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Dear Emily

‘Top down’ cost variability assumptions applied to embankment, culvert and metallic underbridge renewals

Purpose

The purpose of this letter is to set out, in more detail, our ‘top down’ cost variability assumptions in relation to the following variable usage cost categories:

- embankment renewals;
- culverts renewals; and
- metallic underbridge renewals.

It also forms part of our response to the request in ORR’s consultation document on the variable usage charge and a freight-specific charge for us to use reasonable endeavours to improve our estimates of cost variability with respect to civils structures and earthworks. Separately, we have also written to you in response to the Morgan Tucker report, commissioned by colleagues in the freight industry, which largely focuses on our assumptions in relation to brick and masonry underbridge variable usage costs[1].

This letter has been copied to colleagues who attend the monthly variable track access charging meeting for their information.

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[1] Letter from NR to ORR, *Response to the Morgan Tucker report reviewing our Variable Usage Charge estimates and freight caps*, 18 December 2012

All terms in this paper are in 2011/12 prices and at end CP4 efficiency unless stated otherwise.

Background

Network Rail 'freight cap' consultation and conclusions

To inform any decision by ORR in relation to placing any early cap on freight variable usage charges (VUCs) we calculated an initial estimate of freight variable usage costs. We consulted on our initial cost estimate in November 2011 and, following careful consideration of consultation responses, concluded on our consultation to you in March 2012.

A summary of the total variable usage cost estimate included in our conclusions letter is set out in Table 1, below:

Table 1: Updated variable usage cost estimate (2011/12 prices end CP4 efficiency)

Asset type	**Costs (£M per year)**
Track:	**242.4**
Track maintenance and renewals	242.4
Civils:	**25.5**
Embankments renewals	1.9
Metallic underbridge renewals	9.7
Brick and Masonry underbridge renewals	13.3
Culverts renewals	0.5
Signalling:	**13.6**
Maintenance	8.2
Minor works points renewals	5.4
Total	**281.5**

In our conclusions letter we stated that the cost variability assumptions set out in our consultation document in relation embankment, culverts and metallic underbridge renewals remain appropriate. These assumptions are shown in Table 2 below:

Table 2: Civils variability assumptions (2011/12 prices end CP4 efficiency)

Asset type	Annual average (£m)	Percentage variability	Variable usage cost (£m)
Embankment renewals	32.4	6%	1.9
Metallic underbridge renewals	48.7	20%	9.7
Culverts renewals	9.2	5%	0.5

Arup review of Network Rail 'freight cap' consultation

The variable usage cost estimates included in our November 2011 consultation document were reviewed by the independent reporter, Arup.

In respect of earthworks Arup stated the following:

"NR proposes retaining the 6% variability percentage applied to earthworks in PR08. There are credible fatigue type mechanisms for higher plasticity Clay embankments that could be induced by railway traffic loading. However, there is insufficient data to enable a robust estimate of the variable usage charge percentage. In the absence of such information, NR has used its own engineering judgment.[2]"

It also noted the following in relation to civils structures:

"The variable costs to structures are proposed in CP5 to be extended from metallic underbridges to masonry and brick underbridges and to culverts. There is evidence to suggest that these additional structures are and will continue to be affected by heavy axle loads. However, no evidence has been provided by NR on the variability impact. There is, therefore, some uncertainty on these variable costs.[3]"

In terms of the level of uncertainty Arup rated our earthworks and civils structures variable usage cost estimates as "red", commenting that they are based on engineering judgement with no firm evidence on the quantified impact.

Further to the Arup review, in its consultation document on the variable usage charge and a freight-specific charge, ORR asked us to use reasonable endeavours to improve our estimates of cost variability with respect to earthworks and civils structures. We have reviewed these cost estimates, below, and sought to improve them by setting out our rationale in more detail.

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[2] Page ii of the Arup report.
[3] Page ii of the Arup report.

Embankment renewals

We recognise that, where possible, it is preferable to apply a ‘bottom up’ approach to estimating cost variability. However, at present, we do not have the tools to model ‘bottom up’ the level of cost variability associated with embankment renewals. Therefore, if these costs are to be recovered through the VUC in CP5, it will be necessary to apply a ‘top down’ cost variability assumption. We accept that any ‘top down’ assumption is likely to be more uncertain than a ‘bottom up’ one.

Following further review, we continue to consider that embankment renewal costs vary with traffic and these variable costs should be recovered through the VUC. Moreover, we continue to believe that the 6% cost variability assumption applied in CP4 should be retained.

We consider that there is sufficient evidence linking traffic loading to embankment failures and, therefore, costs. We also note that Arup did not conclude that there is no relationship between traffic and embankment costs. Rather, it was in agreement with us and Mott Macdonald that there are credible fatigue type mechanisms for higher plasticity clay embankments that could be induced by railway traffic loading.

Mott Macdonald report - ’The Effects of Railway Traffic on Embankment Stability

In our opinion, the Mott Macdonald report funded by RSSB[4] supports our view that traffic loading effects contribute towards the number of embankment failures. This report reviews previous work and papers on the vulnerability of embankments to train axle load and the effects of embankment clay fill plasticity. We have summarised the report, below, for ease of reference and attached it to the covering email accompanying this letter.

Cumulative plastic strain (permanent strain) at the top of the embankment fill increases exponentially as train axle load increases. For 1 million loading cycles per year, the plastic strain developed as a result of 25 tonne axle loading (typical of freight trains) is approximately 3.5 times that of a 15 tonne axle loading (typical of passenger trains). Soil subjected to repeated large load amplitudes (typical of freight train loading) will experience plastic strains per loading cycle which will accumulate over time until instability develops leading to a requirement for slope repair. Large plastic strains leads to deformation of embankment fill and dishing of the formation leading to water ponding. This increases the requirement for track maintenance and leads eventually to ballast pockets and serviceability failure of the embankment. Dishing of the formation also allows water ponding and ingress of water into the embankment core causing softening of cohesive fill. If dishing of the embankment is not identified for drainage works then ultimate failure may occur.

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[4] Mott MacDonald published a report in March 2011 entitled ‘’The Effects of Railway Traffic on Embankment Stability’’.

Graph 1, in the Appendix 1, shows the relationship between plastic strain and change in deviator stress (difference between principal stresses where principal stresses are maximum and minimum normal stresses applied to an element of soil within the embankment) at clay fill surface. Plastic strain to embankments also increases exponentially with clay plasticity. Due to the exponential nature of the plastic strain curves, embankments composed of high plasticity clay suffer greater plastic deformation and, therefore, require more frequent maintenance than those embankments constructed of low plasticity clay fill. Graph 2, in Appendix 1, shows the relationship between plastic strain and clay plasticity. It shows that high plasticity clay fill will typically experience 2.6 times the amount of plastic strain as a low plasticity clay fill when trafficked by a typical mix of freight trains with 25 tonne axle loads.

We consider that the relationship between train axle load and plastic strain set out in the report is sufficient evidence that embankment costs vary with traffic and that these costs should be recovered through VUCs. Deviator stress in an element of soil within the embankment at clay fill surface is proportional to axle load.

As noted above, if these costs are to be recovered through VUCs in CP5 it will be necessary to make a 'top down' assessment of cost variability based on engineering judgement. Table 1, Appendix 1, shows the proportion of track on high or very high plastic clays by Territory. Based on analysis of geological maps of the railway network, approximately 11.1% of track nationally is on cohesive soils which are classified as high or very high plasticity clays. Our judgement that the 6% cost variability percentage in PR08 should be retained is based on the fact that approximately 11.1% of track nationally is on high or very high plasticity clays, identified as particularly vulnerable to increased plastic strain due to increased tonnage and / or increased frequency of heavy axle loads, reduced by 50% to reflect the fact that approximately half of this track length is on embankment.

We also note that embankment costs have been considered variable with traffic since, at least, the 2000 Access Charging Review and cost variability estimates have ranged from 5-10%[5]. Therefore, our 6% estimate is consistent with previous 'top down' assumptions (and is towards the lower end of the range).

Conclusion

Whilst we recognise that our 'top down' cost variability estimate is likely to be more uncertain than a 'bottom up' one. We consider that not recovering embankment renewal costs through the VUC would reduce cost reflectivity, result in costs not being recovered from those who cause them to be incurred, and potentially provide

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[5] Halcrow, Reporter Mandate – Variable Usage Costs Final report, January 2008.

us with a disincentive to accommodate additional traffic on the network. Therefore, we continue to consider that a 6% cost variability assumption should be applied to embankment renewals.

Culverts renewals

As for embankment renewals, we recognise that, where possible, it is preferable to apply a ‘bottom up’ approach to estimating cost variability. However, at present, we do not have the tools to model ‘bottom up’ the level of cost variability associated with culverts renewals. Therefore, if these costs are to be recovered through the VUC in CP5 it will be necessary to apply a ‘top down’ cost variability assumption. We accept that any ‘top down’ assumption is likely to be more uncertain than a ‘bottom up’ one.

Following review, we continue to consider that culverts renewal costs vary with traffic and these costs should be recovered through the VUC. Moreover, we continue to believe that the 5% cost variability assumption set out in our March 2012 conclusions letter continues to be appropriate. We have sought to improve our cost estimate by explaining the rationale for the 5% cost variability percentage in more detail, below.

Culverts are impacted by traffic in broadly the same way as masonry underbridges. Therefore, we consider that the 14% variability assumption that we propose applying to masonry underbridges is also relevant to culverts. However, the level of cost variability for culverts is attenuated to a degree by their depth below the track. Culverts at shallow depth (less than 3m) are at greater risk and are impacted by every axle as a pulsating load whereas deep culverts only see a general increase in loading as the train passes over the culvert. We consider that approximately 33% of culverts are at shallow depth (less than 3m) and that the renewal costs associated with these assets vary with traffic. The 33% figure is based on data from the earthworks database. This shows that approximately 50% of route miles relate to embankments greater than 3m or cuttings, which we consider are not impacted by traffic. We consider that the 50% of route mileage at grade or less than 3m height would, on some route sections, have less culverts per mile and, therefore, 33% was an appropriate and conservative assumption. We estimate the culverts cost variability percentage to be 5%. This is derived by multiplying the 14% variability assumption proposed for masonry underbridges by the proportion of culverts (33%) that we estimate to be at shallow depth (14% * 33% = 5%).

It should be noted that culverts almost always pass through embankments and therefore movement in the embankment does affect and cause failure of any culverts passing through it. The two assets are intrinsically linked in this respect.

Conclusion

As for embankment renewals whilst we recognise that our ‘top down’ cost variability estimate is likely to be more uncertain than a ‘bottom up’ one. We consider that not recovering culverts renewal costs through the VUC would reduce cost reflectivity, result in costs not being recovered from those who cause them to be incurred, and potentially provide us with a disincentive to accommodate additional traffic on the network. Therefore, we continue to consider that a 5% cost variability assumption should be applied to culverts renewals.

Metallic underbridge renewals

As for embankment and culverts renewals, we recognise that, where possible, it is preferable to apply a ‘bottom up’ approach to estimating cost variability. However, at present, we do not have the tools to model ‘bottom up’ the level of cost variability associated with metallic underbridge renewals. Therefore, if these costs are to be recovered through the VUC in CP5 it will be necessary to apply a ‘top down’ cost variability assumption. We accept that any ‘top down’ assumption is likely to be more uncertain than a ‘bottom up’ one.

Following review, we continue to consider that metallic underbridge renewal costs vary with traffic and these costs should be recovered through the VUC. Moreover, we continue to believe that the 20% cost variability assumption set out in our March 2012 conclusions letter continues to be appropriate. We have sought to improve our cost estimate by explaining the rationale for the 20% cost variability percentage in more detail, below.

The majority of metallic underbridges are approximately 130 years old and were constructed at a lower specification than modern designs reflecting the loading at that time (few axle loads exceeded ten tonnes). Metal fatigue damage depends on the intensity and the number of the stress cycles. The relationship is logarithmic and thus the cumulative damage under a heavy axle load is considerably more than under a lightly loaded axle.

The following equation is included in the CP4 VUC model and is used to apportion metallic underbridge variable usage costs and seeks to model the relationship between damage to metallic underbridges, axle load and speed.

Equivalent Structures Damage = $Ct.A^{3.83}.S^{1.52}$ (per tonne.mile).GTM where,

Ct is a constant: 1.20 for two-axle freight wagons, and 1 for all other vehicles
A is the axle load (tonnes)
S is the operating speed (miles/hour)
GTM is the Gross Tonne Miles

This relationship was derived, in a previous periodic review, by applying regression relationships to a large number of results from fundamental structures damage models.

Serco has recently reviewed the, above, equation as part of its work to re-calibrate VUCs for CP5. It notes in its final report that fatigue damage in steel bridges is typically dependent on stress raised to a power between the range of 3 to 5[6] so the value of 4.83 is at the high end and there is no evidence to suggest that Network Rail's structures have increased susceptibility to stress (Note: The axle load exponent of 3.83 is used when the formula is expressed in terms of per tonne.mile and 4.83 when expressed in terms of per axle mile, given that there is an additional axle load multiplier in GTM). It, therefore, recommends using an axle load exponent of 4 which is more consistent with Euronorm standards. It also found that the speed exponent used in the equation (1.52) is consistent with AREMA guidelines[7] for speed limits on bridges, whereby 1.0 and 2.0 are used for concrete and steel bridges respectively. We consider that the existence of the, above, equation and Serco's review supports our view that metallic underbridge costs vary with traffic.

In addition we note that that metallic underbridge costs have been considered variable with traffic since, at least, the 2000 Access Charging Review and cost variability estimates have ranged from 10-20%[8]. Therefore, our 20% estimate is consistent with previous 'top down' assumptions, albeit at the higher end of the range.

Based on engineering judgement, we consider that it is appropriate to retain the 20% cost variability assumption applied in PR08 because, in our opinion, a 10% homogenous increase in network-wide traffic volumes would result in a 2% increase in renewal costs. Increased traffic volumes will result in more frequent deck renewals and the earlier application of strengthening to prevent the onset of fatigue and stress corrosion than would otherwise be the case. We note that due to the increase in heavy axle load freight traffic in recent years, one could argue that the level of cost variability might have increased since PR08. However, as stated above, we consider that it is appropriate to retain the 20% variability assumption applied in PR08.

Conclusion

As for embankment and culverts renewals, whilst we recognise that our 'top down' cost variability estimate is likely to be more uncertain than a 'bottom up' one. We consider that not recovering metallic underbridge renewal costs through the VUC

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[6] BS EN 1993-1-9:2005 - Eurocode 3. Design of steel structures. Fatigue.

[7] American Railway Engineering and Maintenance-of-Way Association, *Manual for Railway Engineering*, Chapter 15, Steel Structures, Washington, D.C., 2006.

[8] Halcrow, Reporter Mandate – Variable Usage Costs Final report, January 2008.

would reduce cost reflectivity, result in costs not being recovered from those who cause them to be incurred, and potentially provide us with a disincentive to accommodate additional traffic on the network. Therefore, we continue to consider that a 20% cost variability assumption should be applied to metallic underbridge renewals.

Conclusion

We consider that the additional information set out, above, provides sufficient evidence that embankment, culverts and metallic underbridge renewals costs vary with traffic. Moreover, we note that in previous periodic reviews it was accepted that metallic underbridge and embankment renewals costs vary with traffic and thus the relevant proportion of these costs should be recovered through the VUC.

We recognise that our ‘top down’ cost variability estimates are likely to be more uncertain than ‘bottom up’ ones. However, as set out above, we continue to consider that these variable costs should be recovered through VUCs. In respect of embankment costs, we consider that the Mott Macdonald report funded by RSSB supports our view that traffic loading effects contribute towards embankment failures and thus these costs are variable with traffic. In respect of metallic underbridge renewals, we note that Euronorm standards link fatigue damage in steel bridges to axle load, therefore, also supports our view that these costs vary with traffic. In summary, we continue to consider that it is appropriate to retain the variable usage cost estimates set out in our March 2012 conclusions letter to ORR. We will update these cost estimates to take into account the latest cost and traffic data (set out in our Strategic Business Plan) when we conclude to ORR by the end of March 2013.

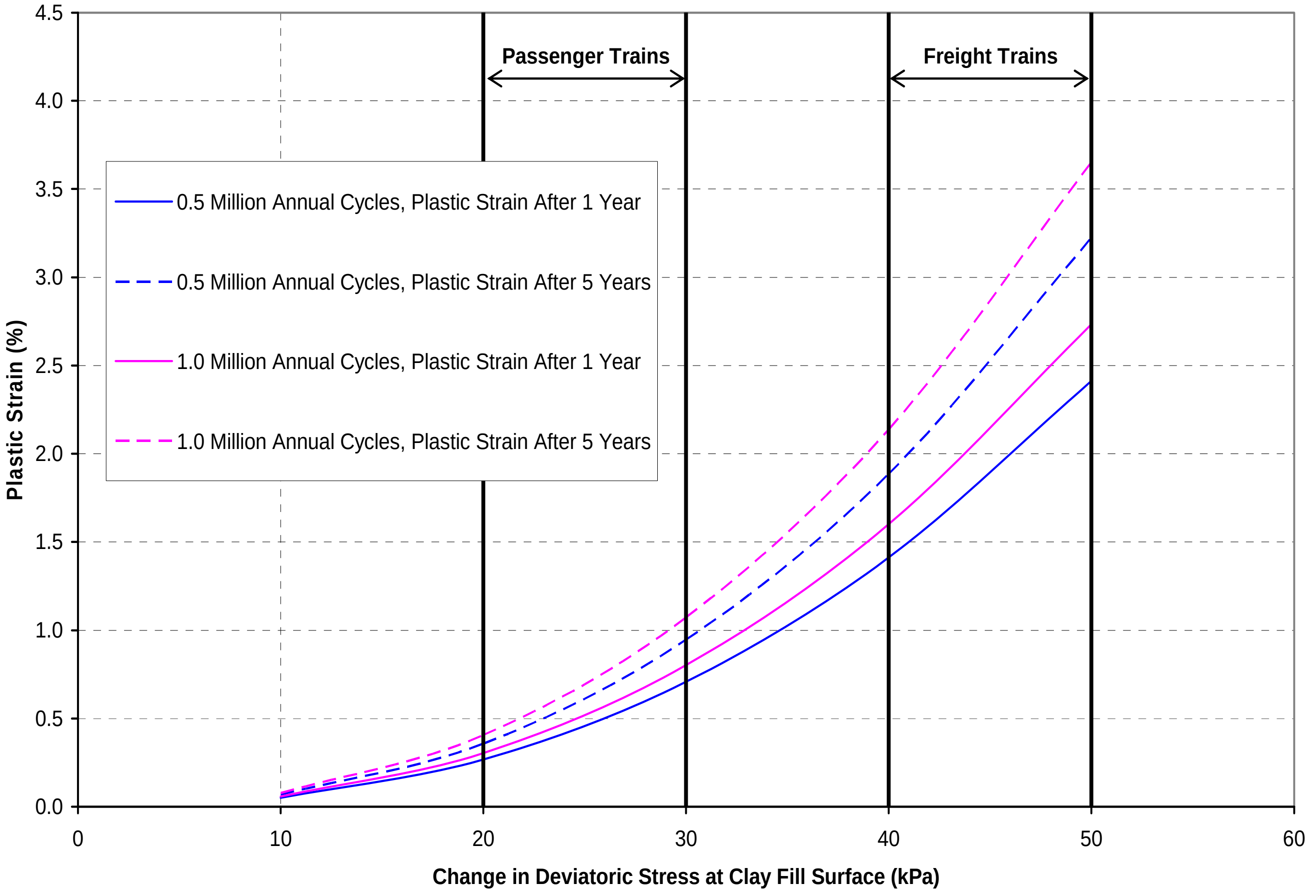
If you would like to discuss any aspect of this letter please do not hesitate to contact me.

Yours sincerely,

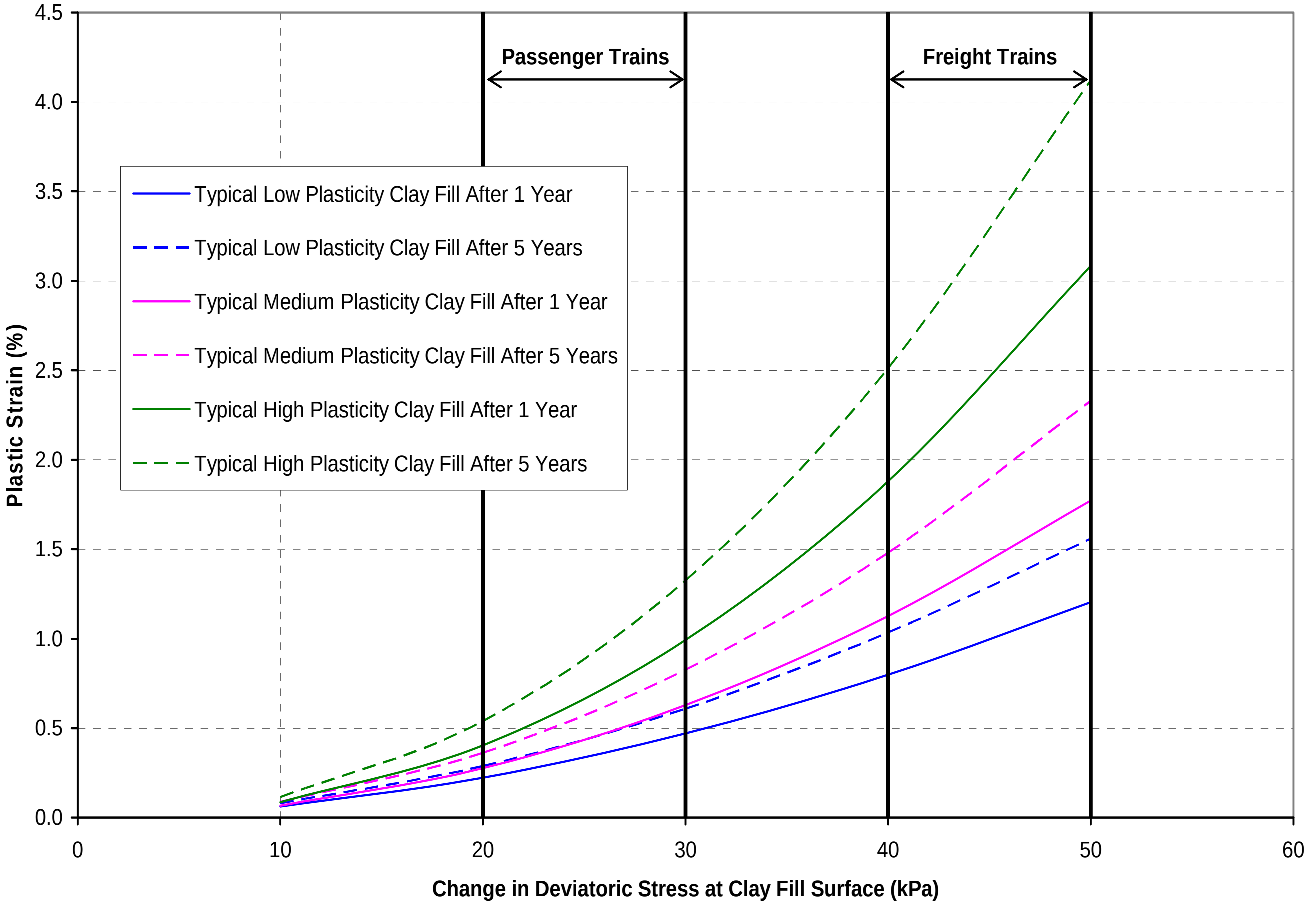
Ben Worley

Senior Regulatory Economist

APPENDIX 1 – ADDITONAL EMBANKMENT INFORMATION



Graph 1: Relationship between plastic strain and change in deviator stress (difference between principal stresses) at clay fill surface



Graph 2: The relationship between plastic strain and clay plasticity

Territory	**% of Territory on High or Very High Plasticity Clays**	**Track length on High or Very High Plasticity Clays (km)**
Scotland	0	0
LNE	6.9%	265km
LNW	3.7%	127km
Western	6.0%	186km
South East	32.3%	1167km

Table 1: Geographic distribution of high or very high plasticity