Transport Infrastructure Construction History in the United Kingdom

Subjects: History

Contributor: Christopher Walker , Ana Heitor , Barry Clarke

The performance of geostructures in the United Kingdom (UK)'s transport network is significantly impacted by their construction age. A considerable portion of railway geostructures were constructed in the late 19th and early 20th century.

unsaturated soil historic transport infrastructure climate change

1. Pre-Regulation

Examples of regulated construction date back to Roman Britain, but do not directly affect the current transport infrastructure network. In the following contents, pre-regulation is defined as construction techniques used from the 19th century to the early 20th century—whereafter regulation was introduced. The majority of the rail network was built during this period, followed by the highway network in the mid 20th century.

1.1. Railway—19th and Early 20th Century

During the 1830s/1840s, nine mainline railways were empirically designed and constructed in the UK, totalling 660 miles, and included 54 million m^3 of earthwork material [1]. Their construction characterises the methods used during the 19th century. Compaction techniques were used in the construction of roads, which were normally built at grade. In the case of the rail network, compaction was only conducted at abutments to avoid differential settlement between the rigid abutment structure and the approach embankments [2]. End-tipping was used as a cost- and time-saving measure to construct the embankments, and often comprised of a singular lift in which horse-drawn earth wagons tipped the fill material from the advancing head (**Figure 1**) [2]. This resulted in a number of failures during construction (**Figure 1**) [1]. Embankment settlements were large but their effects were mitigated by speed restriction and packing of ballast or locomotive ash beneath sleepers until movement subsided [3].

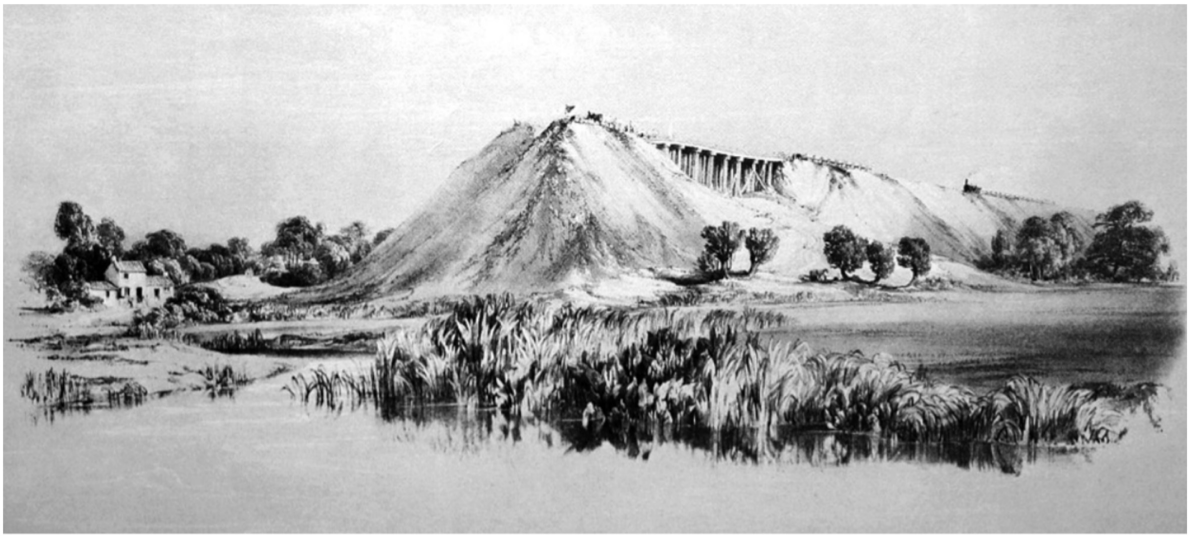

Figure 1. Painting by John Cooke Bourne (1837) showing a temporary wooden viaduct spanning a large failure alongside ongoing end-tipping works during the construction of the Wolverton embankment. Public domain image [4].

The fill material was typically taken from adjacent cuttings as a balance of cut and fill was ensured. This was a time-saving measure which allowed large volumes to be transported over short distances for embankment construction, rather than sourcing more suitable material from borrow pits [1]. No foundations were prepared. In many cases, embankment construction was undertaken without the removal of topsoil and other soft superficial deposits [5].

At this time, side slopes were covered in vegetation, and lineside fires stemming from embers emitted from passing trains somewhat controlled its growth. Over time, vegetation became mature and increased in density; therefore, measures were put in place to control the likelihood of lineside fires with regular maintenance. This was important, as it would have altered the dynamic balance between the beneficial and detrimental effects of vegetation on embankment stability and serviceability [6]. For example, a significant reduction in the density of vegetation may have a positive effect on stability for highly plastic geostructures (soils with large water content range in the plastic state), due to a decrease in seasonal soil moisture changes and therefore a reduction in differential movement along embankment crests [3]. However, this management approach also reduces surface shielding (which would result in an increase in both surface erosion and permeability), root reinforcement, and negatively impact ecological and environmental conditions [6].

Thereafter, in the early 20th century, Proctor [7] introduced modern compaction methods for dam construction. They were based on achieving soil compaction to its maximum dry density at its optimum moisture content, which could be validated using a standard compaction test. By 1936, mechanised plant (e.g., bulldozers and scrappers) were used in the UK to form a compacted embankment fill for Chingford dam [8]. In addition, Atterberg [9] introduced consistency limits, further developed by Terzaghi [10] and Casagrande [11] for use in soil selection. The Transport Research Laboratory was also established in 1933, and in 1948, BS 1377 was published, which included guidance on the use of Proctor compaction testing [8].

The relationship between the beneficial and detrimental effects of vegetation continued in the early 20th century. Lineside fires still posed some risks; therefore, regular maintenance of vegetation by ‘lineside gangs’ continued. This included techniques such as grass scything and tree coppicing. Gellatley, et al. [6] also noted that earthwork slopes on the London Underground were subject to regular burning, resulting in increased grass cover as fires eliminated any young vegetation preferentially.

During this period, earthwork construction on the UK railway network still remained largely empirical. For instance, an intrusive investigation of London Underground (completed circa 1930) by Mcginnity, et al. [12] showed that embankment construction continued with minimal compaction effort. Embankments were often built directly on virgin ground, i.e., topsoil was not removed, there was no ground improvement, and foundations were not routinely considered. This resulted in failures during construction and large settlements post-construction [12].

1.2. Highway—19th and Early 20th Century

Construction of turnpike roads (non-government toll roads) provided the first opportunity for standard empirical road construction methods, one of the most notable being John Loudon McAdam (1756–1836) [8].

McAdam’s system incorporated drainage, ignored use of stone foundations, and included a 30 cm layer of aggregate stone broken up and compressed by passing traffic [13]. This technique was adopted worldwide due to its speed and low cost; however, the advent of the automobile meant a gravel surface, and the lack of firm foundations was not suitable for large vehicles [8]. During this early period of road construction, earthworks were less commonplace due to the ability for roads to be constructed at steeper gradients owing to the small traffic loads and slower speeds (compared to the present day). Prior to the mid-20th century, roads followed the contours of the land known as ‘sidelong ground’, and therefore, earthworks were avoided where possible [5]. Some roads, constructed for horse and cart traffic, contained substantial earthworks in rural hilly areas. However, it was not until the construction of the first major highway (motorways) where lengths of continuous embankments were constructed [14].

Along with the advent of automobiles in the early 20th century, the structure of roads changed to accommodate a faster method of transport, but the fundamentals remained much the same as the previous century. The most significant development stemming from road infrastructure construction was the introduction of the California Bearing Ratio (CBR) by Porter [15], which could be used to assess the thickness of subbase for a given subgrade strength and traffic load. The test was developed in the 1930s by the California Division of Highways to quantify subgrade strength by comparing its bearing capacity with a well-graded crushed stone with a CBR value of 100%. Due to its economic, simple procedure, the test has continued to be adopted for earthwork and pavement construction [16].

2. Post-Regulation

In the latter half of the 20th and 21st century, several pivotal regulations, based on evolving scientific understanding of soils, were standardised for all earthworks including roads and railway, as follows [17]:

- 1951—Specification for Road and Bridge Works introduced ‘end-product’ criteria
- 1959—BS 6031 set out the code of practice for earthworks
- 1969 and 1976—Specification for Highway Works (SWH) introduced ‘method compaction’
- 1975—BS 1377 was updated with new testing procedures
- 1986—SHW included various updates to end-product criteria, method compaction, and fill suitability selection
- 2004—Eurocode 7 (EC7) European standards introduced into UK practice
- 2009—BS 6031 Code of Practice for Earthworks fully updated to reflect modern methods and EC7
- 2021—Underlying principles of the current SHW remain unchanged after the various updates in the 1970s and 1980s

2.1. Railway—Mid 20th and 21st Century

Along with the rise of the automobile, major railway construction slowed in comparison to construction of highways. However, due to the transition from steam power towards combustion engines and electricity for propulsion, vegetation growth became an increasing issue. For example, with the electrification of the London Underground and introduction of diesel engines, there was a decrease in the risk of lineside fires caused by the embers deriving from coal-driven locomotives. This therefore resulted in reduced maintenance efforts. By the late 1960s, most traditional vegetation controls were terminated and replaced with simpler herbicide treatment to control vegetation on and around the tracks themselves [18]. This led to vegetation growth on earthworks banks, which over time was allowed to mature and diversify, leading to several issues including [6]:

- disturbance of substructure and tracks,
- fallen branches,
- fallen trees,
- loss of traction owing to leaf fall,
- settlement or heave of over-consolidated clay soils (plastic clay fills),
- penetration or blocking of drains and ditches.

This resulted in inefficiency and disruption to running services and thus the subsequent publication of vegetation specifications in the Landscape Management Handbook [19] for highways and Network Rail standards. Despite this, the conflict between management/removal of vegetation and potential instability (or beneficial/detrimental impacts), particularly in plastic clay fills, still poses issues. For instance, London Underground now recommends vegetation removal in the upper part of an embankment slope. This is designed to maintain stability but minimise disruption due to plasticity of the London Clay soils [20]. The interest in these beneficial aspects was landmarked by the CIRIA publication ‘Use of Vegetation in Civil Engineering’, which introduced the concept of enhancing soil properties with vegetation [21].

2.2. Highway—Mid 20th and 21st Century

The Preston By-Pass was the first motorway built in the United Kingdom (UK) to highway standards and was completed by 1958 [22]. Due to the increased speed of traffic, a low gradient was required (approximately 1 in 25), which necessitated the implementation of extensive earthworks [5]. The earthworks were constructed to the Specification for Road and Bridge Works, which formalised compaction to an ‘end-product’ criterion by setting a required percentage of dry density to be achieved during testing [22]. Early highways were constructed with 8-ton deadweight rollers, including vibratory rollers by 1976 (SHW edition 5), which later became more commonplace [8].

The construction of the Preston By-Pass took place in glacial tills and alluvial sands and silts. Due to the new specification, material was still sourced from cuttings but now exceptions were made for material deemed ‘unsuitable’. The Ribble Valley contained peat bogs and was found to be of insufficient bearing capacity for embankment construction despite the initial assumption that all excavated material could be reused. Furthermore, due to exceptionally wet weather conditions, excavated material was discarded and replaced with imported fill [23]. These weather conditions also produced instability of cut slopes due to surface runoff, delaying the project [22]. In total 3,400,000 imperial tons of earth was excavated, and a further 668,000 imperial tons was imported for fill [24]. This approach to construction therefore produced more homogeneous fill material compared to past construction techniques, particularly the rail network.

Modern earthwork construction on highways continued at a rapid rate between the 1960s and 1990s, with various improvements made to specifications [5]. This led to a design-based approach, which vastly improved on pre-regulation empirical construction. This largely underpins modern earthwork design with BS 6031 Code of Practice for Earthworks, which introduced the identification of problems such as soft cohesive soils or peat during ground investigation and remediation practices. In addition, in the early 1960s, excess capacity in the chemical industry led to manufacture of geotextiles for use in construction. At this time, their main function was for separation and infiltration between natural ground and fill [25], but further development meant that they could be used as reinforcement in engineered soils.

In contrast to the railway network, motorways have implemented vegetation standards since the 1950s. Consideration for grass establishment was made by introducing a grass dominated topsoil layer with partial management to remove trees. In comparison, railways contains a more mixed mature line side vegetation owing to natural seeding [20]. This means that the relationship between the beneficial and detrimental effects of vegetation, and thus impacts of climate change, are vastly different on the railway network in comparison to highways in the UK

3. Current Regulations

Due to the recent increased recognition of climate change, it is now being considered in the construction and management of the UK transport network. Both Network Rail and Highways England have developed strategies to increase resilience of their networks, which are showcased in the ‘Highways England Climate Change Adaptation

Strategy' and 'Network Rail Climate Change Adaptation Report', respectively [26][27]. Moreover, more emphasis is being put on the consideration of lineside and roadside ecosystems and its incorporation into design standards [28]. For example, Network Rail has reduced its use of herbicide glyphosate by 25% since 2008 [29]. It is probable that these changes to vegetation management are again likely to have an effect on the diversity and density of lineside vegetation in the future.

Furthermore, it is evident that the construction history of highways and railways is extremely distinct. **Table 1** provides a summary of these differences when examined with reference to both pre-regulation practices (railway 19th and early 20th century) and post-regulation practices (railway and highway between 19th and early 20th century). It shows that construction techniques are particularly important to consider for the railway network due to the presence of older structures, often built before the implementation regulation. These structures therefore may produce areas of localised increased vulnerability to the impacts of climate change. This is also being considered and is a prominent part of Network Rails earthwork management review and earthworks technical strategy [30][31].

Table 1. Comparison between both the pre-regulation and post-regulation construction techniques for embankments used during the founding of the UK railway and highway (motorway) network.

Construction/Maintenance	Railway Only Pre-Regulation—19th and Early 20th Century	Railway and Highway Post-Regulation—Mid 20th and 21st Century
Fill Material	Embankment fill sourced from adjacent cuttings with no quality control [1]	Due to the new specifications, material was still sourced from cuttings, but now exceptions were made for material deemed 'unsuitable', e.g., import of fill material during the construction of the Preston By-Pass [22]
Compaction	End-tipping was conducted with no compaction except at bridge abutments due to occurrence of differential settlement [2]	Earthworks were constructed to an 'end-product' criterion by setting a required percentage density or method compaction [8]
Slope Angle	Embankments were formed at the angle of repose, due to end-tipping, and trimmed to 1:2 (vertical: horizontal), in some cases up to 1:1.5 and 16 m in height [5]	Based off stability analysis and empirical observation of different geologies, e.g., infinite slope analysis, method of slices, and finite element calculated using Factor of Safety (FoS) for various construction stages
Foundations	No consideration was made and topsoil was often left in place [5]	Topsoil stripped and various ground improvement techniques used to provide adequate foundation conditions such as geotextiles, deep soil mixing, shallow stabilisation, vibro stone columns and drainage

Construction/Maintenance	Railway Only Pre-Regulation—19th and Early 20th Century	Railway and Highway Post-Regulation—Mid 20th and 21st Century
Vegetation Management	Line-side gangs managed growth of vegetation to minimise the occurrence of line-side fires due to steam locomotion [6]	Mid-late 20th century, no management of vegetation was made on railway geostructures, however several vegetation standards now exist to manage risk and capitalise on its use for bioengineering [30]
Interventions	Ash packed under tracks to combat settlement and in situ burning of clay fills and the addition of ash took place to remediate landslips [30]	Asset management procedures including various monitoring techniques such as piezometers, inclinometers, remote sensing, tiltmeters, and measurement of track geometry

1. Skempton, A.W. Embankments and Cuttings on the Early Railways. Constr. Hist. 1996, 11, 33–49.
2. Nowak, P. Chapter 69 Earthworks design principles. In ICE Manual of Geotechnical Engineering: Volume II; Thomas Telford Ltd.: London, UK, 2012; pp. 1043–1046.
3. O'Brien, A.S.; Ellis, E.A.; Russell, D. Old Railway Embankment Clay Fill—Laboratory Experiments, Numerical Modelling and Field Behaviour. In Advances in Geotechnical Engineering: The Skempton Conference; Thomas Telford Publishing: London, UK, 2004; pp. 911–921.
4. Wikimedia Commons. Wolverton Viaduct—Public Domain Image. Available online: https://commons.wikimedia.org/wiki/File:Wolverton_viaduct.jpg (accessed on 10 September 2021).
5. Briggs, K.M.; Loveridge, F.A.; Glendinning, S. Failures in transport infrastructure embankments. Eng. Geol. 2017, 219, 107–117.
6. Gellatley, M.J.; McGinnity, B.T.; Barker, D.H.; Rankin, W.J. Interaction of Vegetation with LUL Surface Railway Systems. In Vegetation and Slopes: Stabilisation, Protection and Ecology: Proceedings of the International Conference Held at the University Museum, Oxford, 29–30 September 1994; Thomas Telford Ltd.: London, UK, 1995; pp. 60–71.
7. Proctor, R.R. Fundamental principles of soil compaction. Eng. News Rec. 1933, 111, 286–289.
8. Nowak, P.; Gilbert, P. Earthworks: An historical perspective. In Earthworks: A guide; Thomas Telford Ltd.: London, UK, 2015; pp. 1–14.
9. Atterberg, A. Die Plastizität der Tone (The plasticity of clays). Int. Mitt. Bodenkd. 1911, 1, 4–37.
10. Terzaghi, K. Principles of final soil classification. Public Roads 1926, 8, 41–53.
11. Casagrande, A. Research on the Atterberg Limits of Soil. Public Roads 1932, 13, 121–136.

12. Mcginnity, B.T.; Russell, D. Investigation of London Underground earth structures. In Advances in Site Investigation Practice; Thomas Telford Publishing: London, UK, 1995; pp. 230–242.
13. Kodikara, J.; Islam, T.; Sounthararaja, A. Review of soil compaction: History and recent developments. Transp. Geotech. 2018, 17, 24–34.
14. Perry, J.; Pedly, M.; Reid, M. Infrastructure Embankments C550; CIRIA: London, UK, 2003.
15. Porter, O.J. The preparation of subgrades. Highway Res. Board Proc. 1939, 18, 324–331.
16. Alawia, M.H.; Rajab, M.I. Prediction of California bearing ratio of subbase layer using multiple linear regression models. Road Mater. Pavement Des. 2013, 14, 211–219.
17. Nowak, P.; Gilbert, P. Earthworks: A Guide, 2nd ed.; ICE: London, UK, 2015; Available online: https://www.icevirtuallibrary.com/isbn/9780727741851 (accessed on 6 February 2020).
18. Sargent, C. Britain’s Railway Vegetation; Institute of Terrestrial Ecology: Cambridge, UK, 1984.
19. Highways England. Design Manual for Roads and Bridges (DMRB), Volume 10, Section 3, Part 2: Landscape Management Handbook; The Stationary Office: London, UK, 2004.
20. Glendinning, S.; Loveridge, F.; Starr-Keddle, R.E.; Bransby, M.F.; Hughes, P.N. Role of vegetation in sustainability of infrastructure slopes. Proc. Inst. Civ. Eng.-Eng. Sustain. 2009, 162, 101–110.
21. Greenwood, J.R.; Norris, J.E.; Wint, J. Assessing the contribution of vegetation to slope stability. Proc. Inst. Civ. Eng.-Geotech. Eng. 2004, 157, 199–207.
22. Yeadon, H.L. Preston By-pass: The first motorway in the UK. Proc. Inst. Civ. Eng.-Eng. Hist. Heritage 2010, 163, 117–128.
23. Drake, J. Buliding The Motorway. Gaurdian, 5 December 1958; p. 16. Available online: https://www.newspapers.com/clip/90396771/preston-by-pass-construction/(accessed on 8 July 2022).
24. Macmillan, H. Preston By-Pass Official Opening Booklet. Ministry of Transport and Civil Aviation Agent Authority. 1958. Available online: https://www.roads.org.uk/sites/default/files/articles/opening-booklets/prestonbypass.pdf (accessed on 8 July 2022).
25. Sarsby, R.W. Compaction and earthworks. In Environmental Geotechnics; Thomas Telford Publishing: London, UK, 2013; pp. 59–76.
26. Highways England. Climate Change Adaptation Strategy and Framework; England, H., Ed.; Home Office: London, UK, 2009.
27. Network Rail. Claimte Change Adaptation Report; Network Rail Limited: London, UK, 2015.
28. Varley, J. The Network Rail Vegetation Management Review; Home Office: London, UK, 2018.

29. Network Rail. Vegetation Management. Available online: https://www.networkrail.co.uk/communities/environment/vegetation-management/ (accessed on 12 November 2020).
30. Network Rail. A Review of Earthworks Management. Available online: https://www.networkrail.co.uk/wp-content/uploads/2021/03/Network-Rail-Earthworks-Review-Final-Report.pdf (accessed on 20 August 2021).
31. Network Rail. Earthworks Technical Strategy. 2018. Available online: https://www.networkrail.co.uk/wp-content/uploads/2018/07/Earthworks-Technical-Strategy.pdf (accessed on 21 October 2020).