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A Strategy for Managing Uncertainty in Ground Conditions

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Abstract

To support the efficient delivery of the C23 contract of HS2 Phase 1 and to achieve resilience in design, an overarching strategy for managing uncertainty in ground conditions has been developed by the integrated project team for the design and construction activities of the main civil engineering works for an 80km section of the new railway. This strategy is underpinned by a design basis statement known as SMUG developed by the design joint venture with the support of the C23 Integrated Project Team to ensure consistent implementation of the strategy within the design across the entire design team. The design basis statement provides a robust and clear framework for assessing and communicating the uncertainty in ground conditions of any given asset at the start of the detailed design. This knowledge of the ground evolves through each step in the design process recognising it is a dynamic assessment that can improve or worsen as design proceeds and further information becomes available.

The design basis document provides details of how to collaboratively develop the permanent works design while managing the ground risk in accordance with HS2's requirements and industry best practice. It provides a clear understanding and common language when discussing ground risk as an integrated project team, based around the core objectives of ensuring effective communication, enabling informed decisions, and agreeing mitigation actions including prioritisation of the ground investigation programme. It establishes a new industry standard on how uncertainty in ground conditions can be collaboratively assessed, managed, and communicated in large and complex infrastructure projects where GI reliance information is incomplete or delayed.

The adoption of this approach has enabled effective delivery of work packages for C23 impacted by delays in ground investigation delivery arising from constraints to land access and the availability of ground investigation resources as well as project challenges including the COVID pandemic. This focusses on protecting the design and construction programme whilst providing an improved understanding across all parties in relation to joint decision making to ensure assets are designed with an appropriate level of resilience.

Keywords: Ground Risk, Managing Uncertainty, Design and Construction, Framework, Collaboration

1. Introduction

High Speed 2 (HS2) is planned as part of the UK's national high-speed rail network for which Phase 1 involves construction of a new railway line of approximately 230km between London and the West Midlands. The Phase 1 route has been divided into three delivery areas which have been further sub-divided into a series of main works civils contracts. Within Phase 1 Contract C23, the Contractor, comprising an Eiffage, Kier, Ferrovial, and BAM Nuttall joint venture (EKFB), has appointed the Designer, comprising an Arcadis, Setec, COWI joint venture (ASC) to provide detailed design services for the civil engineering assets. The C23 contract represents approximately 80km of new railway line together with extensive associated engineering and environmental infrastructure.

This paper presents details of the management framework developed to address design related issues associated with incomplete or delayed ground investigation reliance information and the associated uncertainty in ground conditions with specific reference to C23. This aims to deliver resilience in the design to describe the robustness necessary to deliver high-speed railway infrastructure suitable for the design life. In this context the framework evolved to account for the additional complexity of delays to ground investigation arising from the COVID pandemic and considered a number of options in relation to mitigating the risks of proceeding with detailed design whilst managing the potential risks to the project. The resulting management structure that has been developed provides a new industry standard for how uncertainty in ground conditions can be collaboratively and transparently assessed, managed, and communicated in large and complex infrastructure projects where GI reliance information is incomplete or delayed.

1.1 Background and Need for Design Basis

As part of the contractual requirements, HS2 Limited set out obligations in relation to understanding and managing uncertainty in the physical conditions, ground investigations and condition surveys and to meet these obligations the contractor prepared a general Strategy document on Managing Uncertainty in Ground Conditions (SMUGC) to support delivery of design and construction activities.

Whilst contemporary industry guidance on the management of geotechnical risk (e.g., BS EN 1997 and CD 622) provides clear direction for establishing the principles of managing geotechnical risk based around hazard identification and risk assessment, there is little guidance in respect of a framework or processes to recognise the impact that uncertainty in ground conditions can have on the timely and cost-effective delivery of resilient design for construction. As such the Designer led the collaborative input to a design basis statement, referred to as the SMUG, detailing how the design teams would approach the management of ground risk in accordance with project requirements, the IPT strategy, and industry best practice.

The strategy and corresponding SMUG design basis document were developed in recognition of the size of the C23 project and the corresponding scale and timetable for delivery of ground investigation information relative to the detailed design programme extending over two years and being undertaken concurrently with the construction programme. The DBS was developed to provide information to the permanent works design teams on how uncertainty in ground conditions should be assessed, managed, and communicated as part of the detailed design and construction. It also provides details on risk mitigation actions to be deployed which may be adopted by the Designer in developing asset specific details or implementation plans.

1.2 Purpose and Objectives

The C23 Main Works Civils Contract was progressed in two stages, Stage 1 Scheme Design and Advanced Detailed Design, and Stage 2 Detailed Design and Construction. HS2 provided data from an extensive preliminary ground investigation at the commencement of Stage 1 with a recognition that more detailed investigation would be required to fully inform detailed design. As part of the development of the proposals for Stage 2 a gap analysis was undertaken on the ground investigation available at the commencement of Stage 1 with a scope of supplementary GI proposed to manage the uncertainty in ground conditions at the detailed design stage. As a result of a number of site constraints, the iterative nature of the investigation process, and the timescales of Stage 1, it became clear that the full scope of the Stage 2 Ground Investigation could not be delivered in advance of the commencement of detailed design.

The underlying principle of the SMUG strategy is to accept that risk associated with uncertainty can be mitigated through resilience in the design as well as the acquisition of additional data. The approach is to close out significant ground related assumptions contained within the compliance requirements for design and handover, by reference to a clearly defined level of knowledge about the potential uncertainty in the ground conditions and the application of a suitable degree of resilience in the resulting design. To achieve this the framework needed to provide a clear understanding and common language between design teams, engineering managers, construction teams and client when discussing and agreeing risk mitigation within the integrated project team.

In establishing the framework to satisfy this overarching purpose, a series of core objectives were identified as part of the design and construction process which were to enable;

- Clear and transparent communication between all parties to allow a rapid understanding of the uncertainty in ground conditions and impact on design decisions
- Informed decisions to be made on how to proceed with detailed design and assurance and agree mitigation actions to reduce the risk of change due to uncertainty in ground conditions
- Prioritisation of ground investigation programme to target locations of highest uncertainty associated risk

From these objectives the framework was developed to provide guidance around four key components which reflect the process of design development and integration into the construction delivery programme;

- Assessment of initial Uncertainty in Ground Conditions
- Ground Investigation Prioritisation
- Managing the potential impact of Uncertainty on Ground Conditions
- Managing the impact of New GI Data during the design process

The approach to addressing these four components is outlined in the following sections of this paper.

2. Assessment of Uncertainty in Ground Conditions (SMUG Classification System)

Underpinning the overall strategy is a classification of uncertainty in ground conditions which has been developed to support communication between the various organisations in the project. The assessment framework is set out in Figure 1 and establishes a five-level categorisation of confidence in the ground conditions with particular reference to the level of uncertainty or anticipated risk of change to the design that may result from further ground investigation or field trials (collectively "GI"). This framework is based on the phased approach to design development for HS2 leading from the Scheme Design established to enable notice to proceed through to the Detailed Design although would be equally applicable to other phasing of design development from preliminary / concept / basic design through to the design for construction.

Class	Description
1	Sufficient GI currently available to support: • Optimisations and Efficiencies requiring additional GI • Development of the Scheme Design into Detailed Design • Alignment with EC7 guidance • Management of ground risk No further GI has been scoped for this asset. **Very low risk** of change to design during construction when proceeding using a reasonably cautious approach in line with EC7
2	Sufficient GI currently available to support: • Development of the Scheme Design into Detailed Design compliance • Alignment with EC7 guidance • Management of ground risk Further GI may be scoped to support further optimisation. **Low risk** of change to design on receipt of GI and during construction when proceeding using a reasonably cautious approach in line with EC7.
3	Insufficient GI currently available to support: • Detailed Design • Alignment with EC7 guidance Further GI has been scoped for this asset to support design and close out the management of ground risk. Considered to be **medium risk** of change following receipt of further GI data when proceeding on developing the scheme design into detailed design using a cautious approach in line with EC7.
4	Insufficient GI currently available to support: • Detailed Design • Alignment with EC7 guidance Further GI has been scoped for this asset to support design and the management of ground risk. Considered to be **high risk** of change following receipt of further GI data when proceeding on developing the scheme design into detailed design.
5	Insufficient GI currently available to support: • Development of a Geotechnical Model Further GI has been scoped for this asset to support detailed design and management of ground risk. Considered to be **very high risk** of change following receipt of further GI data.

Figure 1: Uncertainty Classification System.

In determining the uncertainty in the ground conditions class and assessing the potential for change, consideration needs to be given to several key components and the robustness of the associated design and construction assumptions:

- Ground model (stratigraphy / layer thickness etc.)
- Material parameters (strength / stiffness / permeability etc.)
- Presumed behaviour (pile shaft resistance, ground softening, running sands etc.)

- Groundwater (levels, flows, recharge)
- Features (extent / size / distribution of dissolution features, depth of relic shear surfaces, fault zones, etc.)

The classification for a particular component of design needs to be assessed by reference to the specific design scenario(s) being considered and in particular the sensitivity of the element to potential geohazards in line with the guidance in EC7. In this context the SMUG classification should be both ground conditions specific and asset specific, i.e., while the same GI data may be used to design the foundations of an overbridge and the foundations of the associated earthworks, this GI data may receive different SMUG classifications for the different assets within the design package.

Moreover, these components need to be assessed against knowledge of the wider geological and ground engineering setting reflecting an understanding of the likely variability of the ground and processes which have acted upon it from geological history to anthropogenic changes. Correspondingly the assessment of uncertainty in ground conditions is based on the presumption that construction supervision, inspection and control will be undertaken in accordance with Eurocode 7 and as specified from the design in the GDR.

3. Ground Investigation Prioritisation

Delays in achieving sufficient ground investigation and field trials to enable the detailed design process to be completed to deliver an efficient and safe design can present a significant risk to the design and construction programme. Therefore, all parties worked collectively towards the completion of sufficient GI in advance of commencement of detailed design for a given asset to support a proactive management of uncertainty in ground conditions. Priority locations were identified to align the GI programme with the detailed design programme as far as reasonably practicable, and hence minimise the potential for change where the contractor chooses to proceed with design in the absence of a complete scope of GI.

The prioritisation of the ground investigation for design and construction was undertaken at the beginning of the detailed design phase based around the principles of the overall SMUG classification of the assessment set out above, taking into account the level of uncertainty and the potential impact on the cost, and design and construction programme. This is supplemented at regular intervals though the GI programme with further prioritisation carried out on a case-by-case basis through individual workshops to reflect particular constraints to access and delivery of the ground investigation.

4. Management of uncertainty within the design

The SMUG classification system dictates that design packages assessed as either Class 1 or 2 are a prerequisite to allow development of the detailed design without reliance on further ground investigation. These classifications enable detailed design to progress without the need for additional GI and with no additional resilience incorporated into the detailed design. However, it is recognised that there would be instances where a limited extent of GI information would be available at the planned commencement of detailed design and an asset may therefore be categorised in Class 3 to 5. These classifications are associated with an elevated risk of proceeding to develop the design without sufficient GI to fully characterise the ground conditions and represent a design situation where design cannot necessarily be developed such that is capable of being fully assured.

Class 3 recognises that there is a reasonable understanding of the conditions that may allow design to progress but that some additional measure will be required during detailed design to mitigate the uncertainty if further GI is not provided to amend the classification. Class 4 provides clear indication that there is very significant risk in commencing design without further GI data while Class 5 essentially indicate that design should not progress without some additional data.

Where an asset is not categorised as Class 1 or 2, then the design team would engage with the IPT to notify the project of the risks associated with proceeding with design. As part of the risk reduction process, the IPT can then agree how the identified risks will be mitigated by the affected parties with possible mitigation options to manage the potential risks to the project and enable the commencement of detailed design categorised into three broad options:

1. Delay design to allow the specified GI to be completed
2. Proceed with developing an efficient design using a cautious estimate of the characteristic values/ground conditions carrying an elevated risk of change when the GI is received.

3. Proceed with developing a less efficient design using a more pessimistic (conservative) estimate of the characteristic values/ground conditions with the aim of reducing the risk of change when GI is received.

The uncertainty classification and potential mitigation options were developed to provide a consistent platform for the designer and engineering management team to discuss the details of the risks specific to each asset with the contractor and HS2 and agree a mitigation option. This is intended to be a collective decision to proceed with design, recognising the need to review additional GI results once received to validate design assumptions.

These primary options were further developed as it became apparent that there were ongoing challenges to delivery of the GI in time for finalisation of the detailed design to enable technical assurance of the design in advance of construction. The need to adapt and evolve the strategy to reflect these challenges led to the development of several additional options to mitigate the late delivery of GI. These form subcategories to the original mitigation options and are set out in Figure 2.

Option	Option Description	Design Approach adopted at commencement of design	Options for Route to Design Assurance
1	Postpone detailed design and construction to allow the proposed GI to be completed.	An efficient design can be developed using a cautious estimate of the characteristic values/conditions governing a limit state based on the completed GI information.	Proceed through IDR and L3 with validated design
2	Where an asset is programme critical, proceed with Detailed Design with limited GI information.	An efficient design can be developed using a cautious estimate of the characteristic values/conditions governing a limit state based on limited GI information available.	Outstanding GI reviewed, and design updated prior to IDR.
2A			Proceed through IDR and L3 based on a limited scope of GI with no change to the design (i.e., no increase in robustness to account for uncertainty)
2B			Proceed through IDR and L3 with design elements placed into abeyance (clouded) where the outstanding GI is required to support the design.
2C			Adjust the design to be more cautious and rely upon the existing limited scope of GI.
3	Where an asset is programme critical, proceed with Detailed Design with limited GI information.	A less efficient design can be developed using a more pessimistic, cautious estimate of the characteristic values/conditions governing a limit state based on the limited GI information. It may be possible to review and reduce the proposed scope of GI as a requirement to validate the design. However, the ability to further optimise on the scheme design solution is likely to be removed and additional robustness included.	Outstanding GI reviewed, and design updated prior to IDR.
3A			Proceed to L3 based on a limited scope of GI with no change to the design (i.e., no increase in robustness to account for the increased uncertainty)
3B			Proceed to L3 with selected design elements placed into abeyance (clouded) where the outstanding GI is required to support the design.
3C			Adjust the design to be more cautious to address the uncertainty in ground conditions and rely upon the existing limited scope of GI.

Figure 2: Options for managing change due to uncertainty in ground conditions.

The figure sets out the additional sub-options available to achieve acceptance of the design, based around;

- Placing in abeyance items excluded from assurance to be confirmed on later receipt of GI where the element can be finalised within an agreed range of outcomes without impacting adjacent components
- Adjusting the current detailed design to allow for the current understanding of the uncertainty and potential risk of variation in ground conditions, which may require a more conservative design

The application of these sub-options as mitigation would only generally be applied after the commencement of detailed design reflecting the need for a reasonable level of design maturity to assess reliably but recognising the need to provide sufficient time in advance of the final design review (Interdisciplinary Design Review (IDR)) and the subsequent Technical Assurance Certification Level 3 Assurance (L3) process to allow any mitigation actions to be completed. This is typically identified to be between 50% and 75% detailed design reviews.

The anticipated applicability to an uncertainty class and the implications on design, assurance, and construction of adopting one of these mitigation options has been further developed into an appendix to the framework document which highlights the challenges to the design process and also the additional gateways in respect of hold points that need to be provided for in the design and construction programme to achieve implementation.

In particular, the approach of placing elements of the design in abeyance would only be contemplated for elements of assets with a low or medium consequence on design integration where the IDR meeting should address how items clouded would be managed through the construction stage change process with updates to design deliverables and assurance documentation as necessary. Examples of these elements in relation to design integration include pile lengths governed by bearing requirements (i.e., not lateral stiffness) or foundation treatment beneath an embankment with no immediate site constraints impacting temporary works.

The update to the framework introduced a number of key principles around achieving technical assurance certification - "the route to L3", i.e., the mechanism for enabling release of issue for construction drawings and specifications to allow site works to commence, and the need to recognise an elevated design risk that may require construction stage control measures to manage. As a consequence, a "route to L3 assessment" is prepared by each of the design teams to define the available mitigation options that may be applied for a given design package. To support this process a central engineering panel has been established within the design team to provide guidance and review consistency of the application of the mitigation options to ensure that;

- Implementation of the SMUG is consistent across all package teams
- The classification of individual assets considered the overall strategic objectives
- The assessment and final decision reflected the IPT's appetite for risk

These reviews are implemented by a panel of senior engineering staff within the design team and are undertaken at delivery package level. They follow a standard agenda based on presentation of available information and assessment of the uncertainty in ground conditions and the geotechnical risks that remain unresolved due to availability of ground investigation information. The conclusions and recommendations of the engineering panel are communicated with the wider IPT for the final acceptance of the route to L3 based on risk and benefit and the resultant degree of resilience which exists in the overall design.

5. Managing the impact of new GI Data during the design process

The previous sections set out a process for the clear communication of the level of uncertainty in ground conditions and the options to prioritise the on-going supplementary GI programme to best meet the design programme. Nevertheless, it is anticipated that there will be instances where design proceeds in advance of receipt of sufficient GI data to reduce the uncertainty to an acceptable level (i.e., initial SMUG class 3 or 4 assets). As such a process for managing the receipt of new ground investigation data with the data management system and updating the design team was developed recognising that new information received during the design can have far reaching impacts on the project's cost and programme.

The tracking of the use of data within design to identify what constitutes new data for a given asset relied on the adoption of cumulative databases used to disseminate information to the design team with a clear reference list. Based on a routine series of "data drops" comprising the update of these cumulative databases a change log is produced on publication which is notified across the designer's ground engineering teams allowing individual designers to identify where new data has been uploaded for a particular asset group.

To support the principle of communication of an evolving risk or opportunity to enable effective decision making across the IPT then a “Rapid Impact Assessment” (RIA) process has been established to provide an early indication of the likely outcomes of a detailed assessment. This provided the evidence to facilitate early decision making in relation to the approach to incorporating additional GI into the design ahead of a detailed assessment to confirm the mitigation measures. This process is based around a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis carried out on the new data enabling conclusions to be drawn around the outcomes for design.

These RIA were carried out at agreed stages of delivery of the supplementary GI programme as part of the mitigation strategy to reflect the subset of additional data likely to be critical to controlling the uncertainty in ground conditions and hence reducing the potential for change to an acceptable level. These would typically reflect receipt of a subset of GI results critical to addressing significant assumptions contained within the design such that the level of uncertainty in ground conditions would be elevated to a minimum of uncertainty Class 3.

The outcome of the RIA on an initial SMUG Class 5 package would be to allow the design to proceed, or not, in line with a SMUG re-classification at an improved class. The outcome of the RIA on an initial SMUG Class 4 or 3 package would depend on the stage of development of the design, the available float in the design programme and the likely benefit to the project of disrupting the design process to achieve an amended design. The potential outcomes would be:

- The data validates the current design with the degree of resilience either increased or decreased and the design progresses on current programme
- The data and available programme enable an optimised design to be developed with a suitable but not excessive degree of resilience against residual uncertainty
- The data indicates that the conditions are actually significantly different from that anticipated, and the degree of resilience within the initial design was insufficient, necessitating a redesign

This RIA process also enables optimisation of designs at a later stage of design, post design assurance, where additional resilience introduced in the design for early assets may be reversed on receipt of all available GI where the opportunity existed in the programme. This approach has been adopted for one of the major viaduct structures on C23 where pile lengths were reduced following receipt of additional data which reduced the uncertainty in the ground model across the viaduct and may also be applied to the design of some ancillary or subsidiary assets using data gathered from the construction of primary assets.

6. Conclusions

The development and implementation of a detailed framework for the assessment of uncertainty in ground conditions and classification risk to the design of assets enabled the detailed design development and communication of the risk of change through the design gateways culminating in a clear route to acceptance for construction. The recognition that the adoption of an enhanced degree of resilience within design as a mitigation for uncertainty is a key enabler of this approach. This can expedite effective delivery of critical work packages otherwise impacted by delays in GI delivery, thereby protecting the design and construction programme. It builds on industry standard guidance for management of geotechnical risk by providing an enhanced framework for assessing the uncertainty in ground conditions and the adoption of a consistent set of risk mitigation actions to be deployed which can be developed for future infrastructure projects.

The positive impact of the framework has been achieved through the collaborative input across the IPT, working to identified key reporting dates within the design and ground investigation programme to ensure routine evaluation of progress. It provides the capacity to visualise status and progress across 100s of assets in a coherent manner and is supported by the establishment of a review panel to support the package teams. This latter step is crucial to achieving consistent implementation and buy in from the IPT to enable delivery of designs to be managed whilst accounting for the uncertainty of ground conditions.

Most importantly, the framework provides a common language for use on the project in relation to the description and assessment of uncertainty in ground conditions and their potential impact on the delivery of an assured design. In particular the adoption of the SMUG design framework enables a mechanism to recognise that implementing resilience through increased conservatism as a valid means of dealing with uncertainty even if the ultimate design is more robust that it ultimately needs to be, because of the overall benefit to the project.

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