Another offee shop? An optimized process to assess the impact of above ground pipeline loading and identify suitable mitigation

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Abstract

In today's expanding world, pipeline operators are usually inundated with planning requests from third parties which interact with their pipeline right of way (ROW). This may be in the form of requests for permanent developments, road crossings over pipelines, or temporary access approvals. In order to evaluate the potential impact on the pipeline and whether mitigation is required, each site requires a time-consuming analysis of the pipe condition, ground conditions, construction plans and above ground loads. This paper outlines how a liquid pipeline operator has digitally optimised a process that reviews load distribution requirements covering all credible scenarios along their system in line with API 1102 and supports the management of the process.

Introduction

Managing the integrity of an aging liquid pipeline is already a challenge when you consider the typical pipeline threats such as corrosion, fatigue cracking or even illegal tapping (to name a few). To complicate matters further, operators receive a significant number of planning requests from third parties which interact with their pipeline right of way. These can be in the form of a temporary access track to support farming activities or the proposed installation of a road or carpark as part of a new retail development.

In the UK, each request is evaluated separately by the operator and typically involves several third parties, from developers, sub-contractors, local councils and landowners. This process will include pipeline structural calculations considering the expected above ground loading across the site and determine the appropriate protection requirements (e.g. load bearing concrete slabs or other). In some cases slabbing is specified for impact protection during future construction works, rather than purely for load-bearing purposes.

To try and reduce timelines and increase efficiency, the operator has reviewed their current process to see where improvements can be made. This paper outlines how they have digitally optimised their process to evaluate and manage third party development requests along their system.

Review of Pipeline Incidents caused by Surface Vehicle Loading

Above ground loading from vehicles can cause pipe deflection and deformation, overstress and fatigue due to cyclical loading. This loading, particularly when in combination with known defects can result in a loss of containment.

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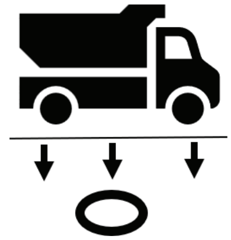

Figure 1. Vehicle loading example.

The number of historic pipeline failures specifically documented as 'caused' by above ground loading is extremely low across the industry. However, this may be misleading as above ground loading may have been a contributing factor in many incidents, with the documented cause of the failure attributed to a particular mechanism (e.g. corrosion). An example of this is a reported gas rupture on an old gas main [1]. Whilst the failure was attributed to 'corrosion', the report also highlights that the shallow depth of cover may have had a significant contribution.

As of 2009, the National Transportation and Safety Board [NTSB] reported four reported pipeline incidents at pipeline railway or road crossings. However, these were all within casings and were corrosion or construction related [1] [2].

In Europe, 29 of the 92 corrosion failures on liquid pipelines between 1971 and 2022 have been reported at road crossings, anchor points or sleeves [3]. As discussed above, the depth of cover and possible contribution of above ground loading at crossings is typically not documented in the incident statistics.

The 2023 PHMSA incident database states that 38 pipeline incidents (14%) were as a result of excavation damage [4]. In addition to pipe loading, construction activities during planned developments present further risks which also need to be managed or mitigated via the installation of a concrete slab.

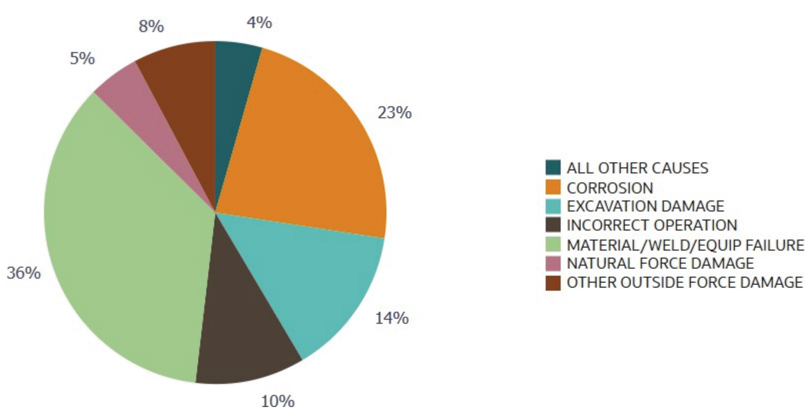

Figure 2. 2023 Incident Statistics - PHMSA

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Industry Guidance

The design and operational requirements for hydrocarbon pipelines are covered by relevant design codes, typically developed by country and region. These codes cover aspects such as minimum depth of cover for different land uses along the ROW, including crossings. In addition to the main design codes, specific specifications, guidance documents and industry papers have been developed aimed at the management of above ground loading or incidental damage of pipelines.
Selected industry references are listed below:

- API 1102: Recommended Practice – Steel Pipelines Crossing, Railroads and Highways [5]
- BS 9295: Guide to the Structural Design of Buried Pipes [6]
- UKOPA – Industry Good Practice Guide (UKOPA/GP/006): Impact Protection Slabs [7]
- CEPA 05-44R1: Development of a Pipeline Loading Screening Process & Assessment of Surface Load Dispersing Methods [1].

This paper discusses how API 1102 and BS 9295 in particular have been applied as part of the digitally optimised process for assessing loads on pipelines.

Operator Challenges

Operators are faced with several challenges associated with third party crossings over pipelines where crossings were not considered during initial design and construction phases. ‘Urban creep’ and construction along development corridors frequently means developments now taking place on what was virgin land or farmland at the initial time of construction. Regulations require that the pipeline right of way and associated risks be managed and mitigated. The overall process of managing these crossings can extend over long periods and may have significant cost implications.
Challenges are typically experienced by operators relating to:

- Data Collection
- Analysis
- Timescales
- Costs
- Documentation/ Auditing

Further descriptions of the operator challenges are provided below.

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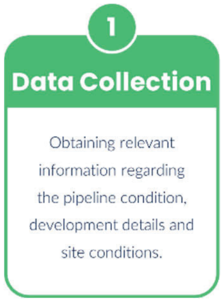


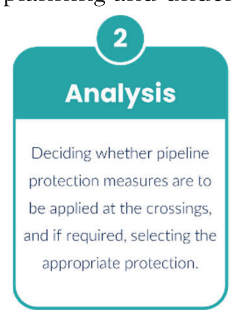
In order to properly assess the impact and potential risk, information is required on the development, proposed loadings, ground conditions, pipeline operation, coating condition and the pipeline materials (including known anomalies) to fully evaluate the suitable actions required to minimise risk. In addition, developments over pipelines may restrict access to the pipeline for future maintenance or monitoring activities.

It is therefore essential for the pipeline condition to be understood and any repair or remediation work to be completed before developments commence. To assess the risks, the details of future developments and activities needs to be understood. For developments or access requirements, the exact location of impacts must be determined, along with the applicable future load on the pipeline. It is also critical to understand or prescribe the nature of construction activities over the line, as this may be the most onerous scenarios in terms of loading or risk of damage to the pipeline. This typically involves a process of engagement with developers. To correctly specify protection the frequency and type of vehicle loadings needs to be understood, for both the construction phase and life of the asset.

Developments are normally developed in a phased manner ranging from preliminary designs through to approved for construction stages. It is therefore critical that the final development information is obtained as soon as possible to allow for the pipeline protection measures to be developed.

Where specific engineered protection measures are to be implemented, site conditions need to be understood. This includes aspects such as the ground conditions at the pipeline, ground bearing capacity, groundwater levels, width of previously excavated trenches and possible contamination. Operators would typically require that geotechnical investigations be undertaken at development sites to obtain the relevant information.

Obtaining information to assess impacts is essential to ensure risks are managed appropriately. Proper planning and understanding requirements can streamline the process.



Various measures exist that can be applied to protect pipelines, including installing physical barriers, increasing depth of cover or restricting activities over the line. It is critical that the requirement for protection is determined first.

Mitigation against above ground loading or possible impact may not be required in all situations. It is important that the risks are understood to determine the appropriate mitigation requirements. Surcharge loads from vehicle loads over pipelines rapidly reduces with depth and where sufficient ground cover is present, no additional protection may be needed, provided compaction and type of layer works above the pipeline is appropriate and construction activities are properly controlled.

Implementation of physical protection has a significant cost impact due to the associated information gathering, engineering inputs and fabrication and construction requirements. Increasing ground cover is another solution that may be considered. Over extended sections this solution also typically becomes expensive and the risk of future erosion or ground level reduction must be controlled.

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A further option of protection is to control future activities over the line by means of fencing, barriers and agreements. It is advantageous for operators to follow a well-defined process for evaluating and deciding on whether protection is needed and then selecting the suitable measure.

The duration for evaluating impacts, determining protection measures and approving and implementing the solutions can be very long. Operators are often under pressure from developers due to aggressive development schedules. This paper will address how the process has been explored and solutions developed that assist in optimizing the system for improving on the decision-making and implementing time.

Significant costs are typically involved with the process of evaluating risks, as well as implementation of protection solutions.

Cost items include operator time and effort, appointment of service providers for inspection campaigns, geotechnical studies and engineering work, however the construction costs when implementing solutions are often orders of magnitudes higher than initial planning costs.

The responsible party for costs for the implementation of protection measures is often determined by servitude, ROW or landowner agreements. Cost may be borne by the developer or the pipeline operator. Regardless of who is responsible, it is required for selected solutions to be based on sound reasoning and proper engineering evaluations and that unduly over conservative and expensive measures are not adopted whilst at the same time ensuring the risks are addressed. As operators often seek to recover costs from developers for such works this can in itself add yet more time to the process. Prior to authorising any spend a developer would typically need a budgetary estimate to be prepared by the operator, then approved by the developer. After this a formal tendering processes may be needed, followed again by approval of the final bids by developer then production of the necessary legal agreements detailing the types of study to be done and methods for cost recovery. Only after this could on-boarding of design contractors take place prior to works actually commencing. Development of a simple, fixed process that could operate under a fixed pricing regime would bring much needed clarity to developers on pricing and speed up the approval process significantly.

It is a requirement for pipeline operators to be able to illustrate that risks on pipelines are diligently managed. This includes the process of managing crossings on pipelines. Given that activities often happen over extended periods and involves an integrated process between various parties, it is important that relevant steps, information gathered, decisions taken and the outcome of implementation is carefully documented. There is significant benefit in standardizing relevant processes, an approach adopted by various global operators.

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Process Optimisation and Development of a Digital Solution

To address the challenges discussed above, studies were undertaken to optimise the process and develop a digital solution. The optimisation involved the following steps.

1) Assessment and mapping of the existing process
2) Workflow design and process optimization
3) Standardising inputs and requirements
4) Digitisation of load analyses
5) Selection of pipeline protection measures
6) Detail design of standard load bearing slabs suitable for a variety of different scenarios
7) Standardised geotechnical investigation (GI) and backfill specifications
8) Digital tool and reporting

Assessment and Mapping of the Existing Process

The project started with a thorough review of the existing workflow, detailing how the data related to each site is typically received, what the outputs are and the overall timescales. This review identified several inefficiencies in the workflow, primarily as a result of lengthy 3rd party assessment timescales, inconsistent data submissions, and repetitive tasks and recommendations. The assessment was undertaken in the form of a workshop attended by the operator, as well as appointed specialist consultants.

Workflow Design and Optimization

To address these inefficiencies, it was clear a new workflow could be developed to mitigate many of these delays. The new process prioritised efficiency, consistency, and scalability while maintaining strict compliance with industry standards such as API 1102 and BS 9295.

A key observation during the data review was of recurring patterns in the types of requests the operator would receive. E.g. temporary access points, car parking lots, or similar, would often require a standard set of loading calculations, and would often result in an output requiring a standard slab design.

The process flow maps the project stages of information and input data required, undertaking load calculations, selection of protection measures and reporting.

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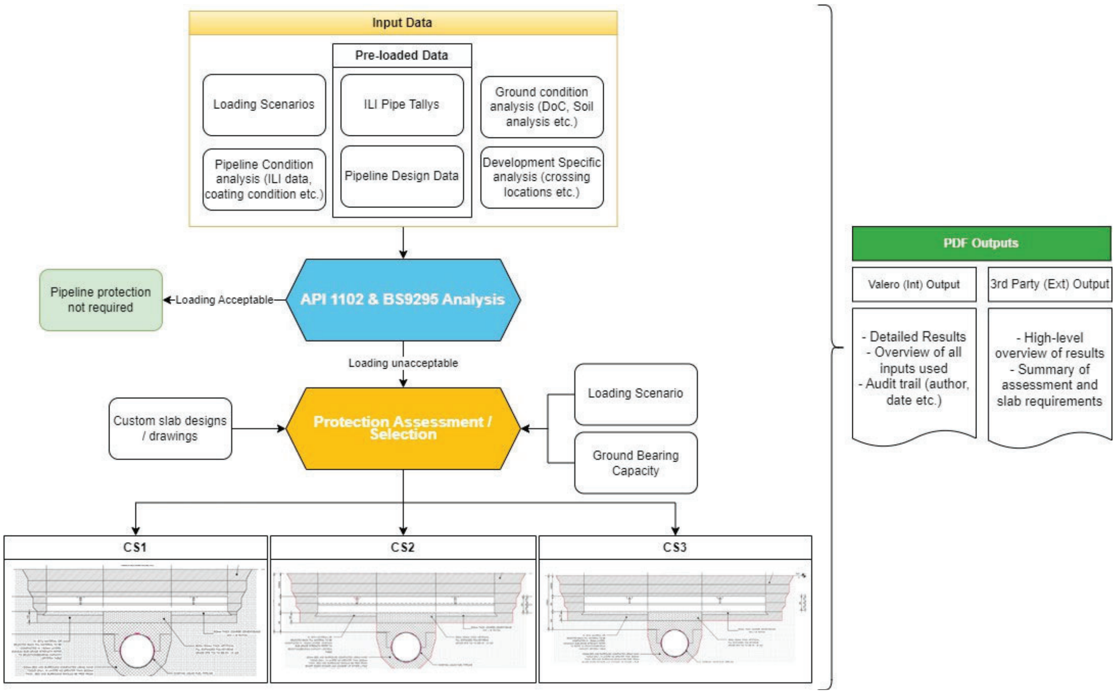

Figure 3. Overview of Process.

The information required to assess the impact of planning applications and associated protection measures are described under operator challenges above. The reality is that the required information is extensive, however the process can be streamlined by understanding what is required and planning for the information gathering activities at an early stage.

As part of the digitisation exercise, standard questions and checklists were developed on information that is needed. This included information from the third-party developer to understand the full impact of the development on the pipeline, extent of loads that the pipeline will be exposed to, information on the existing pipeline and its condition, as well as site ground conditions.

A further activity that was undertaken is to pre-load the existing pipeline tallies and as-built information into the digital solution so that load assessments can be undertaken efficiently and accurately using actual database information. This also reduced the chance for operator error by minimising the number of inputs required.

Digitisation of Load Analyses

Load analyses were digitised based on the requirements of API 1102, as well as BS 9295. Both American and UK standards were adopted as although the pipeline assets that were the subject of the work are based on the United Kingdom, the ultimate pipeline owner is based in the United States. Table 1 details the key details of these codes. Based on selected load criteria, calculations are undertaken on the actual as-built pipeline data for both API1102 and BS 9295 and confirms that all stresses and load conditions are acceptable. Where results were non-compliant this is highlighted and

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a process of selecting appropriate load bearing slabs, or other mitigating measures, are followed. The stress and load calculations undertaken by the respective codes are described in the table below. It is noted that the comparison is provided for the sections for calculating vehicle surcharge loading only and not the full extent of each code.

Table 1. Comparison of API 1102 and BS 9295 Codes

Description	API 1102	BS 9295
Published by	American Petroleum Institute	British Standards Institute
Focus industry	Petroleum Industry. Focus on pipelines under API.	Various, structural design of buried pipelines
Topic of specification	Steel pipelines crossing railroads and highways, cased and uncased.	Comprehensive structural design
Pipe material type	Welded steel pipelines	Various, including steel, ductile iron, concrete, thermoplastics, GRP, etc.
Pipe classification	Welded steel pipelines	Rigid, Semi-rigid, flexible
Minimum cover requirement	- Under highway / road and pipelines transporting HVL - 1.2m - All other surfaces in ROW - 0.9m	- Determined by other liquid fuel or gas codes - 0.9m for construction activities
Loads accounted for	- Internal pressure - External (earth load) - External (live load)	Internal External (earth, ground water) External surcharge (vehicle)
Basis for surcharge loading (vehicles)	- Cooper E 80 loading & standard axle configuration	BS EN 1991-2 (bridge design loading), Load Models 1, 2 and Field
Tyre contact area	0.093 m^2	0.15 / 0.16 m^2
Applicable load cases	- Both single (53.4 kN) and double (44.5kN) axle wheel load evaluated	Main roads (LM1 & LM2) Field loading Other (LM3 & custom) Construction vehicles
Attenuation method of wheel load with depth	- An impact factor is applied that reduces with depth of cover.	- Formulas & tabulated values in code - Alternative Newmark's integration of Boussinesq's formula.
Stress and design checks	- Internal hoop stress - Circumferential stress due to earth load - Cyclic circumferential stress - Cyclic longitudinal stress - Effective stress - Weld fatigue (girth and longitudinal)	- Buckling stability - Ovalisation - Hoop stress
Design evaluation method	Compliance check for stresses and fatigue cases mentioned above.	-Marston-Sprangler (flexible & semi-rigid)
Mechanical protection prescribed	- Mechanical protection required where minimum cover cannot be achieved.	- Not specified, various recommendations including load bearing slabs

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Selection of pipeline protection measures

Pipeline protection measures are typically required where vehicle surcharge load exceeds allowable stress or for other reasons such as temporary construction access, impact protection or where depth of cover over the pipeline is insufficient.

As part of the digitised solution, a process was developed that is integrated with the load calculations and that guides the user in the selection of the appropriate protection measures, if required. The options included the following:

- Bog mats (temporary surface protection for construction access)
- Permanent reinforced concrete load bearing slabs
- Permanent reinforced concrete load slabs (for impact protection)
- HDPE Barriers (for impact protection and pipeline awareness)

In complex cases where extreme or specific complicated vehicle loads are applicable, the operator is advised to undertake a site-specific design.

Detail design of load bearing slabs

As part of the process optimisation, detail designs were undertaken for three types of standard reinforced concrete slabs that can be applied for the majority of scenarios that the operator may encounter.

The designs were done to cover the range of pipeline diameters that are owned by the operator and the selection criteria were established so that different soil bearing capacities and extent of vehicle loads can be accommodated. The slabs were designed to prevent any load from being transferred to the pipeline. The advantages of standardising the design are that it does not require a design to be undertaken for each case encountered and it also allows for the operator to potentially procure protection slabs in bulk avoiding potential delays due to the fabrication process. It also enables the operator to quickly estimate potential costs up-front. The three slab designs and relevant design outputs are shown in the figure below. Where actual site conditions do not allow fitment of pre-cast slabs (for example at curved pipeline sections or where other utilities impinge within the easement/RoW) the standard designs provide a basis of design for these custom designs.

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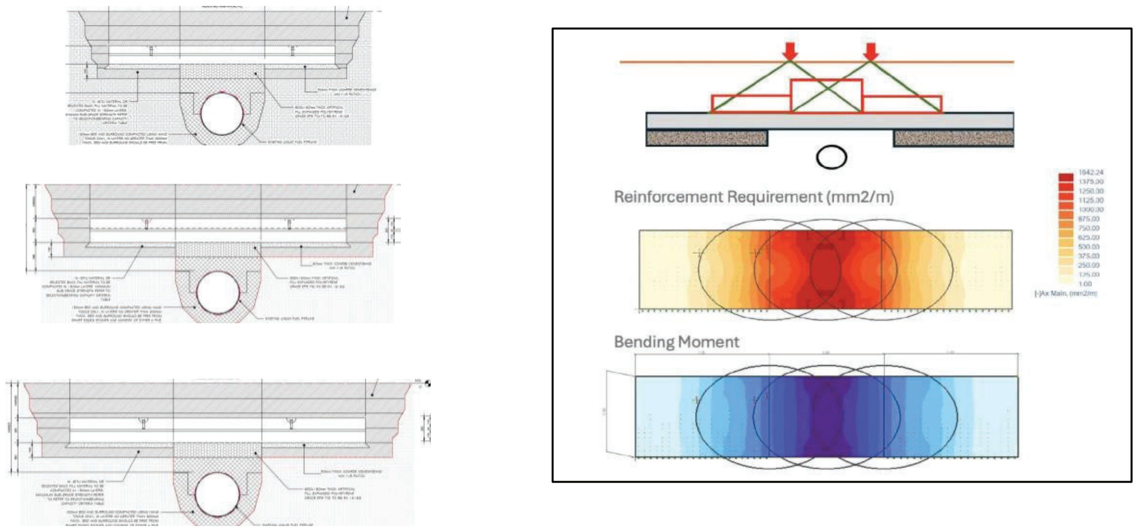

Figure 4. Overview of Slab Analysis.

Standardised geotechnical investigation (GI) and backfill specifications

Developing appropriate specifications for geotechnical investigations to be undertaken at impacted sites, as well as backfill specifications for when mitigating measures are implemented can be a time-consuming process. Whilst each impacted site might be different and would need a specific solution, it is possible to develop a baseline specification to use as a reference and adapt per location or site. As part of the standardisation process a standard GI and backfill specification was developed. The specification sets out the minimum required scope of work, refers to the relevant codes and standards and establishes the requirements for the investigations. The objective is for this to be used as reference documentation when engaging with third party suppliers. Specifications are then to be adapted as part of work undertaken at each site. This document aims to ensure the critical information is always obtained and in a consistent manner.

Digital platform and reporting

The processes described above was developed into a digital platform that supports the operator in managing the impacts of third-party developments on pipelines. This custom-built tool allows the operator to automate critical calculations, incorporate the pre-engineered slab designs, and provides a user-friendly interface for data input and output.

The platform hosts the operator's data sets so that mistakes are minimised and provide a number of prompts/questions to ensure that each user has checked all that should be checked during the analysis (e.g. is any anomaly remediation needed). It allows access to accurate evaluations and automated recommendations.

As part of the output from the tool, automatic reports are generated for both internal (operator) use, as well as external use (issued to third parties, including service providers, developers and contractors). The reports allow access to the assessment results and provides a holistic overview of the process followed that is essential for the operator to illustrate that a suitable process was followed to manage the risk on pipeline assets.

Summary of key advantages

In summary, by following the process described in this paper which involves optimising the workflow, standardising the design and developing a digitised solution, the operator was able to significantly improve the management of the impact of third-party developments or crossings on the pipeline. The following key advantages are highlighted:

- Reduce cost by standardising protection slab designs and avoiding the need for site specific designs in all cases.
- Reduce time by following a well-defined process, optimising input data and load calculations
- Support risk management and auditing by providing detailed reporting on the process followed.

Case Study #1

The operator's onshore UK pipeline network has a combined length of over 300 miles and planning requests from third parties which interact with a pipeline right of way (ROW) is common.
Recently, a landowner had obtained a crossing licence for a service pipe but there was no mention of an access track over the operators 16" diameter pipeline and a further assessment would be necessary to support a permit. When approached, the landowner refused to pay for a conventional assessment and made it clear that he intended to move ahead with construction regardless. This created both legal and technical challenges for the operator.

Operator Options

Whilst there were a few options available to the operator, all were far from ideal, see Table 2.

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Table 2. Operator Option Summary

	Option 1	Option 2	Option 3
Scenario	Grant license without completing any assessment	Seek court injunction	Complete assessment and bear the costs
Advantages	Considered minor crossing so risk is likely low	Work may halt if injunction granted	Full analysis completed to de-risk the situation
	No further damage to relationship with landowner		Audit trail of outcome
Disadvantages	Additional potential liabilities from proceeding with no analysis	Costly, time consuming and no guarantee of success	No chance to recover costs
		Worsens relationship with landowner	Sets precedent for any similar future disputes

Considering the above, the newly developed digital solution was used to quickly analyse the site considering ground condition, operation and local materials in line with both API 1102 and BS9295. The output provided the operator with reassurance to take further action, reducing the sign off timeline from several months to a number of days. This allowed the operator to complete 'Option 3' but without requiring extensive spend on external specialists, and enabled them to grant a license rapidly to avoid the risk of the landowner proceeding without a crossing license.

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