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Ground investigation methods used in high-speed railway for mitigation of dissolution features risk in chalk

Méthodes d'études de sol utilisées dans les chemins de fer à grande vitesse pour atténuer le risque de dissolution dans la craie

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ABSTRACT: Chalk is known to have a potential risk for natural cavities (solution features) and documenting the location and nature of these geohazards is important to infrastructure projects. North Chilterns Area, one of the five projects within the HS2 Main Works Civils Contract, C23 includes cuttings, embankments and viaducts which will be designed and constructed in the formation of Chalk. The risk of presence of dissolution features in this area is high, either as infilled features near formation level in cuttings and embankments or void or infilled features, being present immediately below the toe of foundation piles, along their shafts, or below shallow footings. This paper discusses the risk from dissolution features for selected high-speed railway assets and presents the approach to investigate their presence based on various ground investigation methods, which were employed on the project. These include LiDAR surveys, surface geophysics (electromagnetic, electrical resistivity, microgravity surveys), intrusive ground investigation (boreholes, CPT probing), use of borehole cameras and downhole surveys. The limitations and advantages of these methods are discussed, highlighting the importance of the combined interpretation of ground investigation data to design appropriate mitigation works.

RÉSUMÉ: La craie est connue pour présenter un risque potentiel de présence de cavités naturelles (phénomènes de dissolution); ainsi, documenter l'emplacement et de la nature de ces aléas géologiques est important pour les projets d'infrastructure. La région de North Chilterns, l'un des cinq projets parmi le Contrat HS2 section C23, comprend des déblais, des remblais et des viaducs qui seront conçus et construits dans la craie. Le risque de présence d'éléments de dissolution dans cette zone est élevé, soit sous forme de cavités remplies près du niveau de formation dans les déblais et les remblais, soit sous forme de zones vides ou remplis, étant présentes immédiatement sous la base des pieux de fondation, le long de leur longueur, ou sous des semelles de foundation peu profondes. Cet article discute le risque de dissolution pour certains actifs de ligne de chemin de fer à grande vitesse et présente les démarches pour évaluer leur présence sur la base de diverses méthodes d'études de sol, qui ont été utilisées dans le cadre du projet. Il s'agit notamment des relevés LiDAR, de méthode géophysique de surface (relevés électromagnétiques, de résistivité électrique, de microgravité), d'études de sol intrusives (forages, sondages CPT), de l'utilisation de caméras de forage et de relevés géophysiques de fond. Les limites et les avantages de ces méthodes sont discutés, soulignant l'importance de l'interprétation combinée des données des diverses études de terrains pour soutenir la prise de décision et concevoir des travaux d'atténuation appropriés.

Keywords: Chalk; dissolution features; ground model; geohazard.

1 INTRODUCTION

The High Speed Two (HS2) project is a High-Speed Railway Line currently under construction in the UK. Phase 1 of HS2 runs between London and Birmingham across the English Midlands. This scope is part of the HS2 Main Works Civils Contract C23, awarded to Eiffage Keir Ferrovial Bam (EKFB) JV in partnership with the design JV of Arcadis Setec COWI (ASC). The North Chilterns Area (NCA) section covers an approximate length of 11km; of which approximately 8km is underlain by Chalk bedrock, namely Lewes Nodular Chalk, Holywell Nodular Chalk, New Pit

Chalk, Zig Zag Chalk and West Melbury Marly Chalk. This section of the route is the subject of this paper, as the chalk bedrock has an inherent risk of dissolution features and chalk mining features. These features present a risk to the project and require a strategic and coordinated approach to investigation, risk assessment and treatment.

2 GEOLOGICAL CONTEXT

Dissolution features are a common geohazard in karst geology and occur when slightly acidic rainwater is allowed to infiltrate into calcium carbonate rich bedrock, such as chalk. Features may occur in a variety of forms, as illustrated in Figure 1.

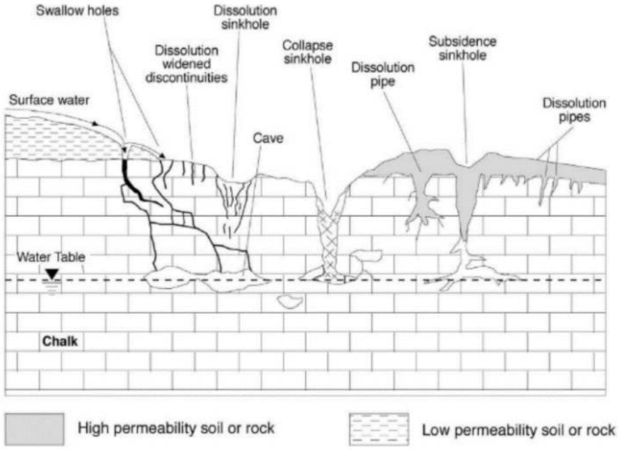

Figure 1. Schematic cross-section of common dissolution feature types (Lord et al, 2002).

Typically, these dissolution features present themselves as localised undulations in the bedrock profile at the interface of the chalk, which are infilled by loose superficial materials. Across the NCA section of the route, these superficial materials generally comprise cohesive Head deposits or Clay with flints.

Risk also exists associated with chalk mining. Historically, chalk was mined and used for spreading on heavy clays or in agricultural lime production, therefore the risk of chalk mines is particularly prevalent in areas where clay overburden is present, which covers most of the study area. It should be noted however in the works undertaken to date that chalk mining features have not been identified across the NCA route.

3 GROUND INVESTIGATION STRATEGY

3.1 Detailed design investigations

An initial phase of ground investigation works was undertaken across the NCA package as part of the detailed design phase. This generally included a suite of boreholes, CPTs and trial pits. As these were undertaken as part of the detailed design, they were not specifically targeted to investigate potential dissolution features. It was determined that these investigations should be undertaken as part of the construction programme to expedite the design works and subsequent approval processes.

However, as part of the detailed design investigation works, a preliminary programme of surface geophysics was undertaken. This comprised microgravity, electromagnetic and electrical resistivity surveys and covered approximately 52% of the total development footprint. The purpose of these works was to inform a preliminary qualitative assessment of the possible extent of dissolution features at each asset, in order that the targeted investigation works during the construction phase could be undertaken.

3.2 Dissolution features investigations

Given the risk of dissolution features extends over an area approximately 8km long, careful planning was required to optimise the ground investigations. This was particularly relevant to ensure best value was obtained from intrusive investigations. A phased approach was adopted utilising ground profiling and geophysics in advance of committing to intrusive investigations. The general phasing and rationale is summarised in Table 1.

Table 1. Summary of ground investigation phases.

Stage No.	Technique (s)	Rationale
1	Phase 1 Geophysics and LiDAR	Preliminary qualitative assessment of risk per asset
2	Phase 2 Geophysics	100% earthworks footprint coverage to identify anomalies for targeted intrusive GI
3	Dynamic probing / boreholes	‘Ground truthing’ of geophysical anomalies to identify features of concern.

3.3 Geophysical Surveys

The success of surface geophysics across this alignment was aided by the characteristics of the land; as this was largely open pasture uninterrupted by significant development and/or services, these works have yielded generally good results.

Three key geophysical techniques have been adopted. Electromagnetic and electrical resistivity surveys were utilised; these are generally reliable to 3-4mbgl and are therefore most useful in areas of shallow overburden. The focus of the geophysical works was microgravity surveying which is generally reliable to 20-25mbgl and can therefore identify most features of concern; this technique was specified to cover 100% of the development footprint.

The results of the geophysical surveys were reviewed to identify areas where the results indicate a varying response of the surrounding ground (Figure 2).

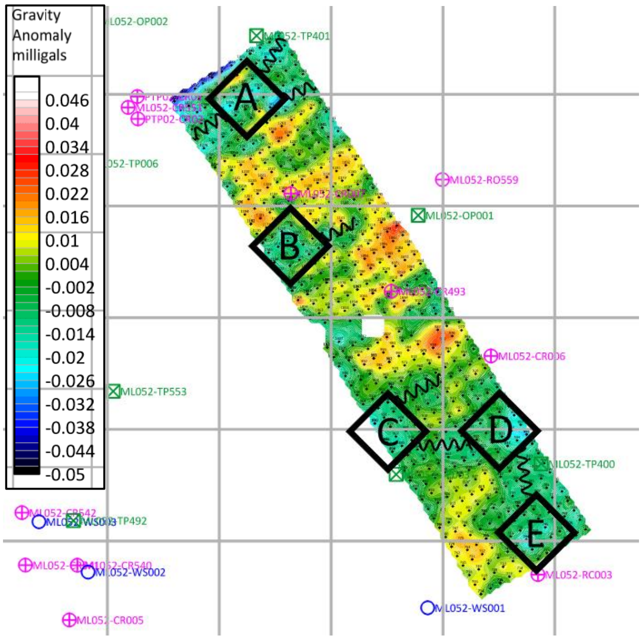

Figure 2. Interpreted microgravity results showing features of concern.

3.4 Targeted intrusive investigations

Where features of concern were identified from the Phase 2 geophysical surveys, intrusive investigations were scoped and targeted to these features as a means of 'ground truthing' the anomalies.

The intrusive investigations comprised a linear array of 9no. dynamic probing positions spanning the direction of the perceived feature of concern at 1.5m centres. The purpose of these was to identify perceived changes in in-situ density at the interface of the chalk materials that may indicate a possible dissolution feature. Following this, a rotary open-holed borehole with down-hole televiewer was targeted adjacent to the dynamic probing positions to confirm the geological interpretation of the probing results. An example of the distribution of these positions is presented in Figure 3.

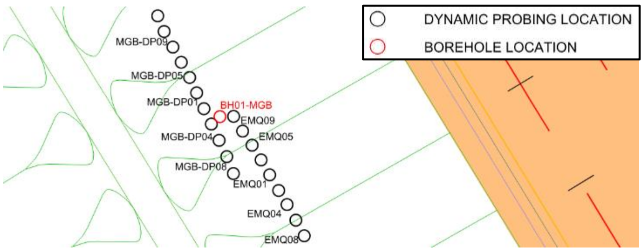

Figure 3. Distribution of intrusive GI at feature 'MG-B / EM-Q'

3.5 Interpretation of results

A review of the findings of the intrusive works was undertaken to assess the features of concern. The stratigraphy determined from the detailed design investigation was firstly superimposed onto the dynamic probing logs to determine the chalk interface profile/level. The probing results were then reviewed to identify zones of low blow counts, which was defined as three or more consecutive results with blow counts between 0-3.

An analysis of the data showed that between 15-25% of the geophysical anomalies could be correlated to solution features; the others could be attributed to other geological reasons including naturally occurring loose zones or localised boulders within the superficial deposits. The overriding principal of the interpretation of these results was to 'prove the negative', i.e., where a feature could not be proven, some interpretation had to be provided as to why the geophysical anomaly was recorded. This analysis fed into a feedback loop with the geophysics review to refine these assessments for each subsequent asset.

Following initial interpretation of the dynamic probing logs, a rotary-open holed borehole with down-hole televiewer was scheduled adjacent to these positions to allow a visual assessment of the chalk and verify the ground model assumptions (see Figure 4).

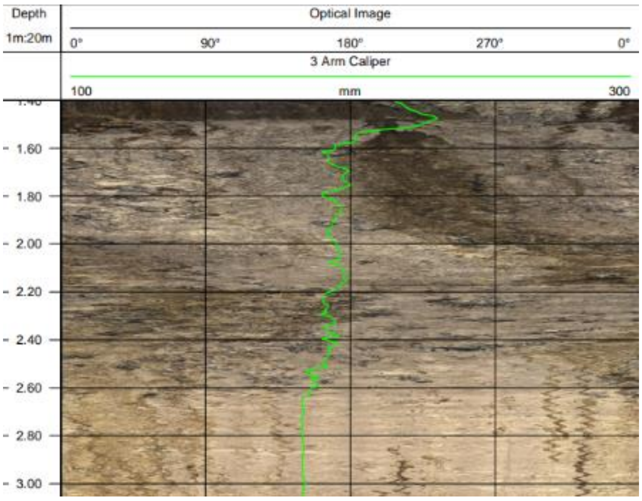

Figure 4. Extract from televiewer log from feature 'MG-B / EM-Q' showing overburden/chalk interface.

An example of an interpreted row of dynamic probing logs for feature 'MG-B' is presented in Figure 5. Characteristically, each of the perceived features identified a zone of low blow counts at chalk interface. Also apparent was a shallower zone of low blow counts within the superficial materials; interpreted as propagated loose material above the feature at an approximate draw angle of ~45-60° away from the edge of the feature.

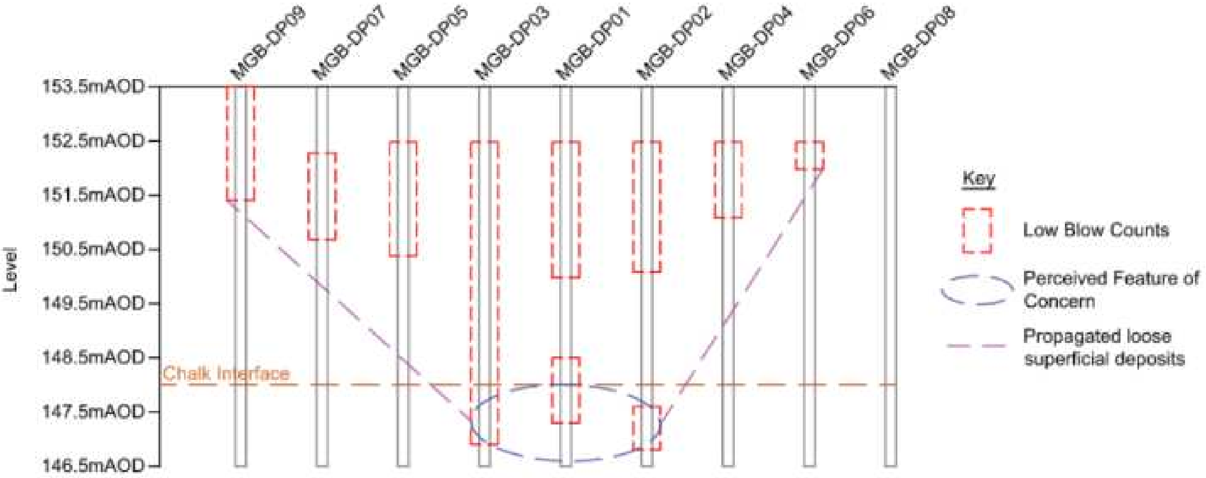

Figure 5. Interpretation of dynamic probing results at feature 'MG-B'.

3.6 Investigation strategy per asset type

The investigation strategy and sequence detailed in the foregoing sections describes the process adopted for earthworks assets (i.e., embankments and cuttings), with Small Dean South Embankment being used as a case study. These earthworks assets account for the majority of the development; however a number of structural assets including viaducts and underbridges are present across the alignment which have adopted a slightly different investigation approach.

The investigation requirements for each structural asset have been determined on an individual basis. To use Small Dean Viaduct as an example, it was determined that due to the relatively small footprint of the abutment foundations as well as significant programme constraints at this asset, Phase 2 geophysical works were replaced with an array of dynamic probes at 1.5m centres across the abutment footprints. The advantage of this approach was that the programme was expedited. No features of concern were identified from these works.

4 RISK ASSESSMENT AND TREATMENT

Where features of concern were identified by investigation, a risk assessment was undertaken to determine if treatment was required. The strategy determined that features were only deemed to require treatment where they were below the high-speed railway or were within the support zone for earthworks/foundations.

4.1 Rock cover ratio assessment

An initial risk assessment was undertaken on features of concern to determine if a suitable rock cover thickness was present above the feature so as to not present a risk to the development. This used a modified version of guidance for treatment of coal mine workings (R.J Piggot and P. Eynon, 1978). For the purposes of the risk assessment, Class 1A1 granular materials to be filled as part of 'excavate and replace' at the formation of earthworks assets were considered to contribute to this competent cover thickness, given the stringent control over the parameters of the placed materials.

As part of this risk assessment process, it was identified that a zone of uncertainty existed between the depth range of geophysical surveys and the depth of features considered to be tolerable within the design. This was particularly relevant to features relating to historic chalk mining (i.e., deeper than the chalk interface level) and is illustrated in Figure 6. This inherently led to some residual risk in the assessment.

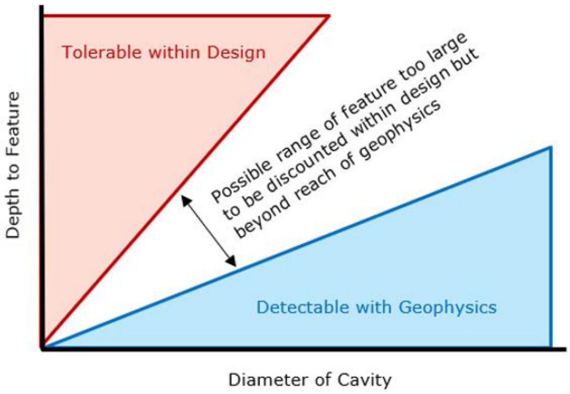

Figure 6. Schematic relationship between feature size and geophysics range.

The rock cover assessment method shown in Figure 7 utilised existing studies regarding collapse mechanisms in chalk (Z.E. Jeffrey et al, 2020, C.N. Edmonds, 2008, T. Waltham, 2008). The relationship was developed considering a conical failure mechanism for chalk grades A-D.

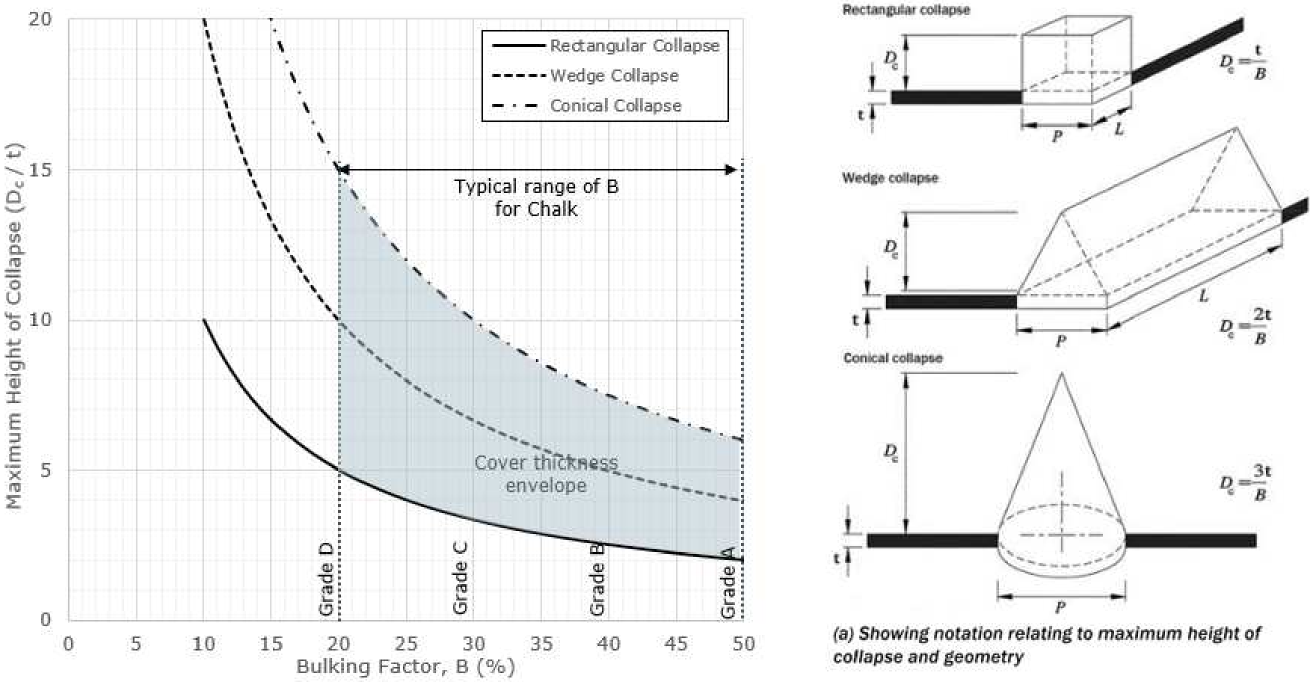

Figure 7. Modified cover assessment method for chalk grades A-D (after Piggot and Eynon, 1978).

This assessment model gives relationships for the cover thickness for each chalk grade, as summarised below:

$$Grade\ A = 6t \quad (1)$$

$$Grade\ B = 7.5t \quad (2)$$

$$Grade\ C = 10t \quad (3)$$

$$Grade\ D = 15t \quad (4)$$

Where *t* is the ratio of feature size versus the thickness (m) of competent cover materials above.

4.2 Treatment Options Hierarchy

Within the overarching strategy, a hierarchy of treatment options was developed between the designer and the contractor which informed the extent of the ground investigations required (see Table 2).

Where the depth to the base of the feature was sufficiently shallow (≈6m below earthworks formation level), the excavate and replace solution was seen as the preferred option, as by nature, this could be implemented under a semi-observational approach. This could therefore minimise the scope of intrusive ground investigations as the extents of the feature could be confirmed during treatment.

Grouting techniques were considered to be less effective at shallow depth due to the complexity of the method in comparison to excavation and replacement. For treatment to depths greater than 6m, grouting would be considered on a case-by-case basis considering the need for additional investigation works and regulatory requirements.

Table 2. Hierarchy of treatment solutions.

Solution	Programme	Cost	Residual Risk
1. Sufficient cover – no physical treatment	Very low	Very low	Low
2. Excavate & Replace using Class 1A1 fill / concrete plug	Low	Moderate	Very Low
3. Drill and Grout (cavity infill) or compaction grouting	High	Moderate / High	Low
4. Spanning / bridging solutions	Low	Low	Moderate

5 TREATMENT IMPLEMENTATION

To illustrate the application of the investigation, risk assessment and treatment strategy detailed within this paper, the implementation of the site works at Small Dean South Embankment is discussed below.

Within the first 500m of the asset, 3no. features of concern were identified, each at the interface of the chalk deposits. Of these, one was situated outside of the support zone for the high-speed railway and embankment therefore did not require treatment. The two remaining features ('MG-B / EM-Q' and 'EM-S') required treatment by excavate and replace.

Figure 8 below shows the excavation to the base of the feature at 'EM-S'. The depth and extent of the feature extended far beyond what was anticipated. It was therefore concluded that the intrusive investigation works at 'EM-S' identified only the outer edge of the feature. This further reinforced the benefit of implementing the excavate and replace under a semi-observational approach. For 'MG-B / EM-Q', the extent of the feature correlated well to the interpretation of the dynamic probing results.

Figure 8. Excavation to base of feature at 'EM-S'.

As part of the backfilling of the feature, a concrete plug was installed at the approximate interface of the natural chalk level. This was to provide an impermeable interface to prevent further long-term deterioration of the chalk, bearing in mind that the mechanism for the initial creation of these features is through infiltration of slightly acidic rainwater. The installation of this concrete plug is shown in Figure 9.

Figure 9. Installation of concrete plug at 'EM-S'.

6 CONCLUSIONS

This paper discusses the approach to the ground investigation, risk assessment and treatment of chalk dissolution features covering an approximate length of 8km of high-speed rail development.

Given the extensive area within which these geohazards exist, the systematic phasing of investigations, firstly comprising geophysics then including targeted intrusive works, has allowed the risk to be effectively managed whilst optimising the extent of the intrusive investigations and programme.

The development of a treatment options hierarchy and tailoring of the investigation strategy per asset type (i.e., cutting / embankment / structure) has further allowed optimisation of the investigation scope. Further, the implementation of excavate and replace earthworks solutions under a semi-observational approach for earthworks assets has allowed the scope of intrusive investigations to be reduced significantly.

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