JUNE 2019
HIGHLANDS AND ISLANDS ENTERPRISE

CAIRNGORM FUNICULAR RAILWAY

VIADUCT STRENGTHENING REPORT

COWI

ADDRESS COWI UK Limited
Bevis Marks House
24 Bevis Marks
London
EC3A 7JB
TEL +44 207 9407 600
WWW cowi.com

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v1	April 2019	First issue	[redacted]	[redacted]	[redacted]
v2	June 2019	Second issue with updated cost estimate and programme options	[redacted]	[redacted]	[redacted]

CONTENTS

APPENDICES

1 Executive Summary

An appraisal report A116993-RP01 v2 and addendum to this report A116993-RP02 Addendum A1 concluded the viaduct supporting the Cairngorm Funicular Railway to be unable to support its original design loadings in its current condition. Key deficiencies are main beams which are overloaded in shear, bearings which are overloaded and misaligned, and piers which are overloaded in bending.

A concept strengthening scheme has now been developed. This comprises the following:

- installation of permanent props to approximately 50% of the piers,
- replacement of all bearings,
- installation of extra bearings at most anchor blocks,
- strengthening the existing concrete beams with external bars - bars are to be installed at all scarf joints, further into the span on approximately 40% of beams and over almost the full span length on 5% of beams.
- reinforcing some beam to beam connections to improve durability.

In addition to the strengthening, changes to emergency procedures are recommended to address the risk of bearing uplift.

The estimated construction cost of the strengthening is £5.85 million +/-20%. Two options for strengthening are considered - an option in which construction would be expected to take place over two summer seasons with completion in October 2021, and an option in which construction takes place in one season with completion in November 2020.

Alternatives to strengthening exist. Options include operating under reduced loading after partial strengthening, load testing to reduce the extent of strengthening, and whole or partial replacement of the viaduct.

2 Introduction

2.1 Scope of study

An appraisal of the viaduct supporting the Cairngorm Funicular Railway has found that in its current condition the structure is unable to support its original design loadings. Operations are currently suspended.

The objective of this study is to develop outline proposals for strengthening in order to determine a budget price and programme for remedial works which would allow the funicular to resume operation. This report describes the proposed strengthening and the budget price. Producing a detailed strengthening scheme for check and procurement or discussing the proposals with the regulatory authorities is not part of COWI's current scope.

2.2 Summary of appraisal

COWI UK Limited undertook an appraisal of Cairngorm Funicular Railway. A description of the facility and the appraisal is contained in the appraisal report A116993-RP01 v2 and addendum to this report A116993-RP02 Addendum A1.

The appraisal identified the following deficiencies:

Element	Deficiency
Main beams	Many spans are overloaded in shear
	Risk that all scarf joint have deficient shear strength
	5 spans are overloaded in hog bending where cast into anchor blocks
	Cracking especially at piers which could lead to reinforcement corrosion and hence a further loss of strength in future
Bearings	At low temperatures some bearings will travel beyond extent of sliding surface due to misalignment
	On all spans vertical and lateral load capacity is exceeded
	Bearings are unable to resist uplift
Piers	Crossheads are overloaded in the steepest part of viaduct
	Columns overloaded in bending and shear on the taller piers
	Piers have low resistance to collision load and could fail if impacted
Pier foundations	Many piers are thought to have rotated due to the inclined bearing loads. Rotation will have occurred over operational lifetime to date and is treated as irreversible.

Table 1 Summary of deficiencies identified in the appraisal

3 Alternatives to strengthening

3.1 Reduced loading

Some elements of the strengthening could be avoided if reduced loading was adopted. This could include a limit on passenger numbers in the carriage. However, not all strengthening could be avoided, and robust operating procedures would be needed to ensure these limits are enforced. This approach does not eliminate any risk of damage to the structure in either of the storm condition load cases.

3.2 Load testing

The scarf joints in the main beams contain unusual details for which strength cannot easily be determined. Therefore, the strength of these joints is uncertain. These joints have been identified as at risk of failure rather than being substandard.

As an alternative to strengthening, the joints could be load tested to determine the existing strength of the detail. If a representative sample of joints pass the load test, this would provide good evidence that the joints are not substandard. With agreement of the regulatory bodies, strengthening could be avoided using this approach. However, there is a risk joints could be damaged by the load test, and consequently extra remedial work needed in addition to strengthening.

A possible testing scheme is shown in Appendix A. The likely number of load tests to achieve a representative sample across the viaduct would be in the order of 10-15 joints. Note that not all joints would be tested and thus residual risk would be mitigated by an appropriate selection of testing areas and testing rig set-up.

3.3 Whole or partial replacement

It is understood that the mechanical and electrical elements of the facility are nearing the end of their design life and hence need to be replaced in the near future.

As an alternative to strengthening, the whole structure could be replaced.

To reduce the scope of strengthening the deck (i.e. everything above the bearings) could be replaced, keeping the existing piers, anchor blocks and foundations. The new deck could be lightweight, reducing loads on the substructures, but if new bearings are used with the same arrangement as the existing bearings then it is likely that much of the pier strengthening will still be required.

If a new deck were to be built with a different bearing arrangement as described in Appendix B then strengthening of the substructure could be avoided. It is not thought to be practical to in install the different bearing arrangement without replacing the deck.

Although this remains an option, the extent and thus cost of this scheme would be expected to be substantially more than strengthening the existing structure. At this stage examining the feasibility of whole or partial replacement is not part of COWI's scope.

4 Basis of strengthening

4.1 Design criteria

Only those parts of the structure that have failed the appraisal to assessment standards are to be strengthened. Parts to be strengthened will be designed to comply with modern design standards, i.e. Eurocodes.

The strengthening is designed to accommodate the design loads, limiting temperatures and wind speeds used in the original design and the appraisal. Hence the strengthened structure should satisfy the following criteria:

Carriage weights:

- Empty carriage: 14,900 kg
- Maximum payload: 9,600 kg (120 persons at 80 kg per person)
- Hence total: 24,500 kg

Shade air temperature limits in operation or out of operation:

- Minimum: -29 °C
- Maximum: +27 °C

Maximum wind gust speeds:

- In operation: 35 m/s
- Out of operation: 75 m/s at top station, 56 m/s at bottom station

Design situations considered in the design:

- In operation: Fully laden moving carriage + wind at 35 m/s.
- Evacuation: Empty static carriage + 5000 kg kentledge + wind at 50 m/s.
- Storm: No carriage + maximum out of operation winds.
- Accidental: Empty static carriage clamped to rails + 5000 kg kentledge + maximum out of operation winds.

In accordance with Eurocodes, loads in the accidental design situation are unfactored. This differs from the approach taken in the original appraisal. Justification for this is given in the addendum to the original appraisal.

These design criteria for concept design would need to be developed into a full basis for design (in the form of an Approval in Principle or similar document) if the design is to progress to detailed design.

4.2 Design life

The original design life is not known. A draft version of EN 13107 is referenced on the original design certificate but that version of the standard is no longer available.

The current version of BS EN 13107 recommends the following design lives for civil engineering elements of funicular railways:

- 20 years for bearings,
- 50 years for the remainder of the supporting structure.

Strengthening proposals are intended as a "long term" solution to the structural deficiencies identified, and therefore there is an intent to achieve the design lives given above in all areas of intervention. However, this cannot be guaranteed for the whole structure as the design is constrained by the existing structure and there is the possibility that new defects in the existing structure may manifest themselves in the future. The risk of further defects has been minimised by non-destructive testing and detailed structural appraisal but cannot be eliminated completely.

Existing undesirable design details and areas of construction which do not comply with the apparent design intent are present in the as-built structure. These undesirable details have led to faster than expected deterioration in the life of the structure to date and will compromise the future design life and durability. The strengthening scheme seeks to address the most significant of these details but enhanced inspection and maintenance procedures are likely to be required to ensure that the design life is maximised.

4.3 Extent of strengthening

Based on the appraisal result the extent of the strengthening scheme is as shown in Appendix D and summarised as follows:

- A total of 43 out of 88 piers are to be strengthened,
- 5 of the 6 anchor blocks are to be strengthened,
- All 196 bearings are to be replaced, (2x93 at piers/anchor blocks 1 to 93, +8 extra at passing loop, +2 at tunnel portal),
- A total of 97 new lateral guide bearings to be added to all piers, (1x93 piers/anchor blocks +3 extra at passing loop, +1 at tunnel portal),

- All beams are to be strengthened at all 360 scarf joints (4x87 piers, +12 extra at passing loop),
- A total of 166 beam ends are to be strengthened at the 1st crossbeam position (2x77 span ends, +12 extra at passing loop)
- A total of 20 beam ends are to be strengthened from the 1st crossbeam up to the 2nd crossbeam positions (2x2+2x3=10 each end of passing loop)
- 13 type 3 to type 3 beam hog connections are to be strengthened (4x2 at piers 46 to 50, +5 more in passing loop).

The above extents need to be confirmed as part of the detailed design and check process, and hence while the above quantities are appropriate for concept design and pricing of the strengthening scheme, quantities may be adjusted up or down as the design progresses.

5 Proposed strengthening details

5.1 General

The following sections describe the proposed details for the concept design. At this stage detailed design and check have not been undertaken. All details and extents need to be confirmed as part of the detailed design and check process, and hence while these details are considered appropriate, there is a risk that details will change.

5.2 Piers

The proposal is to strengthen the piers with inclined props as shown in sketch SK01 rev A in Appendix C. A total of 43 of the 88 piers are to be strengthened as shown within the scheme extents in Appendix D. The piers to be strengthened are generally the taller piers.

It is proposed to use the PERI HD-200 lightweight aluminium or steel system as the main prop elements. The props would be installed tight, but without any significant preload. Hence there is no expectation that the props push any piers back to the vertical position.

The propping is beneficial for the following reasons:

> the existing pier foundations are prevented from further rotation, which is thought to be the cause of the current bearing misalignments,

> the bending moments and shear forces in existing pier columns under imposed loads will be considerably reduced,

> shear in the crosshead outstands will be considerably reduced,

> propped piers will have much greater resistance to impact loads, especially from below, though the props themselves will be vulnerable.

One alternative option was considered but discounted. This was to surround the column pier with an offset concrete jacket which would strengthen the column and restore its stability. While this could achieve all the above aims, the prop proposal is thought to be more effective at preventing further rotation of the foundations, modular in nature and thus more buildable and cheaper to construct.

5.3 Anchor blocks

The proposal is to install additional bearings under the beams just above the anchor blocks as shown in sketches SK12 and SK13 in Appendix C. Five of the six anchor blocks require these additional bearings as shown within the scheme extents in Appendix D.

Laminated elastomeric bearings are proposed. In three of the five locations the new bearings can be supported on the anchor block as shown in SK12. In the remaining two cases the new bearings would be beyond the edge of the anchor block, so a new steel frame is proposed as shown in SK13. Steel frames have been chosen for ease of installation.

The additional bearings work by reducing bending moments in the beam ends that are cast into the anchor blocks. The elastomeric bearings are soft enough to provide sufficient support to live loads without causing the beam ends to rip out of the anchor blocks.

One alternative option was considered but discounted. This was to expose the end of the beam reinforcement extending into the anchor block and connect an extension bar anchored into the main body of the anchor block. While this would achieve the objective, access to the area is blocked by the rail expansion joints, and major works to remove and replace rails would be necessary to enable this option. There is also a significant risk associated with unknown construction details within the existing structure being exposed during any intrusive works. It was deemed more appropriate to mitigate this risk by adding to the existing structure and minimising any intrusive interventions.

5.4 Bearings

The proposal is to replace the existing two bearings at each pier and anchor block with three new bearings as shown in sketch SK05 rev A in Appendix C. All bearings are to be replaced.

An additional new third central bearing is to carry the lateral load only while outer bearings carry vertical load only.

The new bearings are needed for the following reasons.

- the existing bearings are thought to be significantly overloaded,
- many of the bearings are now misaligned, and replacement is the only realistic option to prevent them sliding beyond the extent of their sliding surfaces.

No valid alternative options to the three-bearing arrangement have yet been identified. Despite extensive efforts involving bearing suppliers a solution for replacement with just two new bearings at every pier has not been found (refer to Appendix B for more detailed technical information). The difficulty is designing a bearing to carry the required combination of high lateral and low vertical loads, while fitting within the space available using the existing bearing fixing centres. Further design development may show that it is possible to replace with two bearings for areas below the passing loop where wind loads are less severe, but this has not yet been proven.

The remaining problem identified in the appraisal is that the bearings have no resistance to uplift. The proposal is not to design new bearings for uplift but instead to revise emergency procedures.

Uplift only occurs under the accidental design situation for the areas in and above the passing loop. Currently, in the event of a breakdown and an approaching storm, the emergency procedure is to clamp the carriage to the tracks and install a 5 tonne kentledge in the carriage. This prevents the carriage wheels lifting off the track but in areas above the passing loop does not prevent the bearings uplifting off the piers. A revised emergency procedure might include either some sort of tie-down between deck and pier, or to install a greater weight of kentledge.

Alternative solutions to the uplift problem have been considered. Uplift bearings are available, but as the fixings to the beam and to the pier crossheads do not have any capacity for uplift, no benefit would be achieved. Other options are to accept uplift providing this does not lead to instability or damage, or to accept the risk of damage on the basis that no-one's safety is at risk during such an extreme event.

The implications of any of the approaches noted above needs further consideration between operator, designer and regulatory bodies. Management of residual risk may prove an appropriate mitigating method to reduce whole life costs for the funicular in managing an extreme, rare event.

5.5 Beam shear strengthening

The proposal is to strengthen the main deck beams with external bars as shown in sketches SK14 and SK15 in Appendix C. Beams at all 88 piers have scarf joints and all are to be strengthened as shown in SK14 - a total of 360 joints. Many beams are also to be strengthened at the first crossbeam as shown in SK15, and some beams are to be strengthened up to the second crossbeam. Strengthening locations and scheme extents are given in Appendix D.

The strengthening comprises a series of galvanised yokes and stainless steel preloaded bars installed perpendicular to the rails at around 450mm spacing, fitted between the track supports which are at nominal 900mm spacing.

The strengthening works as follows. According to the "truss analogy" used in reinforced concrete design, concrete webs develop tension when subject to shear. In this structure the shortfall in shear strength along the length of a pre-cast beam is due to a lack of reinforcement in the beams. This reinforcement is intended to resist tension within the section. By pre-compressing the concrete, the concrete can carry much more shear before the web develops net tension.

Several alternative options were identified but discounted as follows:

- Extended bearing plates could have been used at scarf joints to reduce the quantity of strengthening, but these would not have been simple to install and would occupy space needed for new bearings. This would not address strengthening the scarf joints but may have prevented disproportionate collapse in the event of a failure of the scarf joint.

- Longitudinal prestress bars could have been used to relieve shear near the ends of beams, but there were difficulties finding practical ways to connect the prestressed bars to the concrete beams.

- Internal reinforcement could be added to be beams, but this requires very extensive site work including hydro demolition and insitu concreting. The extent of site work coupled with the significant risks of intrusive interventions to a structure with unknown as-built construction details, led to this option being discounted.

- Fibre reinforced plastic (FRP) wraps could be added to the beams, but this also requires extensive site work including insitu concreting. Wrapping FRP would prove difficult given the constraints of the rail on the top flange.

5.6 Continuity strengthening

The proposal is to install new reinforcement where type 3 beams are connected at piers. The new bars will be within the insitu concrete at the piers but connected to existing reinforcement in the beams. A total of 10 of the 88 piers are to be strengthened in this way as shown in sketch SK11 in Appendix C. These are locations where the track is tightly curved in plan and concentrated at and below the passing loop.

The benefit of the new bars is greater control of cracking at these piers and hence an improvement in future durability. Currently there is a lack of reinforcement continuity and large cracks have been observed. The new bars cannot prevent cracking but will control crack widths to a width that reduces future corrosion.

An alternative option is simply to omit this element of the strengthening, and accept the risk of future deterioration. These bars are not needed for strength.

6 Budget estimates

6.1 Estimating method

The strengthening cost estimate is based on the extents described in section 4.3 above and the details described in section 5 above.

The cost estimate for the strengthening has been determined with the assistance of BAM construction. Two versions have been considered, one with construction spread across two summer seasons and one with construction in a single summer season only. The full report including all assumptions and outline programmes are given in Appendix F.

The following key assumptions were made:

- In the two season option the strengthening is constructed over 2 summers: 2020 and 2021, the summer season extending from late May to late October. This includes approximately 5 weeks terminal float.
- In the single season option the strengthening is constructed in the summer of 2020, from early April until late November. This also includes 5 weeks float.
- A review of using a temporary cableway similar to that used in construction proved prohibitively expensive. Helicopters are used to transport materials from a base at the bottom car park to the work sites. In the version with construction in one season, two helicopters would be required at peak periods. The funicular is not available to assist with construction, and no temporary cableway is installed. The single season option relies on the use of purpose built rail mounted lifting trolleys.
- Excavations for foundations are generally carried out by low ground pressure excavators below the passing loop and spider type excavators above the passing loop. All excavations are made good after completion of the works to restore the existing surface material.
- Surplus excavated material is not disposed off-site.

6.2 Construction cost

For either the two season or one season versions, the estimated cost is £5.6 million with a +/-20% margin of error excluding the material cost of the vertical load bearings. This is estimated to add £0.25 million giving a total of £5.85 million +/-20%. The estimate includes 5% for risk and is based on 3.7% Retail Price Index.

6.3 Commentary

The cost estimating exercise is derived using assumptions on productivity, material availability and construction sequencing and methods. Commentary on BAM's report and programmes are included in Appendix F.

Clearly construction over single season requires simultaneous working at more work fronts than the two season option. The two options are the same cost, but the sensitivity to cost increases for weather downtime will be higher for the single season option due to the higher resource levels that are needed on site in order to achieve the accelerated programme.

The single season option is based on an earlier start and later finish than the two season option. Therefore the single season option carries significantly greater weather risk than the two season option, and there is potential overlap with the ski season.

As discussed in section 4.2, enhanced inspection and maintenance will be required to mitigate any accelerated deterioration of the structure but this comes at a cost. No whole life costing has been included in this study for any operator in the future. These long terms costs need consideration when strengthening an existing structure. Assets of the nature of the funicular railway benefit from pro-active management.

The estimate provided is for construction costs only. Additional costs which are not accounted for in this estimate include:

> Project management

> Detailed design and independent check

> Tender document drafting to enable procurement.

> Costs of approvals and liaison with regulators and stakeholders

> Site supervision and designer liaison to address queries or unexpected conditions during construction.

6.4 Further development

To refine the budget estimate the following items could be developed further:

> In view of the considerable cost of helicopter deliveries, reconsider the possibility of using the funicular to aid construction.

> Considerable cost reductions would be achieved by minimising the volume and depth of concrete foundations. This would be a priority for design development of this element of the works.

- Develop bearing designs further to try to eliminate the need for the central bearing in some areas of the viaduct.

COWI recognise that the impact on the local area of the closure of the funicular is significant and the prospect of the closure extending until the end of 2021 is likely to be of great concern. Full unrestricted re-opening of the funicular before the end of 2020 at the earliest carries considerable risks due to the assumed construction period and associated weather risk. These need consideration whilst managing the expectations of the community and public. Even with adequate risk management and contingencies in place during the single season construction programme, there remains a significant risk that environmental conditions experienced on site would prevent achieving this programme.

7 Safety and environment

7.1 Health and Safety

As a designer under the Construction (Design and Management) Regulations 2015, commonly referred to as the CDM Regulations, COWI UK has the following duties at this stage:

- a duty to consider how health and safety risks encountered during construction, maintenance and eventual demolition can be reduced or eliminated;

- a duty to provide information about health and safety risks which cannot be eliminated.

To discharge these duties, COWI UK has assessed health and safety risks and compiled a designer's risk register for the concept design, together with a design decisions log. These are included in Appendix E.

As a designer, COWI must also make the client aware of their obligations under the regulations. COWI have contacted HIE separately regarding their obligations. We further note that a Principal Designer must be appointed before design proceeds to the next stage.

7.2 Sustainability and Environment

The Cairngorm Funicular Railway is situated in a Site of Special Scientific Interest (SSSI) and hence any ground works is highly undesirable.

The most environmentally sustainable strengthening solutions are generally those that preserve existing assets as far as possible. The proposed strengthening to piers and anchor blocks is necessary to achieve this, and hence some ground works are inevitable.

On this project access to work sites is difficult owing to the sloping ground. Some temporary access roads may need to be constructed - this is likely to have a greater effect than the works themselves.

The proposed strengthening in this report has been developed to minimise the amount of work as far as possible. This includes options with minimum material content, and options which avoid the need for heavy plant and equipment.

A designers' environmental risk register is included in Appendix E.

8 Conclusions

8.1 Summary

The viaduct supporting the Cairngorm Funicular Railway is unable to support its original design loadings in its current condition.

A strengthening scheme has been devised to address the failings. The components of the strengthening scheme are described and matched to the deficiencies as shown below:

Element	Deficiency	Strengthening solution	Strengthening extent
Main beams	Many spans are overloaded in shear	Strengthen all scarf joints and overloaded beams using external bars	360 joints. 166 out of 388 beam ends to 1st crossbeam (approx 40%), 20 to 2nd crossbeam (approx 5%).
	Risk that all scarf joint have deficient shear strength		
	5 spans are overloaded in hog bending where cast into anchor blocks	Install new bearings at anchor blocks	5 out of 6 anchor blocks
	Severe cracking at piers which could lead to reinforcement corrosion and hence a further loss of strength in future	Reinforce all type 3 beam connections	13 insitu joint locations at 10 piers (26 repairs)
Bearings	At low temperatures some bearings will travel beyond extent of sliding surface due to misalignment	Replace all bearings - now 3 bearings per pier	196 existing bearings plus 97 new lateral guides.
	On all spans vertical and lateral load capacity is exceeded		
	Bearings are unable to resist uplift	None - Revise emergency procedures	
Piers	Crossheads are overloaded in the steepest part of viaduct	Install props wherever pier and/or pier crosshead is overloaded or pier is at risk of collision	43 out of 88 piers resulting in 46 prop locations (approx 50%)
	Columns overloaded in bending and shear on the taller piers		
	Piers have low resistance to collision load and could fail if impacted		
Pier foundations	Many piers are thought to have rotated due to the inclined bearing loads, but it is not thought this rotation will lead to collapse		

Table 2 Summary of deficiencies identified in the appraisal

The estimated cost of the strengthening has been determined as £5.85 million with a +/-20% margin of error.

Two programme options for the concept strengthening scheme have been explored. One would take place over two summer seasons with completion in October 2021, the other in a single season with completion in November 2020. The single season option assumes a longer construction period of early April to late November and is significantly more exposed to the risk of poor weather. Both approaches deliver the scheme to the same cost estimates.

Alternatives to strengthening exist. Options are discussed in section 3 above.

8.2 Further work

The concept strengthening scheme described in this report has been devised for cost estimating purposes only. The design needs to be developed into a detailed design prior to construction.

Changes to the emergency operating procedures are recommended to address the risk of bearing uplift. Possible actions are described in section 5.4 above.

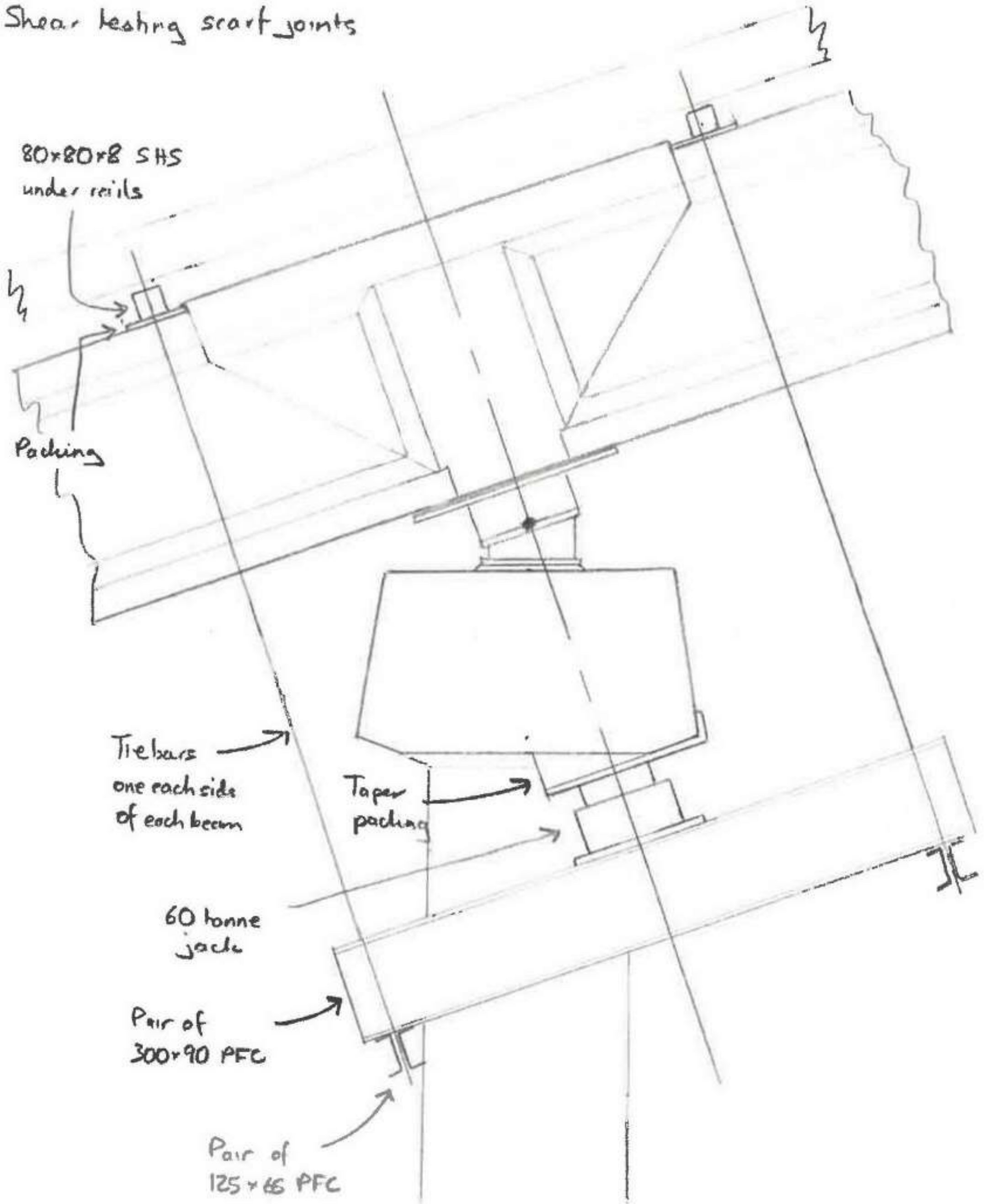
If it is considered necessary to refine the budget price, further development could be undertaken to address the items listed in section 6.4 above.

Appendix A Testing details

Sketch - Shear testing scarf joints

COWI	Project: CAIRNGORM RAILWAY	Doc Nos:	Rev:
			Page:
	Subject: TESTING	Prepared: [redacted]	Date: 28/2/17
Office/Discipline:		Checked:	Date:
BRISTOL / BRIDGE	ATR/Job: A116993	Approved:	Date:

Shear testing scarf joints



Max load

Peak load to be 1.1 × maximum ULS line shear on scarf joint

Note: max ULS line shear = 200kN typical, but 260kN in passing loop

Test method

Load in 10 equal increments with 30s hold points

Measure deflections and observe cracks at each increment (white paint may be useful)

Abort test if severe cracks or deflections become non-linear

Hold final load for 5min

Appendix B Technical notes

TN-03-013: Technical note on bearing articulation

TN-03-014: Technical note on feasibility of a like-for-like bearing replacement

HIGHLANDS AND ISLANDS ENTERPRISE

CAIRNGORM FUNICULAR RAILWAY

BEARING REPLACEMENT OPTIONS

A REVIEW OF ARTICULATION ARRANGEMENT

ADDRESS COWI UK Limited
Bevis Marks House
24 Bevis Marks
London
EC3A 7JB

TEL +44 207 9407 600
WWW cowi.com

CONTENTS

1 Current bearing details

Detailed drawings of the existing bearings are not available. The available information on the bearing details is limited to that shown in the original design drawings and site observations. It is believed that the bearing assemblies consist of a bottom plate, pot bearing, sliding surface, and top plate, as shown in Figure 1. Note that the presence of an elastomeric "pot" permitting rotation has not been verified but is believed to be the most likely configuration. At each pier, one bearing includes a sliding lateral guide to resist transverse loads.

The bearing assemblies have a total depth of 114 mm according to the design drawings, which is consistent with site measurements. The guide width on the guided bearings is not reported but has been scaled from drawings and photographs to be approximately 50 mm.

At the top connection, the bearings are bolted to 20 mm thick plates on the rail support beam soffit. "Tang" plates are welded to the soffit plates and embedded into the in-situ joint concrete (Figure 3 and Figure 4).

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At the bottom connection, the bearings are bolted to either a tapered plate or a steel bearing shoe. The bottom connection type varies with angular inclination. Piers with greater than 9.2° inclination use steel bearing shoes, whilst all others use tapered plates. The tapered plates / steel shoes are welded to dowels that extend approximately 150 mm into grouted pockets in the crosshead beams (Figure 5).

At the anchor blocks (i.e. just below the movement joints) tapered plates / steel shoes are not used as the inclination of the anchor block concrete face approximately matches that of the rail support beams. The bearings are therefore bolted to flat plates that are welded to dowels penetrating into the anchor blocks (Figure 6).

The tapered plates / steel shoes are supported on grout pads. The thickness of the grout pads varies to accommodate construction tolerances but are generally around 50 mm.

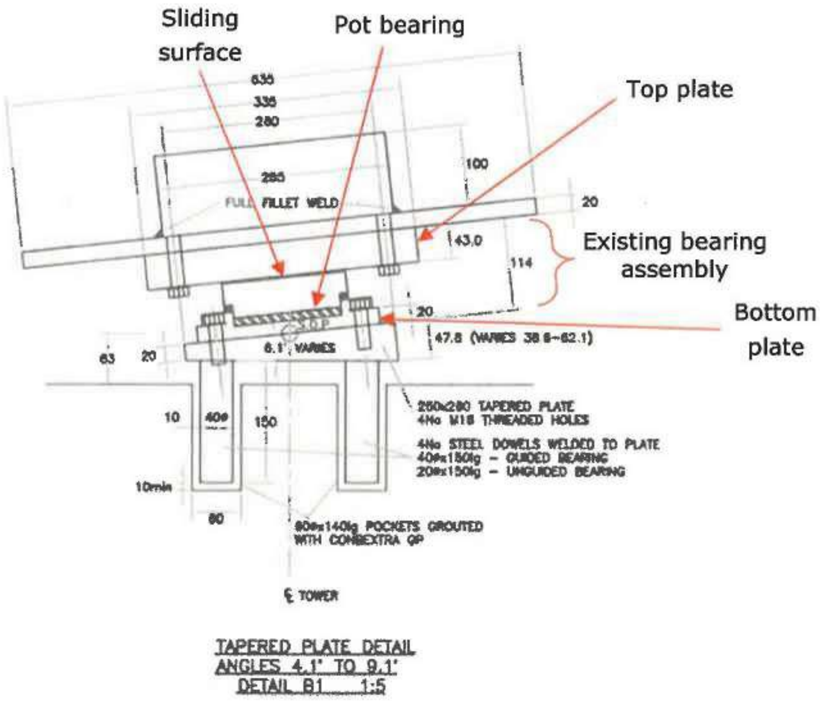


Figure 1 *Current bearing detail at piers with tapered plates (tapered plates used at 62 No. locations)*

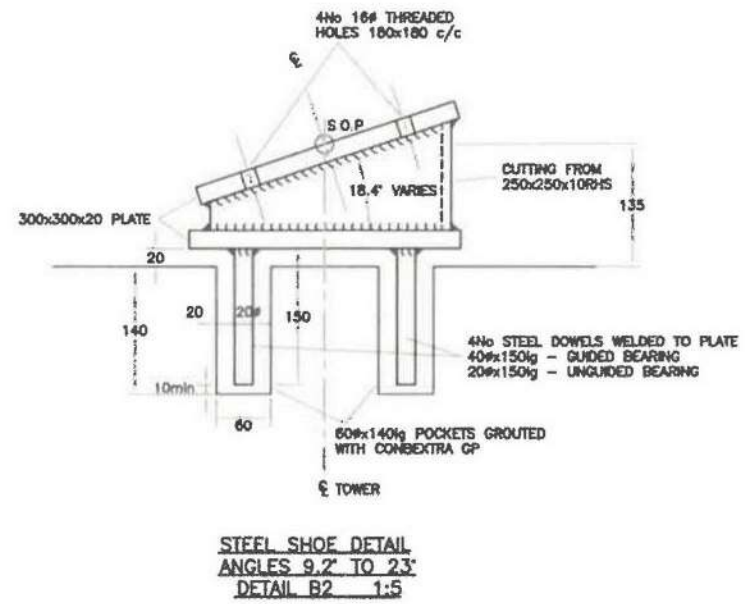


Figure 2 *Steel shoe detail (134 No. locations). Bearing detail otherwise the same as with tapered plates.*

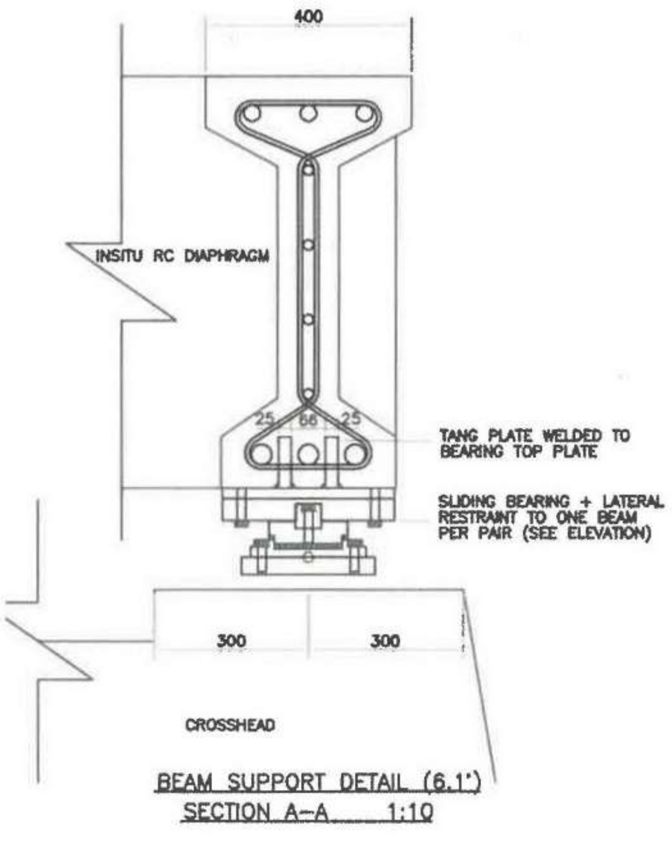


Figure 3 *Cross-section of rail support beam at bearing location (guided bearing shown).*

Figure 4 *Photograph of beam soffit plate and "tang" plate assembly prior to pour of in-situ concrete*

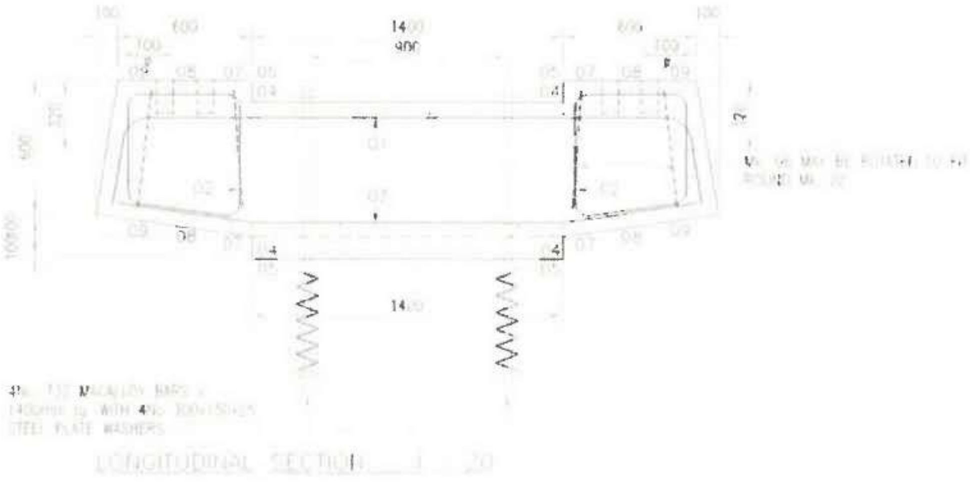


Figure 5 *Crosshead beam detail showing pockets for bearing dowel connection*

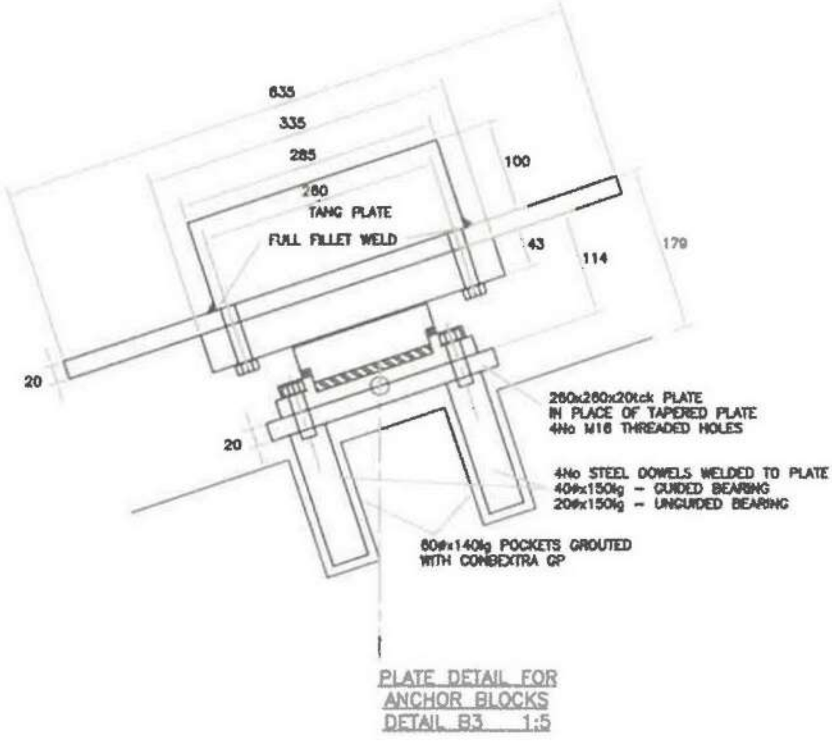


Figure 6 Bearing detail at anchor blocks

Figure 7 Example of free sliding bearing with tapered bottom plate.

Figure 8 *Example of guided bearing with tapered bottom plate*

Figure 9 *Example of free sliding bearing with bottom steel shoe*

Figure 10 Example of guided bearing with bottom steel shoe

2 Replacement options

Observations of the bearings by COWI and ADAC Structures Ltd. have noted that the bearings are misaligned to original design intent (see Section 2.3). As the bearings approach their assumed design life of circa 20yrs the PTFE sliding surfaces are exhibiting significant wear. The bearings have also been calculated to be ~50% overstressed due to SLS loading at the operational wind case, using BS 5400-9.1 criteria. Bearing replacement is therefore deemed necessary, with the new bearings being modified to prevent overstress from occurring.

Two options for bearing replacement are here discussed: (1) maintaining the current bearing inclination, or (2) replacing the inclined bearings with flat bearings with sliding surfaces true to horizontal.

2.1 Keep bearings inclined

Replacing the bearings and keeping the existing inclination would have the following advantages and disadvantages.

Advantages:

- Simpler to replace. Could likely keep beam soffit plates and tapered plates / steel shoes as they are. The photographs of the bearings appear to show adequate dimensions to allow for an increase in sliding surface / pot elastomer area without needing to modify the bolt spacing (a free sliding bearing diameter of 120 mm would give an SLS pressure of approximately 25 MPa and a ULS [accidental wind case] pressure of approximately 45

MPa; the guided bearing is not currently overstressed due to the normal reaction except due to the ULS accidental wind case, with an SLS pressure of approximately 32 MPa).

(Note that keeping the steel shoes assumes that they are in adequate condition. Possible observations of cracks in the shoes by ADAC Structures Ltd. may further investigation and necessitate replacement of the shoes. Replacement of the shoes would either require destructive works in the crosshead beams or site fabrication works to replace the existing hollow sections.)

Disadvantages:

- Does not help with the problems relating to overload of the substructure. Further strengthening works on the substructure would be required.

2.2 Convert to flat bearings

Replacing the bearings and switching to zero inclination could involve essentially inverting the current system, with tapered plates / steel shoes now attached to the beam soffit and a flat plate system on the crosshead beams. It would have the following advantages and disadvantages.

Advantages:

- Removes much or all of the problems relating to overload of the substructure. This would prevent any need to strengthen the piers or foundations.

Disadvantages:

- Assuming that it is impractical to cut the tapered plates or steel shoes on site, destructive works to the crosshead beams maybe required to remove the tapered plates / steel shoes. Destructive works to the beams / in-situ joints would possibly also be required if the new inverted tapered plates / steel shoes could not be attached to the existing soffit plate.

  If the superstructure is to be replaced, it may be simpler to also replace the crosshead beams when removing the tapered plates / steel shoes. The post-tensioned connection between crosshead beams and pier may make for a relatively simple replacement procedure.

  An alternative option may be to install additional inversed taper plates / shoes that effectively create flat surfaces. However, this would require raising the elevation of the track to accommodate the additional taper plates / shoes, which would also necessitate modifying works at locations where the track level is fixed (anchor blocks, tunnel entrance, etc...).

- Additional local axial, bending, and shear stresses may be induced in the rail support beams due to thermal expansion / contraction. The axial compression that is currently induced in the rail support beams due to dead load would no longer occur, which may lower the moment or shear capacities of certain areas of the beams.

- Change in the rail level above the bearings would occur due to thermal expansion / contraction. At the anchor block bearings, this could create a prohibitive change in rail level across the movement joints (see Figure 11). A way of preventing this effect is discussed in the following Section 2.2.1.

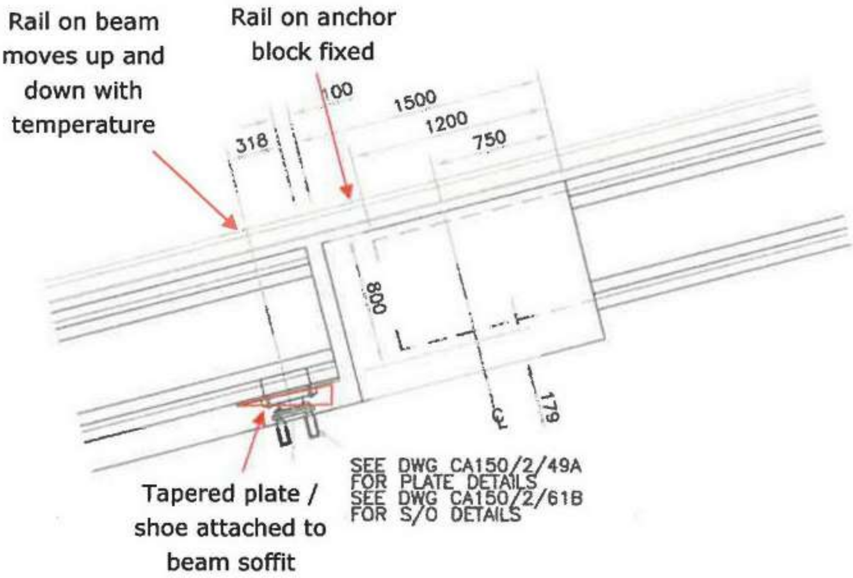


Figure 11 *Effect of flat bearing on rail level at movement joints*

2.2.1 Convert to flat bearings except at anchor blocks (movement joint)

This option is essentially the same as converting to flat bearings but keeping an inclined bearing at the anchor block, which removes the issue of a change in rail level across the movement joint (Figure 11).

However, this option increases the stresses that must be carried by the beams in the span immediately below each movement joint. When thermal expansion occurs, the end of the span at the movement joint will be pushed upwards by the inclined bearing, relative to the pier below. When thermal contraction occurs, the end of the span at the movement joint must deflect downwards under its self-weight to maintain contact with the inclined bearing.

Calculations were undertaken to quantify these effects, based on the assumption that the final span deflects as a cantilevered beam. Partial factors for BD 37 combination 3 were used as the stresses of concern are thermal in nature. It was found that differences in temperature of ±25°C would cause a maximum differential vertical movement of ±25mm, a maximum change in reaction at the inclined bearing of ±7kN, and a maximum change in moment at the pier below the movement joint of ±120kNm.

For the case of thermal expansion, the bending moments induced at the pier below each movement joint would be sagging (i.e. tension on the beam bottom). The beam bottom reinforcement is not continuous through the in-situ joints. Note that due to the construction method, the dead load does not create a permanent hogging moment at supports that would prevent a net sagging moment from developing under such thermal loading. Strengthening works would therefore likely be required to prevent sagging moment failure.

2.3 Correcting the misalignment

Regardless of which option is chosen, if the superstructure is to be kept, steps must be taken to correct the current bearing misalignment. The bearing misalignments measured by ADAC Structures Ltd. and extrapolated to a temperature of 5°C are given in Figure 12. A temperature of 5°C was used as this is the midpoint between the minimum (-19°C) and maximum (29°C) effective bridge temperatures, as described in the Schedule of Basic Assumptions. The misalignments are in all cases positive (i.e. reducing available space for contraction) and less than 120 mm.

If the superstructure is to remain and the bearings kept inclined, a simple way to deal with the misalignment is to use a new bearing top plate that extends to the end of the beam soffit plate, as shown in Figure 13. As the beam soffit plate is 635 mm long and the existing bearing top plates are 335 mm long, this would give an additional 150 mm available for contraction. Additional bolts could be added into site-drilled holes in the soffit plates if required.

A drawback to this method is that the misalignment between the piers and superstructure joints / diaphragms would remain. At extreme cold temperatures, the bearing centreline could be as much as 200 mm misaligned from the joint centreline. This method would also need modification to work in the passing loop where beams are terminated at diaphragms, as the 635 mm long soffit plates extend past the diaphragm width and therefore cannot support load.

Another option for dealing with the misalignment is to attempt to straighten any piers that are leaning in the uphill direction. Note that it has not definitively been determined that all bearing misalignments are due to leaning piers, and therefore further site investigations would be required to verify this before proceeding with this option. This option is not recommended due to high cost and uncertainty.

If the superstructure is to be replaced, the current bearing positions can be accounted for in the new design.

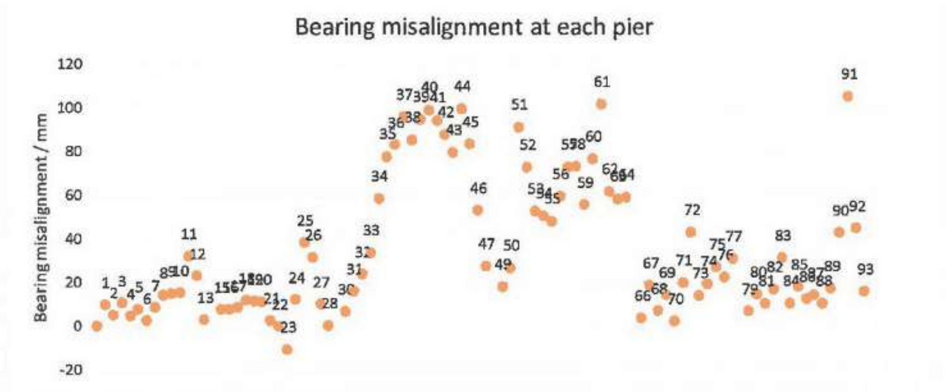


Figure 12 *Theoretical bearing misalignment at 5°C*

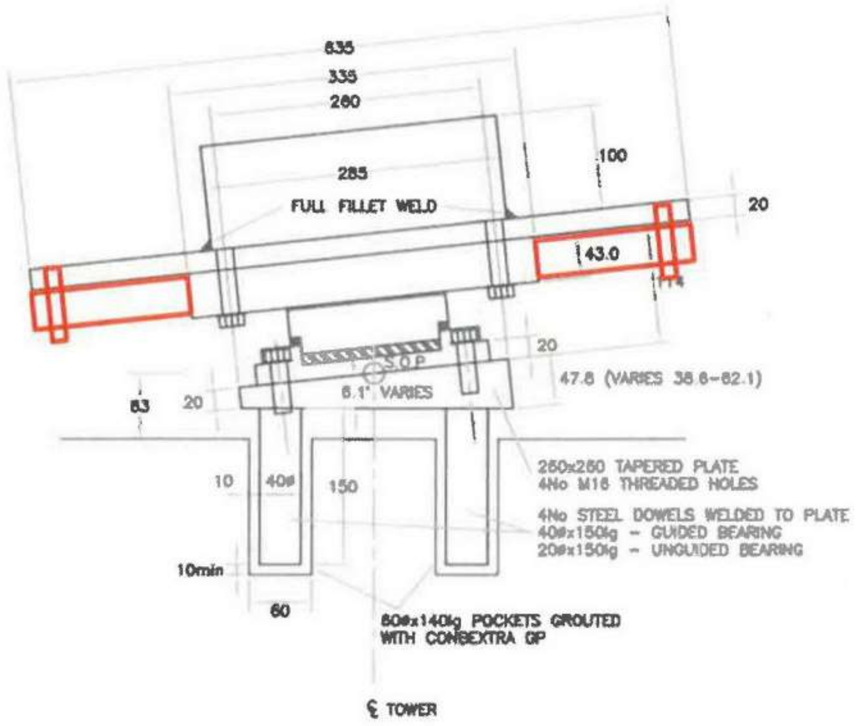


Figure 13 *Option for dealing with misalignment if keeping inclined bearings – use of extended bearing top plate (with possible bolt into site-drilled hole in beam soffit plate)*

3 Recommendation

The following recommendation is based on the assumption that the existing superstructure will remain. If a decision to replace the superstructure is pursued, this recommendation would have to be revisited.

Modification of the current bearing system to incorporate true to horizontal sliding surfaces would eliminate the need for substructure strengthening and also likely prevent any future misalignment due to rotation of the piers. However, these advantages are deemed to be insufficient to justify such a bearing replacement scheme for the following reasons:

- The considerable destructive / fabrication site works required would likely more than negate any economic advantage due to reduced substructure strengthening. Additional strengthening works to permit sagging moment across certain piers would also likely be required (see Section 2.2.1).

- The advantage of preventing any potential further misalignment due to pier rotation may be covered regardless, as the favoured substructure strengthening scheme involves propping of the piers. The piers scheduled for strengthening include those with the largest existing misalignment.

- The local stresses that would be induced in a superstructure with flat bearings due to thermal movements are difficult to accurately predict using analytical methods. These stresses could result in cracking and durability issues over the long term.

It is therefore recommended that maintaining inclined bearings be pursued as the favoured option, despite the associated substructure strengthening requirements. Simple extensions to the top bearing plate can be used as a cost-effective method of allowing for the existing bearing misalignment.

HIGHLANDS AND ISLANDS ENTERPRISE

CAIRNGORM FUNICULAR RAILWAY

BEARING REPLACEMENT

FEASIBILITY STUDY FOR A LIKE-FOR-LIKE REPLACEMENT

ADDRESS COWI UK Limited
Bevis Marks House
24 Bevis Marks
London
EC3A 7JB

TEL +44 207 9407 600
WWW cowi.com

CONTENTS

ANNEXES

PROJECT NO	DOCUMENT NO
A116993	TN-03-014

VERSION	DATE OF ISSUE	DESCRIPTION	PREPARED	CHECKED	APPROVED
V1.0	03-04-2019	For Information	[redacted]	[redacted]	[redacted]

[redacted]

1 Introduction

As part of the strengthening scheme design works, COWI worked with bearing suppliers on a feasibility study for the design of like-for-like replacement of bearings. In this context, "Like-for-like" replacement refers to maintaining the existing bearing articulation within the existing bearing footprint. A like-for-like replacement would require a bearing of larger capacity to fit into existing geometric restraints and bolt attachment positions.

The benefit to a like-for-like replacement for bearings is the elimination of intrusive works at the pier locations. Any remedial works to refurbish bearing fixings would be cumbersome, timely and thus expensive. Pursuing a solution that minimised intervention and reduced risk would benefit both budget and programme.

The preliminary bearing replacement design assumed the following:

1 The existing viaduct superstructure will remain, albeit with strengthening.

2 The existing upper and lower bearing plate will remain with the associated lower taper plate inclination as recommended in the bearing articulation review (see COWI technical note TN-03-013).

3 The Accidental wind case will be considered as a Eurocode Accidental Design Situation. Therefore, all ULS load partial factors are taken as 1.0 and the case is not considered at SLS (as recommended in COWI technical note TN-03-012).

2 Design requirements

2.1 Loads

A.F. Cruden Associates design drawing CA150/2/42 shows a table of "horizontal" and "vertical" bearing loads that are assumed to have formed the basis for the initial bearing design specification. It is assumed the "horizontal" and "vertical" loads correspond to the transverse horizontal force and the normal force, respectively.

These loads are considerably different from those obtained by COWI during the structural appraisal. Table 1 shows a comparison between the two sets of loads. The maximum transverse and normal forces from the design drawings are approximately 30% and 50% lower than those determined by COWI. The design drawings also show uplift as occurring at SLS, but COWI's appraisal found that there is always a compressive normal force at SLS. Both sets of loads have comparable ULS uplift forces.

The full set of loads used for COWI's concept bearing replacement design are given in the bearing schedule shown in Annex A. Note that the ULS uplift loads were not considered in the design. Instead, a minimum normal force of +20kN (compressive) was used at both SLS and ULS. This was because, despite the design drawings showing uplift forces, the existing bearings are not believed to have any capacity to resist uplift. The existing fixing details to the rail support beams and pier crossheads also do not have the capacity to transfer uplift loads. Uplift only occurs in the upper half of the viaduct. Possible methods for dealing with uplift loads in detailed design are further discussed in Section 4.

Table 1 *Comparison of critical bearing loads from the design drawings and COWI's structural appraisal*

Parameter	ULS (kN)		SLS (kN)	
	From design drawings	From COWI appraisal	From design drawings	From COWI appraisal
Transverse force	282.4	380	157.7	230
Normal force (max)	214.9	475	177.8	375
Normal force (min)	-48.4	-65	-25.4	20

2.2 Articulation

A.F. Cruden Associates design drawing CA150/2/42 shows a "required movement" of ±75mm longitudinally.

Based on critical effective bridge temperatures calculated to BD 37/01 and a coefficient of thermal expansion of 12×10^{-6} °C^{-1}, COWI determined a critical SLS (i.e. unfactored) longitudinal movement of ±95mm from a baseline temperature of +5 °C. Note that this demand only occurs at one place: the joint at the top of the longest freely articulating "area" of the viaduct (located at the movement joint on the lower side of anchor block 48). Thermal movement demands are considerably lower at many other areas of the viaduct and vary with distance away from the fixed anchor block supports.

The design of the replacement bearings also had to consider the existing bearing misalignment. Data from a survey of bearing positions by ADAC Structures Ltd. was analysed to determine theoretical bearing misalignments at +5 °C. The maximum misalignment at +5 °C is 112mm. However, this misalignment does not coincide with the location of maximum thermal movements. Pier 44 was found to have the maximum combined misalignment plus thermal movement (approximately 180mm). A misalignment of 85mm (180mm total minus 95mm thermal) was therefore considered in the replacement bearing design. (Note that the misalignment generally only increases the articulation demands associated with contraction of the superstructure.)

Critical rotations were taken from the global line beam analysis, further discussed in the appraisal report.

The full set of articulation demands used in the concept bearing replacement design are given in the bearing schedule shown in Annex A. Note that misalignment was treated as an "irreversible translation" and not factored at ULS. Critical SLS (unfactored) thermal movements were multiplied by a factor of 1.3 to obtain the ULS thermal movements.

2.3 Existing fixing details

The primary reason for maintaining the inclination of the existing bearings in the concept replacement bearing design is the high cost of works associated with modifying the bearing fixings. The existing fixing details were therefore included as a constraint on the concept design.

The existing fixing details are summarised in Figure 1 and Figure 2. These are indicative and merely shows the typical bolt spacing of upper and lower plates Note that the base plate configuration shown is replaced by a built-up hollow section bearing shoe at some piers, but the bolted connection details remain the same. The key constraints are as follows:

- The existing beam soffit plate and base plate are a minimum of 20mm thick. It is assumed the existing plate receives an M16 bolt in blind holes; the same diameter as the existing bolts. Given the considerably higher loads in the replacement bearing design compared with the original design, additional bolts were required to be permitted in the replacement bearing design.

- The existing base plate has four M16 bolts at 180mm square. Additional bolts can be added to site-drilled threaded holes, but the new bolt pattern must remain within the 180mm square area. Wider bolt spacing would either interfere with the hollow sections (at the locations with bearing shoes) or prevent the minimum edge distance from being achieved.

- The existing beam soffit plate is 635mm long. The new bearing top plate and sliding surface must fit within this length while still allowing for the full translation demand due to misalignment plus thermal movements.

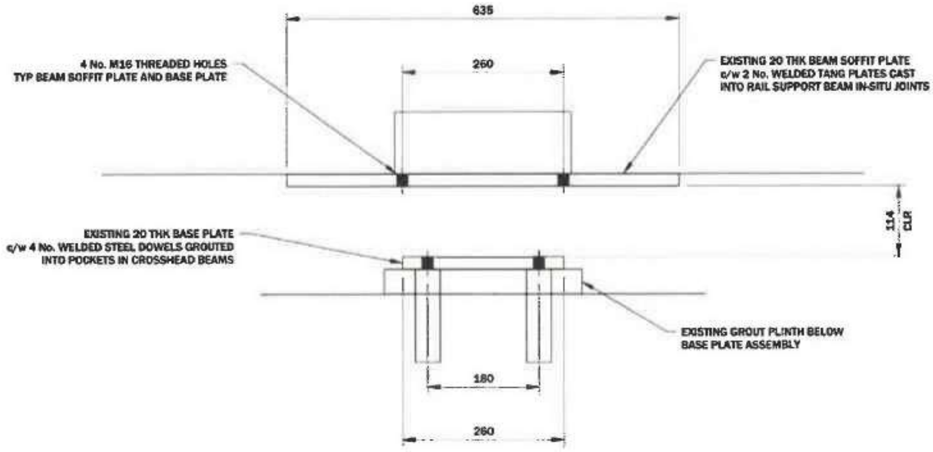


Figure 1 Sketch highlighting typical fixing dimension details – longitudinal section

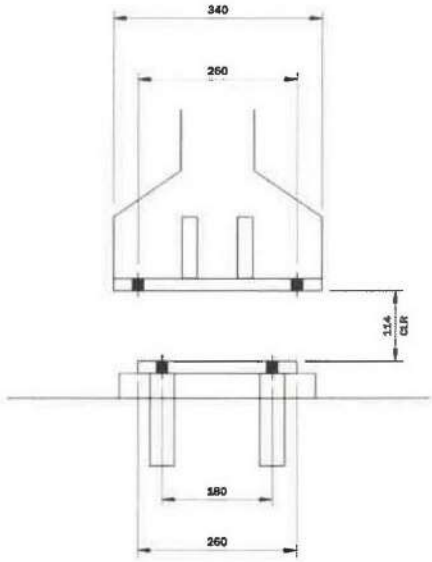


Figure 2 Sketch highlighting typical fixing dimension details – transverse section

The full set of fixing criteria used in the concept bearing replacement design are given in the bearing schedule shown in Annex A.

3 Bearing supplier design review

Two bearing suppliers were provided with the preliminary bearing schedule and requested to investigate the feasibility of a like-for-like bearing replacement scheme. Both suppliers determined that a replacement free sliding bearing could meet the design criteria, albeit with uplift ignored. However, both suppliers were unable to design a satisfactory replacement guided bearing. Design options for the guide bearing that were investigated included:

- A pot bearing + sliding surface + guide assembly (i.e. similar to the existing guided bearing)
- A link bearing (trunnion type) + sliding surface assembly
- A spherical bearing + sliding surface + guide assembly

The spherical guide bearing assembly designed by Ekspan was perhaps the closest to achieving the design criteria. Preliminary drawings of this bearing design are given in Annex B.

The primary issues preventing any of the guided bearing options from meeting the design criteria were as follows:

- A link bearing system was unable to fit within the overall height criteria (114mm)
- The maximum horizontal (transverse) load, in conjunction with the minimum normal compressive load, necessitated a considerably larger

diameter pot/spherical bearing and sliding surface than is used on the existing guide bearing. This created two problems:

- There was no clearance for the baseplate bolts to fit within the 180x180mm available area.
- The sliding surface could not remain within the available 635mm beam soffit plate length at the ULS translation demand.

The geometric constraints, although not present at all locations, resulted in both bearing suppliers being unable to achieve a like-for-like replacement for the guide bearing. The constraint of the base plate 180x180mm bolt fixings proved the most prohibitive problem.

4 Future recommendations for detailed design

A suitable like-for-like guide bearing design that would work for all piers could not be identified. However, the design criteria corresponded to the worst-case loads and translations of any guide bearing in the viaduct. In reality, the force and translation demands vary considerably along the length of the viaduct. It may be possible to use a like-for-like two-bearing replacement scheme at many of the piers by considering a pier-by-pier breakdown of demands during detailed design. The following factors are particularly likely to have a beneficial effect:

- Lower regions of the viaduct are subjected to lower wind speeds and therefore lower transverse forces and higher minimum normal forces. It is possible that a smaller diameter spherical (or pot) bearing could be used in these locations, potentially allowing the baseplate bolt configuration to fit within the available 180x180mm area.
- Regions of the viaduct that are close to an anchor block will exhibit smaller longitudinal thermal movements. Many piers also have limited misalignment. It is therefore apparent that the required upper sliding surface could easily fit within the existing 635mm beam soffit plate length in many cases.

Uplift was not considered in the concept bearing design as the existing fixings have no capacity to resist uplift. Consideration must be given to uplift in the detailed design. It is noted that uplift only occurs in the Accidental wind case (i.e. with a broken-down carriage clamped to the rails during a storm). Works to modify the existing bearing fixings to transmit uplift would likely be prohibitively expensive. Three alternate options for dealing with uplift during detailed design are presented here:

1 Allow uplift to occur. Bearing separation is undesirable, but given that it is only expected to occur in an extremely rare load case, it may be permissible to accept. If this option is pursued, detailed design would have to verify that the occurrence of uplift would not lead to instability or overstress in other areas of the structure.

2 If the Client is willing to accept additional residual risk, remove the Accidental wind case from the design basis entirely. (Note that this option would also reduce the maximum transverse loads and possibly permit a like-for-like replacement at more or all piers.)

3 Adapt the existing operating procedures in the event of a carriage breakdown that involves either:

> clamping the superstructure to the pier to prevent uplift, or

> adding additional kentledge to the carriage to prevent uplift. (Note that this would require on the order of 15 tonnes kentledge.)

5 Conclusions

Bearing design is governed by the combination of low vertical load and high lateral load. Using a single worst-case design bearing specification it has not been possible to confirm a like-for-like bearing replacement scheme is a viable option. However, given the wide variability of load combinations along the length of the viaduct, further detailed design may permit optimization of bearing types for a replacement scheme, thus reducing costs and programme.

Uplift is only critical in the upper half of the viaduct. Uplift could be resisted by additional strengthening and thus costs for preventative measures or HIE may wish to consider management of residual risk in operational management procedures. Further consideration to address uplift concerns are required during future detailed design.

Annex A Concept bearing schedule for a like-for-like replacement scheme

COWI

Bevis Marks House
24 Bevis Marks
London EC3A 7JB

Cairngorm Funicular Railway
Replacement Bearing Schedule

COWI ref:	A116993
Drawing Ref:	n/a
Revision:	preliminary
Date:	01-Mar-19

				Like-for-like replacement	
Symbolic representation of bearing functions (BS EN 1337-1 Table 1)					
Bearing type (BS EN 1337-1 Table 1)				2.3	2.2
No. required				99	97
Seating Material	Upper Surface			Existing steel plate	Existing steel plate
	Lower Surface			Existing steel plate	Existing steel plate
Allowable Average Contact Pressure (N/mm2)	Upper Face	SLS			
		ULS			
	Lower Face	SLS			
		ULS			
Wear Surface Dimensions (mm)	Upper Face		Transverse	340 max.	340 max.
			Longitudinal	635 max.	635 max.
	Lower Face		Transverse		
			Longitudinal		
	Pot		Transverse		
			Longitudinal		
Support Area (minima)	Upper Surface	Longitudinal (mm) (along bridge direction)		635	635
		Transverse (mm) (across bridge direction)		340	340
		Connection to superstructure		Tang plates cast into in-situ stitch joints	Tang plates cast into in-situ stitch joints
	Lower Surface	Longitudinal (mm) (along bridge direction)		260 (300 where bearing shoes are used)	260 (300 where bearing shoes are used)
		Transverse (mm) (across bridge direction)		260 (300 where bearing shoes are used)	260 (300 where bearing shoes are used)
		Connection to substructure		Doweled to crosshead beams	Doweled to crosshead beams
Maximum bearing dimensions (mm)	Overall height (mm)			114 (to match existing)	114 (to match existing)
	Upper surface		Transverse	340 (existing bolt holes at 260)	340 (existing bolt holes at 260)
			Longitudinal	635 (existing bolt holes at 260)	635 (existing bolt holes at 260)
	Lower surface		Transverse	260 (existing bolt holes at 180)	260 (existing bolt holes at 180)
			Longitudinal	260 (existing bolt holes at 180)	260 (existing bolt holes at 180)
Type Of Fixing Required		Upper Face		Bolt to M16 threaded holes	Bolt to M16 threaded holes
		Lower Face		Bolt to M16 threaded holes	Bolt to M16 threaded holes
Design Load Effects (kN)	SLS	Normal	Max.	375	375
			Permanent	80 (40 where beams are non-continuous)	80 (40 where beams are non-continuous)
			Min	20	20
		Transverse		n/a	230
		Longitudinal (i.e. in direction of local inclination)		n/a	n/a
	ULS	Normal		475	475
		Uplift		-65	-65
		Transverse		n/a	380
		Longitudinal (i.e. in direction of local inclination)		n/a	n/a
	SLS combination	Min. normal		n/a	20
		Max coincident transverse		n/a	230
	ULS combination	Min. normal		n/a	-65
		Max coincident transverse		n/a	340
Translation (mm)	SLS	Irreversible	Transverse	-	-
			Longitudinal	-85, +10	-85, +10
		Reversible	Transverse	-	-
			Longitudinal	±95	±95
	ULS	Irreversible	Transverse	-	-
			Longitudinal	-85, +10	-85, +10
		Reversible	Transverse	-	-
			Longitudinal	±125	±125
Rotation (radians)	SLS	Irreversible	Transverse	-	-
			Longitudinal	-	-
		Reversible	Transverse	-	-
			Longitudinal	±0.006	±0.006
	ULS	Irreversible	Transverse	-	-
			Longitudinal	-	-
		Reversible	Transverse	-	-
			Longitudinal	±0.008	±0.008
	Maximum rate (radians/100kN)		Transverse	-	-
			Longitudinal	-	-
Tolerable movement of bearing under transient loads (mm)			Vertical	small	small
			Transverse	-	small
			Longitudinal	-	-
Allowable resistance to translation under SLS loads (kN)			Transverse	-	-
			Longitudinal	-	-
Allowable resistance to rotation under SLS Loads (kNm)			Transverse	-	-
			Longitudinal	-	-

Notes:

1. Sign convention for longitudinal translation is as follows: negative refers to deformations associated with contraction of the superstructure; positive refers to deformations associated with expansion of the superstructure.

2. Longitudinal rotations refer to rotations about an axis perpendicular to the line of track, i.e. rotations associated with hogging or sagging of the superstructure.

3. It is assumed the new bearings will consist of a pot bearing and sliding surface assembly, similar to current arrangement.

4. Top and bottom existing bearing fixings are currently misaligned with one another by up to -115mm or +25mm at a reference temperature of 5°C. This misalignment has been included as an irreversible deformation in the design displacements.

5. It is assumed that all irreversible deformations other than the misalignment (e.g. creep) have already occurred and therefore need not be accounted for in design of the replacement bearings.

6. Provisions shall be made for all new bearings to be replaceable.

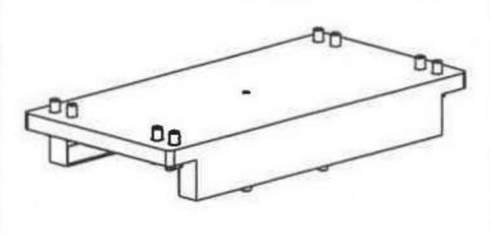
Annex B Ekspan guided spherical bearing preliminary design drawings

CUSTOMER / PROJECT DETAILS		
CLIENT / CUSTOMER	COWI	
PROJECT / STRUCTURE	CAIRNGORM MOUNTAIN RAILWAY	
PRODUCT POSITION REFERENCE (IF APPLICABLE)	GUIDE	
CLIENT / CUSTOMER DRAWING NO. (IF APPLICABLE)	A116993	
PRODUCT DETAILS		
TYPE	EN 1337 - 7 SPHERICAL BEARING	
DESCRIPTION	SPHERICAL BEARING, GUIDE (500kN) - 11GE0050-250	
EKSPAN DRAWING NO.	-	
EKSPAN CALCULATION NO. (IF APPLICABLE)	15508-GD-C01	
DESIGN PARAMETERS - LOADING		
	SLS (kN)	ULS (kN)
MAX VERTICAL LOAD, *Nmax*	375	475
PERMANENT VERTICAL LOAD, *Nperm*	40	-
MIN VERTICAL LOAD, *Nmin*	20	20
MAX TRANSVERSE LOAD, *Vy*	230	380
MAX LONGITUDINAL LOAD, *Vx*		
MAX COMBINED LOAD, *Vr*	-	-
DESIGN PARAMETERS - MOVEMENT		
	SLS +/- (mm)	ULS +/- (mm)
MAX TRANSVERSE MOVEMENT, *vy* (IRREVERSIBLE + REVERSIBLE)	-	-
MAX LONGITUDINAL MOVEMENT, *vx* (IRREVERSIBLE + REVERSIBLE)	180	210
	SLS +/- (Rad)	ULS +/- (Rad)
MAX TRANSVERSE ROTATION, *αy* (IRREVERSIBLE)	-	-
MAX LONGITUDINAL ROTATION, *αx* (IRREVERSIBLE)	-	-
MAX TRANSVERSE ROTATION, *αy* (REVERSIBLE)	-	-
MAX LONGITUDINAL ROTATION, *αx* (REVERSIBLE)	0.006	0.008

ISSUE / CHANGES

ISSUE STATUS	DESCRIPTION	DATE	AUTHORITY
1	PRELIMINARY ISSUE	19/03/19	-
2	PRELIMINARY ISSUE, INCREASE IN TRANSLATION	22/03/2019	

ISOMETRIC / DIMETRIC / TRIMETRIC VIEW



EKSPAN LTD
COMPASS WORKS
410 BRIGHTSIDE LANE
SHEFFIELD
S9 2SP

LATEST REVISION		ORIGINAL DRAWING	
DRAWN	[redacted]	DRAWN	[redacted]
DATE	22nd MAR 2019	DATE	19th MAR 2019
CHECKED	[redacted]	CHECKED	[redacted]

DRAWING NUMBER	15508-GD-00	ISSUE 2
ORIGINAL SCALE	1:10 U.O.S	SHEET 1 OF 2 SHEETS

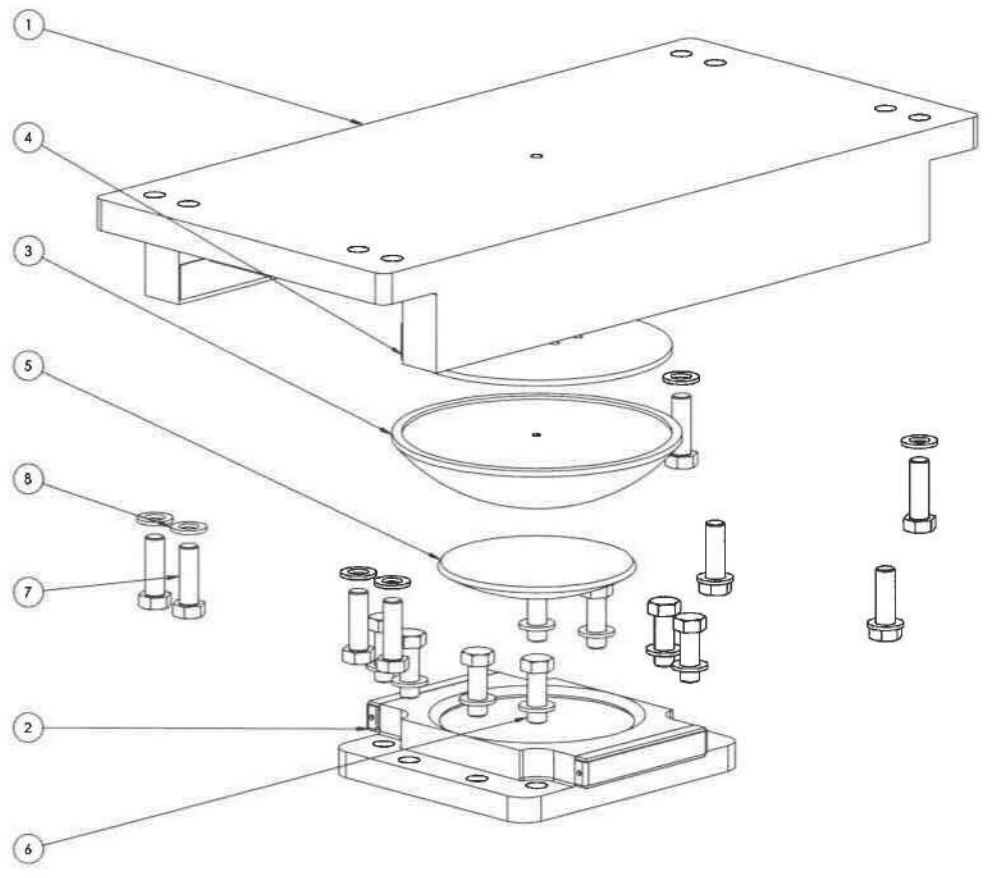
ITEM	DRAWING NUMBER	QTY	DESCRIPTION	MATERIAL
1	15508-GD-01	1	BEARING, SPHERICAL GUIDE, TOP PLATE SUB ASSEMBLY (500kN) - (12GE0050-100)	SUB-ASSEMBLY, REFER TO SPECIFIC DRAWING FOR DETAILS
2	15508-GD-02	1	BEARING, SPHERICAL GUIDE, BASE PLATE SUB ASSEMBLY (500kN) - 12GE0050-100	SUB-ASSEMBLY, REFER TO SPECIFIC DRAWING FOR DETAILS
3	15508-GD-30	1	SPHERICAL BEARING, FREE - PISTON (500kN) - 12GE0050	STAINLESS STEEL, BS EN 10088, 1.4404
4	15508-GD-60	1	SPHERICAL BEARING, FREE - FLAT PTFE (500kN) - 11GE0050	DIMPLED VIRGIN PTFE
5	15508-GD-65	1	SPHERICAL BEARING, FREE - SPHERICAL PTFE (500kN) - 11GE0050	DIMPLED VIRGIN PTFE
6	ND	8	HEXAGON HEAD SCREW - GRADE A (M16 x 45.0 LONG)	STEEL, ELECTROPLATED ZINC COATING - BRIGHT (CLASS 8.8)
7	ND	8	HEXAGON HEAD SCREW - GRADE A (M16 x 50.0 LONG)	STEEL, ELECTROPLATED ZINC COATING - BRIGHT (CLASS 8.8)
8	ND	16	PLAIN WASHER - NORMAL SERIES - GRADE A (M16)	STEEL, ELECTROPLATED ZINC COATING - BRIGHT

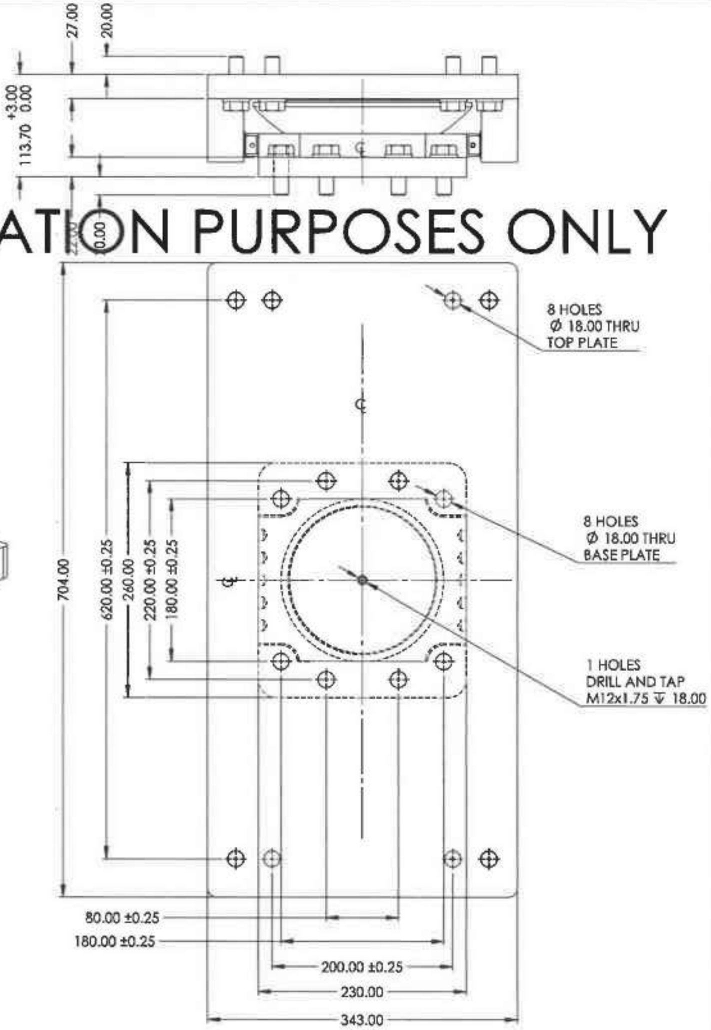
FIRST ANGLE PROJECTION

MODEL DATA FILE: GEOMETRICS | DATUM SETTER | STANDARD CALCULATION SCHEME | XMOD

NOTE: THIS DRAWING SHALL BE USED WITH MODEL FOR COMPLETE PRODUCT DEFINITION

FOR INFORMATION/QUOTATION PURPOSES ONLY





NOTES:

1. SYMMETRICAL ABOUT CENTRELINES.
2. FIXINGS HIDDEN ON PLAN VIEW FOR CLARITY.

BEARING TYPE SPECIFIC NOTES
STRUCTURAL BEARINGS – PART 7: SPHERICAL BEARINGS

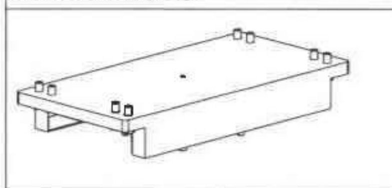
1. DESIGNED AND MANUFACTURED IN ACCORDANCE WITH EN 1337-1:2000, EN 1337-2:2004, 1337-6:2004 AND EN 1337-7:2005
2. CORROSION PROTECTION IN ACCORDANCE WITH EN 1337-9:1997

GENERAL NOTES

1. WHERE APPLICABLE, FOLLOWING CLEANING AND PRIOR TO ASSEMBLY, THE SLIDING MATERIAL FOR GUIDES SHALL BE INITIALLY LUBRICATED BY RUBBING A SMALL AMOUNT OF LUBRICANT (SILICONFETT 300 OR EQUIVALENT) INTO THE SURFACE AND THEN REMOVING THE EXCESS.
2. ENSURE PTFE DIMPLE PATTERN IS ALIGNED WITH THE PRINCIPAL DIRECTION OF MOVEMENT OF THE BEARING AS PER THE RELEVANT FLAT PTFE DRAWING (ITEM 6).
3. FOLLOWING CLEANING AND PRIOR TO ASSEMBLY, DIMPLED PTFE SHALL BE LUBRICATED WITH SILICONFETT 300 (OR EQUIVALENT) ENSURING THAT ALL DIMPLES ARE ADEQUATELY FILLED.
4. APPLY STANDARD SELF ADHESIVE DUST SEAL (~10mm WIDE x 5mm THICK) AROUND THE PERIMETER OF ALL PTFE BEARING SURFACES. THE DUST SEAL SHOULD BE APPLIED TO THE PAINTED METAL AROUND ALL PTFE SURFACES ENSURING THAT A ROBUST SEAL IS MAINTAINED WHERE THE ENDS OF THE SEAL MEET (I.E. MAXIMUM PERMISSIBLE GAP 2mm BETWEEN START AND STOP POSITIONS).
5. ENSURE TOP AND BASE PLATE STRUCTURAL INTERFACES ARE FREE FROM GREASE PRIOR TO INSTALLATION.

ISSUE STATUS	DESCRIPTION	DATE	AUTHORITY
-	SEE SHEET 1	-	-

ISOMETRIC / DIMETRIC / TRIMETRIC VIEW



LATEST REVISION	
DRAWN	[redacted]
DATE	22nd MAR 2019
CHECKED	[redacted]
MANUF.	-

ORIGINAL DRAWING	
DRAWN	[redacted]
DATE	19th MAR 2019
CHECKED	[redacted]
MANUF.	-

UNLESS OTHERWISE SPECIFIED :-
ANGLES ARE IN DEGREES AND DECIMAL PARTS OF A DEGREE
DIMENSIONS ARE IN MILLIMETERS
TOLERANCE ON DIMENSIONS ± 0.50
TOLERANCE ON ANGLES ± 2°
SURFACE TEXTURE VALUES IN MICROMETERS
SURFACE TEXTURE TO BE 6.3µm
BREAK SHARP EDGES 0.30 ± 0.20

SPECIALIST APPROVALS: -

DO NOT SCALE

EKSPAN
EKSPAN LTD
COMPASS WORKS
410 BRIGHTSIDE LANE
SHEFFIELD
S9 2SP

PART NAME: SPHERICAL BEARING, GUIDED (500kN) - 11GE050-250

APPROXIMATE WEIGHT	DRAWING NUMBER		ISSUE
111.96 KG	15508-GD-00		2
	ORIGINAL SCALE	1:4 U.O.S	SHEET 2 OF 2 SHEETS

FILELOCATION

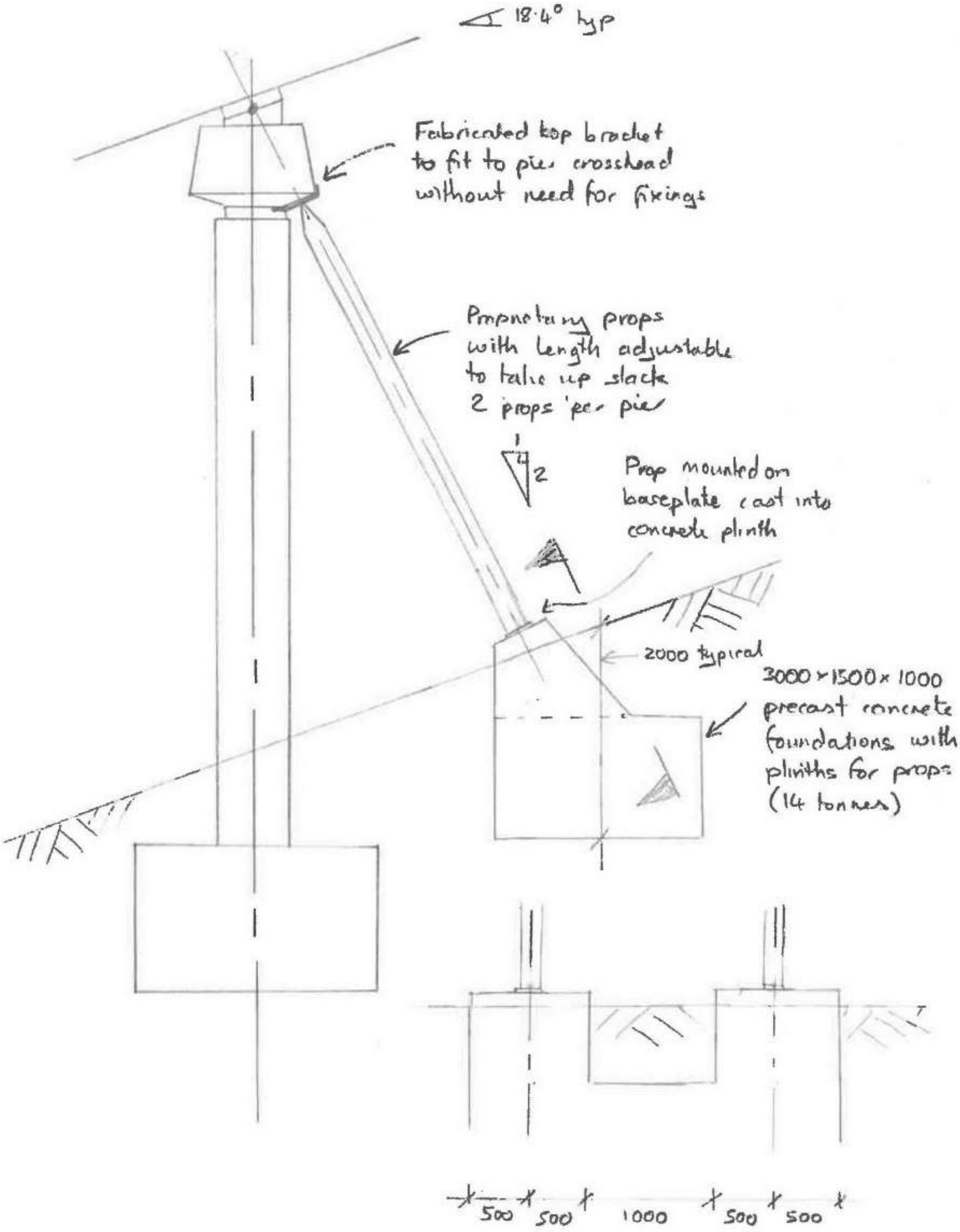
Appendix C Strengthening scheme details

Sketches:

SK01 rev A	Substructure - pier propping
SK05 rev A	Bearings
SK11	Type 3 beams - continuity
SK12	Anchor blocks 0, 65 and 78
SK13	Anchor blocks 14 & 29
SK14	External shear reinforcement at scarf joints
SK15	External shear reinforcement at first crossbeam

COWI	Project: CAIRNGORM RAILWAY	Doc Nos: SK01 rev A	Rev:
			Page:
	Subject: STRENGTHENING	Prepared: [redacted]	Date: 7/3/19
Office/Discipline: BRISTOL / BRIDGE		Checked:	Date:
	ATR/Job: A116993	Approved:	Date:

Substructure



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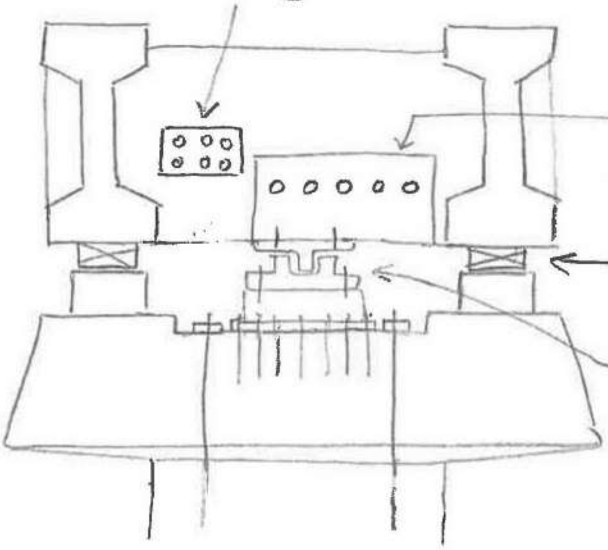
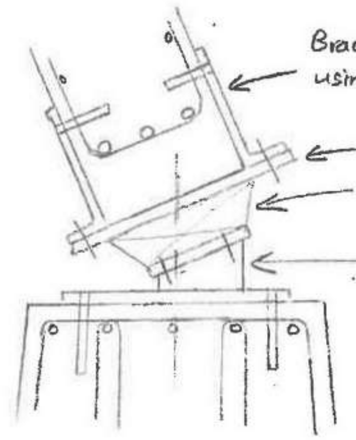
			Page:
	Subject: STRENGTHENING	Prepared [redacted]	Date: 12/2/19
Office/Discipline: BRISTOL / BRIDGE		Checked:	Date:
	ATR/Job: A116993	Approved:	Date:

Bearings



Bearing loads (ULS) vertical 400 kN max, -50kN min (uplift)
lateral 340 kN

Typical sizes 200 to 300 square for pot/spherical bearing
300 × 500 for guide bearing



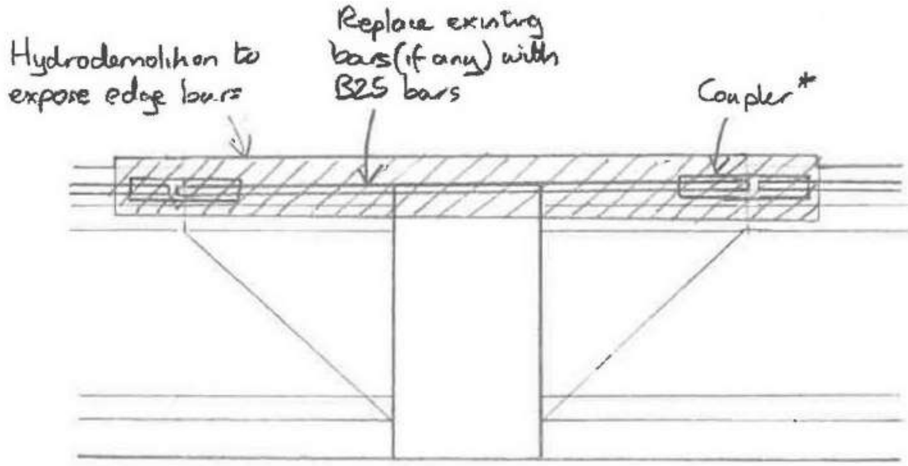
Say 300kg steelwork per guide bearing

Resin anchors M20 stainless steel with minimum 150 embedment into concrete

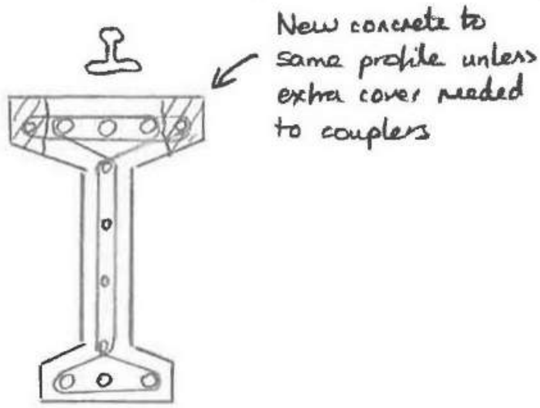
All steel grade S355J2 galvanised

COWI	Project: CAIRNGORM RAILWAY	Doc Nos: SK 11	Rev: 1
			Page:
	Subject: STRENGTHENING	Prepared: [redacted]	Date: 12/2/19
Office/Discipline: BRISTOL / BRIDGE		Checked:	Date:
	ATR/Job: A116993	Approved:	Date:

Type 3 Beams only



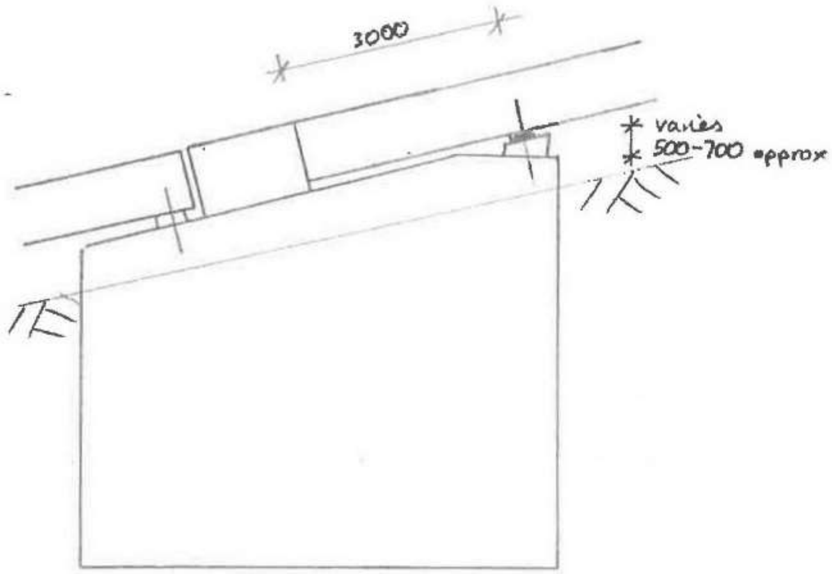
*e.g. Ancon MBT couplers
(258 long 54 dia)

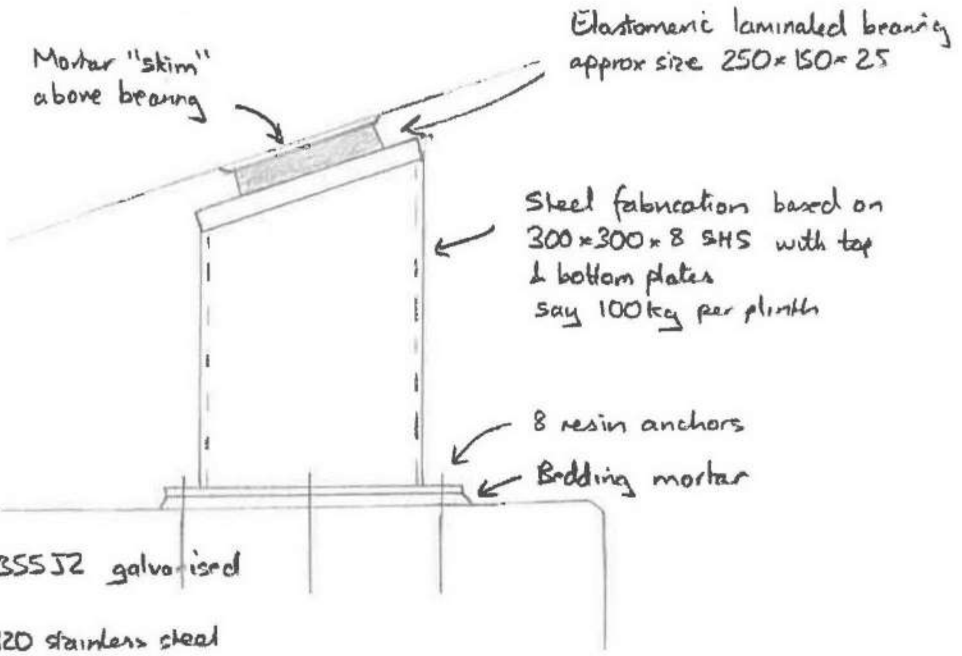


New concrete C40/50
with similiar colour to existing beams
[Possibly self compacting concrete]

COWI	Project: CAIRNGORM RAILWAY	Doc Nos: SK12	Rev:
			Page:
	Subject: STRENGTHENING	Prepared: [redacted]	Date: 14/3/19
Office/Discipline: BRISTOL / BRIDGE		Checked:	Date:
	ATR/Job: A116993	Approved:	Date:

Anchor blocks 0, 65, 78





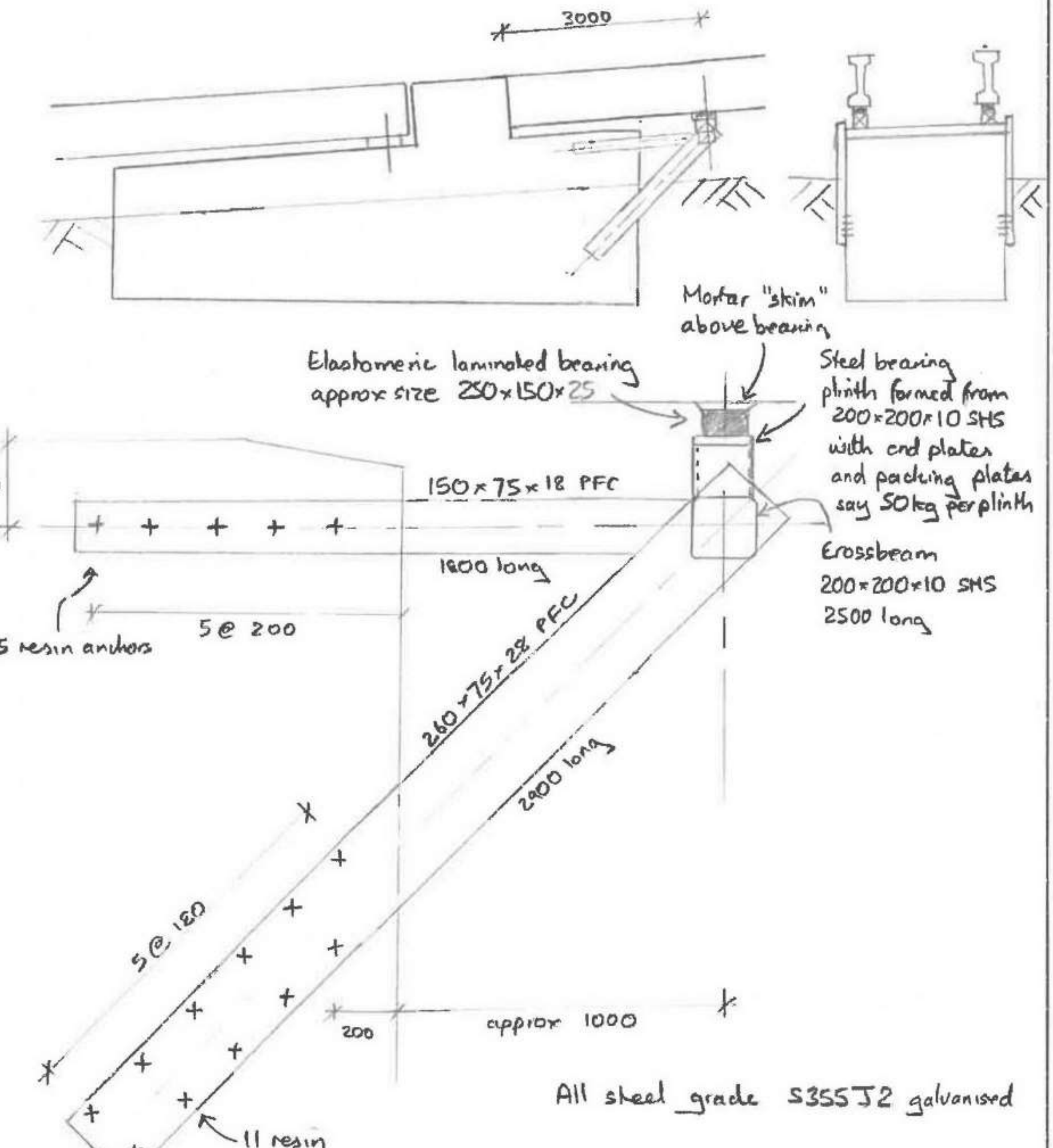
All steel grade S355J2 galvanised

Resin anchors M20 stainless steel
with minimum 150 embedment into concrete

COWI	Project: CAIRNGORM RAILWAY	Doc Nos: SK13	Rev:
			Page:
Office/Discipline: BRISTOL / BRIDGE	Subject: STRENGTHENING	Prepared: [redacted]	Date: 12/3/19
		Checked:	Date:
	ATR/Job: A116993	Approved:	Date:

Anchor blocks 14 & 29

Steel frame supports bearing, since bearing would otherwise be off the anchor block



All steel grade S355J2 galvanised

Resin anchors M20 stainless steel with minimum 150 embedment into concrete

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			Page:
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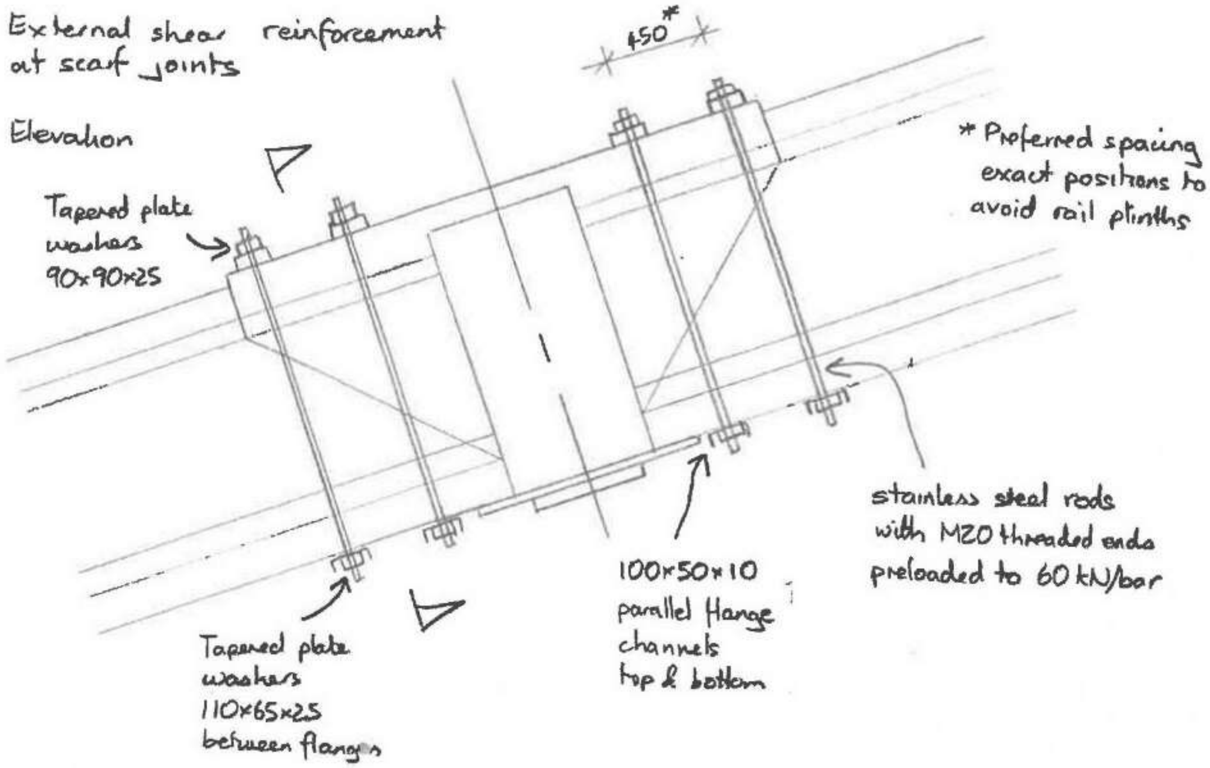
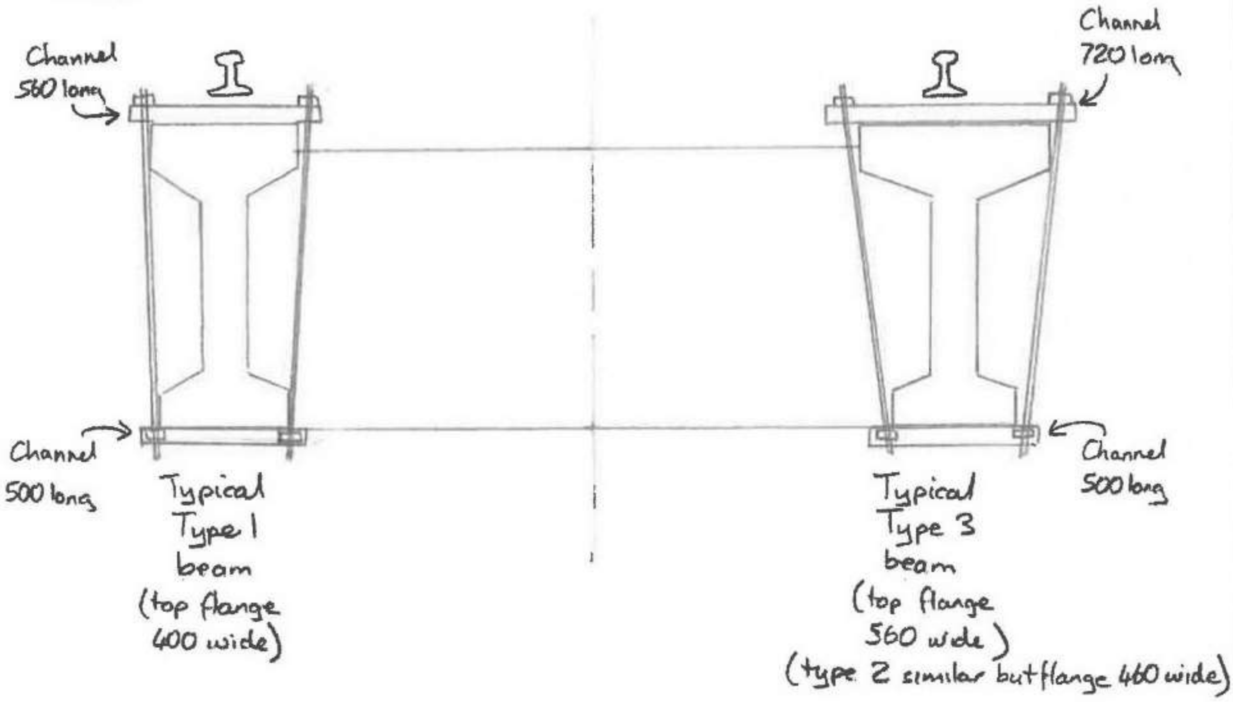
Office/Discipline:		Checked:	Date:
BRISTOL / BRIDGE	ATR/Job: A116993	Approved:	Date:

External shear reinforcement at scarf joints

Elevation



Section

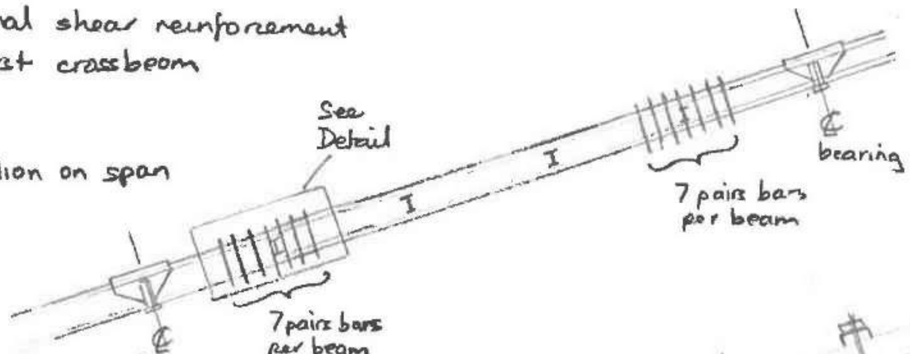


Stainless steel rods	grade A4-70
Steel channels and washers	grade S355J2 galvanised

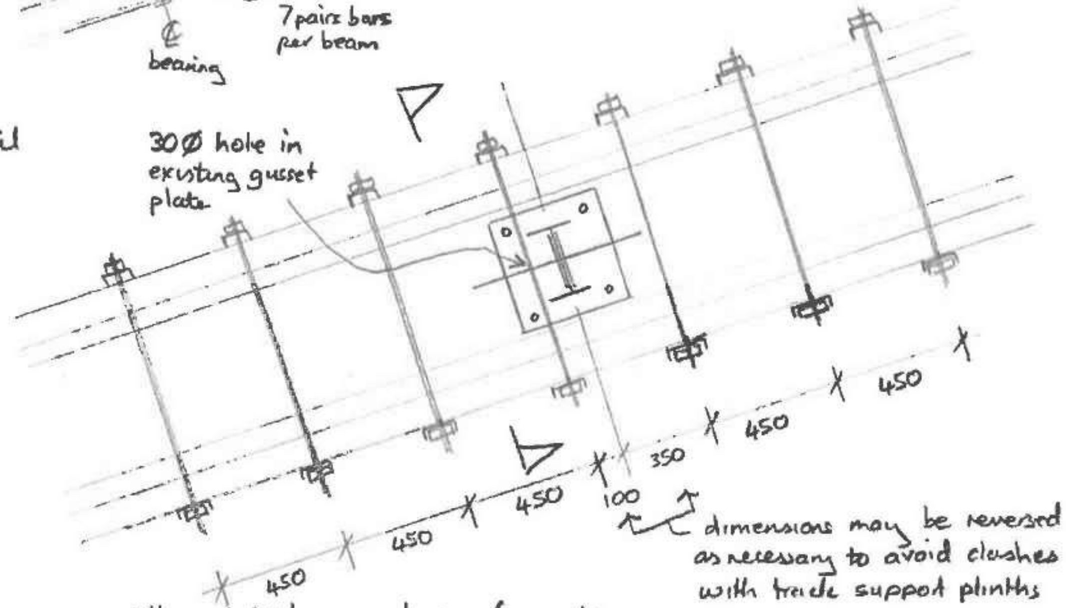
COWI	Project: CAIRNGORM RAILWAY	Doc Nos: SK15	Rev:
			Page:
Office/Discipline: BRISTOL /BRIDGE	Subject: STRENGTHENING	Prepared: [redacted]	Date: 18/3/19
		Checked:	Date:
	ATR/Job: A116993	Approved:	Date:

External shear reinforcement at first crossbeam

Elevation on span

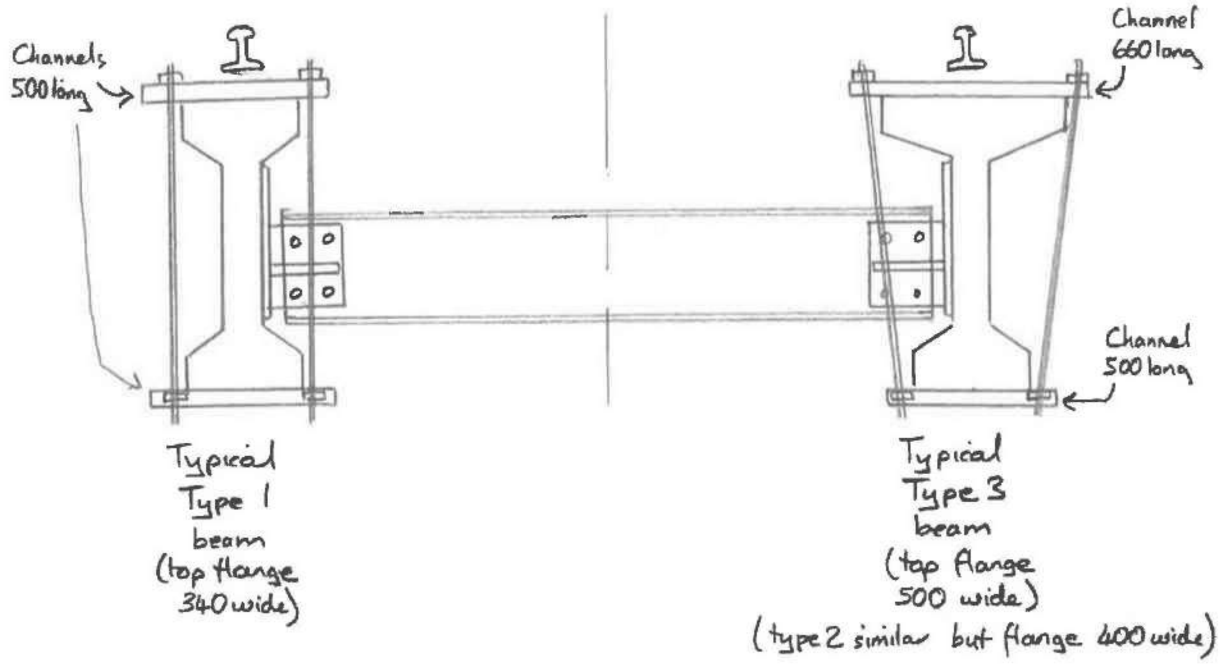


Detail



Other details as at scarf joints

Section



Appendix D Strengthening scheme extents

Tabulated chart of locations to be strengthened

Graphical view of deck strengthening

Graphical view of pier strengthening

A116993
Cairngorm Mountain Railway
Summary of strengthening extents

		Piers							Anchor blocks			Bearings						Beam shear strengthening														Type 3 connections			
Area	Pier number	Is the pier to be propped?	Sketch reference	Number of props per pier	Reason = Column overload	Reason = Crosshead overload	Reason = Existing bearing misaligned	Reason = Collision risk	Is the anchor block to be strengthened?	Sketch reference	Reason = Beam overloaded in hog	Are bearings to be replaced?	Sketch reference	Number of vertical load bearings per pier	Number of lateral load bearings per pier	Reason = Existing bearings overloaded	Reason = Existing bearing misaligned	Are the scarf joints to be strengthened?	Sketch reference	Number of joints per pier	Reason = Strength uncertain	Is the span below to be strengthened at 1st crossbeam?	Is the span above to be strengthened at 1st crossbeam?	Is the span below to be strengthened up to 2nd crossbeam?	Is the span above to be strengthened up to 2nd crossbeam?	Sketch reference	No of beams strengthened at 1st crossbeam in span below	No of beams strengthened at 1st crossbeam in span above	No of beams strengthened at 2nd crossbeam in span below	No of beams strengthened at 2nd crossbeam in span above	Reason = Beam overloaded in shear	Are type 3 connections to be strengthened?	Sketch reference	Number of type 3 connections per pier	Reason = Improve durability by reducing cracking
1	0 Anchor								Yes	SK12	✓												Yes			SK15		2			✓				
	1											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓	Yes	Yes			SK15	2	2			✓				
	2	Yes	SK01/A	2				✓				Yes	SK05/A	2	1	✓		Yes	SK14	4	✓	Yes				SK15	2				✓				
	3	Yes	SK01/A	2				✓				Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	4											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	5											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓		Yes			SK15		2			✓				
	6											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓	Yes	Yes			SK15	2	2			✓				
	7											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓	Yes	Yes			SK15	2	2			✓				
	8											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓	Yes				SK15	2				✓				
	9											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	10											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	11											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	12											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	13											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	14											Yes	SK05/A	2	1	✓																			
2	14 Anchor								Yes	SK13	✓												Yes			SK15		2			✓				
	15											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	16											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓		Yes			SK15		2			✓				
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	29											Yes	SK05/A	2	1	✓																			

A116993
Cairngorm Mountain Railway
Summary of strengthening extents

		Piers							Anchor blocks			Bearings						Beam shear strengthening														Type 3 connections			
Area	Pier number	Is the pier to be propped?	Sketch reference	Number of props per pier	Reason = Column overload	Reason = Crosshead overload	Reason = Existing bearing misaligned	Reason = Collision risk	Is the anchor block to be strengthened?	Sketch reference	Reason = Beam overloaded in hog	Are bearings to be replaced?	Sketch reference	Number of vertical load bearings per pier	Number of lateral load bearings per pier	Reason = Existing bearings overloaded	Reason = Existing bearing misaligned	Are the scarf joints to be strengthened?	Sketch reference	Number of joints per pier	Reason = Strength uncertain	Is the span below to be strengthened at 1st crossbeam?	Is the span above to be strengthened at 1st crossbeam?	Is the span below to be strengthened up to 2nd crossbeam?	Is the span above to be strengthened up to 2nd crossbeam?	Sketch reference	No of beams strengthened at 1st crossbeam in span below	No of beams strengthened at 1st crossbeam in span above	No of beams strengthened at 2nd crossbeam in span below	No of beams strengthened at 2nd crossbeam in span above	Reason = Beam overloaded in shear	Are type 3 connections to be strengthened?	Sketch reference	Number of type 3 connections per pier	Reason = Improve durability by reducing cracking
3	29 Anchor								Yes	SK13	✓												Yes			SK15		2			✓				
	30											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
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	57	Yes	SK01/A	2	✓		✓	✓				Yes	SK05/A	2	1	✓	✓	Yes	SK14	4	✓	Yes	Yes	Yes		SK15	2	2	2		✓				
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	65											Yes	SK05/A	2	1	✓	✓																		

A116993
Cairngorm Mountain Railway
Summary of strengthening extents

		Piers							Anchor blocks			Bearings						Beam shear strengthening														Type 3 connections			
Area	Pier number	Is the pier to be propped?	Sketch reference	Number of props per pier	Reason = Column overload	Reason = Crosshead overload	Reason = Existing bearing misaligned	Reason = Collision risk	Is the anchor block to be strengthened?	Sketch reference	Reason = Beam overloaded in hog	Are bearings to be replaced?	Sketch reference	Number of vertical load bearings per pier	Number of lateral load bearings per pier	Reason = Existing bearings overloaded	Reason = Existing bearing misaligned	Are the scarf joints to be strengthened?	Sketch reference	Number of joints per pier	Reason = Strength uncertain	Is the span below to be strengthened at 1st crossbeam?	Is the span above to be strengthened at 1st crossbeam?	Is the span below to be strengthened up to 2nd crossbeam?	Is the span above to be strengthened up to 2nd crossbeam?	Sketch reference	No of beams strengthened at 1st crossbeam in span below	No of beams strengthened at 1st crossbeam in span above	No of beams strengthened at 2nd crossbeam in span below	No of beams strengthened at 2nd crossbeam in span above	Reason = Beam overloaded in shear	Are type 3 connections to be strengthened?	Sketch reference	Number of type 3 connections per pier	Reason = Improve durability by reducing cracking
5	65 Anchor								Yes	SK12	✓																								
	66											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	67	Yes	SK01/A	2	✓							Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	68											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	69											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	70											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	71	Yes	SK01/A	2		✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	72	Yes	SK01/A	2	✓	✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	73	Yes	SK01/A	2	✓	✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	74	Yes	SK01/A	2	✓	✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	75	Yes	SK01/A	2	✓	✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	76	Yes	SK01/A	2	✓	✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	77	Yes	SK01/A	2	✓	✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓		Yes			SK15		2			✓				
	78											Yes	SK05/A	2	1	✓																			
6	78 Anchor								Yes	SK12	✓																								
	79	Yes	SK01/A	2		✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	80	Yes	SK01/A	2		✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	81	Yes	SK01/A	2	✓	✓						Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	82											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	83											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	84											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	85											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	86											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	87											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	88	Yes	SK01/A	2	✓							Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	89	Yes	SK01/A	2	✓							Yes	SK05/A	2	1	✓		Yes	SK14	4	✓														
	90	Yes	SK01/A	2	✓		✓	✓				Yes	SK05/A	2	1	✓	✓	Yes	SK14	4	✓														
	91	Yes	SK01/A	2	✓		✓	✓				Yes	SK05/A	2	1	✓	✓	Yes	SK14	4	✓														
	92	Yes	SK01/A	2	✓		✓					Yes	SK05/A	2	1	✓	✓	Yes	SK14	4	✓														
	93											Yes	SK05/A	2	1	✓		Yes	SK14	4	✓		Yes			SK15		2			✓				
	94											Yes	SK05/A	2	1	✓																			
		No of piers		No of props								No of locations		No of bearings				No of piers		No of joints		No of span ends					No of beam ends					No piers		No connections	
Total		43		92								94		196	97			88		360		35	42	4	4		76	90	10	10		8		13	

A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax: 01463 719201
email: crudens@aol.com

Client:
CAIRNGORM CHAIRLIFT COMPANY

Project:
CAIRNGORM FUNICULAR

Drawing:
LONGITUDINAL SECTION
SHEET 1 OF 7
CHAINAGE 0 – 340

Drawing No. CA150/2/11 Drawn By [redacted]
REV. F Date 08/02/99 Scale 1:500

Revisions Date By
A 26/2/99 [redacted]
Column chainages and top rail levels added.
Column bases added.

B 15/4/99 [redacted]
Ref pt. A & Bottom Station altered.
Borehole and trial pit information added.
Tower types shown.
Table amended.

C 17/5/99 [redacted]
Ref pt. A moved to elevation 637m. Table amended.

D 15/10/99 [redacted]
Towers 0–4 have been altered due to existing features.
Table amended for revised Vertical alignment.
Designed steel sections added.
Extent of Bottom Station has been updated.
Supports from new station are added.

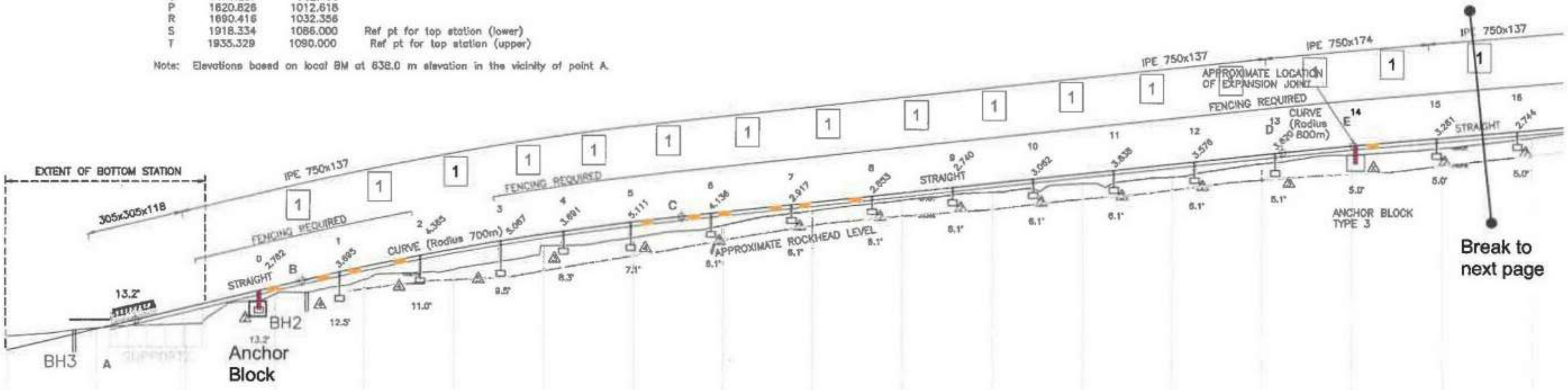
E 24/3/00 [redacted]
Angle of brackets added.
Locations of required pedestrian walkway and fencing are added.
Foundation levels on towers 0–4 have been amended.

F 9/11/00 [redacted]
Pedestrian walkway removed.

Point	Chainage	Elevation	Remarks
A	28.716	637.000	Ref pt for bottom station
B	65.956	645.709	
C	150.668	660.103	
D	284.566	674.471	
E	300.409	676.012	
F	435.580	687.802	
G	452.067	689.070	
H	898.677	761.500	Ref pt for middle station (lower)
J	912.057	765.000	Ref pt for middle station (upper)
K	999.208	789.752	Mid-point of line
L	1165.781	846.479	
M	1191.462	855.691	
N	1408.929	939.087	
O	1471.287	962.795	
P	1620.626	1012.618	
R	1690.416	1032.356	
S	1918.334	1086.000	Ref pt for top station (lower)
T	1935.329	1090.000	Ref pt for top station (upper)

Note: Elevations based on local BM at 638.0 m elevation in the vicinity of point A.

NOTES
BASED ON GROUND RADAR INFORMATION
3.620 HEIGHT OF RAIL LEVEL ABOVE TOP OF FOUNDATION
COLUMN TYPE(SEE DRG. CA150/2/40–41)



Total this page
Brown 0 span ends
Red 0 span ends
Orange 11 span ends
Blue 0 piers
Purple 2 anchor blocks
Pink 0 anchor blocks

1 Beam type
Requires strengthening at 1st & 2nd crossbeams due shear utilisation > 1
Requires strengthening at 1st crossbeam due shear utilisation > 1
Strengthening recommended at 1st crossbeam due to high shear utilisation
Strengthening recommended over piers - connect 25 dia bars to reduce cracking

Requires strengthening to anchor block due to bending utilisation > 1
Strengthening recommended due to high bending utilisation

Note: All scarf joints require strengthening (not shown above)

DATUM 550.00m

CHAINAGE	000.00, 20.00, 40.00, 60.00, 80.00, 100.00, 120.00, 140.00, 160.00, 180.00, 200.00, 220.00, 240.00, 260.00, 280.00, 300.00, 320.00, 340.00
EXISTING GROUND LEVEL	633.37, 635.14, 636.04, 642.73, 645.95, 648.22, 653.53, 655.494, 655.26, 657.386, 658.10, 660.861, 661.37, 662.839, 663.72, 664.984, 665.50, 668.214, 667.50, 667.592, 668.97, 669.701, 672.01, 671.919, 674.148, 300.898, 675.401, 675.47, 677.408, 677.83
COLUMN CHAINAGE	56.316, 74.316, 92.316, 110.316, 124.316, 139.299, 157.248, 175.204, 193.160, 211.116, 229.072, 247.028, 264.984, 282.940, 300.898, 318.852, 336.808
TOP RAIL LEVEL	643.455, 647.610, 651.340, 654.581, 656.769, 658.789, 660.809, 662.736, 664.663, 666.590, 668.516, 670.443, 672.370, 674.297, 676.055, 677.621, 679.187
TOP OF FOUNDATION LEVEL	639.761, 642.325, 646.277, 647.942, 652.929, 653.678, 656.673, 659.819, 661.810, 663.850, 665.454, 666.505, 668.784, 670.477, 674.360, 676.443

Drawing: LONGITUDINAL SECTION 1 OF 7 CHAINAGE 0 – 340
Drawing No. CA150/2/11 Revision F

A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax:01463 719201
email: crudens@aol.com

Client
CAIRNGORM CHAIRLIFT COMPANY

Project
CAIRNGORM FUNICULAR

Drawing
LONGITUDINAL SECTION
SHEET 2 OF 7
CHAINAGE 360 – 700

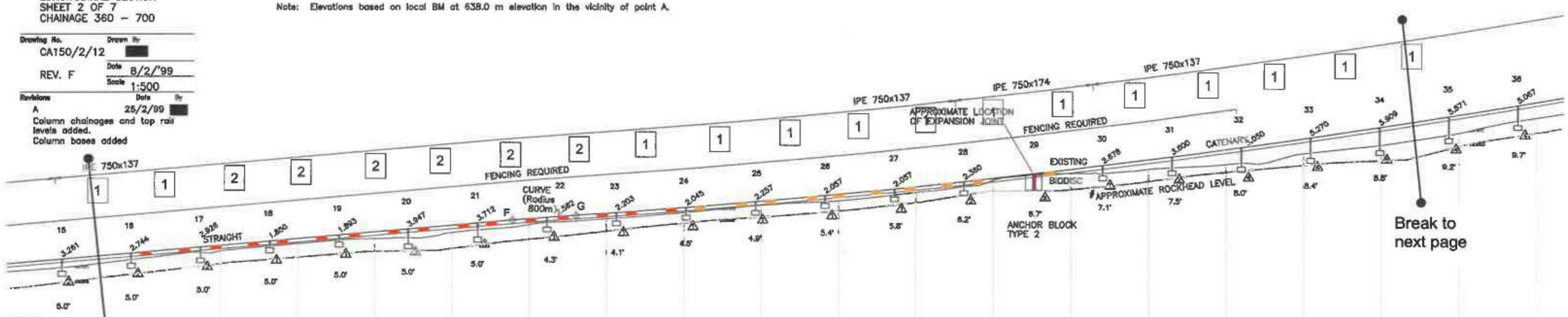
Drawing No. CA150/2/12 Drawn By [redacted]
REV. F Date 8/2/'99 Scale 1:500

Revisions Date By
A 26/2/99 [redacted]
Column chainages and top rail levels added.
Column bases added

Point	Chainage	Elevation	Remarks
A	28.716	637.000	Ref pt for bottom station
B	85.956	645.709	
C	150.668	660.103	
D	284.566	674.471	
E	300.409	678.012	
F	435.580	687.802	
G	452.087	689.070	
H	898.677	761.500	Ref pt for middle station (lower)
J	912.057	765.000	Ref pt for middle station (upper)
K	999.208	789.752	Mid-point of line
L	1165.781	848.479	
M	1191.462	855.691	
N	1408.929	939.087	
O	1471.287	962.785	
P	1620.826	1012.618	
R	1690.416	1032.356	
S	1918.334	1086.000	Ref pt for top station (lower)
T	1935.329	1090.000	Ref pt for top station (upper)

Note: Elevations based on local BM at 638.0 m elevation in the vicinity of point A.

NOTES
BASED ON GROUND RADAR INFORMATION
3.600 HEIGHT OF RAIL LEVEL ABOVE TOP OF FOUNDATION
COLUMN TYPE(SEE DRG. CA150/2/40–41)



BLOCK
B 15/4/99 [redacted]
Borehole and trial pit information added.
Tower typ
Table am
C [redacted]
Table am
D [redacted]
Table amended for revised Vertical alignment.
Designed steel sections added.
E 9/11/99 [redacted]
Angle of brackets added.
Locations of required pedestrian walkway and fencing are added.
F 9/11/00 [redacted]
Pedestrian walkway removed.

1 Beam type
Requires strengthening at 1st & 2nd crossbeams due shear utilisation > 1
Requires strengthening at 1st crossbeam due shear utilisation > 1
Strengthening recommended at 1st crossbeam due to high shear utilisation
Strengthening recommended over piers - connect 25 dia bars to reduce cracking

Requires strengthening to anchor block due to bending utilisation > 1
Strengthening recommended due to high bending utilisation

Note: All scarf joints require strengthening (not shown above)

Total this page
Brown 0 span ends
Red 16 span ends
Orange 10 span ends
Blue 0 piers
Purple 1 anchor block
Pink 0 anchor blocks

DATUM 590.00m

CHAINAGE		360.00		380.00		400.00		420.00		440.00		460.00		480.00		500.00			520.00
EXISTING GROUND LEVEL	679.445	679.75	681.203	681.62	682.592	682.94	682.[illegible]	681.52	685.258	686.85	686.963	688.15	688.338	689.77	689.697	690.955	691.71	692.799	692.90
COLUMN CHAINAGE	354.765		372.720		390.674		408.630		426.585		444.557		462.551	480.538		498.511		518.474	
TOP RAIL LEVEL	680.753		682.319		683.885		685.451		687.017		688.534		689.788	691.131		692.612		694.229	
TOP OF FOUNDATION LEVEL	677.827		680.469		681.992		681.504		683.305		685.972		687.585	689.086		690.355		692.172	

CHAINAGE		540.00		560.00		580.00		600.00		620.00		640.00		660.00		680.00			700.00
EXISTING GROUND LEVEL	694.525	695.10	696.172	698.26	699.506	700.00	699.980	701.11	701.569	702.37	702.622	705.26	705.372	707.379	707.44	710.241	710.60	713.478	714.64
COLUMN CHAINAGE	534.424		552.361		570.283		588.189		606.078		623.950	641.804		659.639		677.453		695.246	
TOP RAIL LEVEL	695.982		697.871		699.897		702.058		704.353		706.784	709.349		712.048		714.880		717.845	
TOP OF FOUNDATION LEVEL	693.925		695.511				699.380		700.753		701.734	704.079		706.139		709.309		712.778	

Drawing
LONGITUDINAL SECTION 2 OF 7
CHAINAGE 360 – 700
Drawing No. CA150/2/12
Revision. F

A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax:01463 719201
email: crudens@aol.com

Client
CAIRNGORM CHAIRLIFT COMPANY

Project
CAIRNGORM FUNICULAR

Drawing
LONGITUDINAL SECTION
SHEET 3 OF 7
CHAINAGE 700 – 1040

Drawing No. CA150/2/13 Drawn By [redacted]
REV. F Date 8/2/'99
Scale 1:500

Revisions Date By
A 26/2/99 [redacted]
Column chainages and top rail levels added.
Column bases added

B 15/4/99 [redacted]
Borehole and trial pit information added.
Tower types shown.
Table amended.

C 17/5/99 [redacted]
Table amended.

D 15/10/99 [redacted]
Table amended for revised Vertical alignment.
Tower 45 has been altered due to existing water course.
Designed steel sections added.

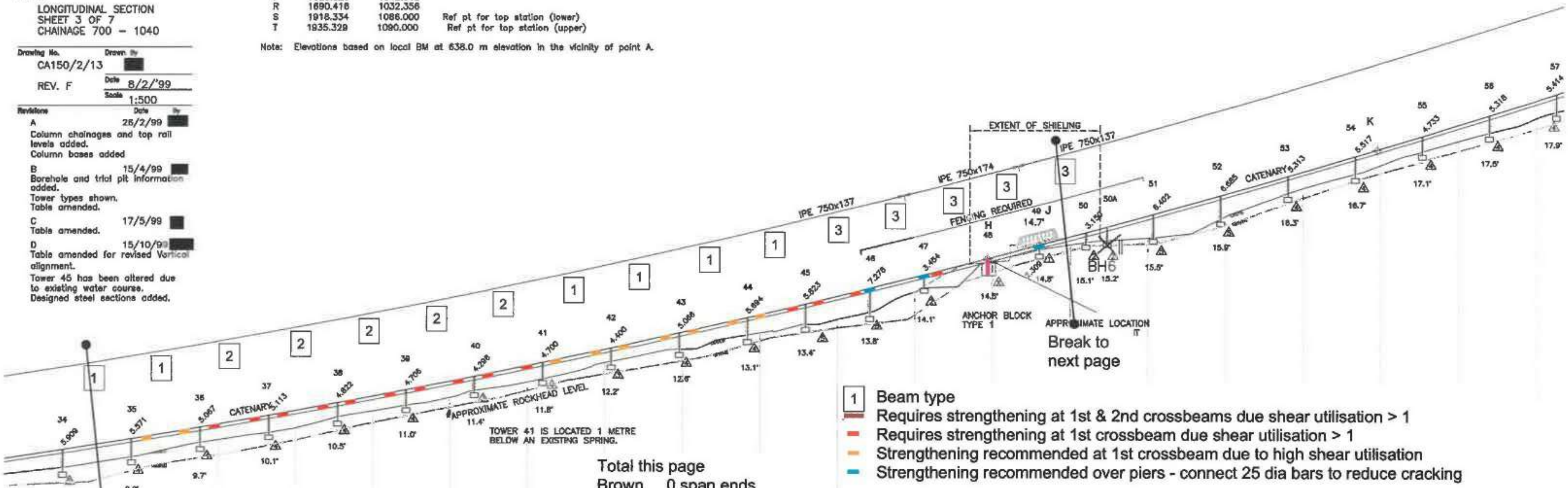
E 24/3/00 [redacted]
Angle of brackets added.
Locations of required pedestrian walkway ... ted.
Foundatio... has been am...

F [redacted]
Pedestrian ...
DATUM ...

Point	Chainage	Elevation	Remarks
A	28.716	637.000	Ref pt for bottom station
B	65.956	645.709	
C	150.668	660.103	
D	284.566	674.471	
E	300.409	676.012	
F	435.580	687.802	
G	452.067	689.070	
H	898.677	761.500	Ref pt for middle station (lower)
J	912.057	765.000	Ref pt for middle station (upper)
K	999.208	789.752	Mid-point of line
L	1165.781	846.479	
M	1191.462	855.691	
N	1408.929	939.067	
O	1471.287	952.795	
P	1620.826	1012.618	
R	1690.416	1032.356	
S	1918.334	1086.000	Ref pt for top station (lower)
T	1935.329	1090.000	Ref pt for top station (upper)

Note: Elevations based on local BM at 638.0 m elevation in the vicinity of point A.

NOTES
BASED ON GROUND RADAR INFORMATION
HEIGHT OF RAIL LEVEL ABOVE TOP OF FOUNDATION
COLUMN TYPE(SEE DRG. CA150/2/40–41)



1 Beam type
Requires strengthening at 1st & 2nd crossbeams due shear utilisation > 1
Requires strengthening at 1st crossbeam due shear utilisation > 1
Strengthening recommended at 1st crossbeam due to high shear utilisation
Strengthening recommended over piers - connect 25 dia bars to reduce cracking

Requires strengthening to anchor block due to bending utilisation > 1
Strengthening recommended due to high bending utilisation

Note: All scarf joints require strengthening (not shown above)

Total this page
Brown 0 span ends
Red 14 span ends
Orange 9 span ends
Blue 3 piers
Purple 0 anchor blocks
Pink 1 anchor block

CHAINAGE	700.00	720.00	740.00	760.00	780.00	800.00	820.00	840.00	860.00	880.00	900.00	920.00	940.00	960.00	980.00	1000.00	1020.00	1040.00

EXISTING GROUND LEVEL																		
714.64	716.814	717.68	720.269	722.12	723.428	725.59	727.331	729.64	730.550	734.68	734.803	738.059	738.11	741.300	742.35	745.88	747.234	752.93
754.612	761.073	760.83	763.704	765.06	765.727	766.87	767.213	771.760	772.41	778.148	779.69	783.063	785.66	789.563	791.95	794.201	797.93	

COLUMN CHAINAGE	713.017	730.765	748.488	766.188	783.861	801.510	819.132	836.726	851.816	868.326	882.332	898.677	912.057	924.048	929.509	941.400	958.751	976.095	993.405	1010.680	1027.919
TOP RAIL LEVEL	720.943	724.173	727.534	731.027	734.650	738.403	742.285	746.298	749.823	753.840	757.323	761.500	765.000	768.206	769.686	772.960	777.845	782.861	788.000	793.261	798.644
TOP OF FOUNDATION LEVEL	715.830	719.351	722.828	726.731	729.950	734.003	737.219	740.602	743.770	746.562	753.869		762.681	765.058		766.558	771.160	777.548	782.483	788.528	793.328

Drawing
LONGITUDINAL SECTION 3 OF 7
CHAINAGE 700 – 1040
Drawing No. CA150/2/13
Revision. F

A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax:01463 719201
email: crudens@aol.com

Client
CAIRNGORM CHAIRLIFT COMPANY

Project
CAIRNGORM FUNICULAR

Drawing
LONGITUDINAL SECTION
SHEET 4 OF 7
CHAINAGE 920 – 1260

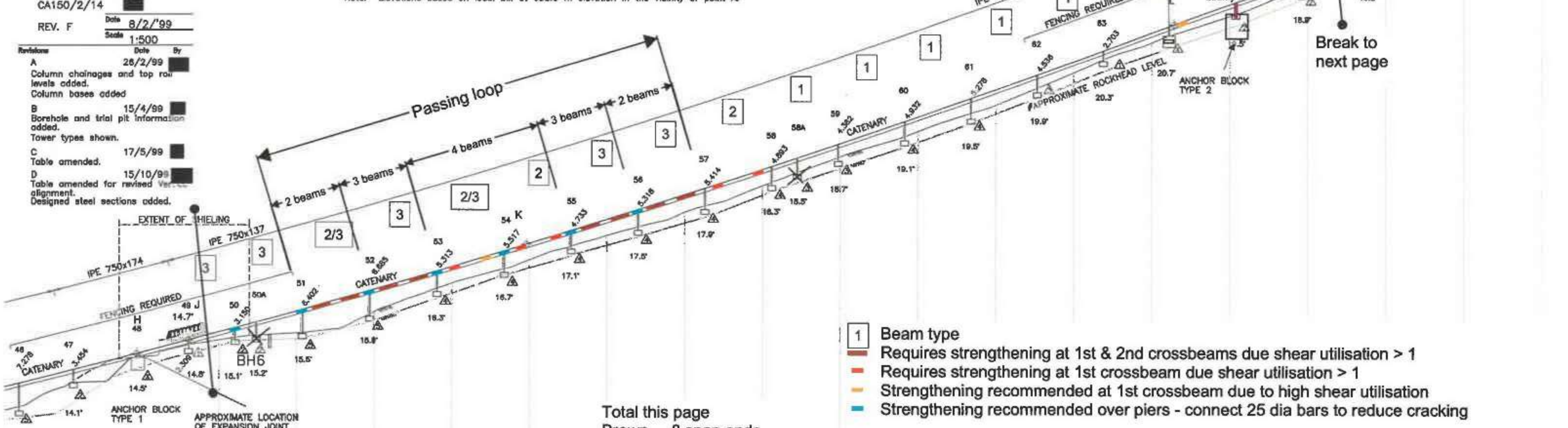
Drawing No. CA150/2/14 Drawn By [redacted]
REV. F Date 8/2/'99 Scale 1:500

Revisions Date By
A 26/2/99 [redacted]
Column chainages and top rail levels added.
Column bases added
B 15/4/99 [redacted]
Borehole and trial pit information added.
Tower types shown.
C 17/5/99 [redacted]
Table amended.
D 15/10/99 [redacted]
Table amended for revised Vertical alignment.
Designed steel sections added.
E 9/11/99 [redacted]
Angle of brackets added.
Locations of required pedestrian walkway and fencing are added.
F 9/11/00 [redacted]
Pedestrian walkway removed.

Point	Chainage	Elevation	Remarks
A	28.715	637.000	Ref pt for bottom station
B	65.956	645.709	
C	150.668	660.103	
D	284.566	674.471	
E	300.409	676.012	
F	435.580	687.802	
G	452.087	689.070	
H	898.677	761.500	Ref pt for middle station (lower)
J	912.057	765.000	Ref pt for middle station (upper)
K	999.208	789.752	Mid-point of line
L	1165.781	846.479	
M	1191.462	855.691	
N	1408.928	939.087	
O	1471.287	962.795	
P	1620.826	1012.618	
R	1690.418	1032.356	
S	1918.334	1086.000	Ref pt for top station (lower)
T	1935.329	1090.000	Ref pt for top station (upper)

Note: Elevations based on local BM at 638.0 m elevation in the vicinity of point A.

NOTES
BASED ON GROUND RADAR INFORMATION
3.820 HEIGHT OF RAIL LEVEL ABOVE TOP OF FOUNDATION
COLUMN TYPE(SEE DRG. CA150/2/40–41)



Total this page
Brown 8 span ends
Red 5 span ends
Orange 2 span ends
Blue 7 piers
Purple 1 anchor block
Pink 0 anchor blocks

1 Beam type
Requires strengthening at 1st & 2nd crossbeams due shear utilisation > 1
Requires strengthening at 1st crossbeam due shear utilisation > 1
Strengthening recommended at 1st crossbeam due to high shear utilisation
Strengthening recommended over piers - connect 25 dia bars to reduce cracking

Requires strengthening to anchor block due to bending utilisation > 1
Strengthening recommended due to high bending utilisation

Note: All scarf joints require strengthening (not shown above)

DATUM 710.00m

CHAINAGE: 920.00, 940.00, 960.00, 980.00, 1000.00, 1020.00, 1040.00, 1060.00, 1080.00, 1100.00, 1120.00, 1140.00, 1160.00, 1180.00, 1200.00, 1220.00, 1240.00, 1260.00

EXISTING GROUND LEVEL: 765.59, 765.727, 766.87, 767.213, 771.760, 772.41, 778.148, 779.69, 783.083, 785.66, 789.563, 791.95, 794.201, 797.93, 799.368, 804.72, 805.502, 812.100, 812.21, 817.282, 818.73, 823.065, 825.53, 829.889, 833.95, 837.891, 841.68, 844.836, 848.55, 849.839, 855.382, 858.21, 860.907, 862.81, 867.092, 869.67, 873.586, 877.13

COLUMN CHAINAGE	TOP RAIL LEVEL	TOP OF FOUNDATION LEVEL
924.046	768.206	765.056
929.509	769.688	
941.400	772.960	766.558
958.751	777.845	771.160
976.095	782.881	777.548
993.405	788.000	782.483
1010.680	793.261	788.528
1027.919	798.844	793.326
1045.122	804.147	798.733
1062.288	809.770	804.677
1068.907	811.974	
1079.416	815.513	811.131
1096.506	821.373	818.441
1113.557	827.352	822.074
1130.569	833.447	828.911
1147.541	839.658	836.955
1164.472	845.984	
1181.551	852.252	849.239
1198.621	858.132	854.468
1215.653	864.021	859.736
1232.650	870.012	866.468
1249.813	876.107	872.783

Drawing LONGITUDINAL SECTION 4 OF 7 CHAINAGE 920 – 1260 Drawing No. CA150/2/14 Revision. F

A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax: 01463 719201
email: crudens@aol.com

Client
CAIRNGORM CHAIRLIFT COMPANY

Project
CAIRNGORM FUNICULAR

Drawing
LONGITUDINAL SECTION
SHEET 5 OF 7
CHAINAGE 1220 – 1560

Drawing No. CA150/2/15 Drawn By [redacted]
REV. F Date 8/2/'99
Scale 1:500

Revisions Date By

A 26/2/99 [redacted]
Column chainages and top rail levels added.
Column bases added

B 15/4/99 [redacted]
Borehole and trial pit information added.
Tower types shown.

C 17/5/99 [redacted]
Table amended.

D 15/10/99 [redacted]
Table amended for revised Vertical alignment.
Designed steel sections added.

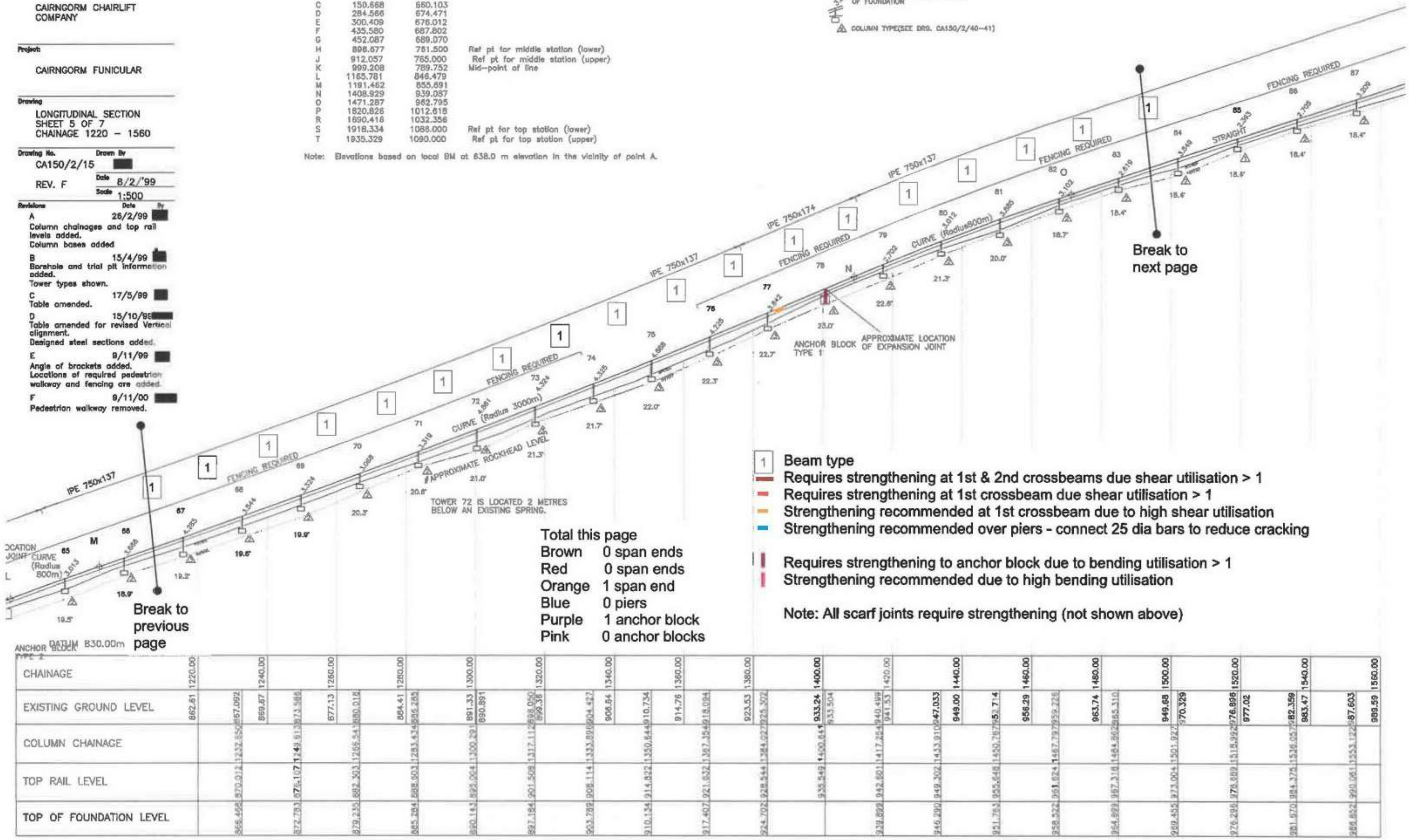
E 9/11/99 [redacted]
Angle of brackets added.
Locations of required pedestrian walkway and fencing are added.

F 9/11/00 [redacted]
Pedestrian walkway removed.

Point	Chainage	Elevation	Remarks
A	28.716	637.000	Ref pt for bottom station
B	65.956	645.709	
C	150.668	660.103	
D	284.566	674.471	
E	300.409	676.012	
F	435.580	687.802	
G	452.087	689.070	
H	898.677	761.500	Ref pt for middle station (lower)
J	912.057	765.000	Ref pt for middle station (upper)
K	999.208	789.752	Mid-point of line
L	1165.781	846.479	
M	1191.462	855.691	
N	1408.929	939.087	
O	1471.287	962.795	
P	1820.826	1012.618	
R	1690.416	1032.356	
S	1918.334	1088.000	Ref pt for top station (lower)
T	1935.329	1090.000	Ref pt for top station (upper)

Note: Elevations based on local BM at 638.0 m elevation in the vicinity of point A.

NOTES
BASED ON GROUND RADAR INFORMATION
3.820 HEIGHT OF RAIL LEVEL ABOVE TOP OF FOUNDATION
COLUMN TYPE(SEE DRG. CA150/2/40–41)



Total this page
Brown 0 span ends
Red 0 span ends
Orange 1 span end
Blue 0 piers
Purple 1 anchor block
Pink 0 anchor blocks

1 Beam type
Requires strengthening at 1st & 2nd crossbeams due shear utilisation > 1
Requires strengthening at 1st crossbeam due shear utilisation > 1
Strengthening recommended at 1st crossbeam due to high shear utilisation
Strengthening recommended over piers - connect 25 dia bars to reduce cracking

Requires strengthening to anchor block due to bending utilisation > 1
Strengthening recommended due to high bending utilisation

Note: All scarf joints require strengthening (not shown above)

Drawing LONGITUDINAL SECTION 5 OF 7 CHAINAGE 1220 – 1560 Drawing No. CA150/2/15 Revision F

A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax:01463 719201
email: crudens@aol.com

Client
CAIRNGORM CHAIRLIFT COMPANY

Project
CAIRNGORM FUNICULAR

Drawing
LONGITUDINAL SECTION
SHEET 6 OF 7
CHAINAGE 1460 – 1800

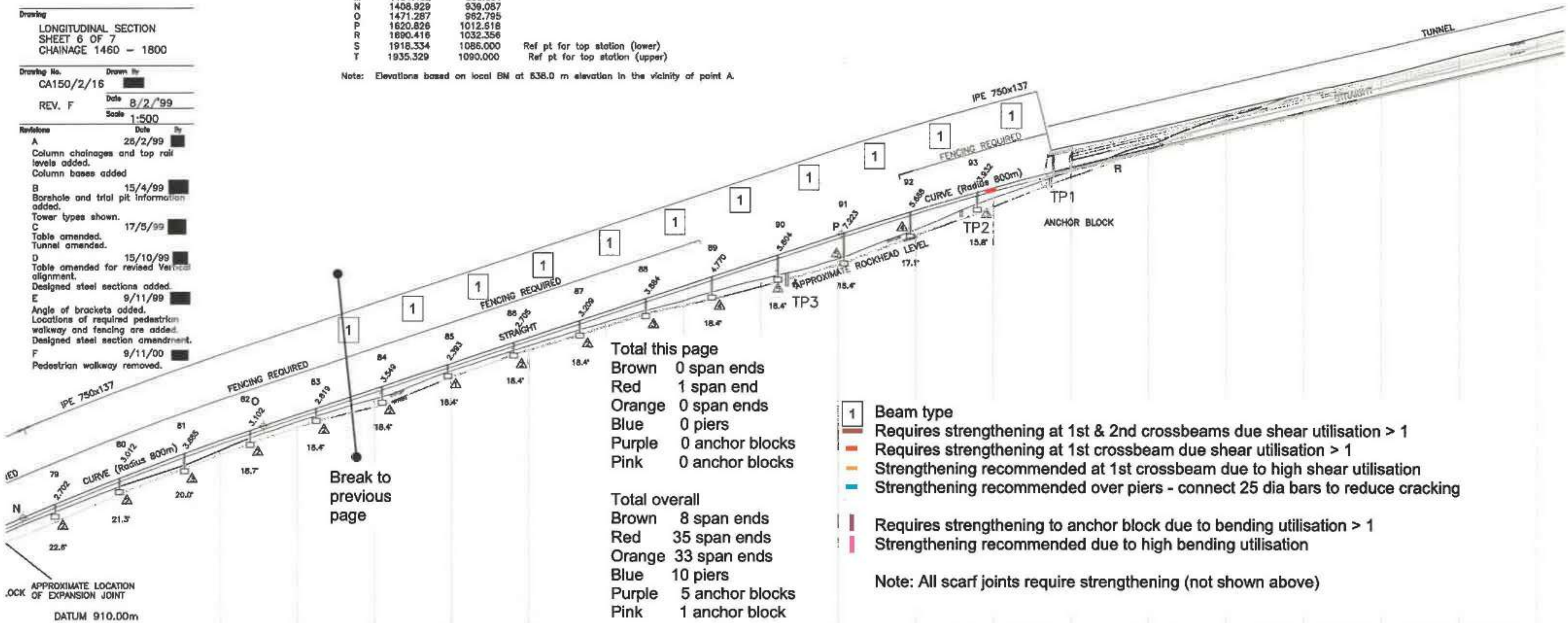
Drawing No. CA150/2/16 | Drawn By [redacted]
REV. F | Date 8/2/'99 | Scale 1:500

Revisions	Date	By
A Column chainages and top rail levels added. Column bases added	26/2/99	[redacted]
B Borehole and trial pit information added. Tower types shown.	15/4/99	[redacted]
C Table amended. Tunnel amended.	17/5/99	[redacted]
D Table amended for revised Vertical alignment. Designed steel sections added.	15/10/99	[redacted]
E Angle of brackets added. Locations of required pedestrian walkway and fencing are added. Designed steel section amendment.	9/11/99	[redacted]
F Pedestrian walkway removed.	9/11/00	[redacted]

Point	Chainage	Elevation	Remarks
A	28.718	837.000	Ref pt for bottom station
B	85.958	645.709	
C	150.688	660.103	
D	284.588	674.471	
E	300.409	676.012	
F	435.580	687.602	
G	452.087	689.070	
H	898.677	761.500	Ref pt for middle station (lower)
J	912.057	765.000	Ref pt for middle station (upper)
K	999.208	789.752	Mid-point of line
L	1165.761	846.479	
M	1191.462	855.691	
N	1408.929	939.087	
O	1471.287	962.795	
P	1620.826	1012.618	
R	1690.416	1032.356	
S	1918.334	1086.000	Ref pt for top station (lower)
T	1935.329	1090.000	Ref pt for top station (upper)

Note: Elevations based on local BM at 838.0 m elevation in the vicinity of point A.

NOTES
BASED ON GROUND RADAR INFORMATION
3.820 HEIGHT OF RAIL LEVEL ABOVE TOP OF FOUNDATION
△ COLUMN TYPE(SEE DRG. CA150/2/40–41)



Total this page
Brown 0 span ends
Red 1 span end
Orange 0 span ends
Blue 0 piers
Purple 0 anchor blocks
Pink 0 anchor blocks

Total overall
Brown 8 span ends
Red 35 span ends
Orange 33 span ends
Blue 10 piers
Purple 5 anchor blocks
Pink 1 anchor block

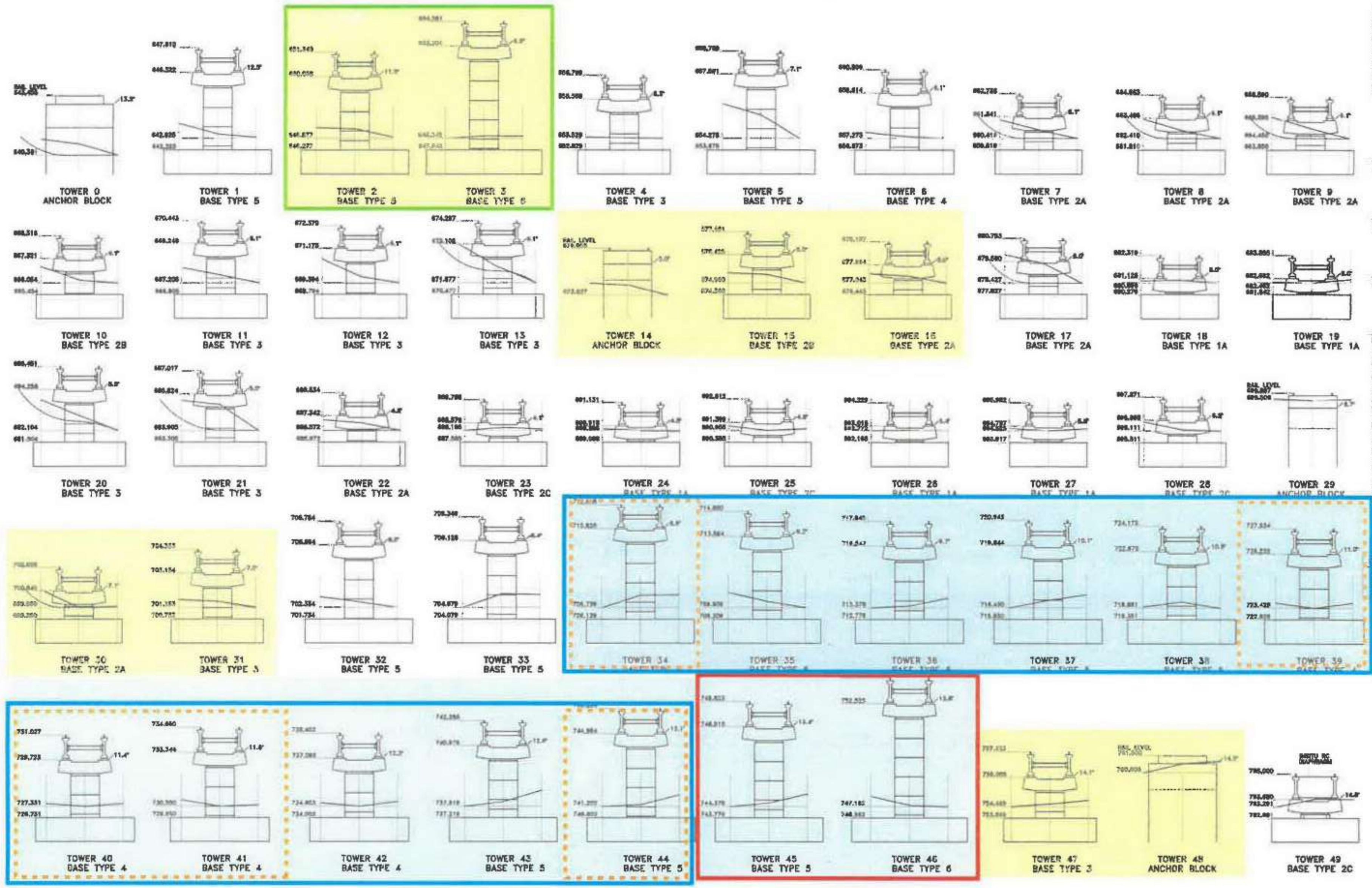
1 Beam type
Requires strengthening at 1st & 2nd crossbeams due shear utilisation > 1
Requires strengthening at 1st crossbeam due shear utilisation > 1
Strengthening recommended at 1st crossbeam due to high shear utilisation
Strengthening recommended over piers - connect 25 dia bars to reduce cracking

Requires strengthening to anchor block due to bending utilisation > 1
Strengthening recommended due to high bending utilisation

Note: All scarf joints require strengthening (not shown above)

CHAINAGE	1460.00, 1480.00, 1500.00, 1520.00, 1540.00, 1560.00, 1580.00, 1600.00, 1620.00, 1640.00, 1660.00, 1680.00, 1700.00, 1720.00, 1740.00, 1760.00, 1780.00, 1800.00
EXISTING GROUND LEVEL	956.29, 959.226, 963.74, 965.310, 969.68, 970.329, 976.898, 977.02, 982.359, 983.47, 987.503, 989.59, 992.677, 995.03, 997.380, 1000.72, 1001.944, 1006.09, 1008.355, 1013.488, 1013.60, 1020.144, 1021.81, 1028.79, 1035.53, 1042.86, 1048.56, 1053.33, 1058.71, 1063.44
COLUMN CHAINAGE	1467.797, 1484.862, 1501.927, 1518.992, 1536.057, 1553.122, 1570.187, 1587.251, 1604.316, 1621.381, 1638.536, 1655.852
TOP RAIL LEVEL	961.624, 967.318, 973.004, 978.689, 984.375, 990.061, 995.746, 1001.432, 1007.117, 1012.803, 1018.290, 1023.403, 1029.831, 1034.612, 1039.319, 1044.027, 1048.734, 1053.441, 1058.149
TOP OF FOUNDATION LEVEL	958.522, 964.699, 969.455, 976.296, 981.670, 985.852, 991.862, 996.682, 1001.313, 1005.580, 1012.602, 1019.471

Drawing LONGITUDINAL SECTION 6 OF 7 CHAINAGE 1460 – 1800 | Drawing No. CA150/2/16 Revision. F



A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax:01463 719201
email: crudens@aol.com

Client
CAIRNGORM CHAIRLIFT COMPANY

Project
CAIRNGORM FUNICULAR

Drawing
TOWER ELEVATIONS
SHEET 1 OF 2

Drawing No.	Drawn By
CA150/2/44	AM
REV. G	Date OCT 1999
	Scale 1:100

Revisions	Date	By
A Angles/Levels added.	28/10/99	[redacted]
B Table showing tower heights.	28/10/99	[redacted]
C Amended drawing due to revised bearing details and concrete beams.	12/4/00	[redacted]
D Base type amendments.	14/4/00	[redacted]
E Towers 4-34 amended due to revised bearing detail.	20/4/00	
F Tower base 0 is now an anchor block	25/4/00	
G Anchor blocks updated. Passing loop towers 48 to 53 are added.	24/7/00	

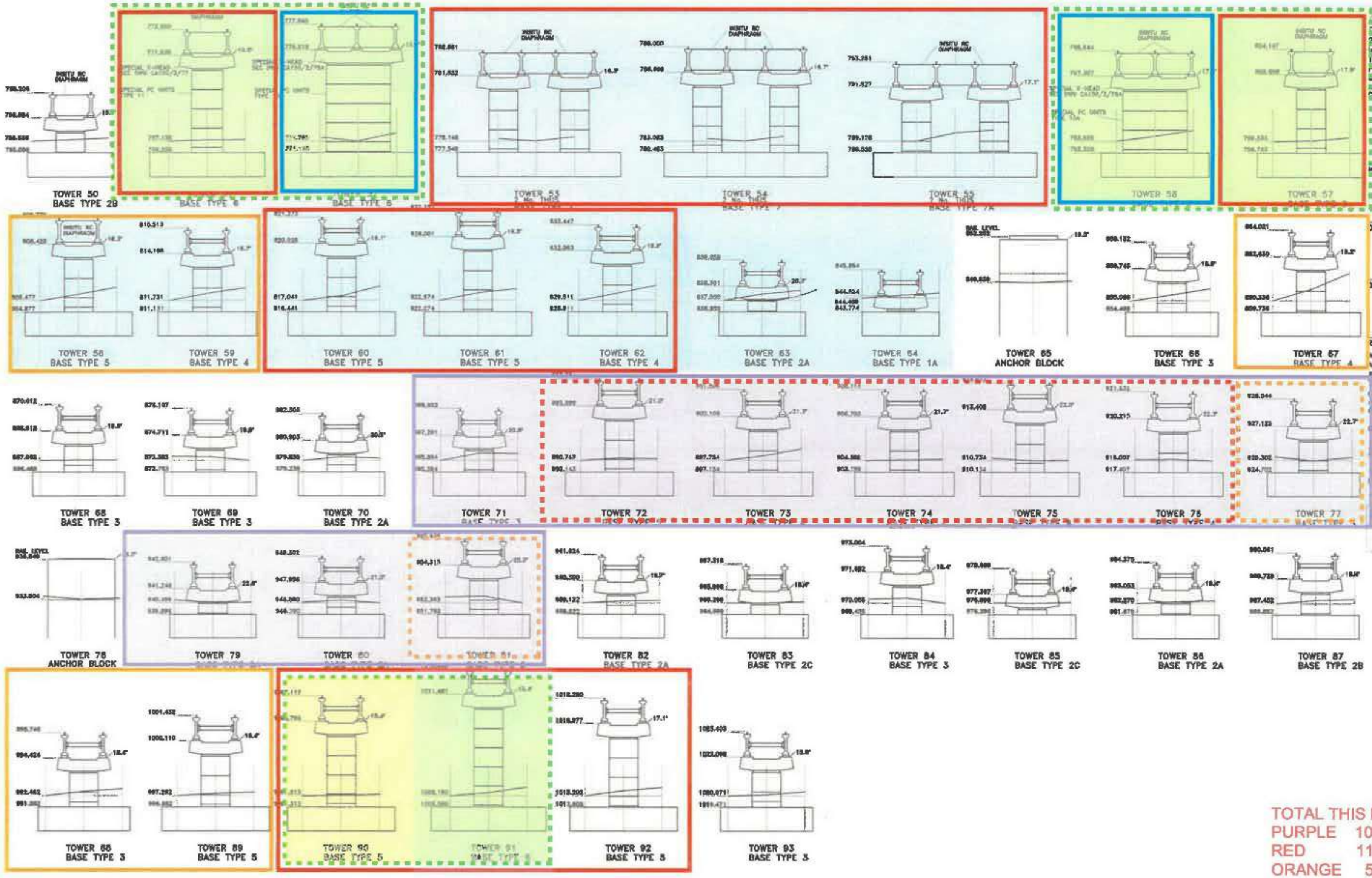
CONTRACT ISSUE
FOR CONSTRUCTION ☑
FOR INFORMATION ONLY ☐

Key:
BLUE SHADING - PIERS WITH BEARINGS MISALIGNED >50mm
PURPLE SHADING - PIER CROSSHEAD OVERLOADED
YELLOW SHADING - ADJACENT TO ACCESS ROAD

PURPLE OUTLINE - REQUIRES STRENGTHENING TO SUPPORT CROSSHEAD
RED OUTLINE - REQUIRES STRENGTHENING DUE TO PIER UTILISATION >1.00
ORANGE OUTLINE - STRENGTHENING RECOMMENDED SINCE PIER UTILISATION VERY HIGH
BLUE OUTLINE - STRENGTHENING RECOMMENDED SINCE BEARINGS MISALIGNED AND PIER UTILISATION HIGH
GREEN OUTLINE - STRENGTHENING RECOMMENDED TO GIVE RESILIENCE TO COLLISION LOAD

Note: BASED ON UNFACTORED ACCIDENTAL DESIGN SITUATION.

TOTAL THIS PAGE	
PURPLE	0
RED	2
ORANGE	0
BLUE	11
GREEN	2
TOTAL	15



A.F.Cruden Associates
Consulting Engineers
24 Bank Street
Inverness IV1 1QU
Tel: 01463 719200
Fax: 01463 719201
Email: crudens@aol.com

Client: CAIRNGORM CHAIRLIFT COMPANY

Project: CAIRNGORM FUNICULAR

Drawing: TOWER ELEVATIONS SHEET 2 OF 2

Drawing No. CA150/2/45 | Drawn By [redacted]

REV. F | Date OCT 1999 | Scale 1:100

Revisions	Date	By
A ...ngles/Levels added.	28/10/99	[redacted]
...ble showing tower heights.	28/10/99	[redacted]
...mended drawing due to revised bearing ...etails and concrete beams.	12/4/00	[redacted]
...ase type amendments.	14/4/00	[redacted]
...nchor blocks updated. Passing loop ...wers 48 to 58 are added.	24/7/00	[redacted]
...ower 64 is no longer an anchor block ...has been relocated to tower 65.	27/7/00	[redacted]

CONTRACT ISSUE
FOR CONSTRUCTION ☑
FOR INFORMATION ONLY ☐

TOTAL THIS PAGE

PURPLE	10	
RED	11	(incl 3 doubles)
ORANGE	5	
BLUE	2	
GREEN	0	
TOTAL	28	

Key:
BLUE SHADING - PIERS WITH BEARINGS MISALIGNED >50mm
PURPLE SHADING - PIER CROSSHEAD OVERLOADED
YELLOW SHADING - ADJACENT TO ACCESS ROAD

PURPLE OUTLINE - REQUIRES STRENGTHENING TO SUPPORT CROSSHEAD
RED OUTLINE - REQUIRES STRENGTHENING DUE TO PIER UTILISATION >1.00
ORANGE OUTLINE - STRENGTHENING RECOMMENDED SINCE PIER UTILISATION VERY HIGH
BLUE OUTLINE - STRENGTHENING RECOMMENDED SINCE BEARINGS MISALIGNED AND PIER UTILISATION HIGH
GREEN OUTLINE - STRENGTHENING RECOMMENDED TO GIVE RESILIENCE TO COLLISION LOAD

Note: BASED ON UNFACTORED ACCIDENTAL DESIGN SITUATION.

TOTAL OVERALL

PURPLE	10	
RED	13	(incl 3 doubles)
ORANGE	5	
BLUE	13	
GREEN	2	
TOTAL	43	

Appendix E Health, Safety and Environment

Design decision log

Designers' health and safety risk register

Designers' environmental risk register

COWI

DESIGN DECISION LOG

Job Ref.: A116993-002 Project: Cairngorm Funicular Railway – Concept Design Development Sheet No./Rev. v1

Prepared By:	Date:	Checked By:	Date:	Approved By:	Date:
[redacted]	14/2/19 updated 7/3/19 12/3/19 4/4/19	[redacted]	21/2/19 09/04/19	[redacted]	14/04/19

Ref	By	Date	Design Decision
DDL1	COWI	14/2/19	Strengthening will be undertaken so that all parts of the structure failing appraisal to *highway bridge assessment standards* will be re-appraised or strengthened to pass *Eurocode bridge design standards*. The accidental load case of a stranded carriage in storm winds will be treated as a *Eurocode Accidental Design Situation* with unfactored loads and reduced material factors.
DDL2	COWI	14/2/19	Strengthening will also be extended to selected parts of the structure which strictly pass the appraisal, but almost fail. This is done to rationalise the strengthening design and to reduce the risk that a category 3 independent checker will require additional strengthening at a later stage.
DDL3	COWI	14/2/19 updated 7/3/19	Selected piers could be strengthened by either propping or jacketing: • Propping - Consists of a new foundation and an inclined prefabricated prop. This largely eliminates risk of future bearing misalignment and pier overturning. • Jacketing - Enclose the existing pier in new offset reinforced concrete jacket to increase bending strength and to reduce uplift on foundations. This reduces the risk of future bearing misalignment and pier overturning. The selected option is propping. This solution is more modular in nature, requires less in-situ concrete and has less intrusive intervention into the existing structure. The latter is preferable as risk of unknown as-built conditions are minimised
DDL4	COWI	14/2/19	Pier strengthening will also be extended to tall piers where bearings are misaligned and hence it is suspected that the pier has rotated. This reduces potential future movement of piers.
DDL5	COWI	14/2/19	Pier strengthening will also be extended to tall piers which are adjacent to the access track and hence may be vulnerable to vehicle collision.
DDL6	COWI	14/2/19 updated 4/4/19	All bearings to be replaced by either: • 2 bearings per pier as existing - one sliding guided bearing and one free sliding bearing. • New arrangement involving 3 bearings per pier - one lateral load only guide bearing and 2 vertical load bearings. The selected option for concept design is 3 bearings. Currently it is believed the 2 bearing arrangement cannot be made to work at all locations. Further review will be required at detailed design stage.

<table>
<tr><th>Ref</th><th>By</th><th>Date</th><th>Design Decision</th></tr>
<tr><td>DDL7</td><td>COWI</td><td>14/2/19 updated 7/3/19</td><td>Selected beams will be strengthened in shear at around the 1st crossbeam by one of the following:
Prestress - an inclined bar relieves shear from the end of the beam,
External shear reinforcement - threaded bars outside the beam,
New shear reinforcement - new shear links within concrete,
Fibre Reinforced Polymer (FRP) wrapping - install new bands of FRP.
After commentary from CMSL operatives, HIE and BAM the selected option is strengthening by external shear reinforcement. This solution;
is modular in nature,
requires no intrusive intervention into the existing structure,
reduces risk of unknown as-built conditions,
permits future inspection and maintenance at a later date.</td></tr>
<tr><td>DDL8</td><td>COWI</td><td>14/2/19 updated 7/3/19</td><td>All beam scarf joints will be strengthened as there is uncertainty about the strength of the joint - its strength cannot be proven. This will comprise either:
Safeguarding by extended bearing plate - This might not prevent shear cracking but should prevent cracking developing to full shear failure,
Strengthening by one of the methods in DDL7 above.
After discussion with HIE and their risk approach, the selected option is strengthening by external shear reinforcement.</td></tr>
<tr><td>DDL9</td><td>COWI</td><td>14/2/19</td><td>All piers where type 3 beams are connected will be strengthened so that the 25 diameter bars are continuous. This should reduce hog cracking in future.</td></tr>
<tr><td>DDL10</td><td>COWI</td><td>14/2/19 updated 12/3/19</td><td>Beam ends cast into anchor blocks will be strengthened by one of the following:
extend the hog bars extending from the main beams by coupling them to bars drilled and anchored into the main base,
reduce hog moment by providing new soft bearing on the main base or a frame attached to the main base in front of the cast in connection.
The intrusive nature of the first option is undesirable. The selected option is to provide new soft bearings.</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
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</table>

DESIGNERS HEALTH AND SAFETY RISK REGISTER

Project Name: Cairngorm Mountain Railway – Concept Design Development   Project Nos: A116993-002

Revision Number:	Prepared By:	Date:	Checked By:	Date:	Approved By:	Date:	Notification of Risk to Stakeholders:	Date:
1	[redacted]	14/2/19	[redacted]	17/3/19	[redacted]	14/04/19	Comments and copy of this register included in concept design report to the client	16/04/19
2	[redacted]	08/5/19	[redacted]	31/05/19	[redacted]	07/06/19	Updated copy included in revised concept design report to the client	07/06/19

Hazard Type:	O – Occupational Health		C – Construction		F – Functional (End Use / Demolition)
Consequence Factor	1. No injury or illness caused	2. Minor injury or illness resulting in less than one shift lost time	3. Medium injury or illness resulting in less than one month lost time	4. Major injury or illness resulting in more than one month of lost time	5. Fatality
Likelihood	1. Never to very low likelihood of occurrence during the course of the project for design life of Scheme	2. Very unlikely to occur during the course of the project or design life of the Scheme	3. Unlikely to occur during the course of the project or design life of Scheme	4. Likely to occur during the course of the project or design life of Scheme	5. Very likely to occur during the course of the project or design life of Scheme

ELEMENT OF WORKS		HAZARD LOG			RISK ASSESSMENT						
DDL Ref		**Haz Ref No**	**Description**	**Type**	**Consequence**	**Likelihood**	**Risk**	**Mitigative Action Rqd; Party Best Able To Manage Risk**	**Consequence**	**Likelihood**	**Alarp Risk**
DDL1	Strengthening generally	HAZ1	Structure overloaded due to environmental conditions being more severe than design load cases	F	5 - Fatality	2 - Very unlikely	10	DESIGNER - Address same load cases as original design, but with Eurocode interpretation of accidental design situation, which does not endanger any people. Verify that storm wind speed is realistic. Agree design load cases with regulator. OPERATOR – Management of the funicular to an approved operating manual. Close railway when operating conditions exceeded. Inspect before re-opening.	5 - Fatality	1 - Very low likelihood	5
DDL1	Strengthening generally	HAZ2	Working in mountain environment - hypothermia due to low temperatures and wind chill	O/C	5 - Fatality	3 - Unlikely	15	CLIENT - Allow strengthening in summer and allow extra time to make up for lost days. CONTRACTOR - Close site when necessary. Provide adequate welfare facilities and protective clothing for the anticipated environmental conditions. DESIGNER - Design to allow off-site fabrication as far as possible.	5 - Fatality	2 - Very unlikely	10
DDL1	Strengthening generally	HAZ3a	Being struck by train, or entangled in machinery	C	5 - Fatality	2 - Very unlikely	10	CLIENT & CONTRACTOR - If railway is to be used during construction period, then agree working and warning procedures.	5 - Fatality	1 - Very low likelihood	5
DDL1	Strengthening generally	HAZ3b	Being struck by rail mounted trolley.	C	5 - Fatality	4 - Likely to occur	20	CONTRACTOR - If rail mounted trolleys are to be used, then use a trolley design with low risk of run-away downhill and also use	5 - Fatality	2 - Very unlikely	10

ELEMENT OF WORKS		HAZARD LOG			RISK ASSESSMENT						
DDL Ref		Haz Ref No	Description	Type	Consequence	Likelihood	Risk	Mitigative Action Rqd; Party Best Able To Manage Risk	Consequence	Likelihood	Alarp Risk
								positive stops on rails able to halt a run-away trolley. Agree working and warning procedures for trolley movements.			
DDL3	Pier Propping - Use of precast elements	HAZ4	Crushing hazard from heavy precast elements	C	5 - Fatality	2 - Very unlikely	10	CLIENT - Allow temporary access roads and use of appropriate plant to deliver and install items safely.	5 - Fatality	1 - Very low likelihood	5
DDL5	Pier Strengthening for collision	HAZ5	Collapse due to construction plant colliding with structure	C	5 - Fatality	2 - Very unlikely	10	CONTRACTOR- Phase pier strengthening of vulnerable piers early in project.	5 - Fatality	1 - Very low likelihood	5
DDL7	Shear strengthening of beams	HAZ6	Structure overloaded due to construction loads	C	5 - Fatality	3 - Unlikely	15	CONTRACTOR, DESIGNER- Allowable temporary loading prior to strengthening to be agreed with designer.	5 - Fatality	2 - Very unlikely	10

Note: Not included risks due prestress, jacking, hydro demolition, drilling or ordinary reinforced concrete hazards, as these are typical construction hazards which a competent Contractor should be able to manage.

DESIGNER'S ENVIRONMENTAL RISK REGISTER

Project Name: Cairngorm Mountain Railway – Concept Design Development　　Project Nos: A116993-002

Revision Number:	Prepared By:	Date:	Checked By:	Date:	Approved By:	Date:	Notification of Risk to Stakeholders:	Date:
1	[redacted]	14/2/19	[redacted]	17/03/19	[redacted]	11/04/19	Comments and copy of this register included in concept design report to the client	16/04/19

Hazard Type:	O – Occupational Health		C – Construction		F – Functional (End Use / Demolition)
Consequence Factor	1. No environmental impact	2. Limited impact on local scale (i.e. site or immediate area)	3. Limited impact on wider scale or moderate impact on local scale	4. Moderate impact on wider scale or high impact on local scale	5. High impact on wider scale
Likelihood	1. Never to very low likelihood of occurrence during the course of the project for design life of Scheme	2. Very unlikely to occur during the course of the project or design life of the Scheme	3. Unlikely to occur during the course of the project or design life of Scheme	4. Likely to occur during the course of the project or design life of Scheme	5. Very likely to occur during the course of the project or design life of Scheme

ELEMENT OF WORKS		HAZARD LOG			RISK ASSESSMENT						
DDL Ref		**Haz Ref No**	**Description**	**Type**	**Consequence**	**Likelihood**	**Risk**	**Mitigative Action Rqd; Party Best Able To Manage Risk**	**Consequence**	**Likelihood**	**Alarp Risk**
DDL1	Strengthening generally	ENV1	To access the site for strengthening works, temporary access roads will need to be constructed in a SSSI	C	3 - moderate impact on local scale	5 - certain	15	Client to arrange permissions. Contractor's temporary works designer to limit damage. All areas to be made good after completion with original topsoil material to enable regeneration and the method to be agreed with relevant stakeholders.	2 - moderate impact on local scale	5 - certain	10
DDL3	Pier strengthening	ENV2	With either option, existing ground will have to be excavated within the SSSI.	C	3 - moderate impact on local scale	5 - certain	15	Client to arrange permissions.	2 - limited impact on local scale	5 - certain	10
DDL9	Intrusive works in reinforced concrete	ENV3	For the Type 3 repairs, reinforced concrete will need to be brioken out within a SSSI area by either HydroDem or hand break-out.	C	3 - moderate impact on local scale	5 - certain	15	Use suitable containment and catchment to contain, collect and dispose of arisings from break-out activity.	2 - limited impact on local scale	5 - certain	10

Appendix F Cost estimate and programme for construction

BAM - Buildability Review & Budget Pricing Report inc. Cost Summary, v3

BAM - Strengthening Work Budget Programme – Two Season, v3.1

BAM - Strengthening Work Budget Programme – Single Season, v3.2

Commentary

bam
Infrastructure Advisory

COWI

Cairngorm Mountain Funicular Railway Remedial Works

Buildability Review & Budget Pricing

31 May 2019
4012-COWI-r-0101

bam

bam
Infrastructure Advisory

COWI

Cairngorm Mountain Funicular Railway

Buildability Review, plus Preparation of an Indicative Budget & Programme

Report number: 4012-COWI-r-0101

Client: Cowi UK Limited

Author
Name: [redacted]
Direct line: [redacted]
E-mail: [redacted]@bamnuttall.co.uk

3	Fourth Issue	[redacted]	31-05-2019	[redacted]	31-05-2019	[redacted]	05-06-2019
2	Third Issue	[redacted]	29-05-2019	[redacted]	29-05-2019	[redacted]	29-05-2019
1	Second Issue	[redacted]	26-04-2019	[redacted]	29-04-2019	[redacted]	29-04-2019
-	First issue	[redacted]	29-03-2019	[redacted]	29-03-2019	[redacted]	29-03-2019
Revision	Status	Author	Date	Verified	Date	Released	Date

Table of Contents

Introduction

COWI UK Limited have been commissioned by Highlands and Island Enterprise (HIE) to investigate the problems identified with the funicular railway on Cairngorm Mountain and to provide advice on the options available to HIE to rectify these problems.

This advice includes recommendation as to the optimum technical solutions to be used and also to provide an indicative price and programme for undertaking these repairs.

COWI has engaged BAM Nuttall Infrastructure Advisory Services (BAM) to provide assistance with the development of the technical solutions and to provide budget and planning services.

Background and purpose

The Cairngorm Funicular Railway was opened in 2001 and has a 2km route from a base station at an elevation of 635m to a top station at an elevation of 1,097m.

The railway is owned by HIE and until recently was operated under a long-term lease arrangement by CairnGorm Mountain Limited (CML), a subsidiary of Natural Retreats. During inspections in 2018 aspects of the condition of the asset caused concern and COWI has been engaged to carry out a detailed engineering assessment of the railway and to recommend remedial works. Such is the concern about the condition of the asset that the railway was closed to the public in October 2018, with the operator (CML) subsequently placed into administration.

The closure of the railway has attracted nationwide publicity due to the negative impact of its closure on tourism in the Strathspey area and the consequent reduction in employment locally.

It is understood that as the owner of the asset HIE wish to establish whether it is technically and economically feasible to repair the existing asset and will then compare that option with alternatives such as its complete replacement or removal.

COWI have supervised intrusive investigative works and have developed details of the proposed remedial works but given the demanding environmental conditions, access and environmental constraints it is desired to obtain the input of an experienced contractor to develop a budget and programme for this work.

Scope of work

The scope of works undertaken by BAM is;

- Attend site visit with COWI, HIE and Cairngorm Mountain.
- Provide buildability advice to COWI to assist with the selection and development of preferred solutions for each intervention
- Undertake basic planning of the construction operations required to deliver these interventions.
- Prepare an outline programme for the execution of the works
- Engage with their supply chain to determine budget prices for materials or specialist services needed for the delivery of the proposed solutions.
- Develop a budget price for undertaking these works.
- Prepare a list of key assumptions that have been used in the development of the outline programme and budget price.
- Run a scenario whereby the works are carried out in a single season.

bam
Infrastructure Advisory

COWI

Input data

In undertaking this commission BAM has relied upon the following documents:

- A116993_Rp01_v2 Appraisal Report, plus associated Appendices A to E inclusive.
- A116993 Strengthening extents 190328
- A116993 Strengthening extents layout deck 190328
- A116993 Strengthening extents layout piers 190213
- COWI sketches as follows:
  - SK01revA
  - SK05revA
  - SK12
  - SK13
  - SK14
  - SK15

Deliverables

BAM has prepared the following deliverables, which are included as Appendices to this report:

- Schedule of assumptions used in preparing the programme and budget for the proposed remedial works (Appendix A)
- Outline programme for undertaking the proposed remedial works (Appendix B)
- Budget price for undertaking the proposed remedial works, including a commentary on the degree of accuracy or 'bandwidth' of the budget (Appendix C)
- Examination of the scenario where the works are undertaken in one season (Appendix D).

Concept Development

Based on the work done to date BAM has noted the following areas which it is considered may allow a reduction in the cost and also potentially the time to complete the works. These areas are therefore recommended for further ongoing investigation:

- Disposal of excavation arisings from works to piers and anchor blocks.

  Given the significant cost associated with helicopter transport identified in the initial budgeting exercise it is clear that there is significant cost associated with the relocation of this material to the Ptarmigan restaurant area. If it can be distributed locally at the pier and anchor block locations then a saving of more than £200k could potentially be secured.

- Review of foundation details in order to reduce the volume of concrete required.

  Currently the foundation design requires a considerable amount of concrete, which is contributing significantly to the cost of the helicopter transport. If this can be reduced then a significant cost and time saving could potentially be available.

- Continue to work with bearing suppliers to try to identify a solution that avoids the need for the introduction of a third central bearing.

  Currently a third bearing is needed in the centre of each crosshead in order to provide the lateral resistance that is needed. If through further dialogue with bearing manufacturers it proves possible to remove the need for this bearing or to limit its use to certain sections of the track only then a significant saving in time could potentially be achieved.

Appendix A – Schedule of Assumptions

In preparing the outline programme and cost for the works the following assumptions have been made:

1. The construction season will run from the last week of May 2020 to the third week in October 2020 and similarly from May 2021 to October 2021.
2. Any material placed/stored on the mountain can remain there between the two seasons.
3. No flying constraints will be imposed on helicopter movements during this period and adequate space and environs will be provided for landing and take-off.
4. Adequate storage and welfare areas will be made available at the Shieling, Lower Carpark and if necessary Ptarmigan.
5. Whilst ground disturbance will be kept to a minimum, we have made no provision for other environmental constraints beyond the use of spider excavators, low ground pressure (LGP) equipment and run-off silt screens
6. A 2" pump has been allowed for the management of any water inflow into excavations.
7. We have made provision for setting aside the top peat for reinstatement at the end.
8. We have assumed the ground is sufficiently stable for the excavation sides to be battered, with no need for temporary support equipment.
9. We have assumed the soil to be *gravel,* or weathered rock and there is no excavation in rock
10. We have assumed the use of LGP excavation plant below the Sheiling and spider type excavation equipment above it.
11. It is assumed that our plant selection can work unhindered below the existing structure. Time does not allow us to assess areas of limited height but we have used low production rates to account for this.
12. Notwithstanding our obligation to mitigate noise, we have not made provision for specific noise reduction measures beyond those expected in urban areas.
13. Excess excavated material will be left in heli sacks at the Ptarmigan for future use by Cairngorm Mountain
14. Excavated material is suitable as backfill
15. Average prop lengths is 2.6m+1m cast in, with prop base on the 1st pour
16. An allowance only has been made for the prop head arrangement.
17. We have made provision for 75mm blinding to prop bases
18. There is no constraint on the striking time for formwork and this can be struck the following day.
19. Prop plinth, SK01 rev A, has vertical face
20. Bagged backfill stays at bases over winter
21. Construction tolerances will be designed into the anchor block bearing support frame
22. The 25mm bar ends are where we expect them to be in the repairs to the scarf joints and we do not have remove additional concrete to find the ends. We have therefore allowed for removing 2m of the PC beam flange by saw cutting and hand breaking to expose the 25mm bar.
23. It has been assumed that prior to strengthening works, the structure load will be transferred to the crosshead using 2nr 200t jacks. When the load is off the bearings they will be unbolted and slid out and replace by the new bearings attached to the existing base plate with the same bot arrangement.
24. Some materials are from mainland Europe so there is a procurement risk associated with Brexit, which it is not possible to allow for due to the level of uncertainty.
25. The lateral bearing is designed for in situ fit up and construction tolerances
26. Access risk for coring rig for lower bearing plate holes

Appendix B – Outline Programme

Attached separately. Titled:
190531 CAIRNGORM FUNICULAR RAILWAY STRENGTHENING v3.1

Cairngorm Funicular Strengthening Work
Budget Programme.

Programme commentary:

In planning the Works we had safety concerns regarding the excavation works being incomplete over the ski season. We have therefore resourced the activities to mitigate against this risk.

The logic behind the sequence is that the props should go in first because:

a. They stabilise and strengthen the support prior to any superstructure strengthening.
b. The excavation is backfilled in time to permit the erection of the access scaffold to the pier heads and the first cross beam locations.

Not all of the prop bases can be excavated at the same time because the excavations will be left open and exposed to the weather, we have therefore planned on progressing two at a time.

The bearing, lateral and pot/spherical, replacements go in prior to the strengthening and hence stiffening of the beams. The jacking of the beams off the crosshead is to remove the load from the existing bearings, to facilitate their removal. There is a risk that the bearing encasement may be fused to the base plate and this risk should be considered when compiling the project risk register.

T3 to T3, 25mm rebar repair will be carried out prior to the scarf joint strengthening as these two details have an interface to manage.

The bearing, scarf joint and T3 repairs have been combined, insofar that they are to be done at the same time to minimise access arrangements eg the scaffold will be erected and taken down once at each location, rather than a protracted access hire.

We have been cognisant of the helicopter time and movements and the plan is based on one helicopter. This will require optimal time and motion planning at a later date.

Appendix C – Budget Price

Our estimated budget is £5.6m with a +/- 20% margin of error. A breakdown of these costs is included in this appendix.

The above excludes the pot/spherical bearing costs as details of these are necessary for a material quote to be included in our estimate. Notwithstanding this, we have include the cost of the fixing effort ie equipment and labour to replace the bearings.

We have included 5% for Risk and 3.7% RPI over the period.

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Cairngorm Funicular Railway Remedial Works

Buildability Review & Budget Pricing

WORK COST SUMMARY - TWO SEASONS

	Direct Work Costs			
1	SK01 Pier head propping (46 locations @ 43 piers)	46	nr	[redacted]
2	Anchor Block Additional Bearings			
a)	SK12 Anchor Blocks 0, 65 & 78	6	nr	[redacted]
b)	SK13 Anchor Blocks 14 & 29	4	nr	
3	SK05 New bearing replacement (2nr per pier)			
a)	Replace existing spherical / pot bearings (excl. material costs of spherical / pot bearings)	196	nr	[redacted]
b)	Install new lateral restraint guide	97	nr	[redacted]
4	SK11 Scarf joint reinforcement steel replacement	26	nr	[redacted]
5	External PCC beam shear reinforcement			
a)	SK14 Ext shear reinforcement @ scarf joints	360	nr	[redacted]
b)	SK15 Ext shear reinforcement @ 1st crossbeam	166	nr	
c)	SK15 Ext shear reinforcement @ 2nd crossbeam	20	nr	
	Total Direct Net Cost			[redacted]
	Helicopter costs included in above direct net costs	[redacted]		
	Preliminaries & General Condition Costs			
	Season 1 - May 2020 to Oct 2020			[redacted]
	Season 2 - May 2021 to Oct 2021			[redacted]
	Total Indirect Net Cost			[redacted]
	Other identified costs (Insurances, inflation effects, etc.)			[redacted]
	O&P @ 12.2%			[redacted]
	General Risk @ 5%			[redacted]
	Potential Construction Costs			[redacted]

Appendix D – Single Season Scenario

As part of the exercise to consider the cost of undertaking the strengthening works to the funicular railway BAM has also looked at the scenario whereby the works are undertaken over a single season.

The benefit of this approach is that it allows works to be completed significantly earlier than would otherwise be the case. However, it is more sensitive to a poor weather season than the baseline approach and carries the risk that in the event of a bad year the works may not be completed before the winter arrives and work has to be suspended.

Our conclusion is that it is possible to complete the works within a single season by deploying sufficient resources, including a second helicopter, and by extending the working period into the shoulder months when weather conditions are less favourable.

Our analysis shows that it should be possible to complete the works in a single season for a similar cost as for two seasons.

Appendix D1 –

Schedule of Additional Assumptions – Single Season

In addition to the assumptions noted in Appendix A above, a number of further assumptions should be noted in relation to this scenario:

1. The construction season will run from the start of April 2020 to the end of October 2020
2. It will be possible to operate two helicopters at once during the initial period of prop installation.
3. A purpose built rail mounted lifting equipment will be developed and deployed to support the squads working on bearing replacement and mechanical strengthening.

Appendix D2 –

Outline Programme – Single Season

Attached separately. Titled:
190531 CAIRNGORM FUNICULAR RAILWAY STRENGTHENING v3.2

Cairngorm Funicular Strengthening Work
Outline Programme - Single Season

Programme commentary:

The commentary noted in general also applies to this scenario; the key difference being that in order to achieve the works within a shortened period a second helicopter will need to be deployed and the number of squads used increased. Specifically, in order to complete the works in a single season the following squads would need to be deployed in the field:

- Squad Type 1:
  - Propping to piers
  - 3 No. squads required
  - Each squad works on two foundations at the same time.
- Squad Type 2:
  - Bearing replacement
  - Scarf joint mechanical strengthening
  - Cross beam mechanical strengthening
  - 7 No. squads required
- Squad Type 3:
  - Concrete strengthening at scarf joints
  - 1 No. squad required
- Squad Type 4:
  - Provision of scaffold access to above teams
  - 1 No. squad required
- Squad Type 5:
  - Logistics support to above teams
  - 1 No. squad required

Appendix D3 –

Budget Price – Single Season

Our estimated budget is £5.6m with a +/- 20% margin of error.

Once again this excludes the pot/spherical bearing costs as details of these are necessary for a material quote to be included in our estimate.

As part of the analysis of this option we have undertaken an assessment of the impact of increasing resource levels in order to complete the works in a single season and the additional support that will be required to ensure that the teams undertaking the works can operate at maximum efficiency.

Key changes are as follows:

- Extension of the season in order to allow works to be completed within the period, with the sequencing set so as to minimise the risk of weather delay during the shoulder periods.
- Requirement for full time helicopter support for a period of 10 weeks, with a second visiting helicopter in addition over this period in order to meet demand.
- Increase in levels of supervisory staff and supporting personnel, plus associated levels of accommodation and general site plant.

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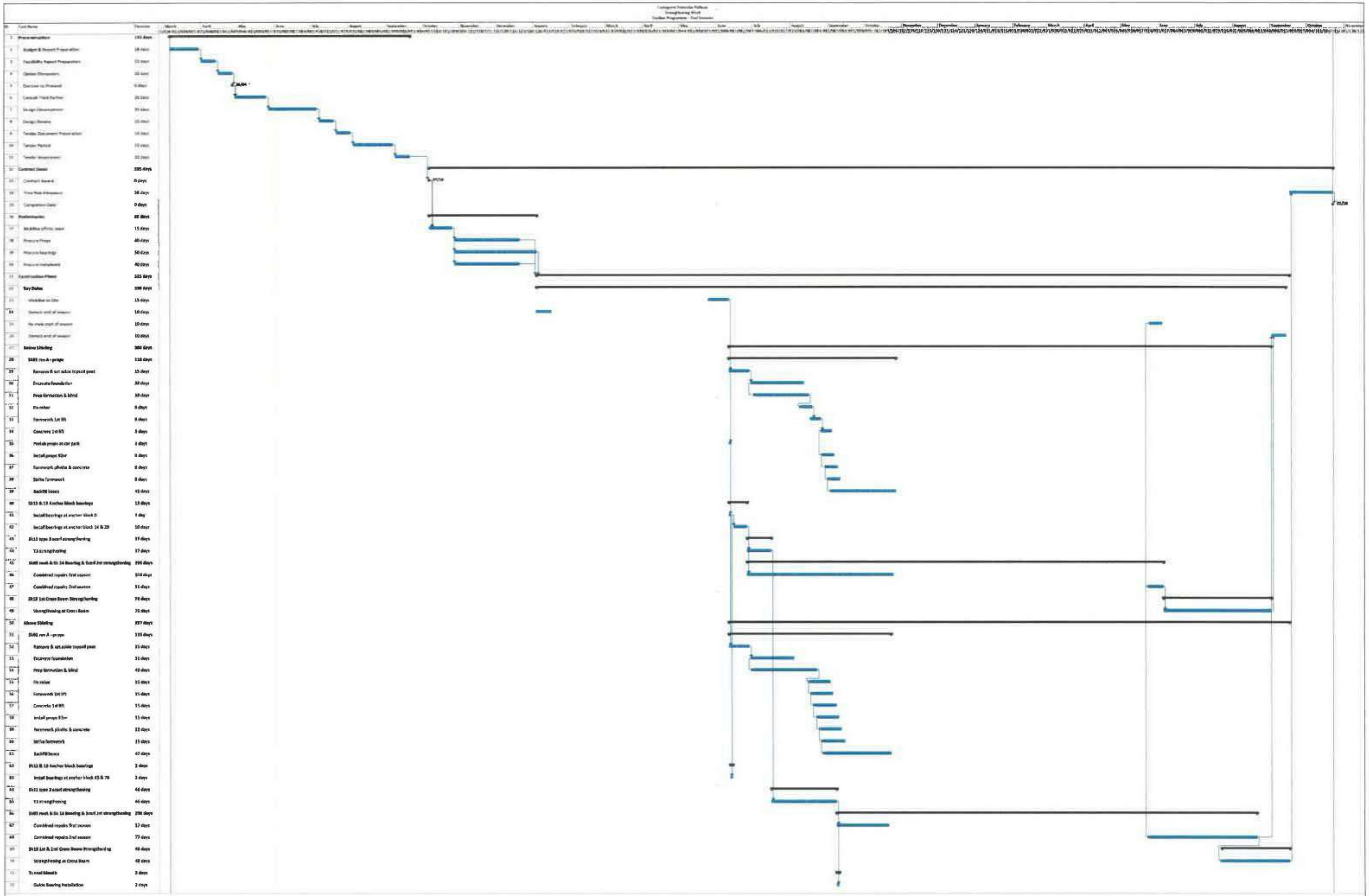
Cairngorm Funicular Railway Remedial Works
Buildability Review & Budget Pricing

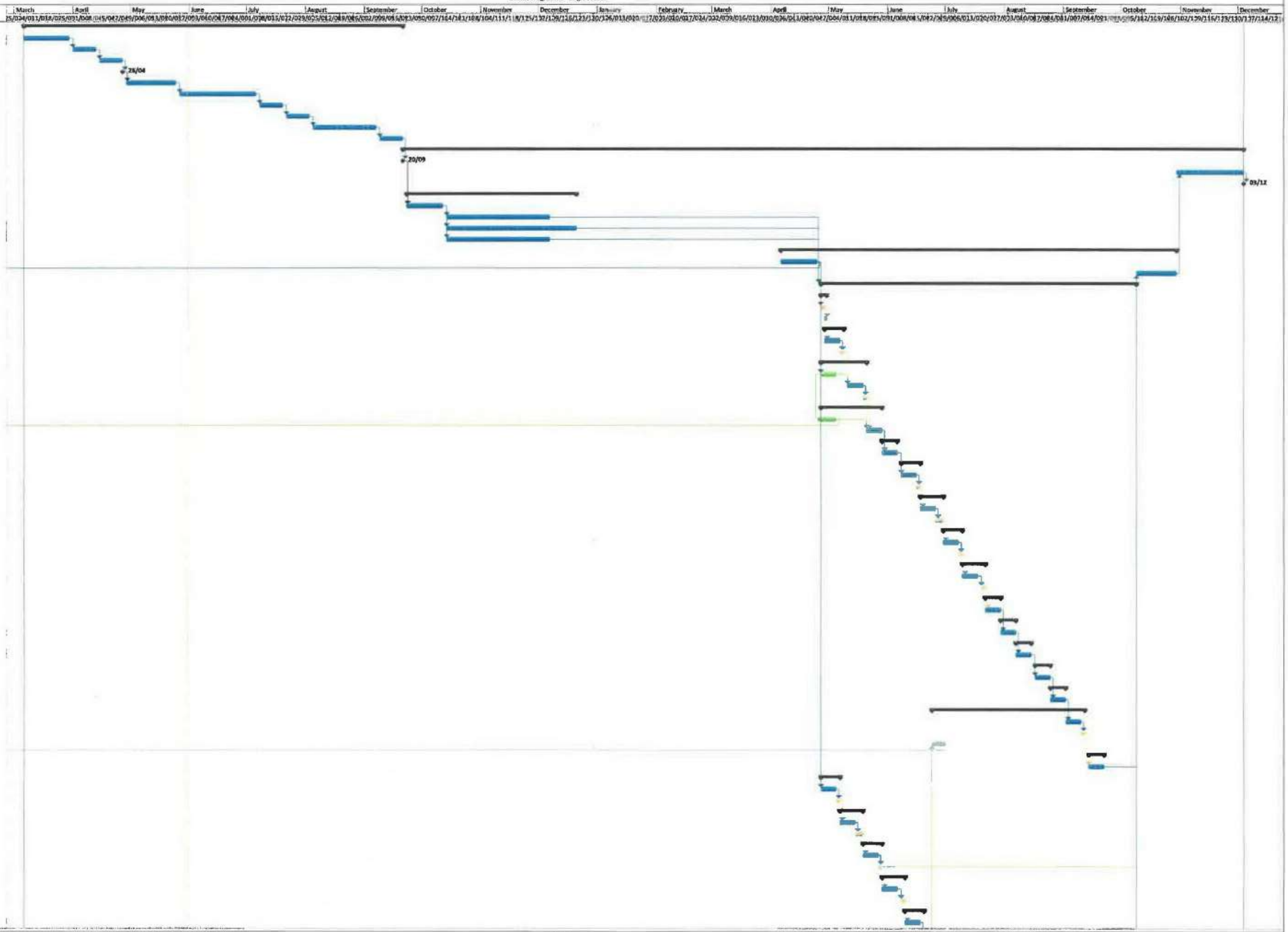
WORK COST SUMMARY - ONE SEASON

	Direct Work Costs			
1	SK01 Pier head propping (46 locations @ 43 piers)	46	nr	[redacted]
2	Anchor Block Additional Bearings			
a)	SK12 Anchor Blocks 0, 65 & 78	6	nr	[redacted]
b)	SK13 Anchor Blocks 14 & 29	4	nr	
3	SK05 New bearing replacement (2nr per pier)			
a)	Replace existing spherical / pot bearings (excl. material costs of spherical / pot bearings)	196	nr	[redacted]
b)	Install new lateral restraint guide	97	nr	[redacted]
4	SK11 Scarf joint reinforcement steel replacement	26	nr	[redacted]
5	External PCC beam shear reinforcement			
a)	SK14 Ext shear reinforcement @ scarf joints	360	nr	[redacted]
b)	SK15 Ext shear reinforcement @ 1st crossbeam	166	nr	
c)	SK15 Ext shear reinforcement @ 2nd crossbeam	20	nr	
	Total Direct Net Cost			[redacted]
	Preliminaries & General Condition Costs			
	Prelims - April 2020 to November 2020 (excl helicopter costs)			[redacted]
	Helicopter costs (2nr heli squads covering f/time + p/time on site)			[redacted]
	Total Indirect Net Cost			[redacted]
	Other identified costs (Insurances, inflation effects, etc.)			[redacted]
	O&P @ 12.2%			[redacted]
	General Risk @ 5%			[redacted]
	Potential Construction Costs			[redacted]


Contract Award
Completion Date
Preliminaries
Key Dates
Below Sliding
Excavate foundation
Prep formation & blind
Formwork, plinths & concrete
Strike formwork
Backfill bases
Install bearings at anchor block 14 & 29
T3 strengthening
Combined repairs first season
Combined repairs 2nd season
Strengthening at Cross Beam
Above Sliding
Guide Bearing Installation
585 days
0 days
15 days
40 days
50 days
40 days

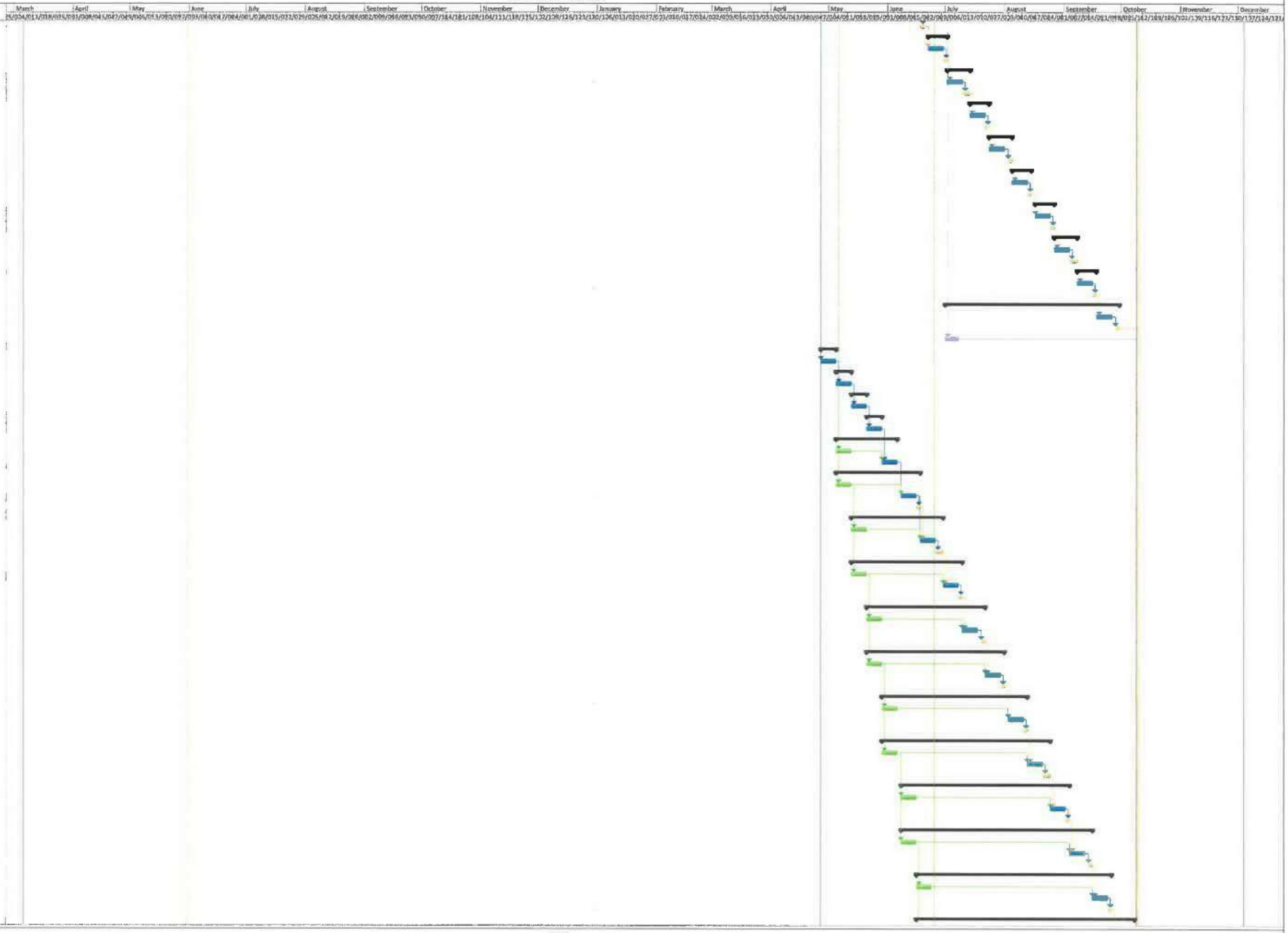
Cairngorm Funicular Railway
Strengthening Work
Outline Programme - Single Season

ID	Task Name	Duration
1	**Preconstruction**	**143 days**
2	Budget & Report Preparation	18 days
3	Feasibility Report Preparation	10 days
4	Option Discussions	10 days
5	Decision to Proceed	0 days
6	Consult Third Parties	20 days
7	Design Development	30 days
8	Design Review	10 days
9	Tender Document Preparation	10 days
10	Tender Period	25 days
11	Tender Assessment	10 days
12	**Contract Dates**	**314 days**
13	Contract Award	0 days
14	Time Risk Allowance	25 days
15	Completion Date	0 days
16	**Preliminaries**	**65 days**
17	Mobilise offsite team	15 days
18	Procure Props	40 days
19	Procure bearings	50 days
20	Procure metalwork	40 days
21	**Site Establishment**	**149 days**
22	Mobilise to Site	15 days
23	Demobilise from site	15 days
24	**Construction Phase**	**119 days**
25	**Anchor 0**	**3 days**
26	Crossbeam Strengthen	2 days
27	Additional Bearings	1 day
28	**Pier 1**	**8 days**
29	Bearings & Scarf Strengthen	6 days
30	Crossbeam Strengthen	2 days
31	**Pier 2**	**18 days**
32	Propping	6 days
33	Bearings & Scarf Strengthen	6 days
34	Crossbeam Strengthen	2 days
35	**Pier 3**	**24 days**
36	Propping	6 days
37	Bearings & Scarf Strengthen	6 days
38	**Pier 4**	**6 days**
39	Bearings & Scarf Strengthen	6 days
40	**Pier 5**	**8 days**
41	Bearings & Scarf Strengthen	6 days
42	Crossbeam Strengthen	2 days
43	**Pier 6**	**8 days**
44	Bearings & Scarf Strengthen	6 days
45	Crossbeam Strengthen	2 days
46	**Pier 7**	**8 days**
47	Bearings & Scarf Strengthen	6 days
48	Crossbeam Strengthen	2 days
49	**Pier 8**	**8 days**
50	Bearings & Scarf Strengthen	6 days
51	Crossbeam Strengthen	2 days
52	**Pier 9**	**6 days**
53	Bearings & Scarf Strengthen	6 days
54	**Pier 10**	**6 days**
55	Bearings & Scarf Strengthen	6 days
56	**Pier 11**	**6 days**
57	Bearings & Scarf Strengthen	6 days
58	**Pier 12**	**6 days**
59	Bearings & Scarf Strengthen	6 days
60	**Pier 13**	**6 days**
61	Bearings & Scarf Strengthen	6 days
62	**Anchor 14**	**58 days**
63	Bearings & Scarf Strengthen	6 days
64	Crossbeam Strengthen	2 days
65	Additional Bearings + Frame	5 days
66	**Pier 15**	**6 days**
67	Bearings & Scarf Strengthen	6 days
68	**Pier 16**	**8 days**
69	Bearings & Scarf Strengthen	6 days
70	Crossbeam Strengthen	2 days
71	**Pier 17**	**8 days**
72	Bearings & Scarf Strengthen	6 days
73	Crossbeam Strengthen	2 days
74	**Pier 18**	**8 days**
75	Bearings & Scarf Strengthen	6 days
76	Crossbeam Strengthen	2 days
77	**Pier 19**	**8 days**
78	Bearings & Scarf Strengthen	6 days
79	Crossbeam Strengthen	2 days
80	**Pier 20**	**8 days**
81	Bearings & Scarf Strengthen	6 days



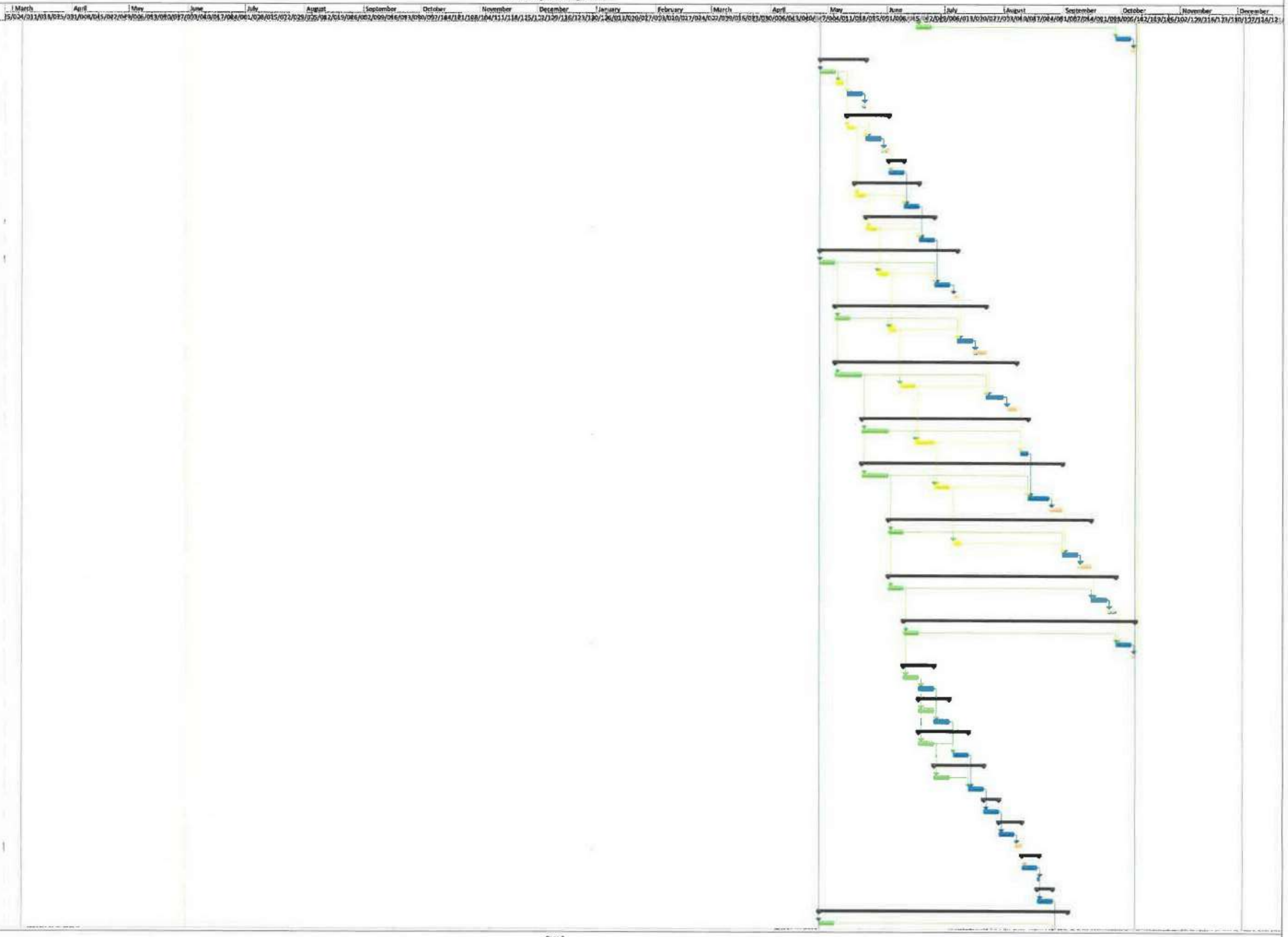
Cairngorm Funicular Railway
Strengthening Work
Outline Programme - Single Season

ID	Task Name	Duration
82	Crossbeam Strengthen	2 days
83	**Pier 21**	**8 days**
84	Bearings & Scarf Strengthen	6 days
85	Crossbeam Strengthen	2 days
86	**Pier 22**	**8 days**
87	Bearings & Scarf Strengthen	6 days
88	Crossbeam Strengthen	2 days
89	**Pier 23**	**8 days**
90	Bearings & Scarf Strengthen	6 days
91	Crossbeam Strengthen	2 days
92	**Pier 24**	**8 days**
93	Bearings & Scarf Strengthen	6 days
94	Crossbeam Strengthen	2 days
95	**Pier 25**	**8 days**
96	Bearings & Scarf Strengthen	6 days
97	Crossbeam Strengthen	2 days
98	**Pier 26**	**8 days**
99	Bearings & Scarf Strengthen	6 days
100	Crossbeam Strengthen	2 days
101	**Pier 27**	**8 days**
102	Bearings & Scarf Strengthen	6 days
103	Crossbeam Strengthen	2 days
104	**Pier 28**	**8 days**
105	Bearings & Scarf Strengthen	6 days
106	Crossbeam Strengthen	2 days
107	**Anchor 29**	**85 days**
108	Bearings & Scarf Strengthen	6 days
109	Crossbeam Strengthen	2 days
110	Additional Bearings + Frame	5 days
111	**Pier 30**	**6 days**
112	Bearings & Scarf Strengthen	6 days
113	**Pier 31**	**6 days**
114	Bearings & Scarf Strengthen	6 days
115	**Pier 32**	**6 days**
116	Bearings & Scarf Strengthen	6 days
117	**Pier 33**	**6 days**
118	Bearings & Scarf Strengthen	6 days
119	**Pier 34**	**24 days**
120	Propping	6 days
121	Bearings & Scarf Strengthen	6 days
122	**Pier 35**	**32 days**
123	Propping	6 days
124	Bearings & Scarf Strengthen	6 days
125	Crossbeam Strengthen	2 days
126	**Pier 36**	**34 days**
127	Propping	6 days
128	Bearings & Scarf Strengthen	6 days
129	Crossbeam Strengthen	2 days
130	**Pier 37**	**42 days**
131	Propping	6 days
132	Bearings & Scarf Strengthen	6 days
133	Crossbeam Strengthen	2 days
134	**Pier 38**	**44 days**
135	Propping	6 days
136	Bearings & Scarf Strengthen	6 days
137	Crossbeam Strengthen	2 days
138	**Pier 39**	**52 days**
139	Propping	6 days
140	Bearings & Scarf Strengthen	6 days
141	Crossbeam Strengthen	2 days
142	**Pier 40**	**54 days**
143	Propping	6 days
144	Bearings & Scarf Strengthen	6 days
145	Crossbeam Strengthen	2 days
146	**Pier 41**	**62 days**
147	Propping	6 days
148	Bearings & Scarf Strengthen	6 days
149	Crossbeam Strengthen	2 days
150	**Pier 42**	**64 days**
151	Propping	6 days
152	Bearings & Scarf Strengthen	6 days
153	Crossbeam Strengthen	2 days
154	**Pier 43**	**72 days**
155	Propping	6 days
156	Bearings & Scarf Strengthen	6 days
157	Crossbeam Strengthen	2 days
158	**Pier 44**	**74 days**
159	Propping	6 days
160	Bearings & Scarf Strengthen	6 days
161	Crossbeam Strengthen	2 days
162	**Pier 45**	**82 days**



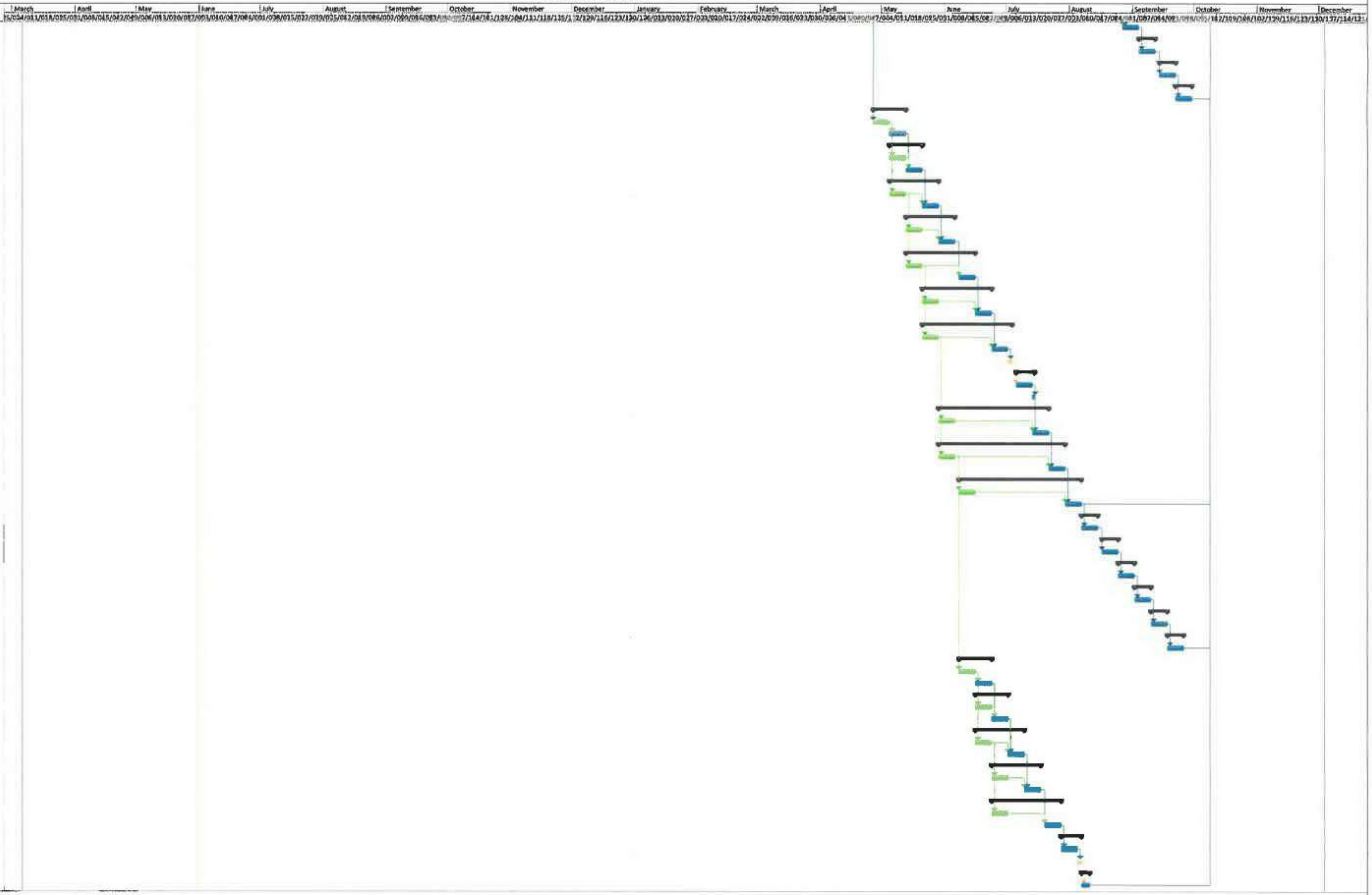
Cairngorm Funicular Railway
Strengthening Work
Outline Programme - Single Season

ID	Task Name	Duration
163	Propping	6 days
164	Bearings & Scarf Strengthen	6 days
165	Crossbeam Strengthen	2 days
166	**Pier 46**	**18 days**
167	Propping	6 days
168	Concrete Scarf Strengthening	4 days
169	Bearings & Scarf Strengthen	6 days
170	Crossbeam Strengthen	2 days
171	**Pier 47**	**16 days**
172	Concrete Scarf Strengthening	4 days
173	Bearings & Scarf Strengthen	6 days
174	Crossbeam Strengthen	2 days
175	**Anchor 48**	**8 days**
176	Bearings & Scarf Strengthen	6 days
177	**Pier 49**	**24 days**
178	Concrete Scarf Strengthening	4 days
179	Bearings & Scarf Strengthen	6 days
180	**Pier 50**	**26 days**
181	Concrete Scarf Strengthening	4 days
182	Bearings & Scarf Strengthen	6 days
183	**Pier 51**	**52 days**
184	Propping	6 days
185	Concrete Scarf Strengthening	4 days
186	Bearings & Scarf Strengthen	6 days
187	Crossbeam Strengthen	2 days
188	**Pier 52**	**57 days**
189	Propping	6 days
190	Concrete Scarf Strengthening	4 days
191	Bearings & Scarf Strengthen	6 days
192	Crossbeam Strengthen	5 days
193	**Pier 53**	**69 days**
194	Propping	10 days
195	Concrete Scarf Strengthening	6 days
196	Bearings & Scarf Strengthen	7 days
197	Crossbeam Strengthen	5 days
198	**Pier 54**	**63 days**
199	Propping	10 days
200	Concrete Scarf Strengthening	8 days
201	Bearings & Scarf Strengthen	4 days
202	**Pier 55**	**75 days**
203	Propping	10 days
204	Concrete Scarf Strengthening	6 days
205	Bearings & Scarf Strengthen	7 days
206	Crossbeam Strengthen	5 days
207	**Pier 56**	**76 days**
208	Propping	6 days
209	Concrete Scarf Strengthening	4 days
210	Bearings & Scarf Strengthen	6 days
211	Crossbeam Strengthen	5 days
212	**Pier 57**	**85 days**
213	Propping	6 days
214	Bearings & Scarf Strengthen	6 days
215	Crossbeam Strengthen	3 days
216	**Pier 58**	**87 days**
217	Propping	6 days
218	Bearings & Scarf Strengthen	6 days
219	Crossbeam Strengthen	2 days
220	**Pier 59**	**12 days**
221	Propping	6 days
222	Bearings & Scarf Strengthen	6 days
223	**Pier 60**	**12 days**
224	Propping	6 days
225	Bearings & Scarf Strengthen	6 days
226	**Pier 61**	**18 days**
227	Propping	6 days
228	Bearings & Scarf Strengthen	6 days
229	**Pier 62**	**18 days**
230	Propping	6 days
231	Bearings & Scarf Strengthen	6 days
232	**Pier 63**	**6 days**
233	Bearings & Scarf Strengthen	6 days
234	**Pier 64**	**8 days**
235	Bearings & Scarf Strengthen	6 days
236	Crossbeam Strengthen	2 days
237	**Anchor 65**	**7 days**
238	Bearings & Scarf Strengthen	6 days
239	Additional Bearings	1 day
240	**Pier 66**	**6 days**
241	Bearings & Scarf Strengthen	6 days
242	**Pier 67**	**94 days**
243	Propping	6 days



Cairngorm Funicular Railway
Strengthening Work
Outline Programme - Single Season

ID	Task Name	Duration
244	Bearings & Scarf Strengthen	6 days
245	Pier 68	6 days
246	Bearings & Scarf Strengthen	6 days
247	Pier 69	6 days
248	Bearings & Scarf Strengthen	6 days
249	Pier 70	6 days
250	Bearings & Scarf Strengthen	6 days
251	Pier 71	12 days
252	Propping	6 days
253	Bearings & Scarf Strengthen	6 days
254	Pier 72	12 days
255	Propping	6 days
256	Bearings & Scarf Strengthen	6 days
257	Pier 73	18 days
258	Propping	6 days
259	Bearings & Scarf Strengthen	6 days
260	Pier 74	18 days
261	Propping	6 days
262	Bearings & Scarf Strengthen	6 days
263	Pier 75	24 days
264	Propping	6 days
265	Bearings & Scarf Strengthen	6 days
266	Pier 76	24 days
267	Propping	6 days
268	Bearings & Scarf Strengthen	6 days
269	Pier 77	32 days
270	Propping	6 days
271	Bearings & Scarf Strengthen	6 days
272	Crossbeam Strengthen	2 days
273	Anchor 78	7 days
274	Bearings & Scarf Strengthen	6 days
275	Additional Bearings	1 day
276	Pier 79	38 days
277	Propping	6 days
278	Bearings & Scarf Strengthen	6 days
279	Pier 80	44 days
280	Propping	6 days
281	Bearings & Scarf Strengthen	6 days
282	Pier 81	44 days
283	Propping	6 days
284	Bearings & Scarf Strengthen	6 days
285	Pier 82	6 days
286	Bearings & Scarf Strengthen	6 days
287	Pier 83	6 days
288	Bearings & Scarf Strengthen	6 days
289	Pier 84	6 days
290	Bearings & Scarf Strengthen	6 days
291	Pier 85	6 days
292	Bearings & Scarf Strengthen	6 days
293	Pier 86	6 days
294	Bearings & Scarf Strengthen	6 days
295	Pier 87	6 days
296	Bearings & Scarf Strengthen	6 days
297	Pier 88	12 days
298	Propping	6 days
299	Bearings & Scarf Strengthen	6 days
300	Pier 89	12 days
301	Propping	6 days
302	Bearings & Scarf Strengthen	6 days
303	Pier 90	18 days
304	Propping	6 days
305	Bearings & Scarf Strengthen	6 days
306	Pier 91	18 days
307	Propping	6 days
308	Bearings & Scarf Strengthen	6 days
309	Pier 92	24 days
310	Propping	6 days
311	Bearings & Scarf Strengthen	6 days
312	Pier 93	8 days
313	Bearings & Scarf Strengthen	6 days
314	Crossbeam Strengthen	2 days
315	Tunnel Mouth	2 days
316	Guide Bearing Installation	2 days



Appendix F – Single Season Programme Commentary: Summer 2020

Commentary from BAM to reduce cost estimate of remedial works;

- Foundation size – same comment as for two season option.
- Foundation depth – same comment as for two season option.
- Review of bearing replacement options – same comment as for two season option.

Assumptions by BAM for consideration and appreciation by HIE;

- Any flying constraints over the site are unknown to BAM. Any constraints could be more severe for the single season option as at peak periods two helicopters will need to operate.
- Adequate areas to be made available for the provision of welfare and storage facilities at Shieling, carpark and possibly ptarmigan. These areas to be identified by HIE. Note that this provision will need to be greater for the single season option than the two season option due to the larger labour force and the need for concurrent activities.
- BAM have assumed purpose built rail mounted lifting trolleys will be used for bearing replacement and mechanical strengthening operations. This is stated as necessary to the finding that the one season option is the same cost as the two season option.
- As with the two season option, BAM states small risk from Brexit outcome against procurement risk from Europe.
- As with the two season option, there is a risk of bearings fused to existing structure. A trial on-site by HIE could mitigate this risk and identify any unforeseen issues at this stage with bearing replacement in general.
- Post completion, any excess excavated material will be stored for HIEs use adjacent to the ptarmigan building. HIE need to consider this. No provision to remove off excess material off site has been allowed.

Comments on BAMs Assumptions:

1 – Construction period - Early April 2020 to end of October 2020. This is a longer season than considered for the two season option but allows for 3 weeks mobilisation and demobilisation at the beginning and end of the season.
7 – BAM intend to re-use top soil for environmental restraints.
8 - Battered sides for an excavation may lead to an extremely large hole, especially up the hill.
9 – No hard breakout required. Backfill material only for foundations.
10 – Use of plant equipment seems sensible. Difficultly in sourcing enough of a single machinery type may be encountered. This risk is mitigated by consideration of purpose built rail mounted lifting trolleys on the existing funicular.
11 – A sensible allowance is assumed for poor access under existing structure
13 – No allowance for removal of excess excavated material.
15 – Prop costs have been averaged by length. Seems logical for cost estimating exercise.
22 – No hydro demolition is considered for T25 bar repairs.
23 – Bearing replacement assumes use of existing taper plates and upper tang plates with existing bolt hole diameters and spacing. Temporary jacks are assumed to be adequate to remove load off superstructure.
25 – Adequate tolerance allowance on lateral bearings is required during detailed design.
26 – Access of equipment for additional lateral bearing and drilling requirement is a risk.
28 – A key assumption for the budget price, mentioned again in Appendix C.

Comments on Programme in general:

- The programme assumes a 5 week tender period starting in early August with Contract award on 20th September 2019. However early activities are not shown as being critical to the completion date.
- Procurement of bearings is shown as 10 weeks. This appears optimistic given the quantities involved. However the programme shows approximately 6 months being available before bearings have to be delivered.
- The start on site is in early April beginning with a 3 week mobilisation period. Bearing replacement works commence in late April. This involves much greater weather risk than the late May start considered in the two season option, and potentially overlaps with the ski season.
- Work is carried out initially on five work fronts, expanding to seven work fronts later.
- Where pier propping is to be carried out, this is undertaken prior to other works.
- Where T25 bars are to be connected, this is undertaken prior to shear strengthening.
- Bearing replacement is followed immediately by shear strengthening – i.e. only short requirement for scaffold tower at any location.
- Completion is shown at the end of November following a 3 week demobilisation period and 5 weeks programme float.

Appendix F – Two Season Programme Commentary: 2020-2021

Commentary from BAM to reduce cost estimate and reduce programme;

- Foundation size – Reduce volume of concrete and thus weight for delivery by helicopter and number of visits. This can be reviewed in detailed design and volume of concrete/weight of material kept to a minimum.
- Foundation depth – reduce excavation volume. Depth of excavation shall be kept to a minimum during detailed design.
- Review of bearing replacement options – Eliminate requirement for the additional lateral guide at some locations. Extensive work has been undertaken on this. A project wide result was not found. Detailed design can review a spilt bearing design approach for different areas.

Assumptions by BAM for consideration and appreciation by HIE;

- A materials store over winter months is assumed to be available on site at the Cairn Gorm Mountain resort. This includes back fill material.
- Any flying constraints over the site are unknown to BAM are not considered during the construction period.
- Adequate areas to be made available for the provision of welfare and storage facilities at Shieling, carpark and possibly ptarmigan. These areas to be identified by HIE.
- BAM states small risk from Brexit outcome against procurement risk from Europe.
- Risk of bearings fused to existing structure. A trial on-site by HIE could mitigate this risk and identify any unforeseen issues at this stage with bearing replacement in general.
- Risk of integrity and thus re-use of existing taper plates. Detailed inspection and a trial conducted by HIE on worse areas could mitigate this risk.
- Post completion, any excess excavated material will be stored for HIEs use adjacent to the ptarmigan building. HIE need to consider this. No provision to remove off excess material off site has been allowed.

Comments on BAMs Assumptions:

1 – Construction period – Two summer seasons. Site activity from last week in May to third week in October. A short season, but realistic.
7 – BAM intend to re-use top soil for environmental restraints.
8 - Battered sides for an excavation may lead to an extremely large hole, especially up the hill.
9 – No hard breakout required. Backfill material only for foundations.
10 – Use of plant equipment seems sensible.
11 – A sensible allowance is assumed for poor access under existing structure
13 – No allowance for removal of excess excavated material.
15 – Prop costs have been averaged by length. Seems logical for cost estimating exercise.
22 – No hydro demolition is considered for T25 bar repairs.
23 – Bearing replacement assumes use of existing taper plates and upper tang plates with existing bolt hole diameters and spacing. Temporary jacks are assumed to be adequate to remove load off superstructure.
25 – Adequate tolerance allowance on lateral bearings is required during detailed design.
26 – Access of equipment for additional lateral bearing and drilling requirement is a risk.
27 – A reasonable assumption is made.

Comments on Programme in general:

- Pier strengthening works are undertaken first and props are installed including excavation, foundation casting and back filling.
- Two prop locations are worked on simultaneously.
- Bearings, T25 repair (if required) and Shear strengthening undertaken at one location all at same time – i.e. only short requirement for scaffold tower at any location.
- Bearings replaced prior to shear strengthening of scarf joints and beams.
- T25 repairs prior to shear strengthening of scarf joints.
- Use of one helicopter only assumed.
- Assumes access to site 7th Oct.
- Procurement of 3 months with 4 months float for bearings, metalwork and props – means a delay in awarding contract will not affect completion date.

Other considerations:

- Consideration of use of the maintenance trolley was given but the temporary works and works needed to protect the existing funicular has high risks.
- Much time was spent by BAM looking at phased approach to the lower half and upper half and it was considered unachievable. Too many interfaces for differing intervention solutions increased risk.