits. Beyond the London Clay margin these deposits are in many places disturbed by solution subsidence effects associated with the presence of solution features which have developed in the underlying Chalk.

The second test site was on Southover Heath, Dorset a rural area to the south west of London. Again, the Cretaceous Chalk limestone bedrock is overlain by Tertiary and Quaternary deposits. In particular the Palaeocene Reading beds are extensively piped into the underlying Chalk as are the high level fluvial gravels.

In the first site the solution features are predominantly solution pipes with no surface dolines being present. Evidence of solution features in this area was reported in the ground investigations carried out for the construction of the M25 London orbital motorway which passes through the central part of the test site. Within the second site the solution features are also predominantly solution pipes, although surface dolines are also present.

In order to examine the influence of seasonal and diurnal spectral variations on the response from solution features developed on the chalk or its overburden it was necessary that the data should be acquired on a multitemporal basis.

Figure 3  
Location of  
Test Sites



## 4.2 Data Acquisition

Ideally the data was required during spring, summer and autumn, and for each day before dawn and during mid morning and mid afternoon. This would ensure the sampling of a characteristic cross section of ground temperatures and general ground conditions. Poor weather conditions over the test sites somewhat reduced the multitemporal coverage that could be achieved in practice, and the data acquired is summarised in Table 1.

Table 1

Season (Date)	Site 1 Southover Heath, Dorset	Site 2 Swanley, Kent
<u>Spring</u> (28th April, 1986)	None acquired	11:30
<u>Summer</u> (17th July, 1986)	08:45	09:30
<u>Autumn</u> (19th September, 1986) (20th September, 1986)	09:20 16:00	None acquired 13:30

## **5. ASSESSMENT OF THE SUCCESS OF AIRBORNE REMOTE SENSING TECHNIQUES**

### 5.1 General Observations

Preliminary visual analysis of selected sub scenes of the airborne remote sensing data (comprising aerial photography, MSS and thermal IR linescanning) has enabled the following general conclusions to be reached:

(1) solution features with a surface expression (Figure 1, Case D and G) were generally detectable in all geological situations, both upon bare chalk surfaces and where a superficial deposit was present. The main problem which arose in these circumstances was the problem of discriminating between natural ground subsidence and artificially created features,

(2) most infilled solution pipes which were detected occurred either on bare chalk surfaces just beyond a superficial deposit margin (Figure 1, Case E), or along the margin of superficial deposits (Figure 1, Case F). Where superficial deposits thickened to more than 2 to 3 metres such features

were rarely detected (Figure 1, Case I). Also, where solution pipes contained metastable infills (Figure 1, Case H), and the materials above the cavities were undisturbed, detection was generally not possible due to the lack of contrast in physical properties. However, the fact that in many cases solution features, both with and without, surface expression were able to be detected indicates the potential benefit of the technique to planners and engineering geologists.

Clearly, in terms of spatial resolution, it is important to ensure that the features under investigation are at least equivalent to the IFOV (Instantaneous Field of View) of the sensor if direct detection is to be successful. Furthermore, in practice the feature should normally be at least two to three times the IFOV to allow for the detection of low contrast features.

## 5.2 Aerial Photography

Two periods were identified as being significant when using panchromatic aerial photography for the detection of solution features. Diurnally, the optimum period for detection was generally found to be when solar reflectance was at a maximum. This avoids the hours when long shadows occur that would otherwise obscure significant tonal patterns. Nevertheless, photography taken at low sun angles may also be beneficial since it enhances the surface expression of ground subsidence features. Seasonally, in temperate climatic zones such as the UK, early Autumn following prolonged dry weather appears to provide the best contrast for the detection of infilled solution features which have no surface expression.

## 5.3 Thermal IR and MSS Imagery

The spectral resolution of the sensor is clearly of greatest importance when indirect criteria such as stressed vegetation or soil moisture variations are being used to infer the presence of a solution feature. In addition the multitemporal response from a solution feature can have a critical effect on its detection. This is particularly important if thermal IR data is being used since the diurnal ground temperature variation may easily exceed the size of the anomaly associated with, for example, moisture variations in the vicinity of a solution feature. Pre-dawn has tended to be the preferred period for such data acquisition, primarily because the effects of direct solar radiation are at a minimum. Lynn (1986), however, has suggested that the maximum diurnal temperature range and the greatest thermal variation between different soils and surface materials occurs during mid-morning and after local noon, supporting the case for obtaining daytime imagery. An assessment of the validity of the conclusions from this work is currently being investigated in order to determine the optimum time period for data acquisition.

The investigations to date suggest that thermal imagery acquired in the early to mid-morning period is superior to that acquired

during mid-afternoon. However, the inability to acquire imagery during the pre-dawn period limits the extent to which this can be specified as the optimum period for data acquisition. Seasonally the current work indicates that Autumn is the preferred period for acquiring thermal data. Further work is required with the MSS data to assess the value of different band combinations for solution feature detection. It is proposed to examine the potential use of the optimum index factor as applied to airborne MSS data acquired in the UK by Greenbaum (1987).

#### 5.4 Limitations and Practical Detection Difficulties

A number of practical detection problems have been encountered which could severely limit the usefulness of airborne remote sensing for this type of application. Among the more significant are:

- (1) masking of areas of potential subsidence by heavy vegetation and areas of woodland,
- (2) the effect of shadows cast along the boundaries of areas masking features of interest,
- (3) fields that have been ploughed for many successive years removing previously existing indications of solution features, and,
- (4) urban development which has also destroyed tonal patterns associated with the presence of solution features.

Other problems can arise when attempting to identify and classify the type of feature which can be detected on the images. For solution features which have no surface expression, it is necessary to be cautious of other anomalous ground tonal patterns such as those caused by archaeological remains and agricultural crop watering patterns.

One particularly difficult feature to interpret is a surface depression. On the Chalk outcrop of southern England there are numerous man-made surface depressions which have been created by the mining or quarrying of chalk for application on fields to neutralise acid soils. After a period of deterioration these old workings frequently assume a similar appearance to a naturally formed doline. Thus the user of remote sensing imagery should appreciate that the surface morphology of an identified circular ground depression can, by itself, often be insufficient to infer its origin. Other forms of spatial distribution analysis should help to discriminate between the presence of natural or artificial features. In the end, however, final proof of the origin of a potential solution feature can only be confirmed by direct ground investigation such as drilling a borehole or excavating a trial pit through the feature.

#### **6. CONCLUSIONS AND FUTURE WORK**

Soluble carbonate rocks outcrop in many parts of the world and karst processes have resulted in the formation of a variety of solution features. Certain forms of solution feature are



metastable and can give rise to ground subsidence problems. Airborne remote sensing is recommended as a technique to be used at, or immediately after, the desk study stage of a site investigation. An assessment of the various remote sensing techniques indicates that aerial photography should generally be the first source of data to be used for the detection of solution features which have a surface expression. However, where it is necessary to use indirect evidence in order to infer the presence of solution features, it is suggested that airborne thermal IR and MSS imagery should be used to supplement the aerial photography. Indeed, thermal IR and MSS imagery are particularly helpful in detecting material responses of the ground to underlying karstic features where there is an absence of a surface topographic expression.

Several difficulties have been identified which can restrict the use of airborne remote sensing techniques, including the problem of determining the optimum conditions for obtaining imagery. Some recommendations for acquiring data have been provided in the paper and future work will concentrate on the inter-band spectral correlation of the MSS datasets with a view to determining the optimum three-band combination.

For the future it is suggested that consideration should be given to using airborne remote sensing data more extensively as a component of a spatial subsidence hazard assessment model, such as that developed by Edmonds et al (1987). At present this particular form of hazard prediction is carried out manually, but the digital nature of the data lends itself to computer manipulation and it is suggested that the hazard prediction could be enhanced by using a Geographical Information System (GIS). This would effectively combine the spatial and spectral information from the remote sensing data with spatial data from existing map sources (topographic, geological etc.) and non-spatial sources of data (such as borehole information). At present a variety of database management systems are being considered together with methods of optimising the data interpretation (Rosenbaum, 1987) and methods of presenting the results.

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