Carrier Wire Neutral Sections – Love them or hate them?

PWI Lunch and Learn

6th January 2026

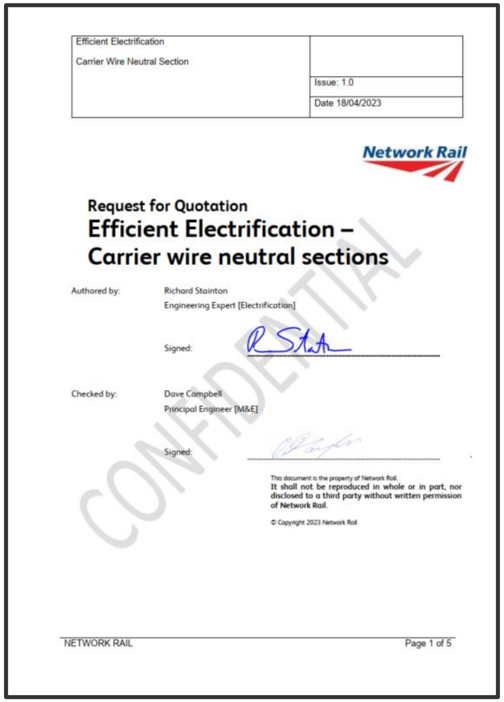
Presenter: Jonathan Harris

Furrer+Frey
Overhead contact lines

Who am I and what is this about?

Jonathan Harris

Senior Electrification Engineer



Efficient Electrification Carrier Wire Neutral Section	
	Issue: 1.0
	Date 18/04/2023

Network Rail

Request for Quotation
Efficient Electrification – Carrier wire neutral sections

Authored by: Richard Stainton
Engineering Expert [Electrification]

Signed:

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Principal Engineer [M&E]

Signed:

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Rob Daffern

Principal Engineer

Dr Sam Hayes

Mathematician

Mariusz Sledz

Innovation Engineer

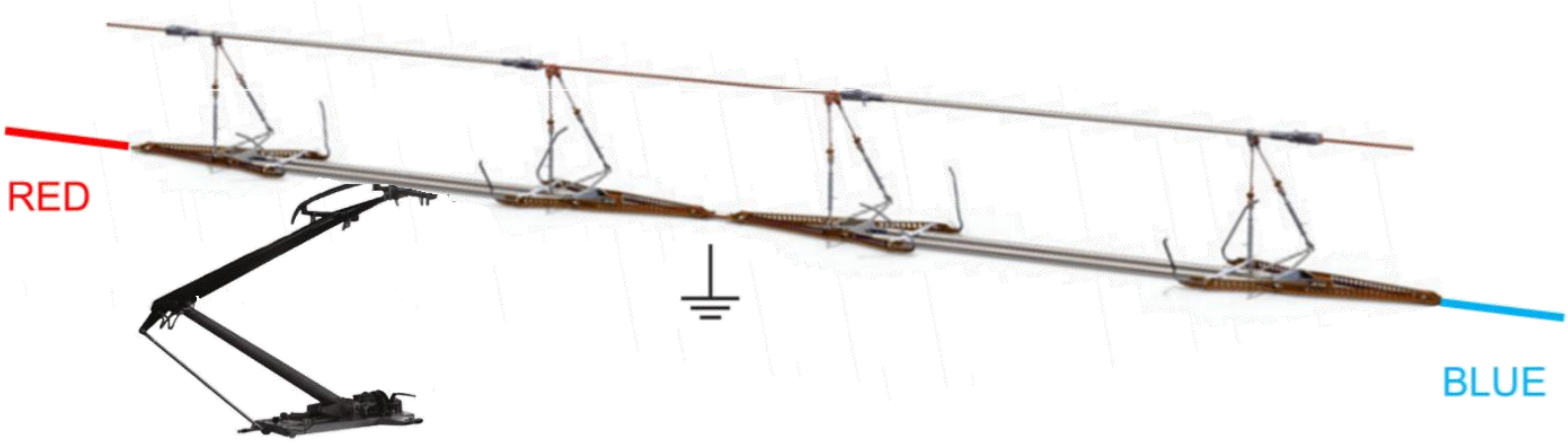
Agenda

+ Carrier Wire Neutral Sections – How do they work
+ Who we consulted
+ What has happened since Great Western Electrification
+ Neutral Section Types – Standards vs GB vs Rest of the World
+ Interesting neutral section concepts
+ Arthur Flury Neutral Sections (AFNSs) vs Carrier Wire Neutral Sections (CWNSs) today
    + Capital Cost
    + Maintenance
    + Reliability
+ Driving Down CWNS Costs
+ Summary of Recommendations

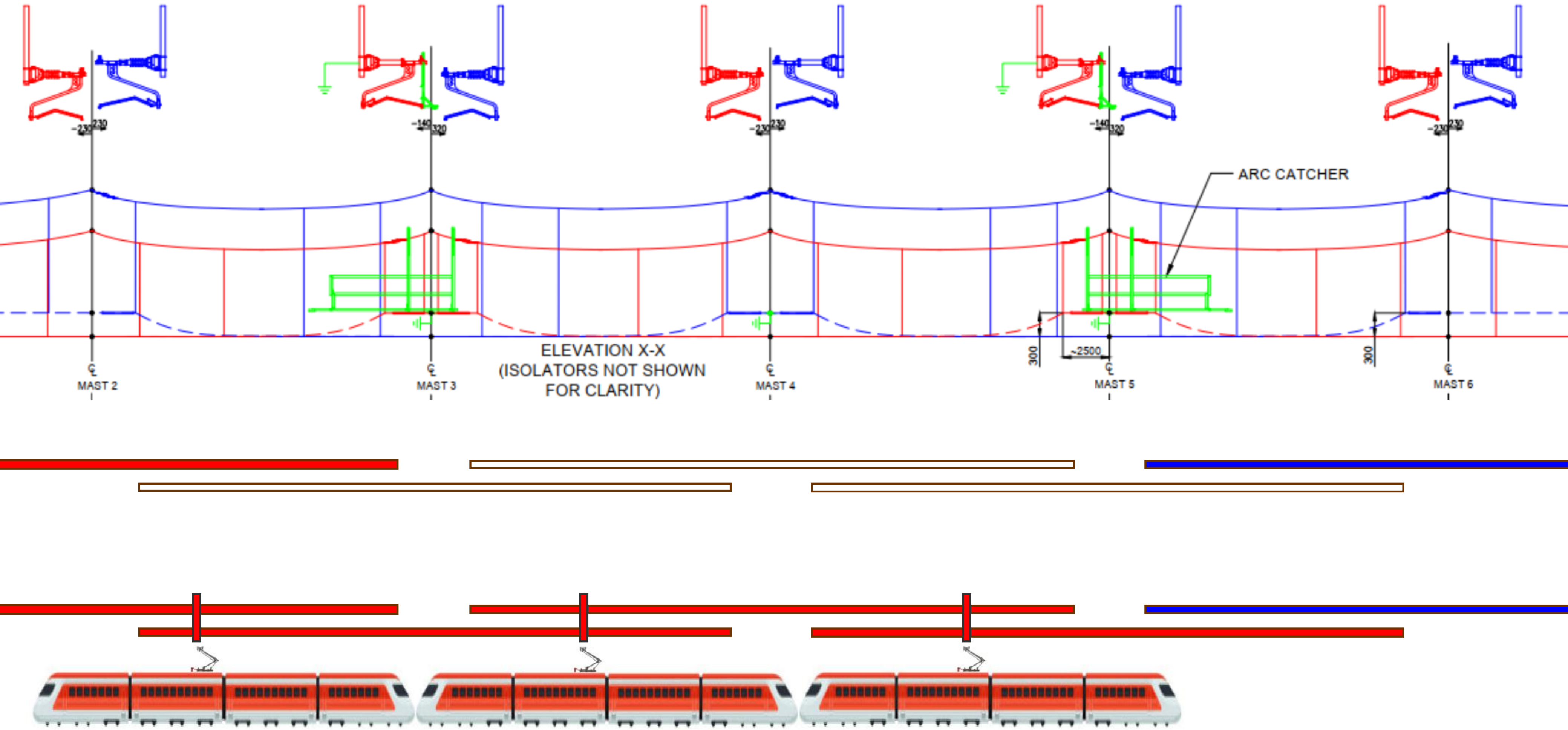
It's assumed attendees have a basic understanding of OLE systems and neutral sections

Neutral Section Principles

- Provides electrical isolation between adjacent power supply sections fed from different substations or phases
- Allows train pantographs to pass safely without creating short circuits or phase conflicts
- Enables maintenance and fault management by separating sections of the electrification system



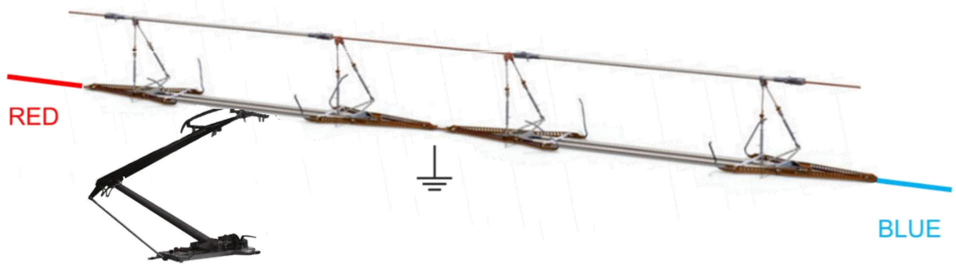
Carrier Wire Neutral Sections – How do they work?



Why do we need CWNSs at all?

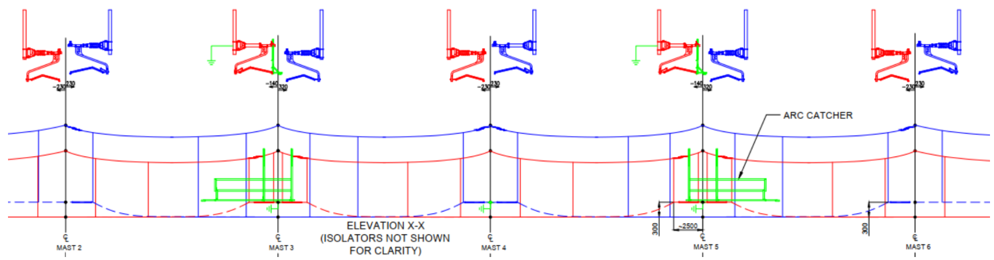
Arthur Flury Neutral Sections

- Simple/short
- Low capital cost
- High maintenance cost (high use/speed)



Carrier Wire Neutral Sections

- Complicated/long
- High capital cost
- Low maintenance/high reliability



Ref:	NR/L1/ELP/27000
Issue:	4
Date:	05 June 2021
Compliance date:	31 July 2021

Statement heading	Policy statement
Carrier wire neutral sections	Carrier wire type neutral sections shall, where reasonably practicable and subject to a suitable designer's risk assessment, be used on renewed OLE systems designed for use at speeds between 101 mph and 125 mph. New OLE systems designed for above 100 mph shall use carrier wire neutral sections. The speed at the neutral section location shall be determined by reference to the declared track design line speed at the neutral section (taking due account of future route speed aspirations).

Who and how we consulted

↓ International ↓

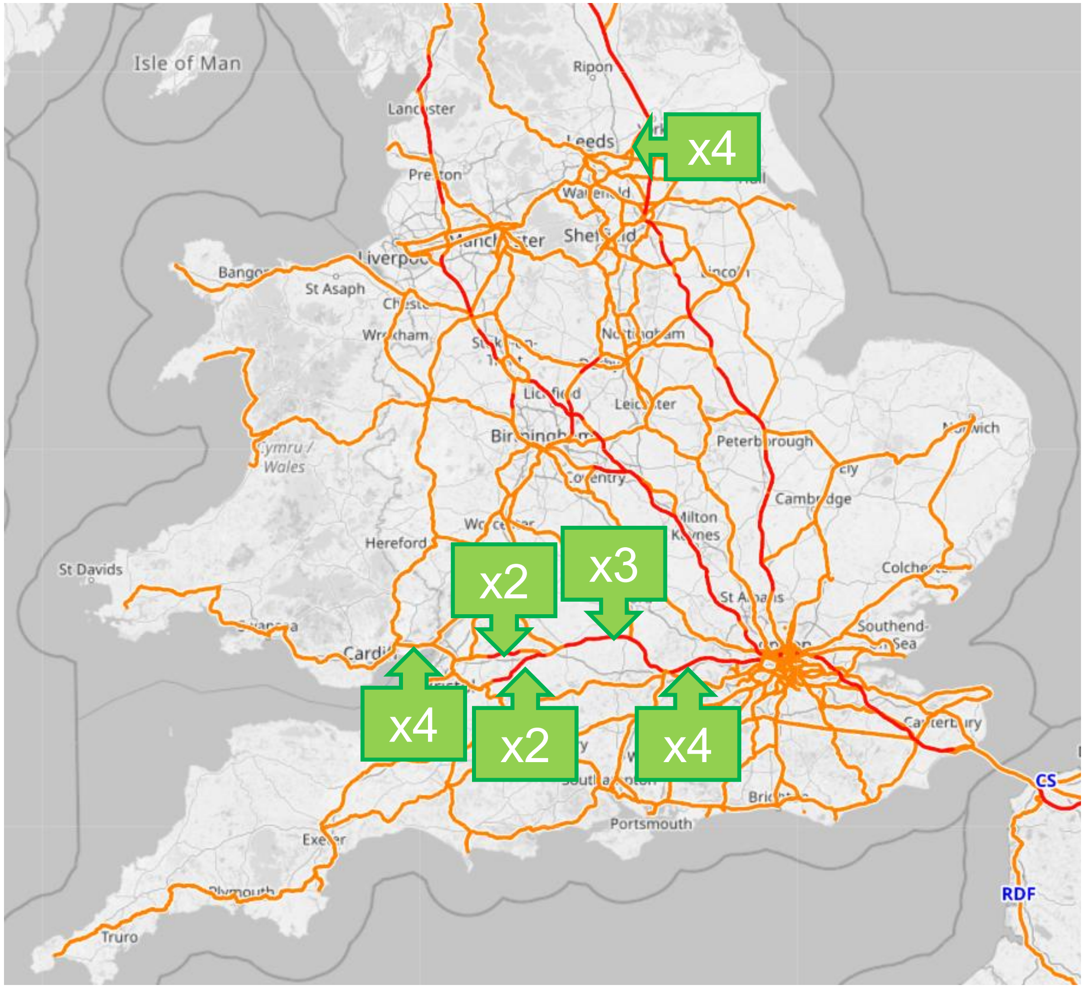
Country	Company	Projects/Regions/ Routes
Australia	WSP Sydney	National
Canada	Gannett Fleming/Metrolinx	National
France/Belgium/ Netherlands	Ex-Eurostar	HS1, TGV Nord
Germany	Furrer+Frey CH	National
Hungary	Consultant	National
India	Furrer+Frey India	National
Italy	Rete Ferroviaria Italiana	National
New Zealand	Kiwi Rail	National
Switzerland	Furrer+Frey CH	National
Turkey	Türkiye Cumhuriyeti Devlet Demiryolları	National
USA	Network Rail Consulting	Massachusetts, Boston
USA	Balfour Beatty US	California Caltrain
Zimbabwe	Ex consultant	None - all OLE stolen

→ Domestic →

Company	Role
Network Rail	Asset Engineer Wales and Western
Network Rail	Engineering Expert (Electrification)
Network Rail	Senior Project Engineer (OLE)
Network Rail	Principal Engineer
Network Rail	Asset Engineer Scotland
Network Rail	Electrical Control Room Manager Western
Network Rail (High Speed)	Senior Electrical Engineer
Amey	Principal Mechanical Engineer OLE
Balfour Beatty	Construction Manager
Consultant	Consultant
Keltbray Infrastructure Services	Engineering Manager
Furrer+Frey	Senior OLE Engineer
Furrer+Frey	Senior OLE Engineer
Furrer+Frey	Principal Engineer

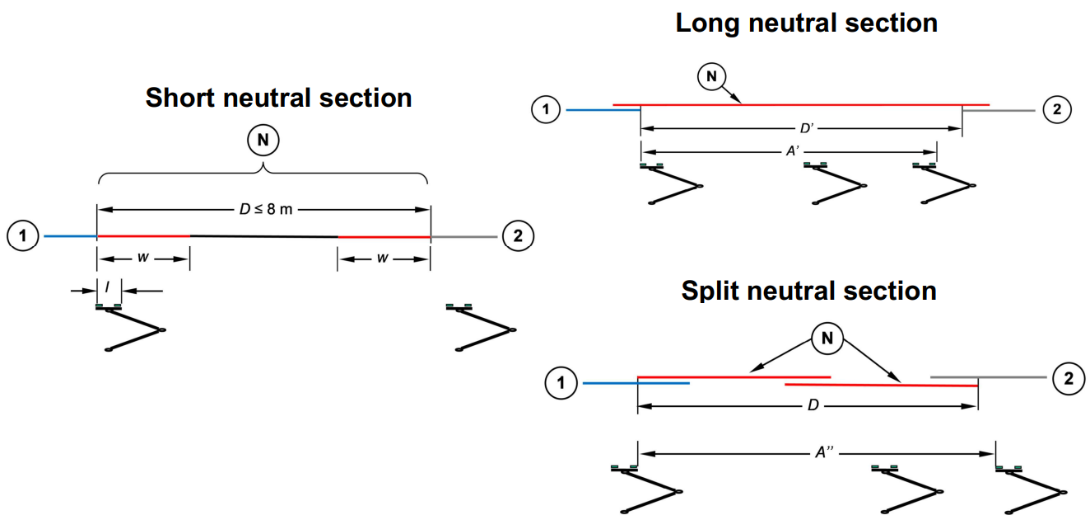
CWNSs – What has happened since Great Western Electrification

+ 15 CWNSs installed in Great Western in service by 2018
+ Four CWNS installed on TRU-East (now in service)
+ Asset policy states "New OLE systems designed for above 100 mph shall use carrier wire neutral sections."
+ Two significant derogations due to cost:
  + Midland Mainline (MML) Electrification, Braybrooke feeder station
  + Transpennine Route Upgrade-West (TRU-West), Ravensthorpe feeder station.
+ Roughly 100 AFNSs installed 2018-2024



Neutral Section Types – Standards

+ Extracts from BS EN 50367

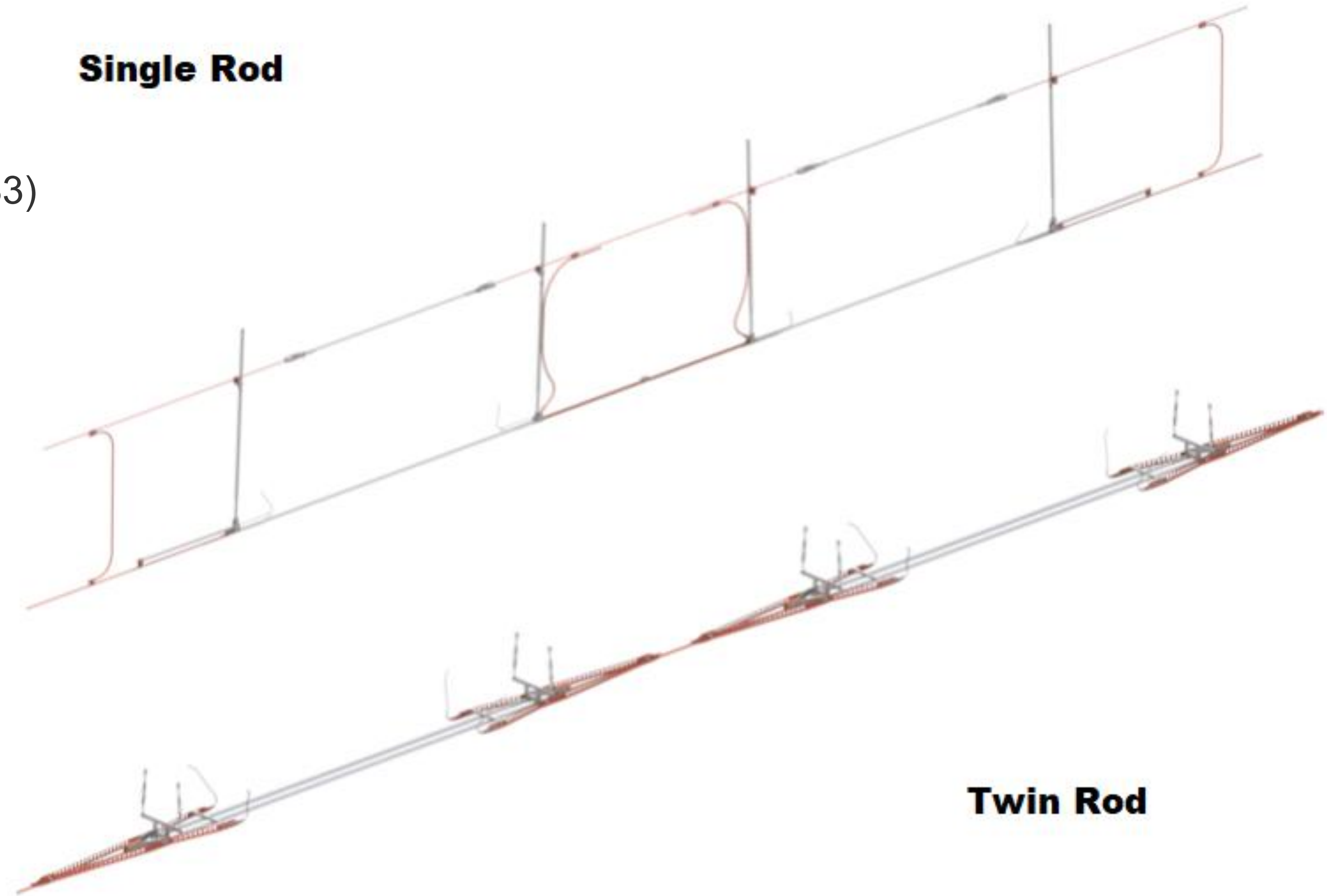


Type	D (Overall Length Including Overlapping Parts	A (Inner Distance Between Contact Strips of Successive Pantographs
Short	≤ 8 m	N/A
Long	> 402 m	< 400m
Split (Configuration 1)	< 142 m	> 142 m
Split (Configuration 2)	< 79 m	> 79 m

Neutral Section Types – Great Britain

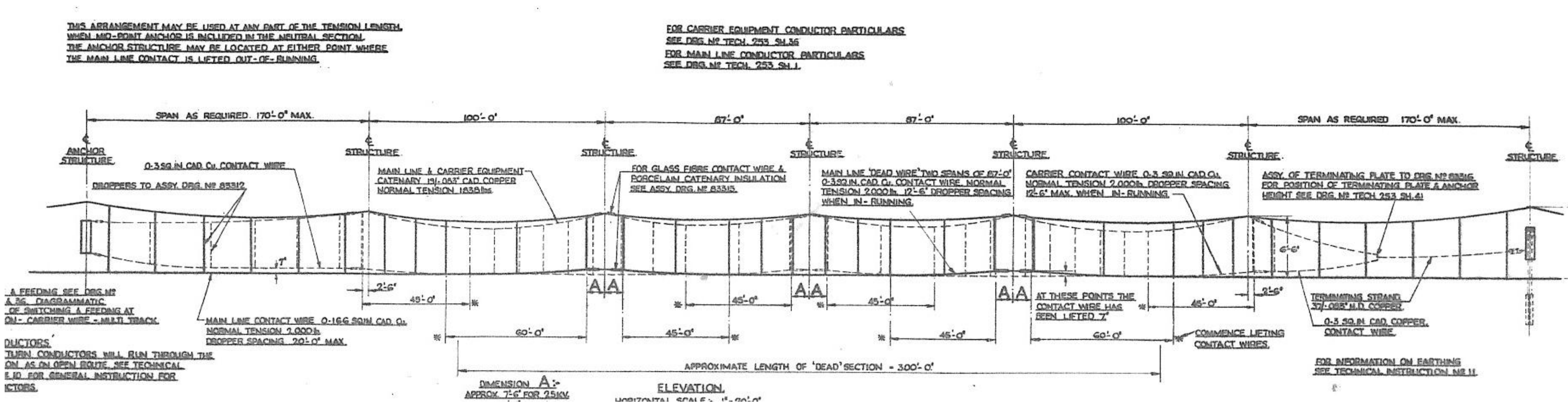
Short Neutral Sections

- Arthur Flury Single Rod (483)
- Twin rod (6)
- BICC (49)

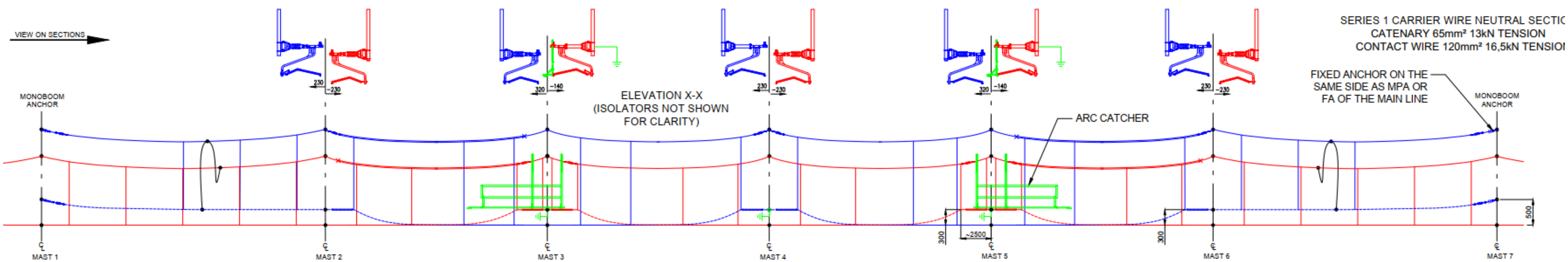


Neutral Section Types – Great Britain

+ Mk1 CWNS used on the Anglia route in the 1960s (all removed)



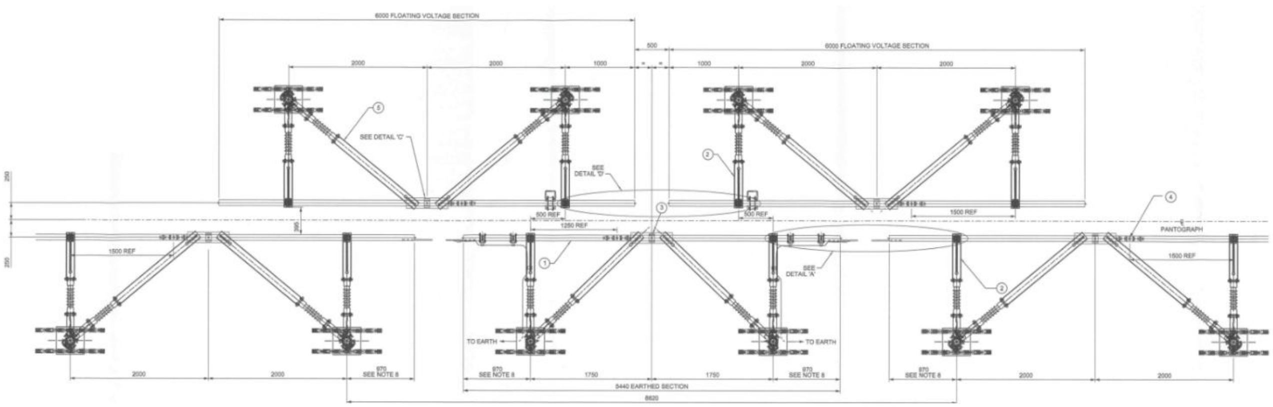
+ Series 1/UKMS CWNS installed on W&W and TRU-East

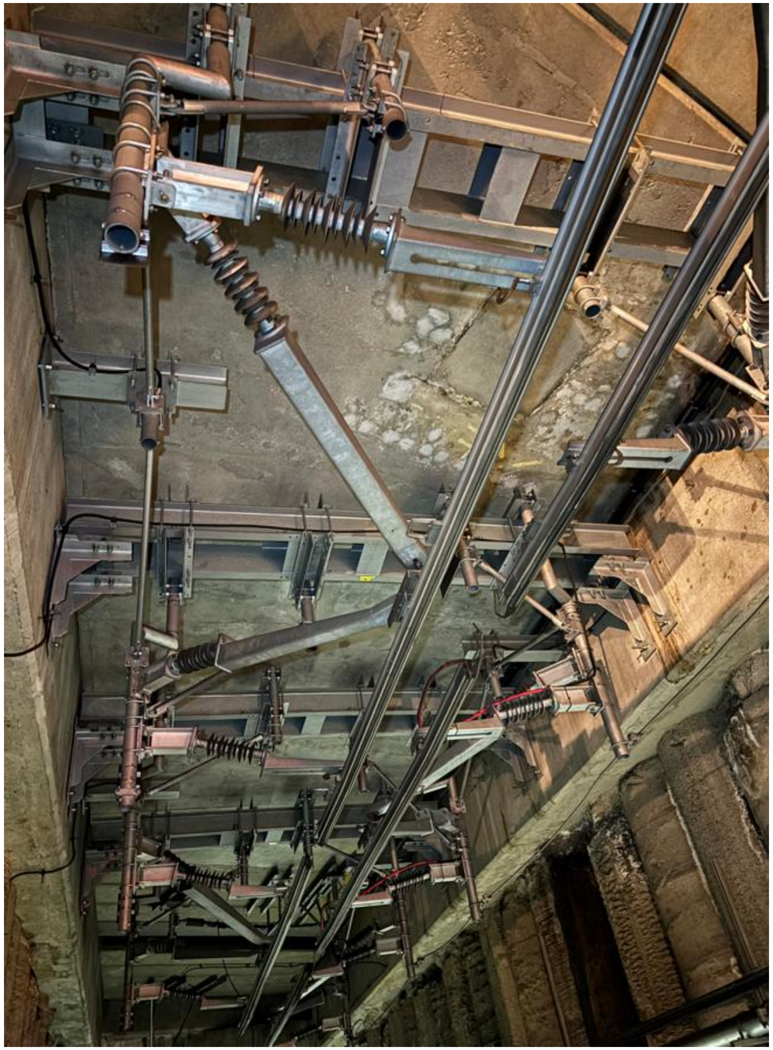


Neutral Section Types – Great Britain

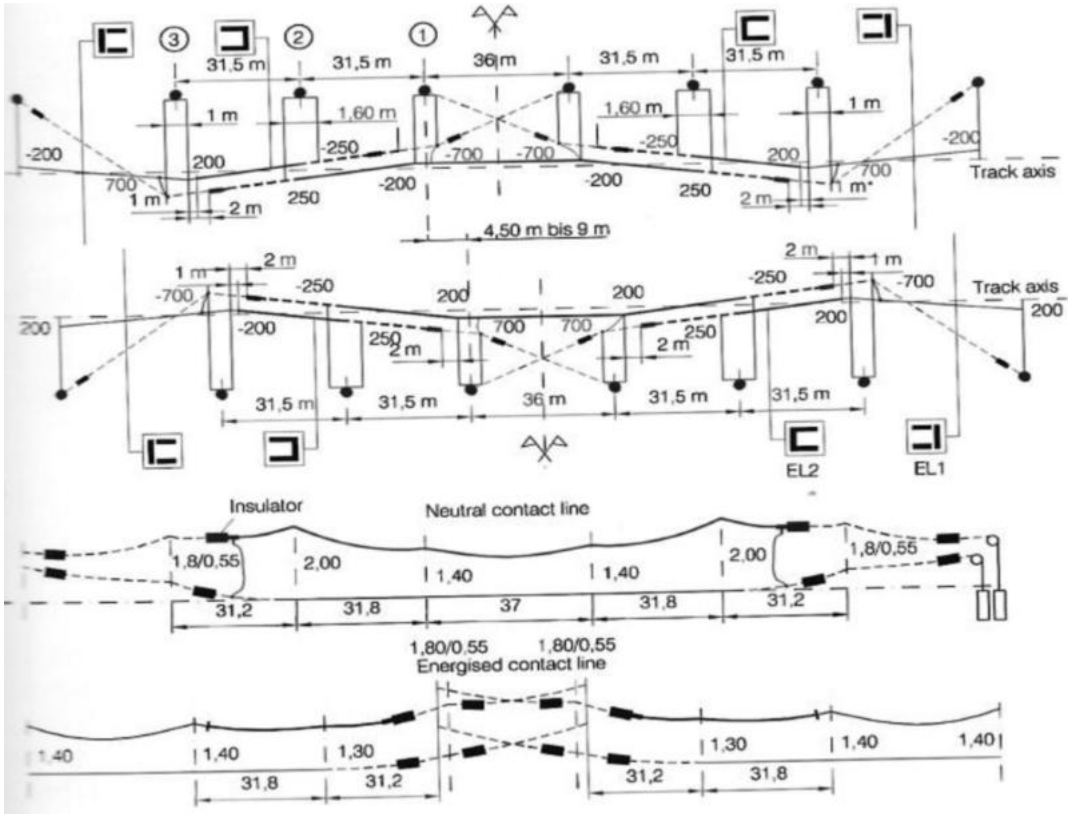
Thameslink Canal Tunnels

+ Conductor Rail Split Neutral Section
+ “Mini CWNS”
+ NOT FURRER+FREY EQUIPMENT



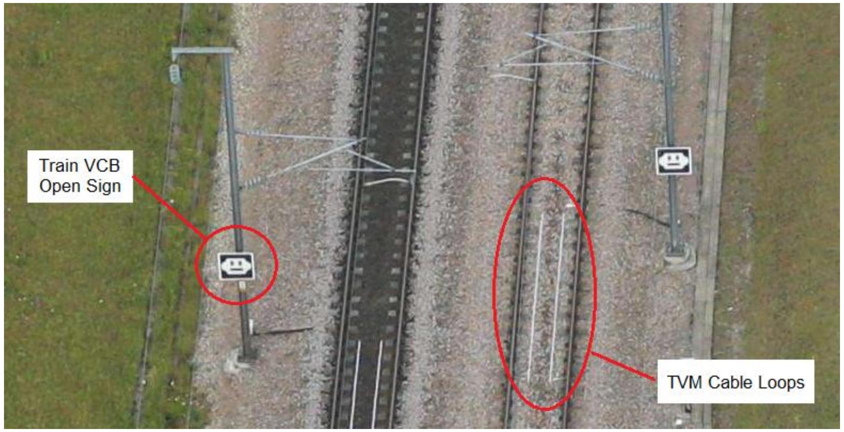


Neutral Section Types – Great Britain



High Speed 1 "Carrier Wire"

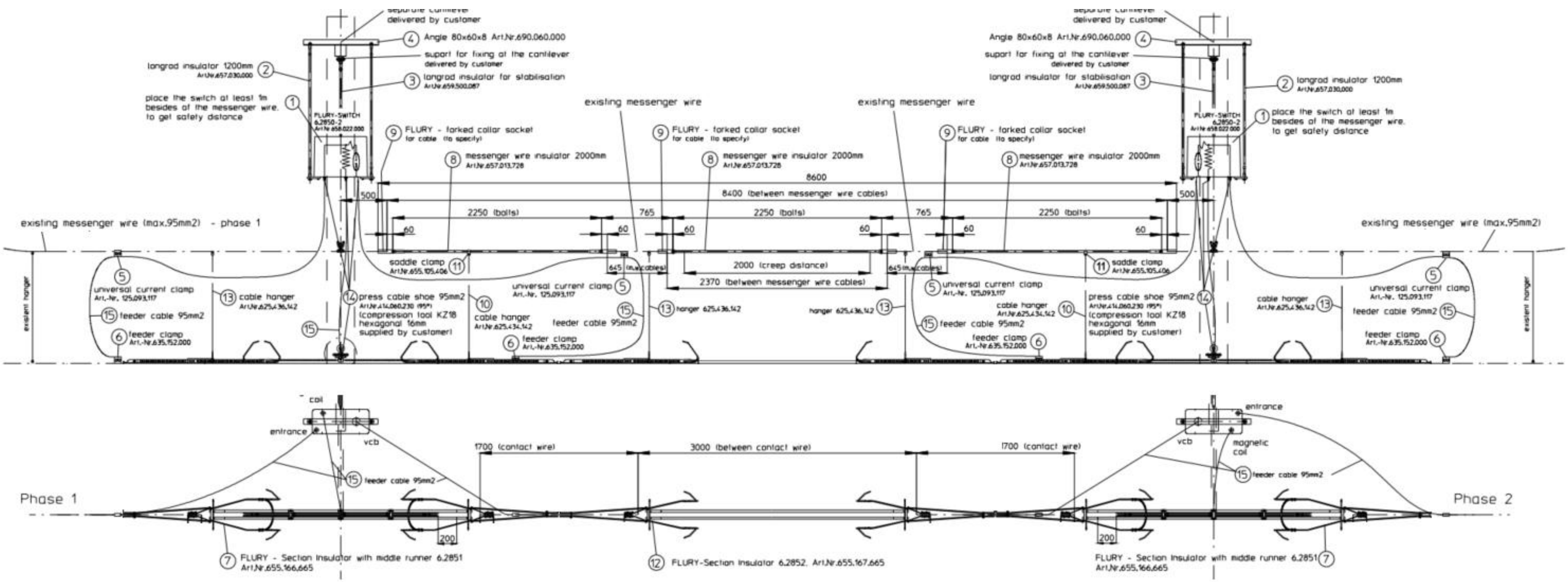
- Only two overlaps
- Madated pantograph spacings L<47m or L>147m
- Several strandings and phase to phase connections have occurred – none caused major incidents
- No APC magnets – uses the TVM system



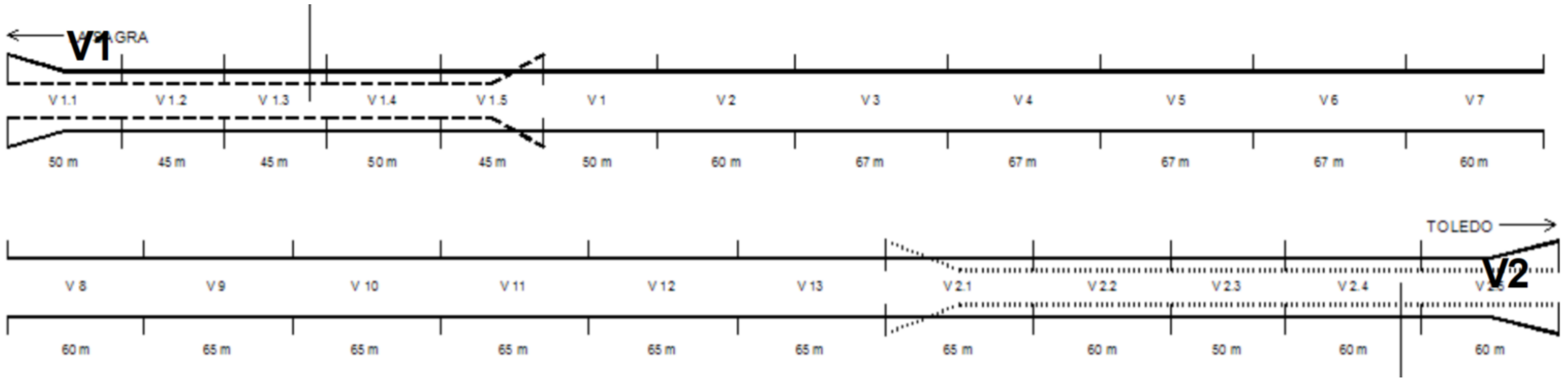
Neutral Section Types – Great Britain

Automatic Switched Neutral Section

- Was used in Dollands Moor sidings and Europe
- Spec'd for 200km/h and 1000A!
- 3x twin-rod section insulators
- Outer SIs have additional copper runner electrically connected to VCB
- Very simple. Very unreliable. All since removed and product discontinued by Arthur Flury

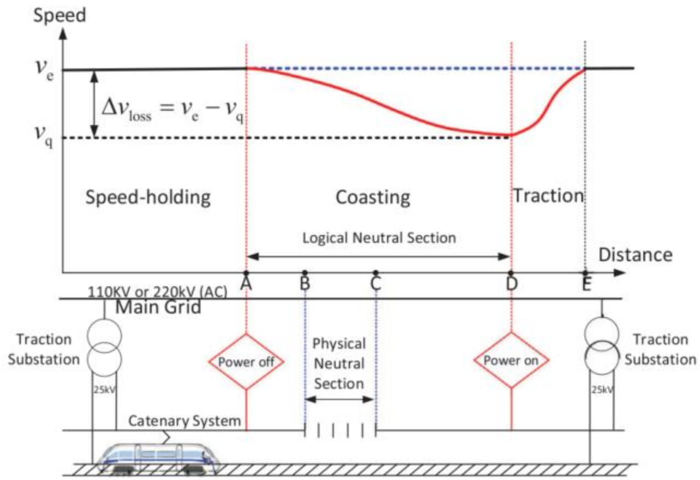


Neutral Section Types – The Rest of the World



Long Neutral Sections

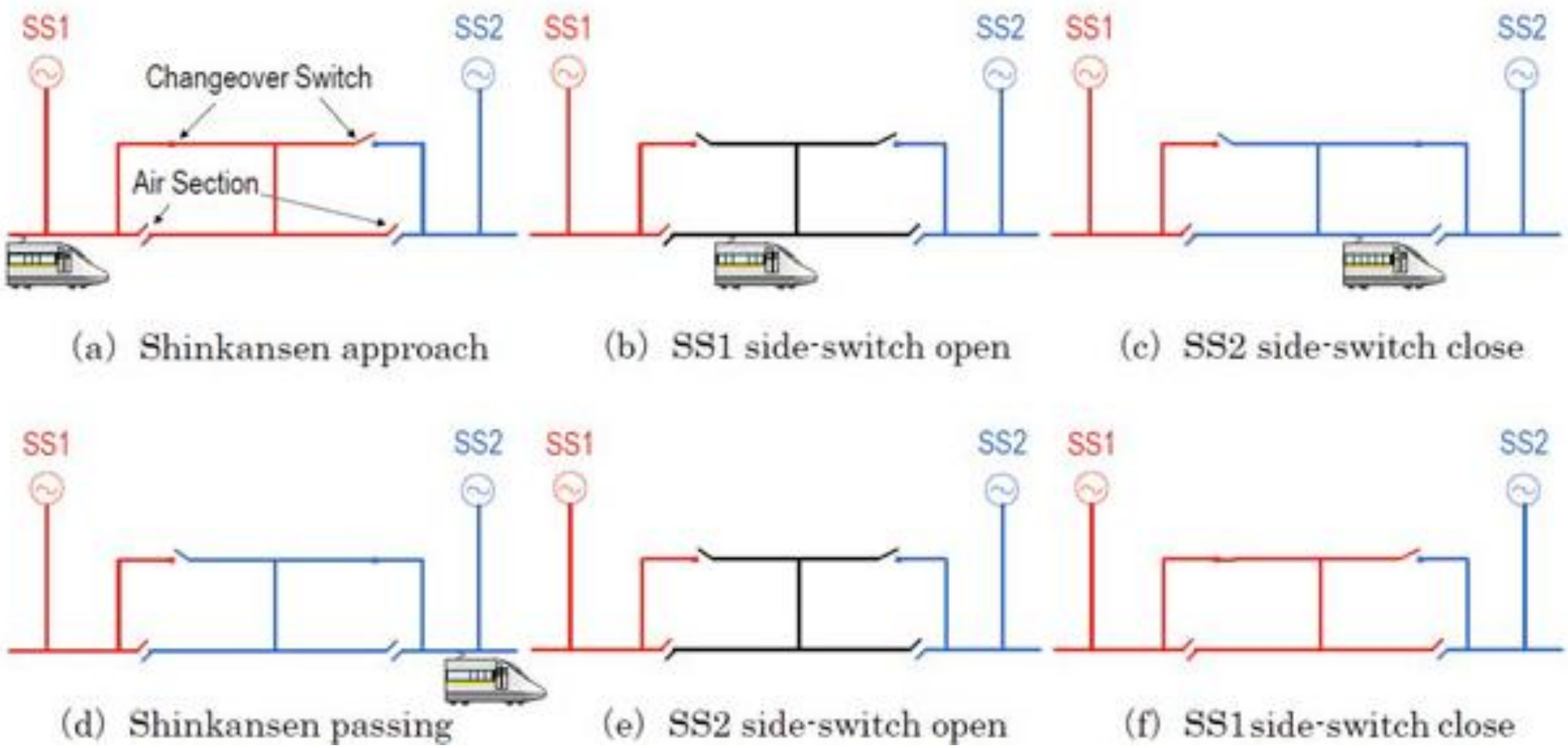
+ Not very common – only in Spain and China
+ Trains are without traction power for long distances (can be up to 1.6 km)
+ Auxiliary supplies are maintained through regenerative braking
+ Speed loss can be significant, even worse with track gradients



Neutral Section Types – The Rest of the World

Shinkansen Changeover Neutral Sections

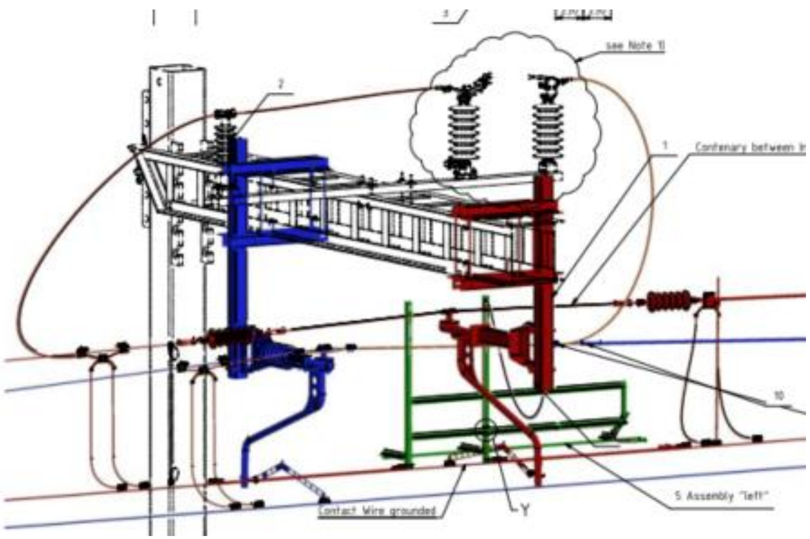
- Operational stages shown below (a) to (f)
- Train is without traction power for at least 0.3s



Neutral Section Types – The Rest of the World

+ Sanwa Tekki Corporation neutral sections for phase to phase (left) and voltage change (right).

Arc Catchers



- Arc catchers unique to UK
- Reduces chances of arc sustaining itself
- Not found anywhere else in the world – potentially because VCB systems are linked to signalling (TVM or ETCS)
- Some countries are considering arc catchers following dewirements including in Gothard Base Tunnel
- Definitely keep them!

Neutral Section Concepts

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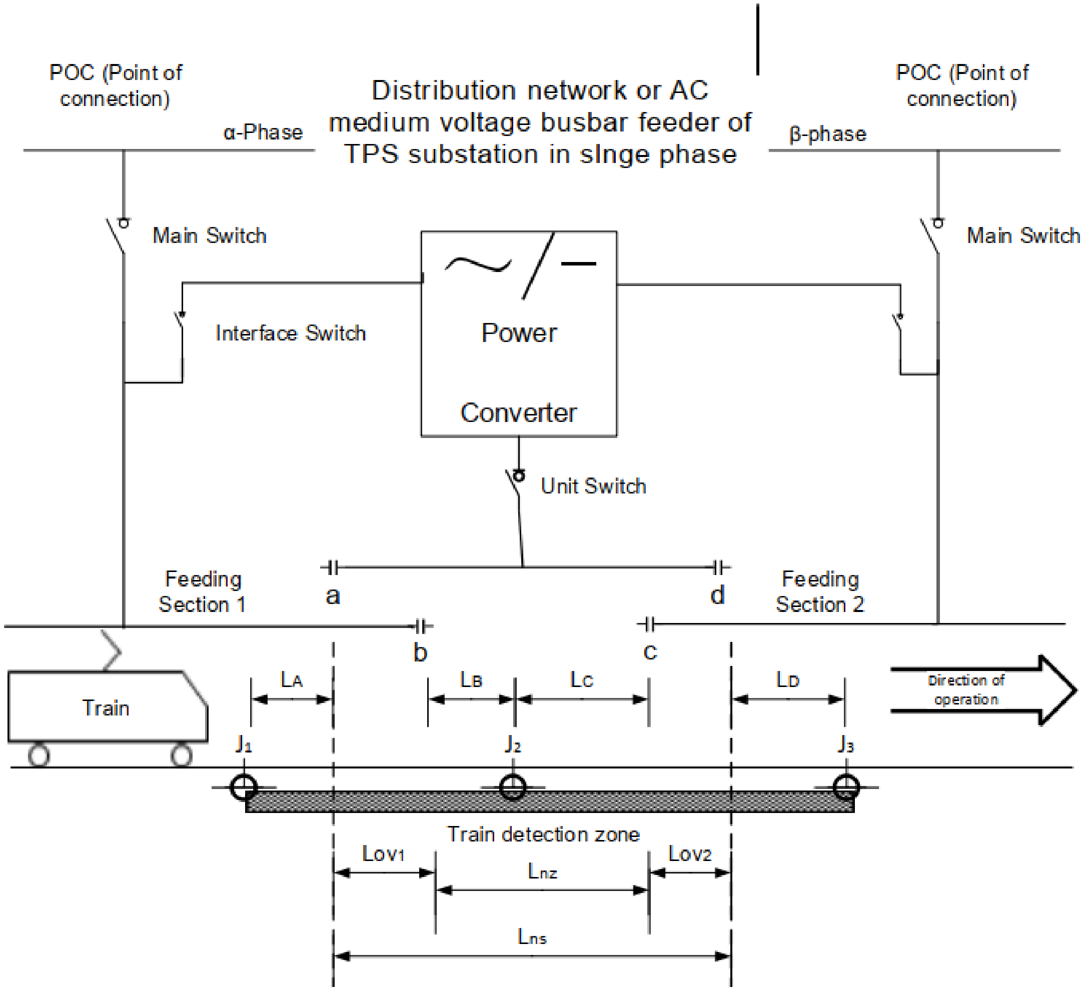
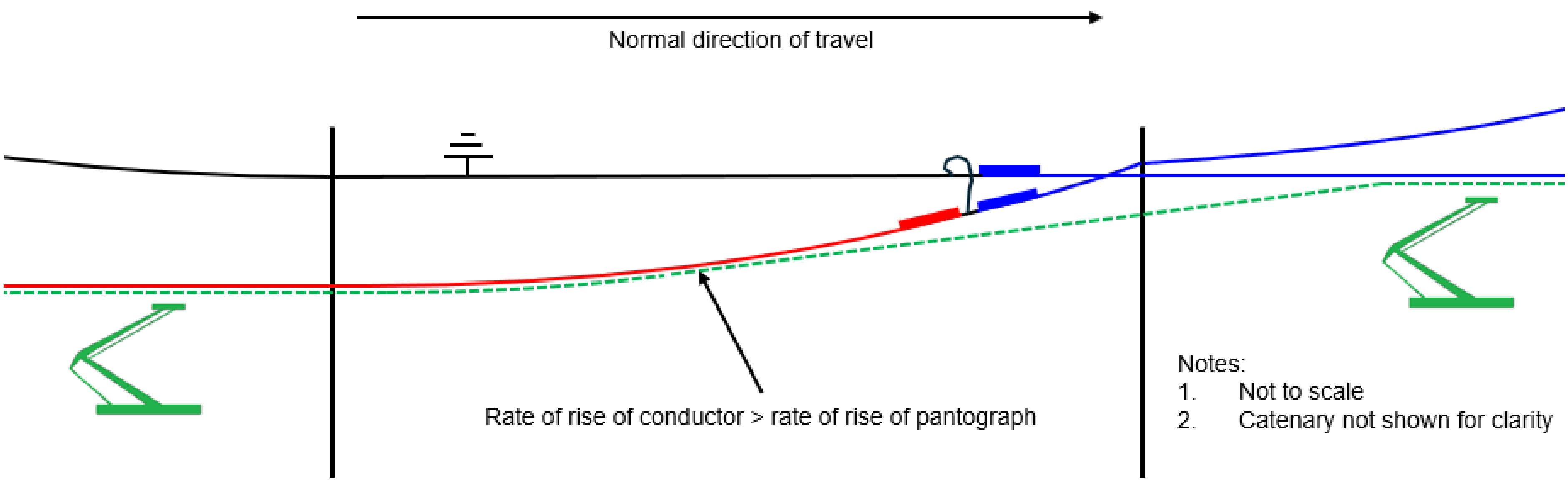
Neutral Section Concepts – NSPS with ACSS

- Principles are set in IEC 63488 Edition 1 (draft at time of review)
- "Neutral Section Passing Systems" (NSPSs) with power supplied using a continuous and flexible auto-energising power converter switch system (ACSS)
- When the train is in the changeover section, a power converter changes the frequency of the AC wave until the phase has been shifted to match that of section 2
- The train sees no interruption in power



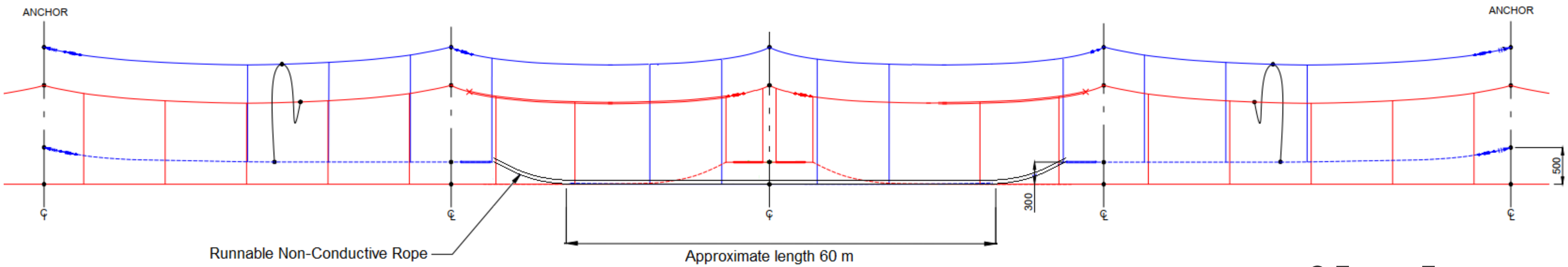
Neutral Section Concepts – “Ski Jump”

- Formed of an overlap with outgoing wire run using very steep gradients
- Neutral section components similar to an AFNS
- Encourages the pantograph to “jump” over the neutral section at line speed
- Still runnable at lower speeds and wrong direction running
- Max slope expected to be 1.5° (UK pantographs typically can rotate +/- 4°)
- Dynamically the “landing” is expected to be compliant



Neutral Section Concepts – Non-conductive carrier wire

- Similar to HS1 Carrier Wire NS
- BUT the carrier wire is formed of non-conductive runnable material
- Neutral section length expected to be approximately 60m
- No hard spots, no arcs, no risk of bridging all air gaps
- However, no means of recovering a stranded train (more on this later)



Arthur Flury Neutral Sections vs Carrier Wire Neutral Sections Today

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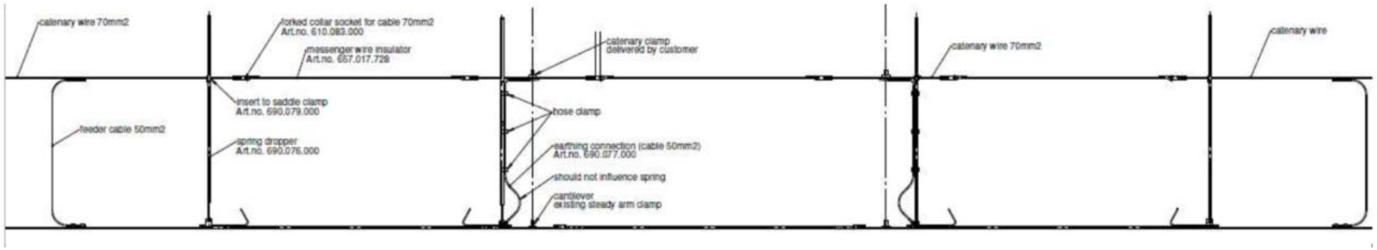
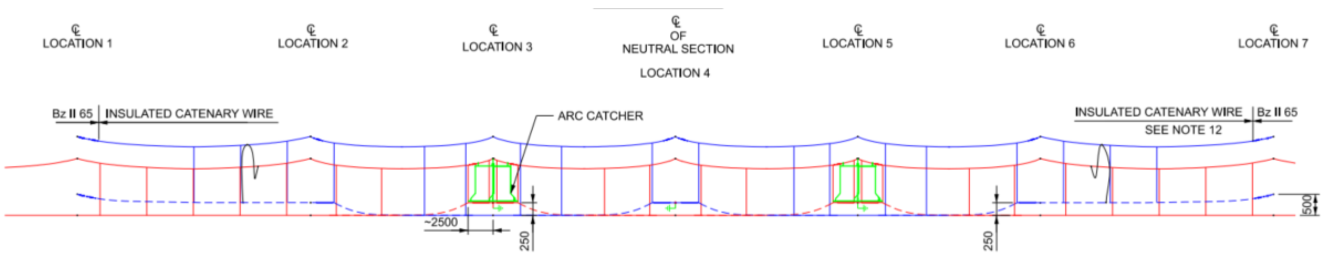
AFNSs vs CWNSs



AFNS – “Arthur Flurys”



CWNSs - “Carrier Wires”

AFNSs vs CWNSs – Capex + Opex

Note: Information provided by Network Rail

Midland Mainline (MML) Electrification, Braybrooke feeder station

Braybrooke Carrier Wire Neutral Section					
OLE Material	1	£	922,795	£	922,795
OLE Install (Plant, labour, Poss support)	1	£	1,505,249	£	1,505,249
P&D Material and install	1	£	567,515	£	567,515
Additional HV cabling due to CWNS length	968	£	159	£	154,342
Total (excluding fee)				**£**	**3,149,902**
Braybrooke Arthur Flurry Neutral Section					
OLE Material	1	£	479,850	£	479,850
OLE Install (Plant, labour, Poss support)	1	£	1,049,614	£	1,049,614
P&D Material and install	0	-		-	
Total (excluding fee)				**£**	**1,529,464**
Potential saving				**£**	**1,620,438**

OPEX Cost Comparison

Assessment By	AFNS	CWNS
NRDD (2014)	£410k	£150k
TRU (2020)	£741k	£185.5k
MMLE (2022)	£726k	£247k

Transpennine Route Upgrade-West (TRU-West), Ravensthorpe feeder station

	OLE / Civils Construction		Maintenance		Whole Life Cost		
Option	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Median**
3 Span CWNS's	£ 1,590,000	£ 2,067,000	£ 228,000	£ 513,000	£ 1,818,000	£ 2,580,000	**£ 2,199,000**
Single Rod NS's	£ 220,000	£ 286,000	£ 570,000	£ 1,282,500	£ 790,000	£ 1,568,500	**£ 1,179,250**
Project Saving	**£ 1,370,000**	**£ 1,781,000**				**WLC Saving**	**£ 1,019,750**

AFNSs vs CWNSs – Capital Cost

+ Two-track railway example

Category	AFNS	Four-Overlap CWNS
Foundations	No effect	Longer piles required for larger structures like portals and anchors Additional piles required for back ties/struts
Structures	No effect	Additional anchor structures for carrier wire Boom structures such as portals/TTCs required instead of STCs for supporting rescue switches and cantilevers Shorter span length driving increase in total number of structures
SPS and Cantilevers	2x Earthed cantilevers required instead of normal cantilever	Additional 10x cantilevers required to support carrier wire
In-Line Equipment	2x Single rod neutral section.	20x cut-in insulation 12x spans of droppers 4x potential equalising jumpers 4x tensioning device and associated equipment 16x jumpers 4x Arc Catchers ~200m of covered catenary
Switching	2x bypass switches with SPS 4x feeds 2x motorised units + LV connections + SCADA connections	8x bypass switches with SPS and pear drive connections 16x feeds 8x motorised units + LV connections + SCADA connections
Feeding	A length of feeder cables from feeder station to both tracks each side of the neutral section	At least 400 m of additional feed and trough routes (this can be several kilometres longer if neutral section has to move to new signalling block)
Miscellaneous	8x APC magnets	8x APC magnets Additional signage such as rear clear signs and end of NS signs

AFNSs vs CWNSs – Capital Cost

Issues siting CWNSs

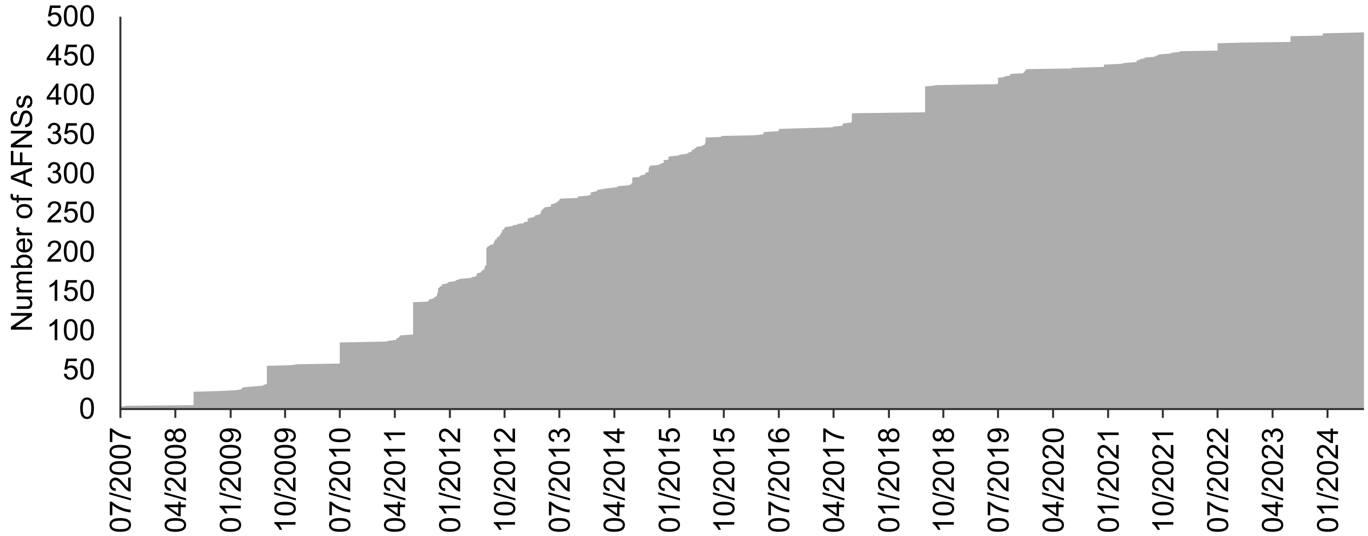
+ Series 1 *goldilocks* guidance became UKMS rules – very onerous
+ UKMS mandates span lengths 40-50m – makes it long! (Series 1 went down to 35m)
+ Wootten Bassett Junction an example of where the CWNS was difficult to site – resulted in two 3.6km feeder cables estimated to cost £1.14M

The following criteria apply to the siting of a CWNS:

1. All elements are at least 100m from a junction or crossover position
2. Contact wire height between 4.4 and 5.0m
3. Contact gradient level or better than 1:2000 for 3 spans each side.
4. Static radial load <1.0kN >0.1kN (not for push off registration arm)
5. System height >1.0m
6. Not under a bridge or in a tunnel
7. Not in known or likely vandalism risk areas

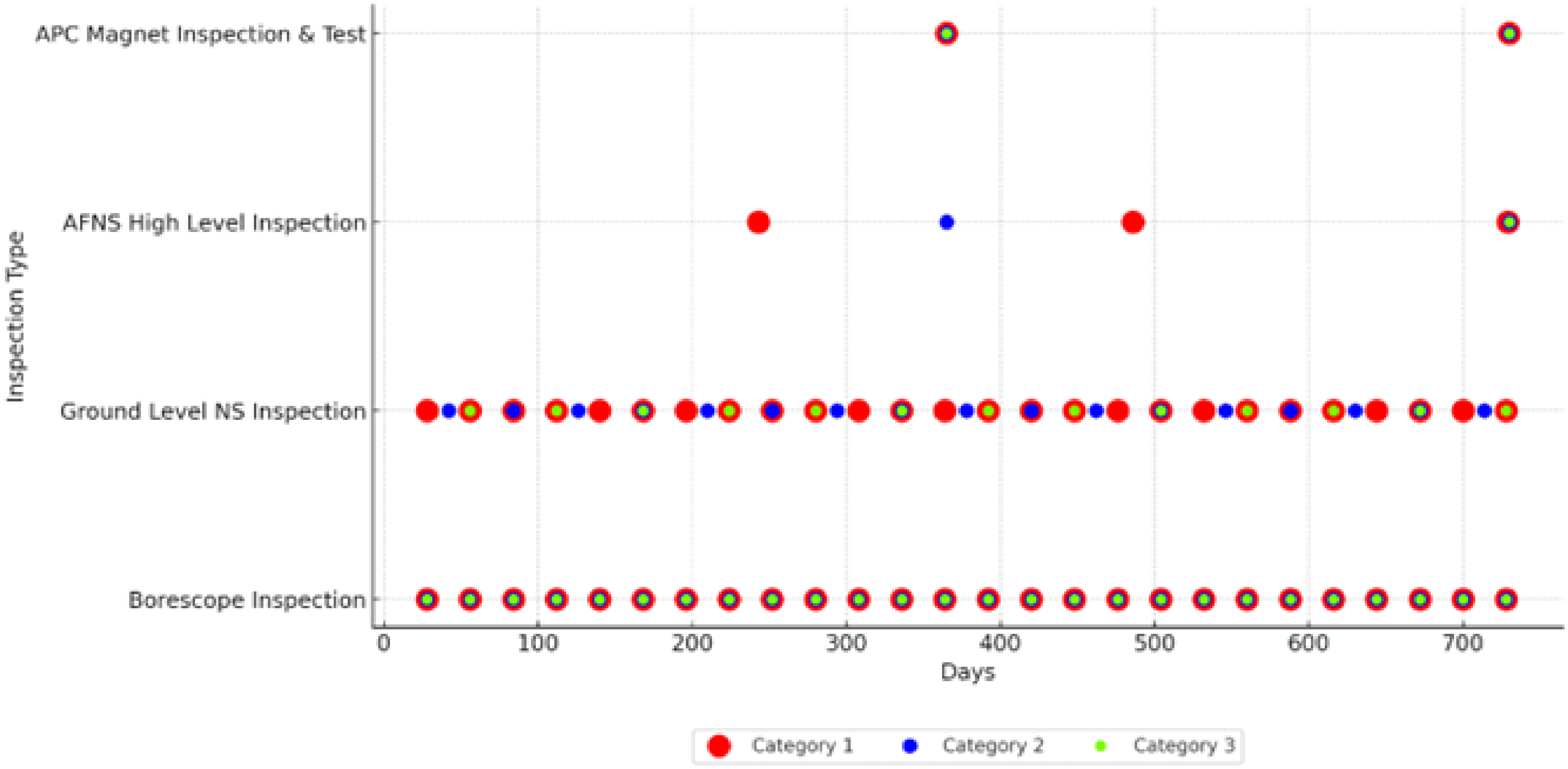
AFNSs vs CWNSs – Maintenance

- National AFNS population 2007-2024
- Data came from:
  - Ellipse Neutral Section Assets
  - Ellipse Neutral Section Work Orders
- Data was messy and required a lot of cleaning



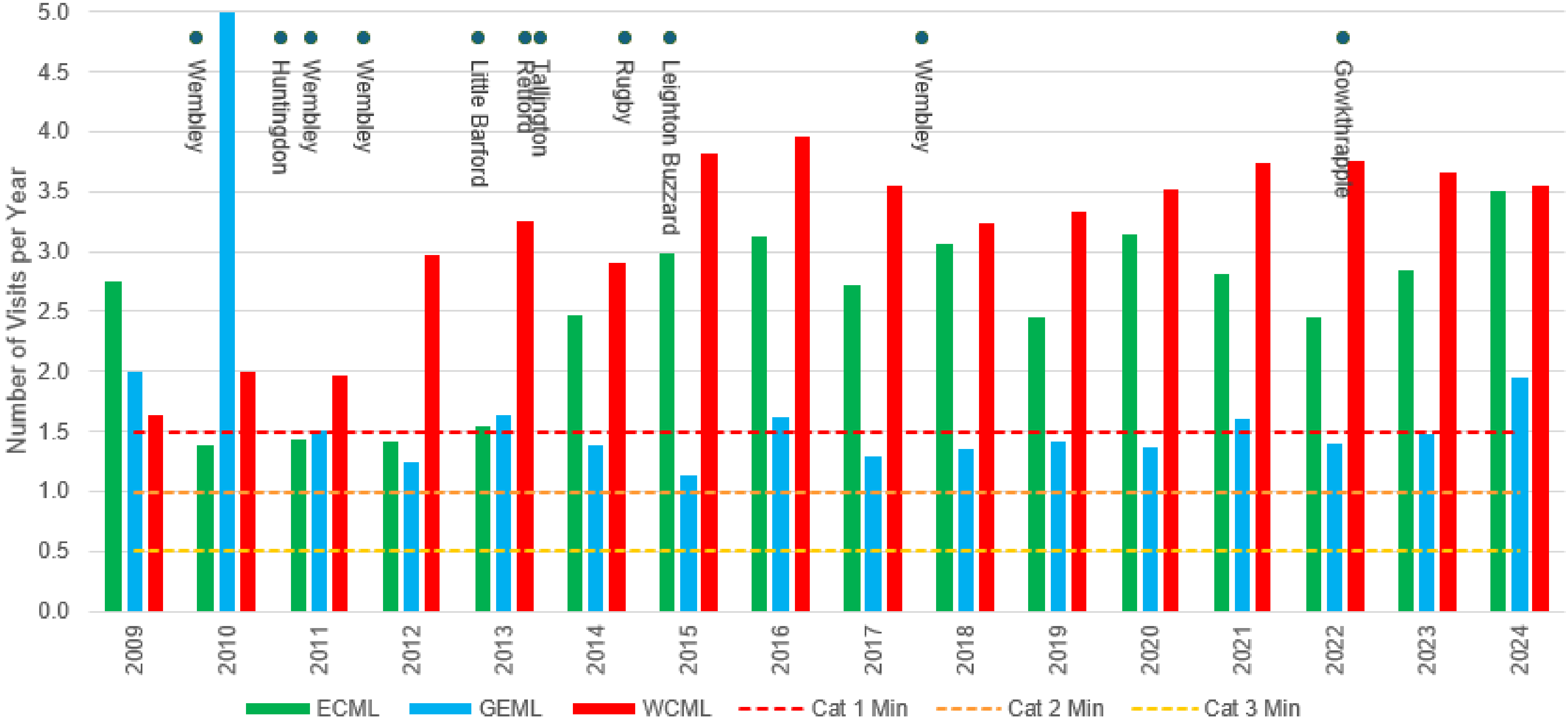
AFNSs– Maintenance Frequencies

+ According to Network Rail standard NR/L2/ELP/21087



AFNSs – High-level Maintenance

+ AFNS high level maintenance visits per year per AFNS by route, NR/L2/ELP/21087 standard maintenance frequencies and approximate dates of major dewirements



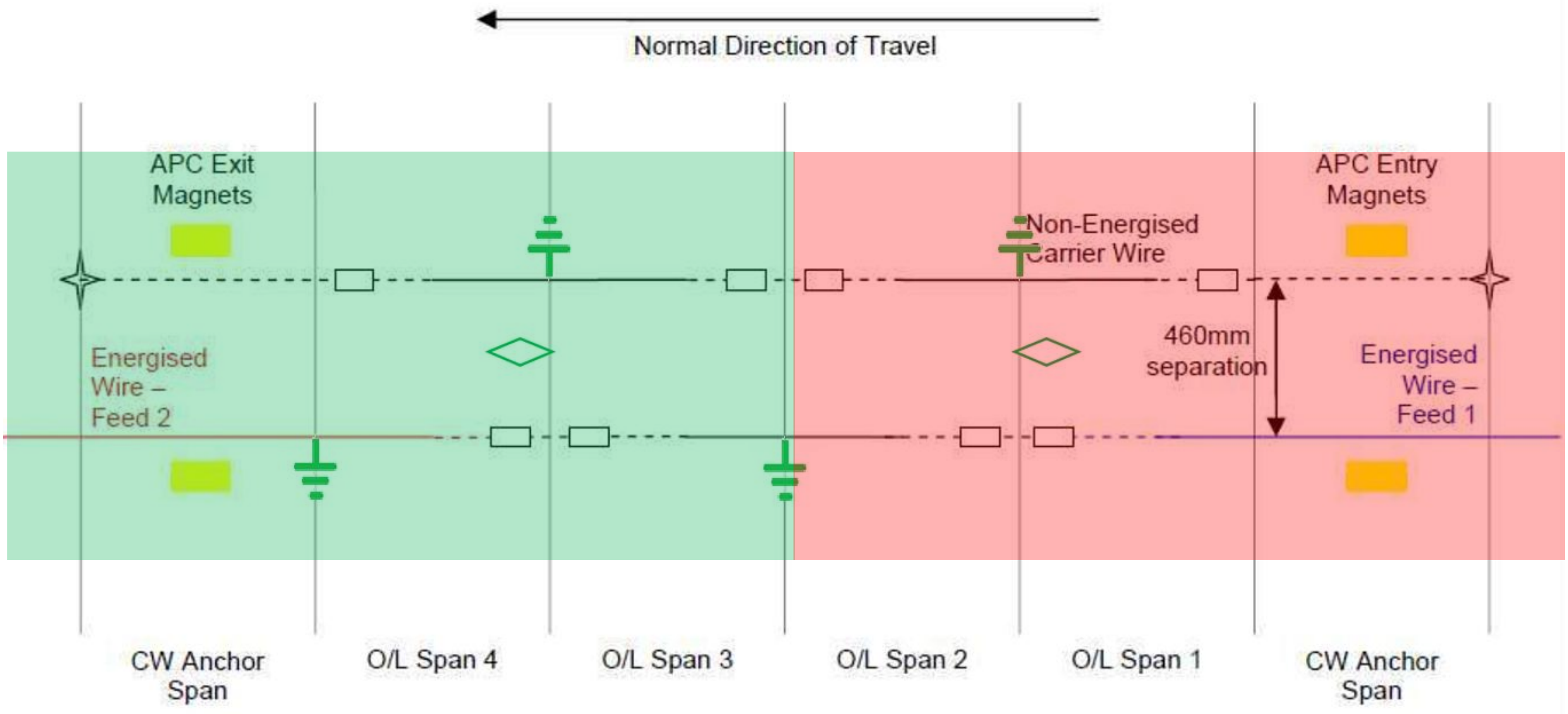
CWNSs – Maintenance

- CWNS maintenance frequencies are not clearly defined in NR/L2/ELP/21087 with the current frequencies defined by the route (W&W)
- The Wales and Western route is in the process of decreasing frequencies
  - High Level: From yearly to 2-yearly (aspiration to increase to 3-yearly)
  - MLE switches increased to 6-yearly
- Aspiration to increase low-level inspections and APC magnet inspections to 26 weeks

- W&W experience is that high level maintenance is difficult. Using Maidenhead as an example:
  - Typically completed at Christmas
  - Back-to-back shifts to get all four roads complete
  - External machines and operators contracted in to support
  - Major coordination between ECRO, OLE, power & distribution teams and third-party plant suppliers

Maintenance – Wales and Western CWNSs

- Alternative isolation of CWNS would allow it to be maintained in two halves



AFNSs vs CWNSs – Maintenance

Route	NS Type	Low Level Yearly Inspection Frequency			High Level Yearly Inspection Frequency		
		21087*	Actual	Future	21087*	Actual	Future
ECML	AFNS	9.17	2.68	-	0.81	2.74	-
GEML	AFNS	6.52	3.70	-	0.50	1.45	-
WCML	AFNS	8.49	4.78	-	0.77	3.60	-
GWML	CWNS	-	9.01	2.00	-	0.66	0.50

*Frequencies are a weighted average based on the number category 1, 2 and 3 neutral sections

- Issues with AFNS low level work order reporting
- Data taken for 2020-2023 years only
- Currently AFNSs get four times more high-level inspections than CWNS (compared to ECML and WCML)
  - This will increase to six times when CWNS frequencies are reduced
- However, CWNS maintenance time on site is greater

AFNSs vs CWNSs - Reliability

To assess the reliability of the short and carrier wire neutral section types, four metrics are defined:

+ The Mean Time between Faults (MTBF),
+ The Mean Pantograph Passages between Faults (MPPBF)
+ The Mean Time between Service affecting Failures (MTBSAF), and
+ The Mean Pantograph Passages between Service Affecting Failures (MPPBSAF).

Ellipse information provided by Network Rail:

+ Fault: Something that needs to be fixed but does not affect operational service
+ Service Affecting Failure: Something that delays trains!

+ Pantograph Passages: Estimated using timetable data and knowledge on rolling stock

AFNSs vs CWNSs - Reliability

- The number of services affecting failures is low, 28 nationally and 24 for the ECML, GEML and WCML routes
- There have been zero service affecting failures for CWNSs (we have had to assume one)
- Analysis focused on pan passages and time in service only

Route	**Line Category**	**Quantity of AFNSs**		**MTBF (Years)**	**MPPBF (Pantograph Passages)**	**MTBSAF (Years)**	**MPPBSAF (Pantograph Passages)**
		Pre 2019	**Post 2019**				
ECML	All	75	76	1.86	75,356	100.33	5,098,565
GEML	All	33	33	12.92	1,407,462	84.01	9,579,165
WCML	All	72	74	1.67	66,447	64.07	2,814,423
National	**All**	**413**	**485**	**5.37**	**N/A**	**148.32**	**N/A**

Route	**Line Category**	**Quantity**	**MTBF (Years)**	**Mean Pantograph Passages Between Faults MPPBF**	**MTBSAF (Years)**	**Mean Pantograph Passages Between SAF MPPBSAF**
Western	All	15	22	845,091	80.15*	3,118,490*

More like 110 now!

Driving Down CWNS Costs

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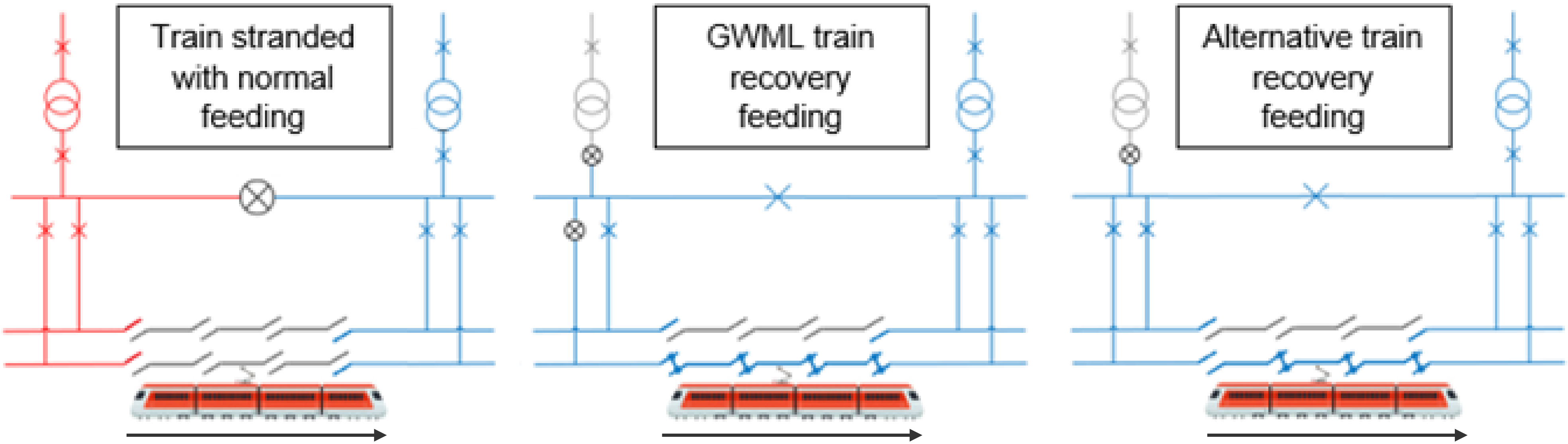
Removing One Recovery Switch



- 25 and 33% reduction in switching components for four- and three-overlap CWNSs respectively
- Requires assessment of protection systems
- Removes ability to bypass feeder station (not always needed)

What if we remove all recovery switches?

- NTSN: “Adequate means (except for the short separation section) shall be provided to allow a train that is stopped within the phase separation section to be restarted”.

- We looked at the likelihood of train stranding on GWML CWNSs:
  - 1707 CCIL incidents over 4.8 years where trains came to a stand for unusual reasons (e.g. Unsolicited brake application, SPAD, AWS brake command, object/person struck by train)
  - 2700 miles of track
  - From this we were able to work out a likelihood of a pantograph stopping for section of track
  - 185 m dead zone of Maidenhead CWNS could see a stranding once every 21 years

- However:
  - A large proportion of services are multi-mode and hence can self-recover
  - Many trains have alternative pantographs that could still be beneath live OLE

- Future services also calculated based on:
  - 50% of BMUs converted back to EMUs
  - 50% of west of England and Wales EMUs with single pantographs
  - 30% of freight pure electric

Remove All Recovery Switches

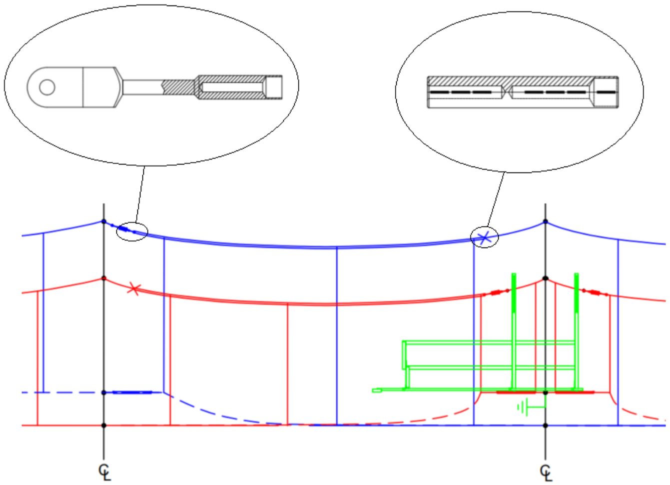
CWNS	Track ID	CWNS Length APC to APC (m)	Prob. of Emergency Stop (10^{-4} m^{-1} $year^{-1}$)	Total Trains per Week	Current		Future	
					Prob. of Stranding (10^{-4} $years^{-1}$)	Time Between Strandings (Years)	Prob. of Stranding (10^{-4} $years^{-1}$)	Time Between Strandings (Years)
Maidenhead	2100	185	2.47	1185	4.99	2004.5	[illegible]	379.0
Maidenhead	1100	185	2.47	1152	5.13	1948.7	[illegible]	369.7
Maidenhead	2200	182	2.47	1102	114	[illegible]	[illegible]	63.1
Maidenhead	1200	182	2.47	1075	117	[illegible]	159	62.9
Didcot	2100	235	1.65	887	[illegible]	[illegible]	71.8	139.3
Didcot	1100	235	1.65	[illegible]	[illegible]	1606.0	49.1	203.6
Didcot	1200	235	[illegible]	[illegible]	0	N/A	116	86.5
WoBaJn MLN	2100	216	[illegible]	[illegible]	0	N/A	77.2	129.5
WoBaJn MLN	1100	[illegible]	[illegible]	472	0	N/A	77.2	129.5
WoBaJn SWB	[illegible]	[illegible]	1.65	399	6.51	1537.0	55.8	179.2
[illegible]	[illegible]	[illegible]	1.65	399	6.51	1537.0	55.8	179.2
[illegible]	[illegible]	216	1.65	452	0	N/A	105	95.3
[illegible]	1200	216	1.65	452	0	N/A	105	95.3
St Brides	2100	216	1.65	519	2.97	3370.1	94.9	105.3
St Brides	1100	216	1.65	519	2.97	3370.1	94.9	105.3
Whole Route					**270**	**37.1**	**1270**	**7.9**

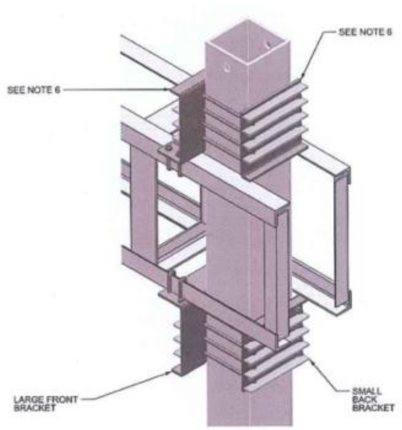
NOTE: Wales & Western first preference is to use another train to pull out stranded train and will avoid using recovery switches if possible

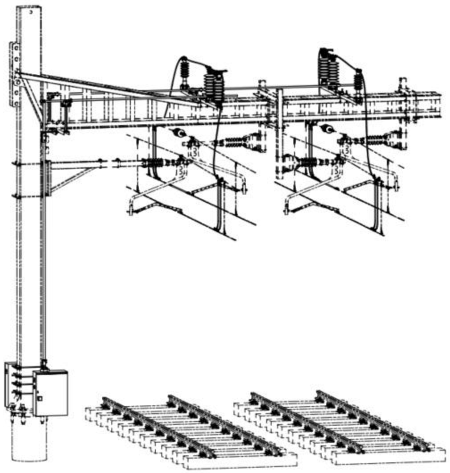
Unlikely

General Constructability Changes

- Covered catenary:
  - Was mandated by NR on Series 1
  - It's hard to source, has to be bought in lengths of 1000m, requires specialist tooling and training for construction and maintenance
  - Arc catchers work – get rid of the covered catenary
- Structures:
  - Most CWNSs use HEX portals – they are complex and expensive
  - Q-booms and TTCs have ample capacity – use them!

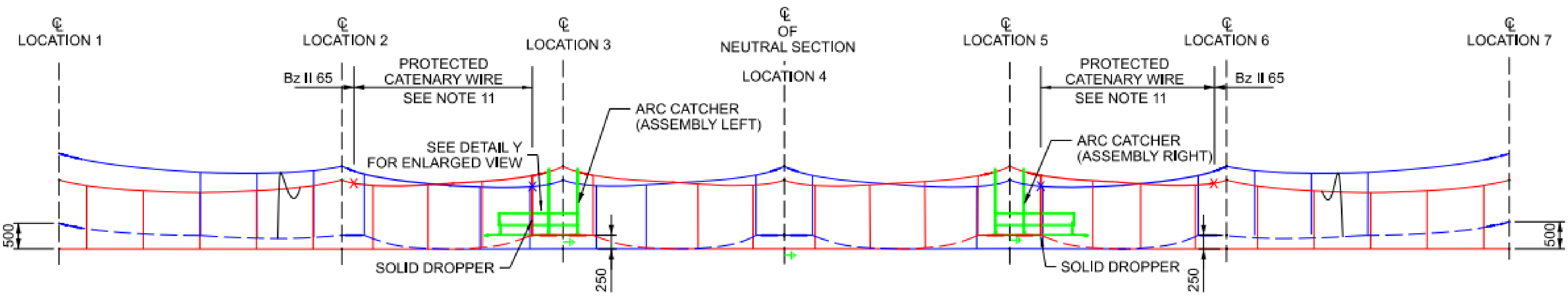




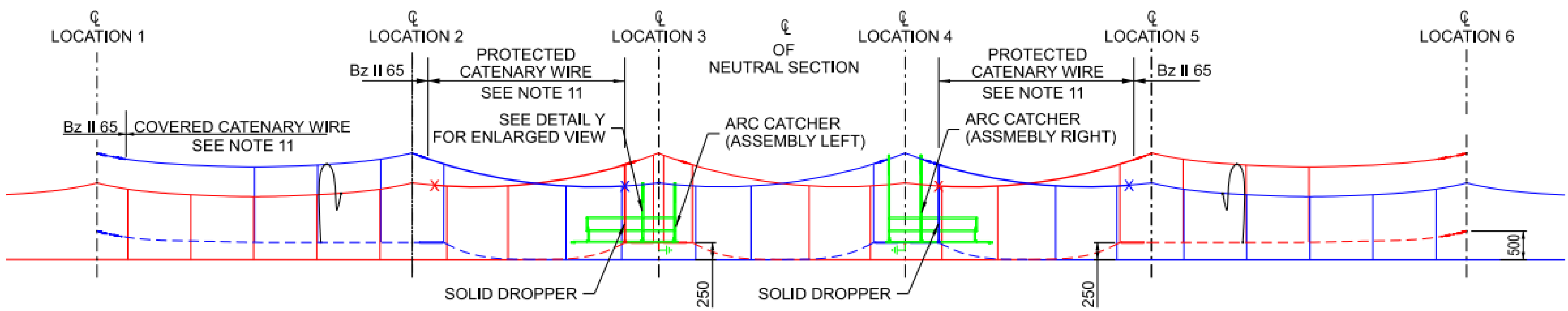


General Constructability Changes – 4-span vs 3-span

+ 4 overlap span



+ 3 overlap span



CWNS Dimensioning Tool

Figure 5-4: Initialisation of the CWNS animation showing the sections of the neutral section. The first phase is the red section on the left, and the second phase is the magenta section on the right.

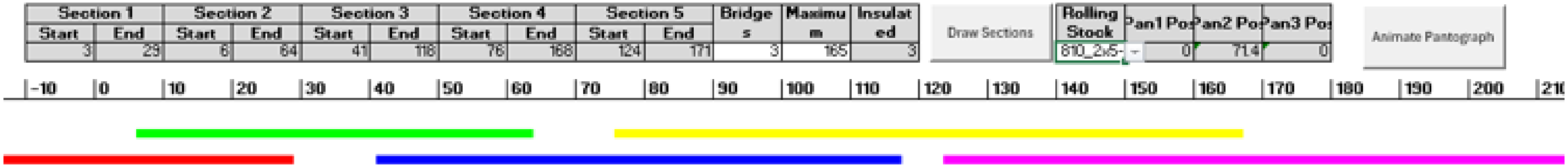


Figure 5-5: Two-pantograph example transiting the neutral section showing the energised sections.

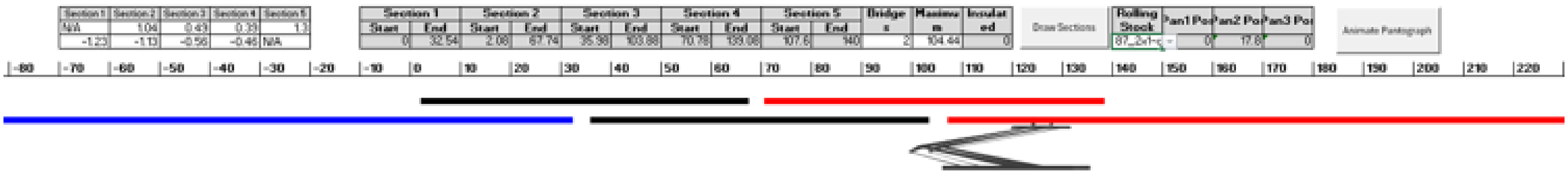
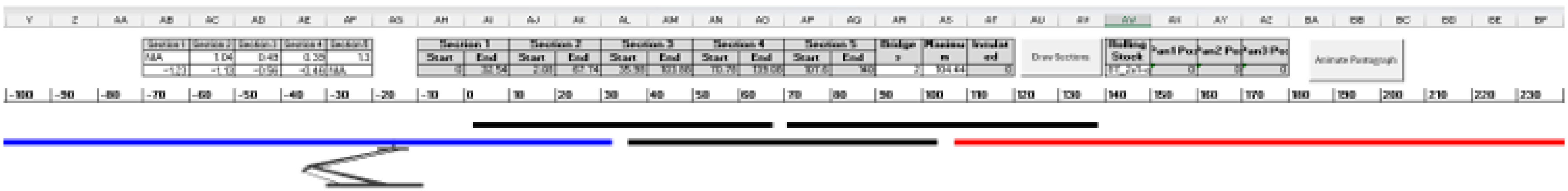


Figure 5-6: Three pantograph example transiting the neutral section showing the energised sections.



3x 40m Overlap Span Compatibility

CWNS Dimensioning Tool Output

Rolling Stock Class	Multiple Configurations (No. of units x cars per unit)	Pantograph Spacing Configuration ID Number	Pantograph 1 position (m)	Pantograph 2 position (m)	Pantograph 3 position (m)	Pass/Fail?
755/756	3x3-car	1	0	65	130	Pass
755/756	3x3-car	2	0	87.1	130	Pass
755/756	3x3-car	3	0	87.1	152.1	Pass
755/756	3x3-car	4	0	42.9	107.9	Fail
755/756	3x3-car	5	0	65	107.9	Fail
755/756	3x4-car	1	0	80.7	161.4	Pass
755/756	3x4-car	2	0	118.5	161.4	Pass
755/756	3x4-car	3	0	118.5	199.2	Pass
755/756	3x4-car	4	0	42.9	123.6	Pass
755/756	3x4-car	5	0	80.7	123.6	Pass
730/0	3x3-car	1	0	72.6	145.2	Pass
730/0	3x3-car	2	0	88.6	145.2	Pass
730/0	3x3-car	3	0	88.6	161.2	Pass
730/0	3x3-car	4	0	56.6	129.2	Pass
730/0	3x3-car	5	0	72.6	129.2	Pass
730/2	3x5-car	1	0	121	242	Pass
730/2	3x5-car	2	0	153.4	242	Pass
730/2	3x5-car	3	0	153.4	274.4	Pass
730/2	3x5-car	4	0	88.6	209.6	Pass
730/2	3x5-car	5	0	121	209.6	Pass
350/360	3x4-car	1	0	81.4	162.8	Pass
350/360	3x4-car	2	0	87.5	162.7	Pass
350/360	3x4-car	3	0	87.5	168.9	Pass
350/360	3x4-car	4	0	75.2	156.6	Pass
350/360	3x4-car	5	0	81.4	156.6	Pass
357	3x4-car	1	0	80.8	161.6	Pass
357	3x4-car	2	0	86.6	161.6	Pass
357	3x4-car	3	0	86.6	167.4	Pass
357	3x4-car	4	0	75	155.8	Pass
357	3x4-car	5	0	80.8	155.8	Pass
387	3x4-car	1	0	82.4	164.8	Pass
387	3x4-car	2	0	89	164.8	Pass
387	3x4-car	3	0	89	171.4	Pass
387	3x4-car	4	0	75.8	158.2	Pass
387	3x4-car	5	0	82.4	158.2	Pass

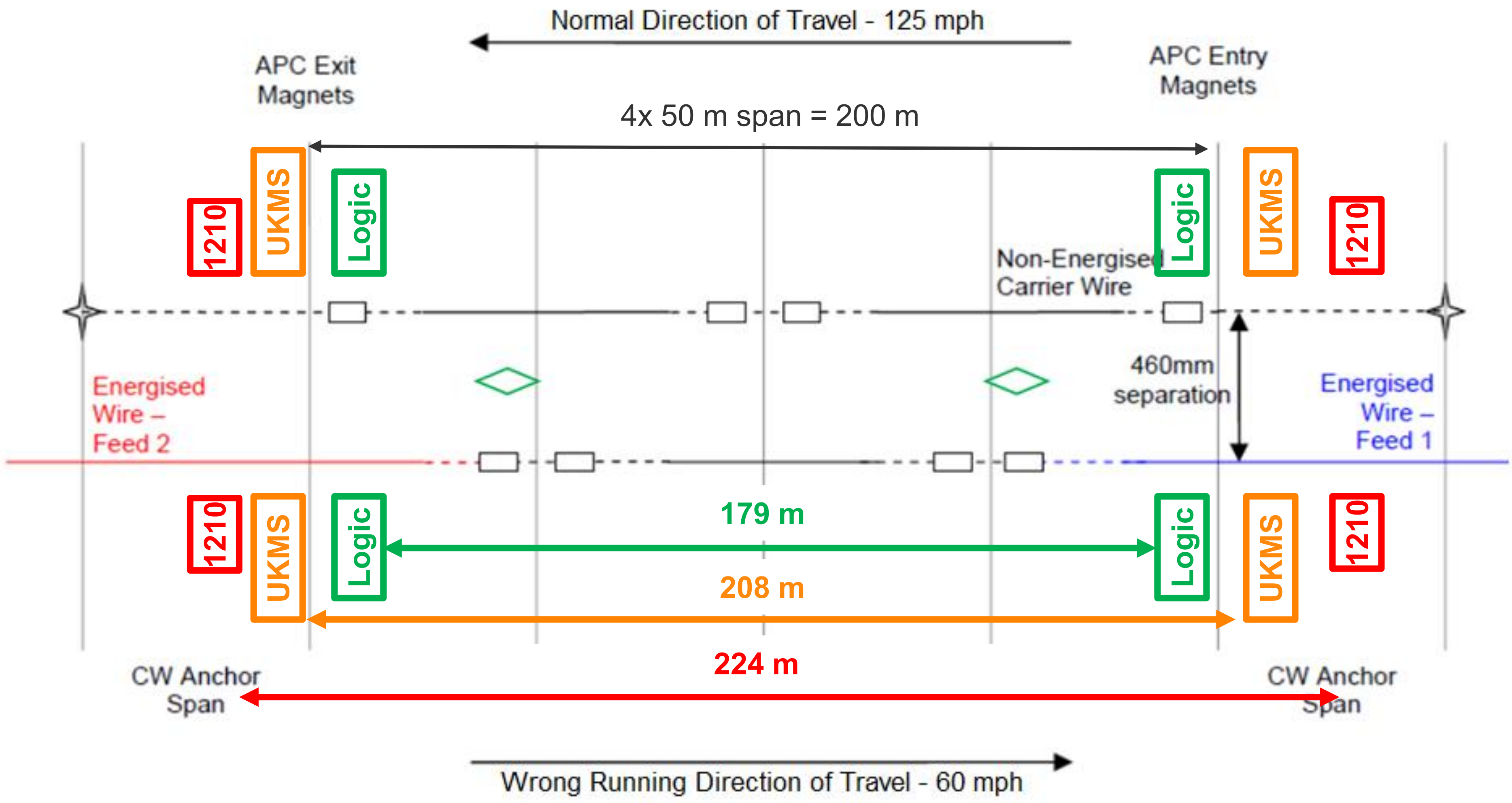
Reducing CWNS length – APC magnet spacing

$$Distance_{APC\text{-}NS} = D / 2 + Receiver_{offset} + (t \times 1.1 \times v_{speed})$$

- *t* is 0.15 s and is for train physical reaction time – can't be reduced
- *Receiver offset* is 7.75 m – could be reduced
- Distance <u>from phase separation section</u> to APC
  - 125 mph: 16.97 m
  - 60 mph: 12.17 m
- What is *D*?
- GLRT1210 Issue 3 more onerous

D overall length of phase separation section as distance between adjacent systems/phases including overlapping parts taking into account the contact wire uplift by pantograph passage and electrical clearances in accordance with BS EN 50119:2020, 5.1.3

Reducing CWNS length – APC magnet spacing



CWNS siting – challenging the “Goldilocks” rules

The UKMS design rules for siting CWNSs have been duplicated from the Series 1 system and are as follows:

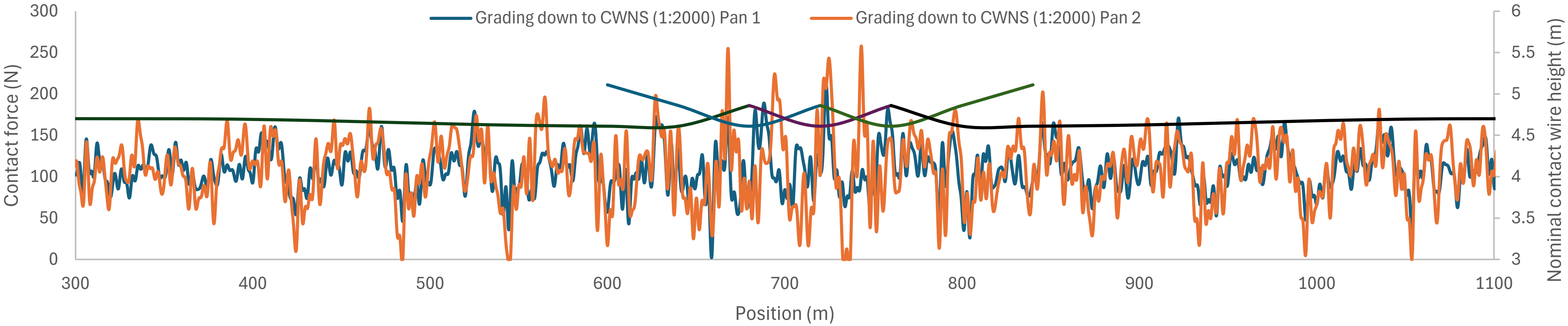
+ All elements are at least 100 m from a junction or crossover position
+ Contact wire height between 4.4 and 5 m
+ **Contact gradient level or better than 1:2000 for 3 spans each side**
+ Static radial load between 0.1 and 1 kN (not for push off registration arm)
+ System height greater than 1 m
+ Not under a bridge or in a tunnel
+ Not in known or likely vandalism risk area

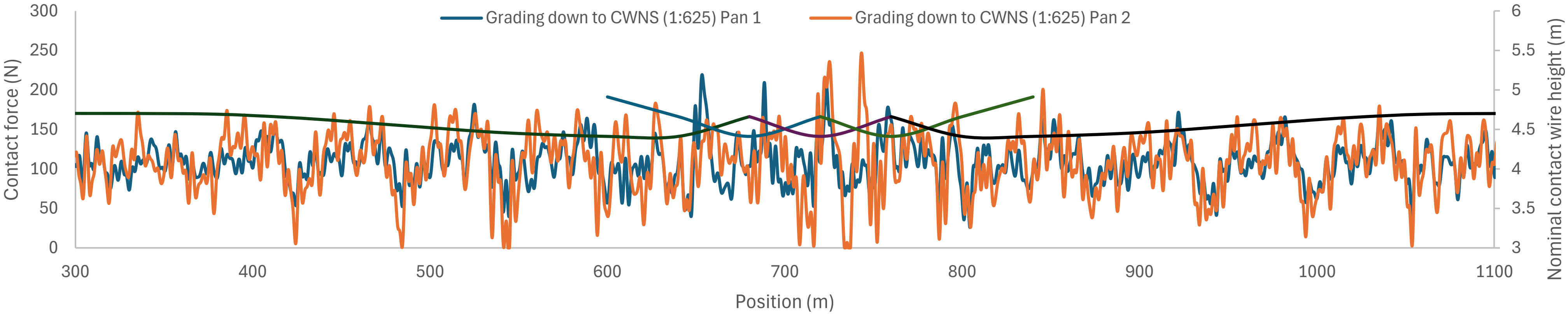
CWNSs – Does the OLE need to be level each side?

+ We performed dynamic modelling for two pantograph train on a four-overlap 40m span CWNS at 125 mph and 200 m pantograph spacing using grading at 1:625 and 1:2000

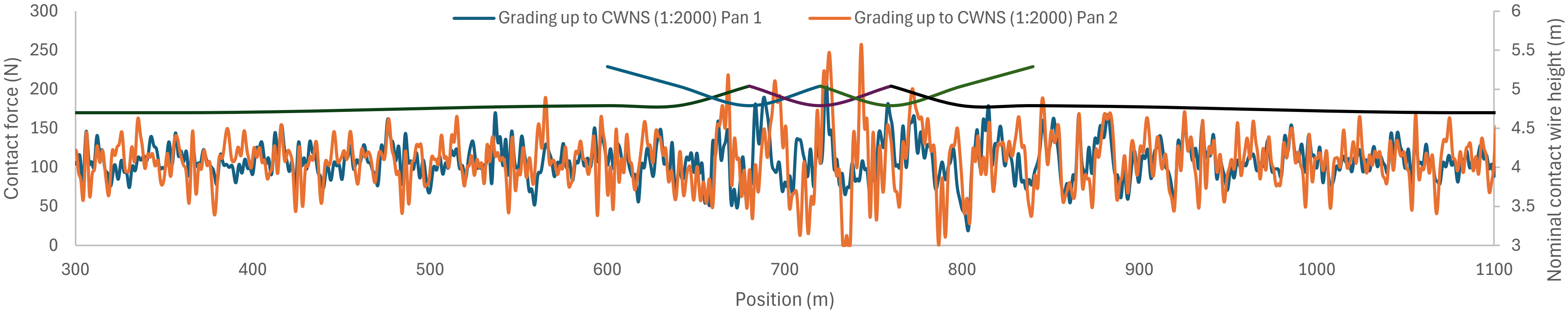
	Grading up to CWNS				Grading down to CWNS			
	1:2000 Gradient		1:625 Gradient		1:2000 Gradient		1:625 Gradient	
	Pan 1	Pan 2	Pan 1	Pan 2	Pan 1	Pan 2	Pan 1	Pan 2
F_m	0.3	0.6	0.3	0.6	0.3	1.0	1.2	0.3
σ	16.2	1.1	14.6	0.5	7.0	21.5	0.9	16.8
F_{min}	5.1	21.6	6.4	21.1	6.3	29.2	12.2	8.1
F_{max}	286.7	33.8	91.9	33.8	118.4	50.9	112.8	37.2
$F_m + 3\sigma$	7.7	0.0	7.0	0.3	3.0	10.7	1.0	7.4
$F_m - 3\sigma$	277.5	80.6	257.3	88.3	106.9	401.4	2.2	39.3
σ / F_m	15.9	1.7	14.4	1.1	7.3	20.3	0.4	17.3

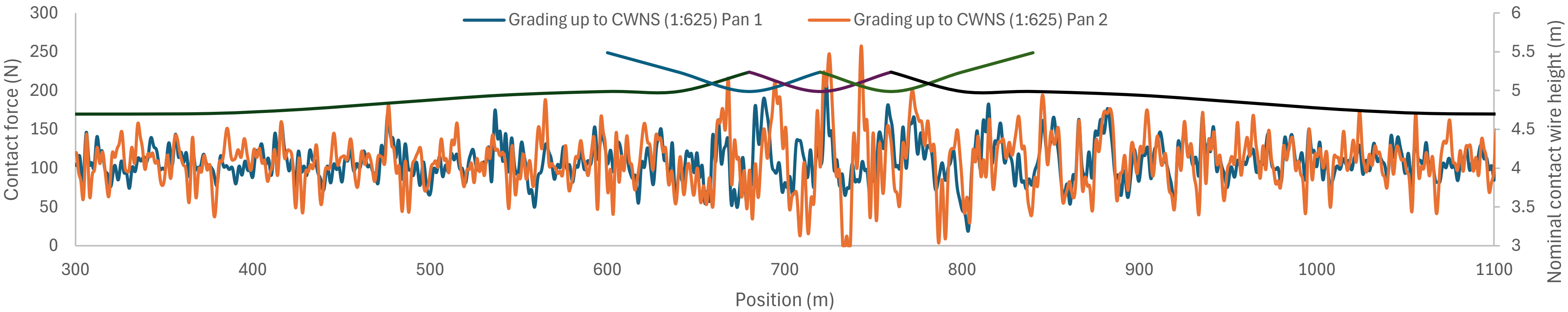
Level Spans Rules – Grading down force traces





Level Spans Rules – Grading up force traces





CWNSs – Does the CW need to be level each side?

NO

Sam told me to say this: “It’s worse but fine dynamically”

Summary of Recommendations

In order of highest impact on reducing capital cost:

- Ditch the recovery switches – you won’t need them
  - Or at least ditch the one for the first overlap
- Use three-overlap span CWNSs where pantograph quantities/spacing allow (or just mandate pantograph spacing like HS1!)
- Abolish the level spans rule and allow maximum grading each side of the CWNS
- Use simpler structures like Q-booms or TTCs
- Replace the covered catenary with contenary
- Reduce the APC magnet spacing (and challenge GLRT1210 wording)
- Use the shortest span permissible (and allow 35m span lengths in UKMS)

If we do all this, then maybe we’ll love CWNSs!!

Thank you for listening

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