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Alternative Road Improvements to Enhance the Sustainability and Resilience of A83 – "Rest and Be Thankful" in Scotland

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***Abstract* - T**he A83 trunk road at the "Rest and Be Thankful" is a key section of the trunk road route which has been impacted serverey by the occurrence of landslides. Over the last 15 years, thousands of tonnes of debris have flowed onto the road blocking and closing this key route to traffic, which has resulted in significant diversions of over 60 kilometres. As a result of this consistent disruption, a long-term solution must be rationalised to provide the route with greater resilience along this section of the A83. Therefore, for the purpose of this study, a conceptual development of three road alignment design schemes will be conducted along with the investigation of the feasibility of a preferable design which will realign the A83 away from the landslide prone slope and achieve the requirements of current UK road design standards. From this data obtained through the design and development of the three different alignment options, it will be possible to compare and analyse each option though different PESTLE factors which will help to identify the benefits and costs in each of the three alignments. This analysis will also be backed up through the application of a scheme assessment process which has worked towards choosing a preferent alignment design option. Finally, after identifying a preferred alignment design option, recommendations will be made in view of the next steps leading towards potential construction. Along with the full analysis of alignment designs, additional designs options where developed to cover sustainable and resilient measures which could help to reduce the likelihood of landslide, prompting further areas of research.

***Keywords*:** Road design, geotechnical design, landslides, resilience, sustainability, highway engineering.

1. Introduction

The A83 road is the main route from the Scottish Central Belt through local settlements until its termination in the town of Campbeltown in the south-western highlands of Scotland. Located to the west of Ardgartan, situated within Glen Croe, the section of the A83 (Figure 1a) in this area has been severely disrupted or completely closed due to large volumes of debris from multiple landslides that have occurred on many occasions at least in the last 15 years [1]. With the regular occurrences of landslides affecting the road, it has become normal to expect lengthy delays or significant detours on another route, the shortest of which is more than 60 kilometres long. Therefore, it has become increasingly popular to seek and develop a long-term solution that will have a collective impact on the reliability and safety of the route and the road users, with various studies being commissioned regarding the impact and possible mitigation for the damage inflicted on the road due to landslides on the trunk road network. The road authority, Transport Scotland [2], for the A83 at the "Rest & be Thankful" (RABT) was advised on several options which could improve the reliability of the trunk road route and recommended on an initial "Do Minimum" approach. This was consequently known as the 'Red Option' [3] which aimed to stem the impact of damage from landslides through the application of landslide mitigation fences. Therefore, because of this current practice, through the agreements and correspondence of the 'A83 Taskforce' Transport Scotland has spent £15M on a mixture of mitigation works and repair work for the damaged caused since 2007 [5].

However, sustainable and resilient design must take into consideration, what the whole life implications will be and what sustainable measures can be incorporated to provide long term benefits and resilience to the construction of the new road alignment. Further to this generic view into the resilience and sustainability of the road alignment, further investigations/ assessments should be undertaken into potential slope stabilisation methods which could be applied to provide long-term benefits to the area, such as complementary eco-engineering works (e.g. the use of vegetation for slope stabilisation and erosion protection) [6] onto the slopes of Beinn Luibhean.

The aim of this paper is to undertake and assess three potential road improvement schemes on the A83 in accordance with the current UK Standards, with a focus on the Design Manual for Roads & Bridges Highway Link Design CD 109 [7]. The three schemes shall provide an all-purpose single carriageway alternative route, which shall be both safe and sustainable. The preferred scheme shall minimise the risk of landslide and rockfall, by realigning the current A83 single carriageway onto a new route while allowing for the provision of more immediate landslide protection along with the application of long-term slope stability measures.

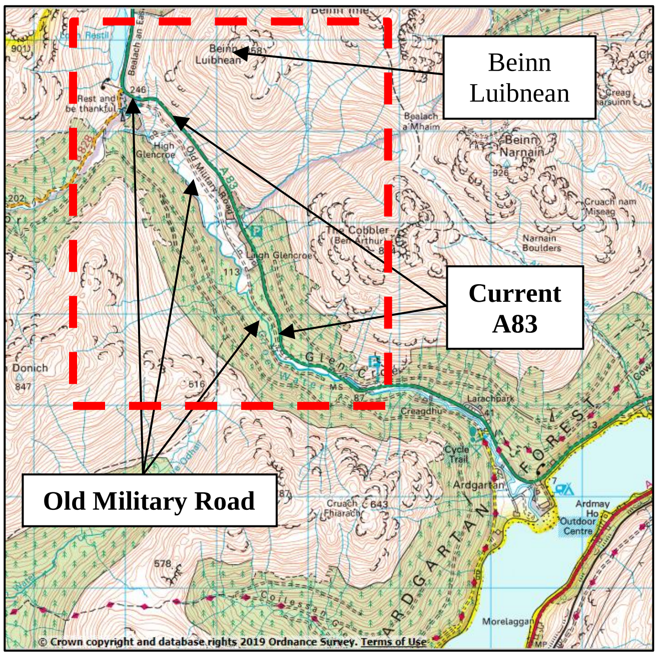

Fig. 1: (a) Location Plan of the A83 in the Loch Lomond & The Trossachs National Park, Scotland.

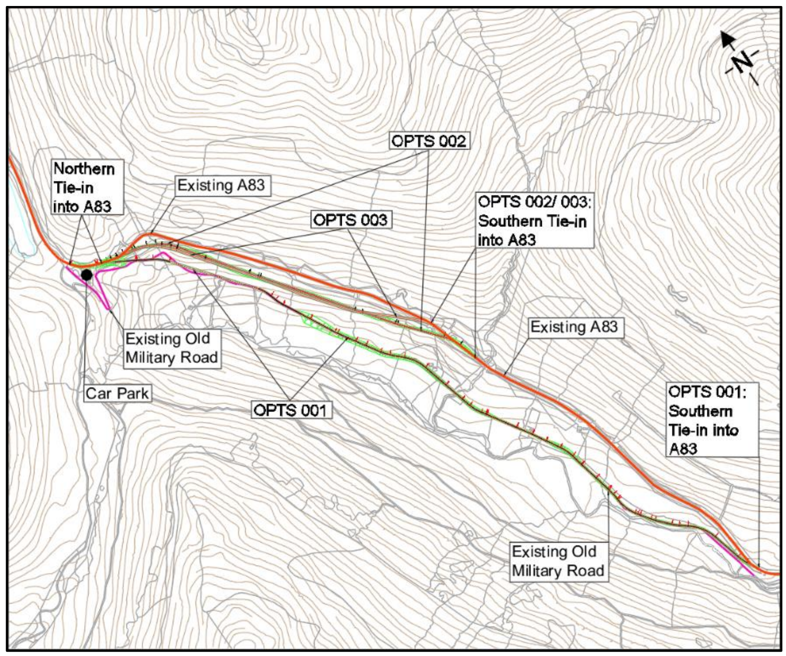

Fig. 1: (b) General Arrangement drawing detailing the proposed options along with the existing routes.

The objectives of this study are: (i) to produce three outline specimen designs that will provide a safe and reliable realignment solution along the 3.7 km section of the A83 running south from the RABT car park. (ii) to undertake a scheme reporting assessment on the three designs, arrive at a preferred option and further develop this to provide a quantified detailed design solution; (iii) to analyse each option against a multitude of factors including: the safety of the new alignment designs along with the sustainability of the different designs (e.g. earthwork cut and fill balance), to determine/outline which option will be the most resilient design in the long term.

2. Materials and Methods

This section will outline the research methods that are going to be used to assist in the compilation of the three design options that are to be created. Further on, from the application of the necessary research methods it will be outlined as to how the analysis of each option will be carried out in relation to the DMRB standards.

2.1. DMRB Standards

The historical background of the project area and the main DMRB standards that will be applied for this research were initially reviewed and analysed on the background of the existing topographical survey data. In order to assist in the design of the three options compliant with the DMRB Standards for Highway Link Design and Earthworks Construction, the relevant documentation and advice (CD 109, 2019 & HA 70/94, 1994; [8]) was followed. The standard engineering requirements for the options' geometrical alignments were identified from the relevant literature as:

- For the horizontal alignments: The design speed for all alignments will be 100 km/h (CD 109, 2019) to match the existing roads speed limit of 96 km/h (60 miles per hour);
- For the vertical alignments: The maximum allowable gradients for the All-Purpose Single Carriageway will be between 6% and 8% (CD 109, 2019).

With these design parameters, the options were developed and analysed in order to identify a preferred option. This was carried out in accordance with a scheme assessment report (DMRB TA 37/93, [4]) which includes an element of PESTLE analysis.

2.2. Data Requirements and Option Development

In order to carry out the data creation for this research, specialised road design and modelling software was used in order to generate the necessary data that can be analysed through the planned assessments. During the initial desktop studies into the location of the RABT A83, a 3D contour model of the grid reference area NN20 was procured from the Amey CAD data library. The .dxf data file was then imported into Autodesk AutoCAD 2017 to be subsequently processed to remove all unnecessary information for the use as a survey model for the area of the A83 RABT. This developed survey model was then exported into Bentley MXROAD Select Series 4 software to be used to help design the vertical alignments of the different design options and to also help conduct quantitated analysis of the models through the software i.e. the quantities of that earthworks the cut/ fill balance. Regarding the different alignment designs, Bentley MXROADS Select Series 4 software was used to create the geometric alignments. This software is a string-based modelling tool [9] that can be used to generate full 3D models of a road alignment. This is achieved by interpolating data from different sources, i.e. topographical survey data imported into the software as survey models and creating different three-dimensional point strings that will form the parameters of a road, surface, earthworks, and geometry.

2.3. PESTLE Analysis

To help in the assessment of the different alignment options, they will be initially analysed through a numerical scoring table developed from the multiple factors of a PESTLE analysis. PESTLE analysis focuses on six different categories of the following areas; Political, Economic, Social, Technological, Legal and Environmental [10]. These different factors can help to identify positive or negative elements of the design data which can then be further investigated and analysed. The PESTLE analysis for this study was carried out in relevance to the real-world topical items such as: what will be the environmental impact of the new alignment or what will be the impact on the local community/economy. Further to the development of each of the three alignment options, a basic cost estimation for each of the options was carried out using SPON's Approximate Estimating [11] in order to analyse the financial/ economic impacts of each option. Different multiplication factors were used for each option to reflect differences in length of construction, preliminaries and cost of materials.

3. Results and Analysis

Using the DMRB standards and the available software and information, four design models were created. These included the three road alignment options (OPTS 001-003; Figure 2a including a viaduct structure; Figure 2b). The fourth model which was developed included a slope drainage design package which has been created to work alongside the three road alignments to help further enhance the sustainability and resilience of the A83 trunk route (Figure 3). In this package, the proposals for the drainage work layout on the slopes surrounding the A83 include the implementation of check dams on all known watercourses that are identified as having significantly fast water flows and contour or cut-off drainage which will carry water across the slope face to a regulation-compliant outfall [12].

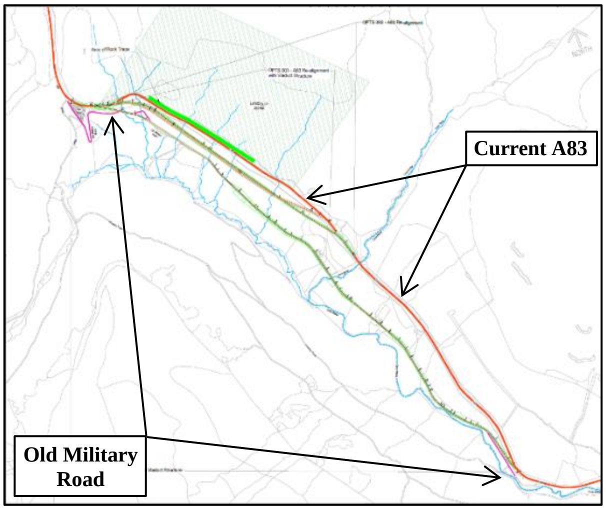

Fig.2: (a) Combined Layout Drawing for the Alignment Option Comparison of the three design options.

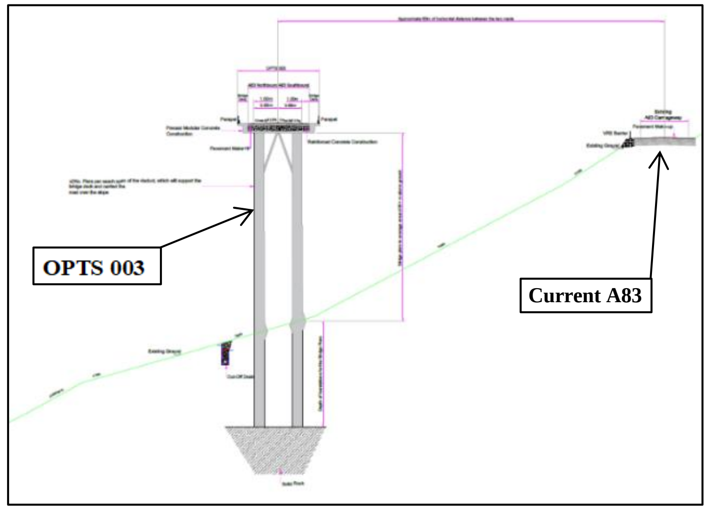

Fig. 2: (b) Cross-Sectional Detail of Option 3 (OPTS 003).

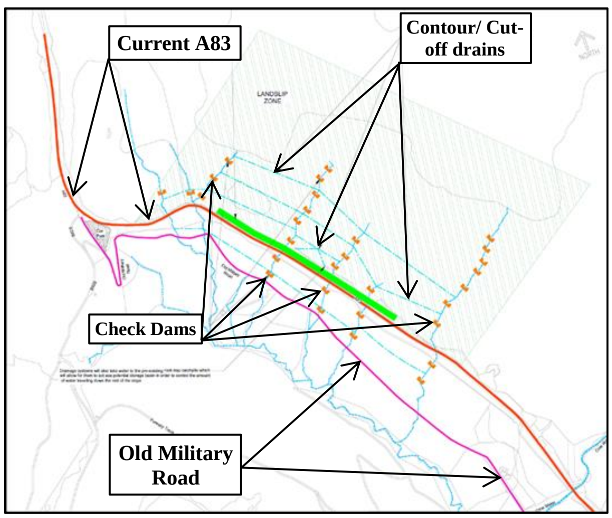

Fig. 3: General Arrangement of the proposed layout of the drainage works package on the surrounding slopes.

Option 1 (OPTS001) has the largest scope in term of the length (3.40km) of the proposed alignment and the sheer size of the structures which are required to ensure the standards are maintained. Due to this alignment following the Old Military Road (OMR) which sits on the floor of Glen Croe, this option requires an elevation gain of 30+m. This is to provide an allowable tie-in to the required standards into the A83 at the Rest and be Thankful visitor car park. Further to this as this option follows the length of the OMR alignment which runs parallel to the A83, there will be several constraints which will need to be addressed throughout the design [13]. These range from an existing bridge structure over the Croe Water which will need to be upgraded to accommodate the larger carriageway, to the proximity of farm buildings to the current OMR which has limiting factors on the route.

The second of the alignment design options (OPTS 002) is the first of the options to focus on a realignment of the A83 onto another section of the slope lower down. At 1.70 km long this alignment is significantly shorter than OPTS 001, which is mostly due to this alignment focusing on the section of the A83 worst affected by the occurring landslides. As seen in Figure 2(a), this alignment completely bypasses a section of the A83 by cutting into and below the current road. With this option having no requirements for a structure other than the implementation of supporting retaining wall structure resulting in the design option less visually intrusive than other options. Furthermore, this design option will not be impacted by any constraints around the placement of the road due to land ownership and land usage as this option uses the untouched landscape between the A83 and OMR. An important factor is the designs ability to still provide access to the existing A83 when construction is complete. As this section of road could then be used to support long term stabilisation measures on the slopes.

The final design option (OPTS 003) which has been developed is a full viaduct structure realignment of the A83. This option has the shortest alignment distance out of the three options at 1.50 km and follows a similar route to OPTS 002. The major difference and reasoning for the design high cost estimation, see Table 1. is the design using a viaduct structure for the full length of the design options alignment. This allows for the new road alignment to float above the slopes, essentially making the route immune to potential landslides. This option will also can still provide access to the existing A83 when construction is complete. As this section of road could then be used to support long term stabilisation measures on the slopes.

The basic cost estimation for each of the options carried out using SPON's Approximate Estimating [11] which is shown on Table 1. As per the estimating handbook [9], the basic value of £1,659,598 has been, multiplied by a factor of 2 for OPTS 002/ 003 and a factor of 2.5 for OPTS 001 to provide a more realistic costing of the Preliminaries and General Items. OPTS 001 is the most expensive of the three options developed. The high costs originate from a combination of being the longest alignment 3.40km on top of requiring an estimated 1.00 km long bridge structure. OPTS 002 totalled under £10 million, mainly because of the lack of an expensive bridge structure along with a shorter overall length in comparison to OPTS 001. This estimation table (Table 1) also breaks down the key engineering components of the design which has included multiple variants of retaining wall structure. The inclusion of these items has been based around the alignments being cut into the side of the slope face underneath the A83, like its original construction. This therefore means it may be best practice to support certain earthworks that go greater in height than 5.0 m vertically to be supported by a retaining structure at the interface of the slope.

The results of the PESTLE analysis are shown in Table 2. OPTS 001, albeit offering the most technological and social benefits, has the political issues of departures from standards and high cost. OPTS 002, albeit offering lowest construction costs and highest sustainability benefits has issues with possible maintenance issues and residual risk in terms of slope instability. OPTS 003 scored similarly to OPTS002 with higher construction costs due to increase in length of road to be affected which will significantly decrease the risks of instability and improve resilience of the solution.

4. Discussion

The results showed that a number of options are feasible for addressing the sustainability and resilience of A83 RABT. In conclusion to the PESTLE analysis of the three design options, OPTS 003 has been proven to have the greatest potential in providing a long-term feasible solution to the landslide prone A83 RABT. This has been confirmed in the option achieving the highest scoring of 16/18 (Table 2) in the PESTLE scoring tables which was further justified in the overall performance of this alignment, when assessed through the core topics of the DMRB document TA 37/93.

With the complete analysis of all three alignment design options, the preferred option has been stated as OPTS 003 – A83 Re-alignment (viaduct structure). As seen through the option analysis conducted through the PESTLE analysis scoring tables, this option scored the highest by having more beneficial factors over the other options. Along with the assessment conducted using PESTLE (Table 2), OPTS 003 was evaluated through the Scheme Assessment Reporting Stage 2 requirements for cost estimation and the engineering assessment which included potential constraints and disadvantages within the parameters of the design itself. This process highlights one of the key factors in which this option has a major advantage over the other two options considered. As detailed in the PESTLE Chart (Table 2) of each option, OPTS 003 was noted as having the most standards compliant alignment design in terms of both the horizontal and vertical designs due to the road alignment following the existing roads parameters by having a similar vertical gradient. This view was supported as with both OPTS 001 & 002, under the 'Political Factors' had concerns highlighted regarding included, encroaching on the maximum allowable gradient of 8%. Even though this option has not been estimated to be the cheapest, it can be assured that it will have the lowest risk in its long-term life span as this option fully removes the road from the side of the slope face and includes a structure which can allow further slope instabilities without blocking the road.

Table 1: Cost estimations of the construction works for the three design options.

<table>
<tr><th>Alignment Option</th><th>Items</th><th>Unit</th><th>Rate (£)</th><th>Quantity</th><th>Total Cost (£)</th></tr>
<tr><td rowspan="4">OPTS 001</td><td><u>Rural All-Purpose Road;</u>
- Single carriageway (7.3m wide)</td><td>m</td><td>1575.00</td><td>(Length)
3400</td><td rowspan="4"><u>39,118,945</u></td></tr>
<tr><td><u>Earth Retention & Stabilisation;</u>
Precast, reinforced concrete unit retaining wall (in-situ foundations)
- 2.0m high</td><td>m²</td><td>605.00</td><td>(Length x Height)
(950.00 x 2.00)
1900</td></tr>
<tr><td>Reinforced concrete bridge with <u>pre-fabricated steel beams</u>;
- Span: 30 m</td><td>m²</td><td>4500.00</td><td>(Length x Width)
(820 x 8.00)
6560</td></tr>
<tr><td><u>Preliminaries and General</u>;
- Workforce - Temporary
- Site Compound - Other Costs</td><td colspan="3">Note; the costing for generic site items has been given as a fixed cost taken from an example in SPONS 2017.</td></tr>
<tr><td rowspan="5">OPTS 002</td><td><u>Rural All-Purpose Road</u>;
- Single carriageway (7.3m wide)</td><td>m</td><td>1575.00</td><td>(Length)
1700</td><td rowspan="5"><u>9,088,696</u></td></tr>
<tr><td><u>Earth Retention & Stabilisation</u>;
Precast, reinforced concrete unit retaining wall (in-situ foundations)
- 2.0m high</td><td>m²</td><td>605.00</td><td>(Length x Height)
(700.00 x 2.00)
1400</td></tr>
<tr><td><u>Earth Retention & Stabilisation</u>;
Reinforced in-situ concrete retaining wall;
- 6.0m high</td><td>m²</td><td>730.00</td><td>(Length x Height)
(500.00 x 6.00)
3000</td></tr>
<tr><td><u>Earth Retention & Stabilisation;</u>
Rock gabions;
- 1.0m thick</td><td>m²</td><td>110.00</td><td>Length x Height)
(500.00 x 1.00)
500</td></tr>
<tr><td><u>Preliminaries and General</u>;
- Workforce - Temporary
- Site Compound - Other Costs</td><td colspan="3">Note; the costing for generic site items has been given as a fixed cost taken from an example in SPONS 2017.</td></tr>
<tr><td rowspan="4">OPTS 003</td><td><u>Rural All-Purpose Road</u>;
- Single carriageway (7.3m wide)</td><td>m</td><td>1575.00</td><td>(Length)
1500</td><td rowspan="4"><u>32,286,696</u></td></tr>
<tr><td><u>Earth Retention & Stabilisation</u>;
Precast, reinforced concrete unit retaining wall (in-situ foundations)
- 2.0m high</td><td>m²</td><td>605.00</td><td>(Length x Height)
(500x2)
1000</td></tr>
<tr><td><u>Reinforced in-situ concrete viaduct</u>;
- Span: 25+ m</td><td>m²</td><td>3500.00</td><td>(Length x Width)
(1000x8)
8000</td></tr>
<tr><td><u>Preliminaries and General</u>;
- Workforce - Temporary
- Site Compound - Other Costs</td><td colspan="3">Note; the costing for generic site items has been given as a fixed cost taken from an example in SPONS 2017.</td></tr>
</table>

Along with the three different alignment options, OPTS 001, OPTS 002 & OPTS 003, the drainage works package intended for implementation on the slopes of Beinn Luibhean, would help to reduce the amount of water flooding the slopes, increasing the likelihood of a potential landslides occurring. This was also developed to work alongside any of the three alignments as a way of further enhancing the resilience of the new road designs in the long-term and thus, providing an enhanced sustainability to the preferred option to further the appeal of taking this option to construction. This package reflects the benefits of multi-disciplinary engineering approach that may increase the sustainability and resilience of the trunk road.

Table 2: PESTLE Analysis scoring Results

PESTLE ANALYSIS SCORING RESULTS				TOTAL SCORE
OPTIONS	**POLITICAL REMARKS**	**ECONOMICAL REMARKS**	**SOCIAL REMARKS**	
OPTS 001	The Roads & local authorities will have several concerns on the design's construction, but these will be considered manageable for the options construction. Further to the vertical alignment requires a steep gradient which will require a 'departures from standards' that's will be approved by the client/ Road's authority.	The high cost estimation for this option construction over others is a factor which will hinder the design greatly due to the other option's similar costs.	While the design will be provided positive benefits to the road users of the A83, the construction period will have a detrimental impact on the properties connecting onto the OMR will also removing the road as usable pedestrian/NMU route which will link the RABT car park to Arrochar.	8/18
OPTS 002	This option is the most simplistic approach to realigning the A83 but there will be concerns with regards to how steep the final gradient of the new alignment will be and the effects it will have on traffic. Further to this gradient will require a 'departures from standards' to be approved by the client/ Road's authority.	The low-cost estimation for this option construction over others is a factor which will aid the design greatly due to the other options inflicting higher costs and increased financial risk.	The road will be able to provide improved resilience in the local areas transport network and decrease/ eliminate the impact of landslides on the section of road.	13/18
OPTS 003	This option acts as a hybrid of the previous two options by taking key areas from the other two options and creating a very viable design which will be viewed positively.	The estimation for this options construction sits in between the other design.	The road will be able to provide high levels of robustness and resilience into the local areas transport network and decrease/ eliminate the impact of landslides on the section of road.	16/18
	TECHNOLOGICAL REMARKS	**LEGAL REMARKS**	**ENVIRONMENTAL REMARKS**	
OPTS 001	There will be no major impacts on the design occurring from technological factors. Due to it meeting all relevant objectives.	Even though the design will be fully compliant, the design does have the greatest risk of Third-Party objection due to its position and alignment through Glen Croe.	This design will have a considerable impact on the local environment, mostly due to the land take required providing a greater risk of impact to the area. This should be mostly mitigated through compliance with SEPA regs for construction projects and carrying out of a detailed environmental impact statement	8/18
OPTS 002	There will be no major impacts on the design occurring from technological factors. Only the site conditions may require more specialist equipment for construction.	The design is fully conversant with the relevant design standards and does not have a high chance of seeking any objections to the land acquisitions and construction.	This design will have a limiting impact on the local environment but will have a restricted land take reducing the risk of impacting the area. This should be mostly mitigated through compliance with SEPA regs for construction projects and carrying out of a detailed environmental impact statement.	13/18
OPTS 003	There will be no major impacts on the design occurring from technological factors. Only the site conditions may require more specialist equipment for construction.	The design is fully conversant with the relevant design standards and is unlikely to receive any major objections to the land acquisitions and construction.	This design will have a limiting impact on the local environment but will have a restricted land take reducing the risk of impacting the area. This should be mostly mitigated through compliance with SEPA regs for construction projects and carrying out of a detailed environmental impact statement.	16/18

The benefit from identifying the option design known as OPTS 003 as an effective engineering design solution is the potential to maintain the usability of the Old Military Road [13] during and after the offline construction of the new viaduct route. Along with the development of a feasible drainage design solution on the landslide prone slopes, the two designs would work alongside one another providing a highly feasible and yet very resilient solution. Therefore, the criteria of the final objective of this study which encompassed the use of multi-disciplinary engineering approach, was successfully achieved through the design development and justification detailed in the previous sections of this paper.

5. Conclusion

As this paper was able to demonstrate the required design output and analysis necessary to meet the stated aim and objectives, there is still an allocation for further work and data collation that would refine some of the design steps that were carried out in this paper. These include, but are not limited to:

- Acquisition of more precise/ accurate forms of data which would further enhance and refine the designs created in this research. This includes data on the topography of the site (including high-definition photogrammetric, LIDAR, aerial, and infrared data) as well as data on the ground conditions (intrusive and non-intrusive data from variety of sources). Furthermore, the combination and analysis of this data with the historical and current hydro-meteorological data series [14] will enable creation of numerical models which can then be analysed under a range of scenarios from which an optimal solution can be found.

- Consideration should be given to implementation of sustainable drainage and slope stabilisation practices [15] which can be used in conjunction with the traditional ‘hard’ engineering stabilisation strategies [16]. The former have the potential to significantly decrease the material costs and construction times and, although potentially requiring more detailed monitoring, can lead to increased sustainability and resilience of the project.
- Considerations should have been made for the initial geometric alignment creation by working with different design software. These would have allowed for more advanced design and modelling properties. This may have had improved the compatibility of taking the core designs onto technical drawings. i.e. using AutoCAD Civils 3D/ MX Open Roads instead of Bentley MXROAD Select Series 4. This would have allowed for the provision of 3D model renderings of the different design options which would have been able to further enhance the visual representation of the different alignments.

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