

DESIGN AND CONSTRUCTION OF THE UK'S FIRST POLYSTYRENE EMBANKMENT FOR RAILWAY USE

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ABSTRACT

This paper describes an innovative solution for the replacement of an old railway bridge, which had become a maintenance liability, by the UK's first expanded polystyrene (EPS) embankment for railway use. It is also believed to be the world's largest EPS embankment for railway use. The innovative solution avoided costly and potentially environmentally damaging foundation works to stabilise the very soft underlying soil deposits.

Keywords: Polystyrene; embankment; railways; new EPS grades.

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SITE LOCATION AND HISTORY

The site is located in the north-west of England, United Kingdom, on the western edge of Manchester, and is close to Irlam, Figure 1. Bridge 193 on the Trans Pennine railway route was built in the 19th Century to cross the River Irwell. In 1899, construction of the Manchester Ship Canal cut off this part of the River Irwell and the river channel subsequently became infilled. Because the old River Irwell channel had been infilled during the early 20th Century, Bridge 193 was not now necessary. The bridge had a long history of maintenance problems, and it was therefore decided to replace the bridge with a new embankment.

PROJECT CONSTRAINTS AND FEASIBILITY STUDIES

The preliminary studies had identified a series of significant constraints which are summarised in Table 1 and Figure 2. The geotechnical investigations had identified deep layers (up to 8m thick) of weak and compressible soils and a relatively high water table. Soapworks waste of variable thickness was identified within this upper layer. The waste was predominately composed of silt size calcite particles. The rest of the channel infill deposits appeared to be natural silts and clays derived from dredging of the nearby Manchester Ship Canal. The ground was contaminated with elevated concentrations of arsenic, the groundwater with petroleum hydrocarbons, methane and volatile organic compounds were present in the gas phase.

An important requirement for Railtrack was to keep the railway operational throughout the construction period, except for a single 100 hour possession period. This meant that stabilisation of the weak ground had to be carried out beneath the bridge deck with a headroom of less than 10m. The vast majority of effective stabilisation techniques in these ground conditions require a headroom of more than 10m. A wide range of possible solutions were considered, a selection of these are summarised in Table 2.

The benefits of the EPS embankment compared with a conventional solution can be summarised as:

- much less disturbance to the existing ground, hence reduced environmental impact. The UK Environment Agency preferred the contaminated material and underlying strata to remain undisturbed; the piles could have formed a contaminant migration pathway.
- the piled solution would cause more disturbance to the existing piers and underlying timber pile foundations.
- the tie-in with the existing embankment would be particularly problematical to design and construct, due to very low headroom.
- the cost of each option was equivalent.

The innovative solution was to pre-load the ground and then construct an embankment with a core of EPS, with shoulders of conventional granular fill, Figure 3. However, there were concerns about the strength and settlement characteristics of EPS under repeated train loading. Additionally, the requirement for the line to be kept operational, except for a 100 hour possession period, meant that only the bridge deck would be removed and that the bridge piers would be left in place and would act as "hard spots" within the EPS embankment. Compared with previous use of EPS in the UK, Sanders (1996), the embankment at Irlam, presented several major challenges because:

- previous experience is predominantly from road embankments. Railway loading is significantly higher and allowable differential settlement much lower than for road embankments.
- the embankment height at 14.5m was believed at the time to be the world's highest for railway use. The previous highest railway embankment was only 4m.

NEW EPS GRADES AND LABORATORY TESTING

Research identified the potential for denser grades of EPS to be manufactured in the UK. These were confirmed by discussions with Vencel Resil, one of the UK's leading EPS manufacturers. Trial production of the new EPS grades with nominal densities of 40kg/m³ and 55kg/m³ were carried out successfully. During an initial review of published data, it was apparent that deficiencies in conventional laboratory testing of EPS would lead to underestimates of the material's deformation modulus, Figure 4. An extensive laboratory testing programme was designed and evaluated, and is the subject of a separate paper to this conference, O'Brien (2001). This led to an

improved understanding of the static and dynamic properties of a wide range of EPS grades. In particular, the new denser EPS grade, with a nominal density of 55kg/m^3 , was about five times stiffer than EPS with a density of 20kg/m^3 .

ANALYSIS AND DETAILED DESIGN

There are a wide range of approaches used for EPS design. Given the importance of the Irlam embankment, and the results of the extensive laboratory testing programme, the current UK approach was believed to be inadequate and an alternative approach was required which would:

- ensure that acceptably low strains were developed under long term static loads and short term dynamic loads from train loading;
- ensure that unstable fatigue type failure would not develop under long term cyclic loading from rail traffic;
- enable lower grade, and cheaper, EPS to be used in areas of lower stress within the embankment;
- would enable a robust link to be developed between routine tests used for quality control, sophisticated laboratory tests used to derive design parameters and the output from non-linear finite difference analyses.

The criteria used was similar to the approach used in Norway for several decades, Frydenlund (1996): limit the EPS utilisation ratio (defined as applied stress divided by unconfined compressive strength from routine tests at 5% strain).

(a) to less than or equal to 0.35 under static load (self weight of embankment).

(b) to less than or equal to 0.56 under live load (loading from trains).

Computer modelling was used to optimise the configuration of the different EPS grades. The analyses used a non-linear constitutive model for the EPS. A detailed description is beyond the scope of this paper, a general description of the model, type L4, is provided by Purzin and Burland (1996). The specific application of a simplified version of this type of model, L1, for EPS is described by O'Brien (2001). Some typical results are shown on Figures 5 and 6. A particular challenge was to cope with the presence of the buried piers which would:

- (a) lead to stress concentrations immediately above the pier (Figure 6), and therefore would require relatively strong EPS grades above the pier to avoid premature yield.
- (b) the reduced depth of EPS above the pier would lead to a 'hard spot' with excessive differential settlement along the approaches to the pier. This would require relatively weak EPS grades to reduce differential settlement.

These contradictory requirements were eventually resolved and the main design features are summarised on Table 3 and illustrated on Figures 7 and 8.

CONSTRUCTION

To minimise long term settlement of the soft ground a 4.5m high pre-loading embankment was constructed under the bridge using granular fill material. This load was slightly higher than the total load of the final EPS embankment. The pre load fill was then re-used to form the shoulders of the final embankment. Instrumentation systems were installed on the bridge and in the underlying ground to evaluate the settlement and horizontal deformation caused by the pre-loading. To avoid damage to the existing bridge foundations, the rate of pre-load embankment construction was carefully controlled. In August 1997, construction of the pre-load embankment commenced. This was successfully completed in October 1997 without damage to the existing bridge foundations, through use of the Observational Method, Powderham (1998). The pre-load was kept in place for about 9 months to induce settlement of the weak underlying soils.

For the permanent embankment the EPS core configuration comprises a total of $13,000\text{m}^3$ of polystyrene in a maximum 18 layers of blocks, arranged in a staggered pattern to avoid continuous vertical joints, Figures 7 and 8. Five grades of polystyrene were used, with nominal densities in the range 20kg/m^3 to 55kg/m^3 . In addition, blocks containing a fire retardant additive were incorporated into the layout to reduce the risk of fire during construction. Construction commenced in July 1998 with careful removal of the pre-load embankment and then construction of a geogrid reinforced granular mattress and gas venting blanket beneath the base of the embankment. Two intermediate concrete slabs, 125mm thick, were poured after, initially five, and then four EPS

layers were constructed. After placement of each EPS layer, the granular fill was placed and compacted against the outside of the EPS to form the shoulders of the embankment, and protect the EPS, Figure 9. Construction continued through August and September up to the underside of the bridge deck, then the final intermediate reinforced concrete slab, 200mm thick, was poured. In October 1998 a 100 hour possession of the railway track was used to remove the redundant bridge, finish the embankment, place the precast concrete troughs and reinstate the track. A 1000 tonne crane was used to carry out the lifting operations in this major logistical exercise, Figure 10. Follow up possessions have been used to raise the linespeed to 85mph, with the potential to increase it to 100mph.

In the UK EPS compressive strength is often based on the strength mobilised at 1% strain during routine tests. This has been shown to be unreliable, O'Brien (2001). For quality control purposes during embankment construction the EPS strengths were checked by routine methods, however the strength was measured at 5% strain. Figure 11 indicates that the standard deviation of test results is much less at 5% strain than at 1% strain, when strength is measured routinely.

Since completion of the embankment, monitoring of instrumentation within and below the embankment has indicated satisfactory performance. A description of post-construction performance will be the subject of a separate paper to be produced in the near future.

CONCLUSIONS

This major scheme for the client Railtrack has resulted in a novel structure using ultra -lightweight fill for the first time on the Railway in the UK. The EPS embankment at Irlam:

- is believed to be one of the world's highest EPS railway embankments;
- it solved a host of conflicting environmental, design, construction and programme constraints;
- is innovative - new stronger grades of EPS were used for the first time in the UK;
- was simple to build - 13,000m³ (7,000 blocks) of fill placed by hand, the last 3,000m³ in some 50 hours. EPS blocks were able to be placed quickly and safely whilst working under low headroom.

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TABLE 1. MAJOR SITE CONSTRAINTS

Type of Constraint	Description
Geotechnical	Deep layers (up to 8m thick) of weak and compressible soils, soft clay silts and soapworks wastes;
Geotechnical	High water table;
Contamination	Soils and groundwater were chemically contaminated.
Client Requirement	Railway had to be kept operational throughout construction, except for 100 hour possession period.

TABLE 2. ALTERNATIVE SOLUTIONS FOR REPLACEMENT EMBANKMENT

Potential Solution	Main Concerns
Conventional Embankment on Piled Raft	Conventional Piling Plant; inadequate headroom.
	Low Headroom Driven Piles: vibration and damage to existing bridge.
	Low Headroom Bored Piles: integrity of pile shaft: poor and variable capacity; costs and risks associated with handling contaminated arisings.
Conventional Embankment without Ground Stabilisation	High risk of of shear failure Excessive Settlement.
Repair of Existing Bridge	Long Term maintenance Costs and Liability.
Encapsulation of Deck supported by Part Height Embankment	Long Term Maintenance; Ground Stabilisation still required.
Embankment with EPS Core and shoulders of conventional fill No. Preloading.	Differential settlement, due to settlements of soapworks wastes and clayey silts in old river channel.

TABLE 3. MAIN FEATURES OF FINAL EMBANKMENT DESIGN

Preloading	Minimise long term differential settlement, due to settlement of underlying soils.
Gas Venting at Base of Embankment	Safe control of methane migrating through underlying soils.
Geogrid reinforced granular layer	Avoid shear failure and limit differential settlement at EPS core/granular fill interface.
EPS core of different grades from 20kg/m ³ density	Minimise cost; minimise differential settlement; avoid overstressing low grade EPS in highly stressed zones.
EPS core geometry, use of "Berms"	Ensure yield stress of underlying soils was not exceeded.
Intermediate reinforced concrete slabs	Levelling screed for buildability; provide additional fire resistance; stress redistribution layer and horizontal restraint through blockwork structure.
HDPE liner	Protect underlying EPS from oil spills.
Reinforced Concrete Trough	Provide "container" for HDPE linear and lateral restraint for granular fill. Efficient means of reducing concentrated stresses from train loading.
Granular Fill/Ballast	Provide conventional track bed for rails.
Structural Connection between troughs over Piers	Minimise differential settlement.



Figure 1. Site Location

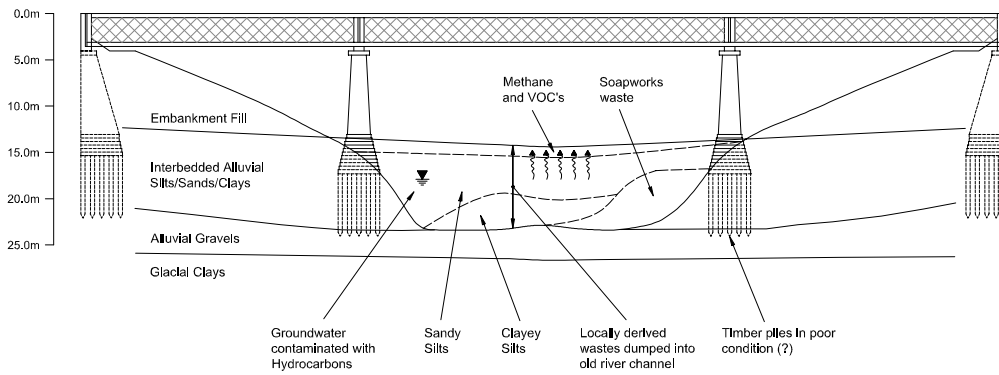
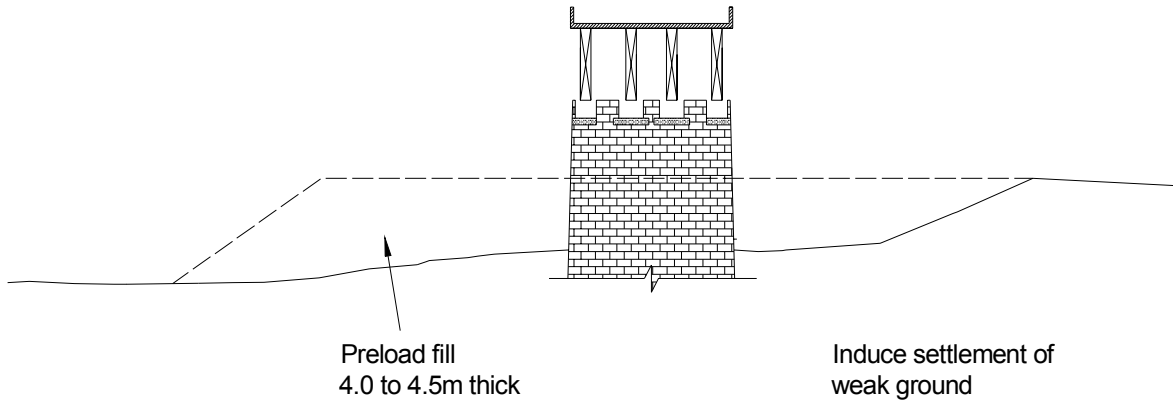
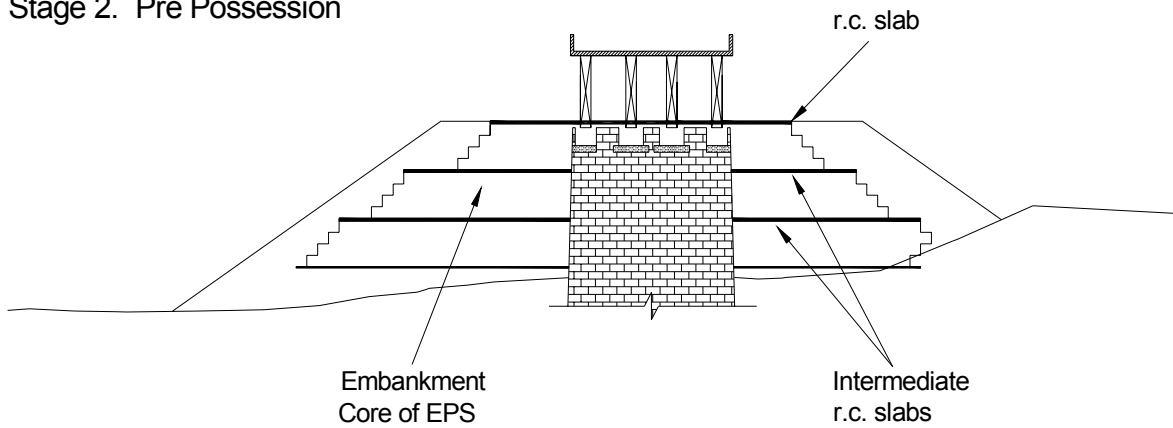


Figure 2. Bridge configuration and ground conditions

Stage 1. Preloading



Stage 2. Pre Possession



Stage 3. During Possession

1. Remove bridge deck
2. Trim pier
3. Final EPS and granular fill layers
4. Place r.c. trough
5. Ballast and track

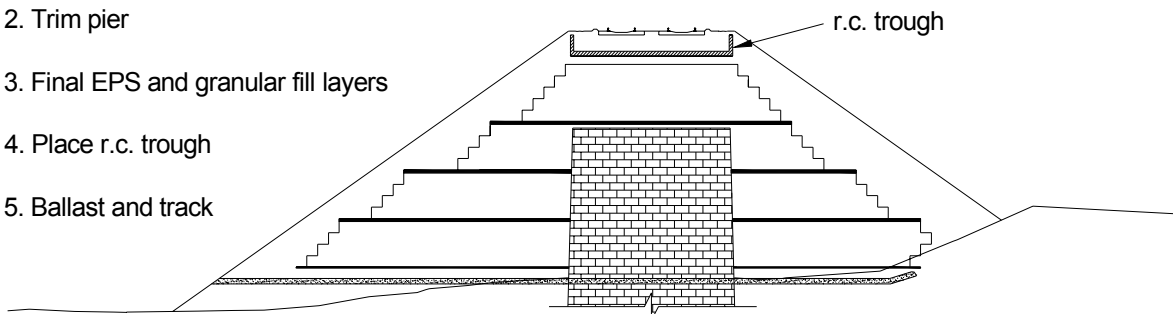
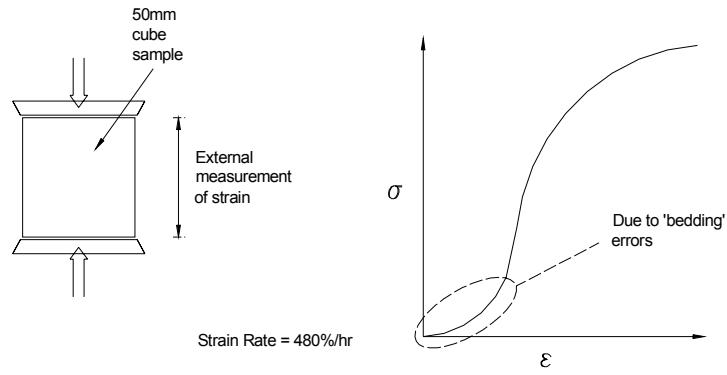


Figure 3. Preferred solution for replacement embankment

a) Conventional test for compressive strength and Young's Modulus



b) Specialist test for compressive strength and Young's modulus

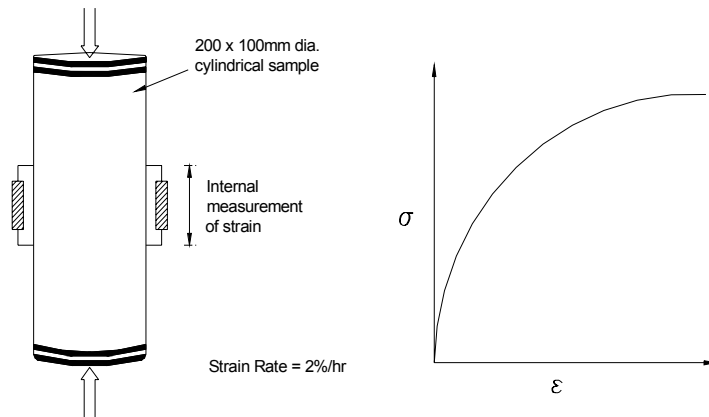


Figure 4. Influence of test techniques on EPS stress-strain curves

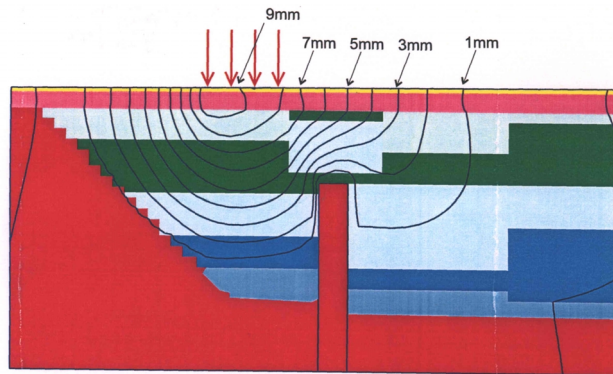


Figure 5. Long section, displacement contours

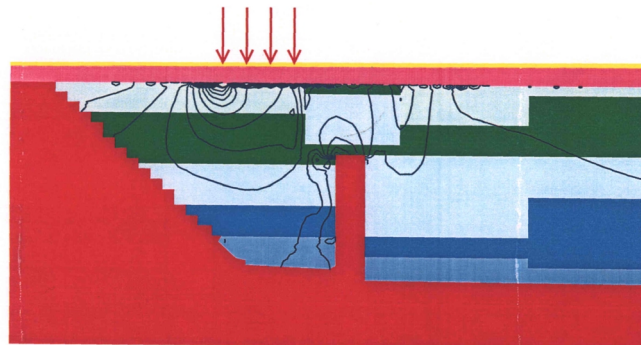


Figure 6. Long section, stress contours

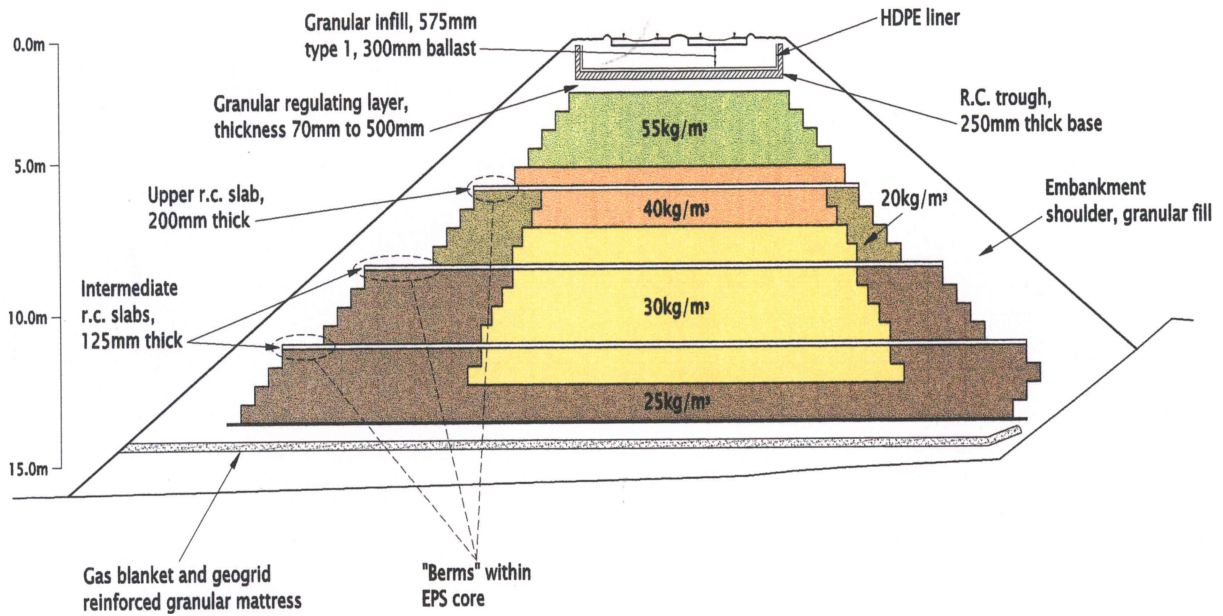
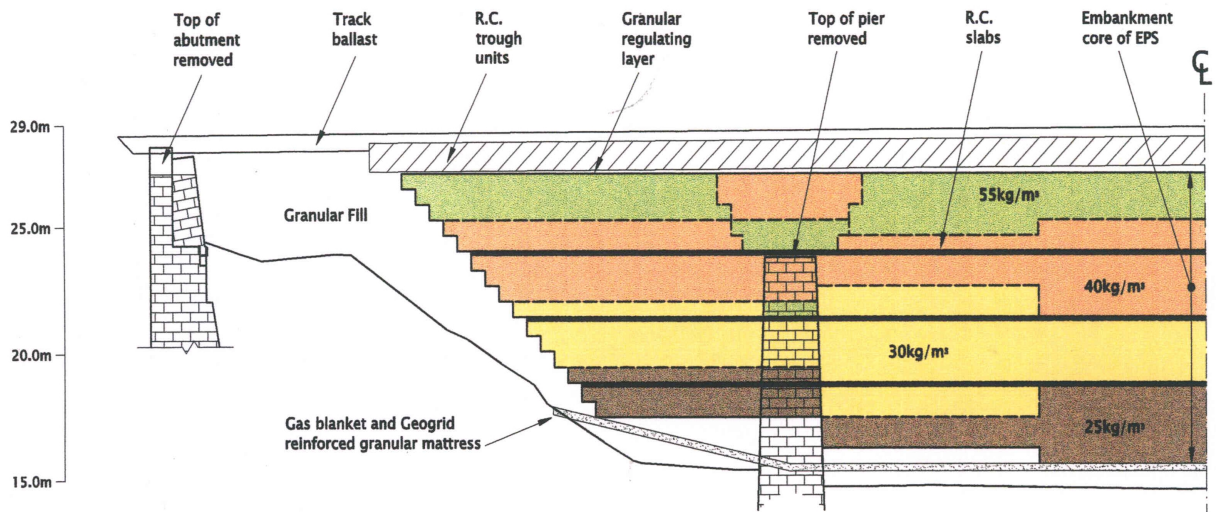


Figure 7. Main components of EPS embankment design



Notes:

1. 55, 40, 30, 25kg/m³: nominal density of different grades of EPS
2. R.C. trough units: 2.5 to 2.9m long: except over two piers 3x7.3m long, pin connections

Figure 8. Main components of EPS embankment design



Figure 9. Continuing to place EPS blocks



Figure 10. Possession works, demolition and removal of bridge deck

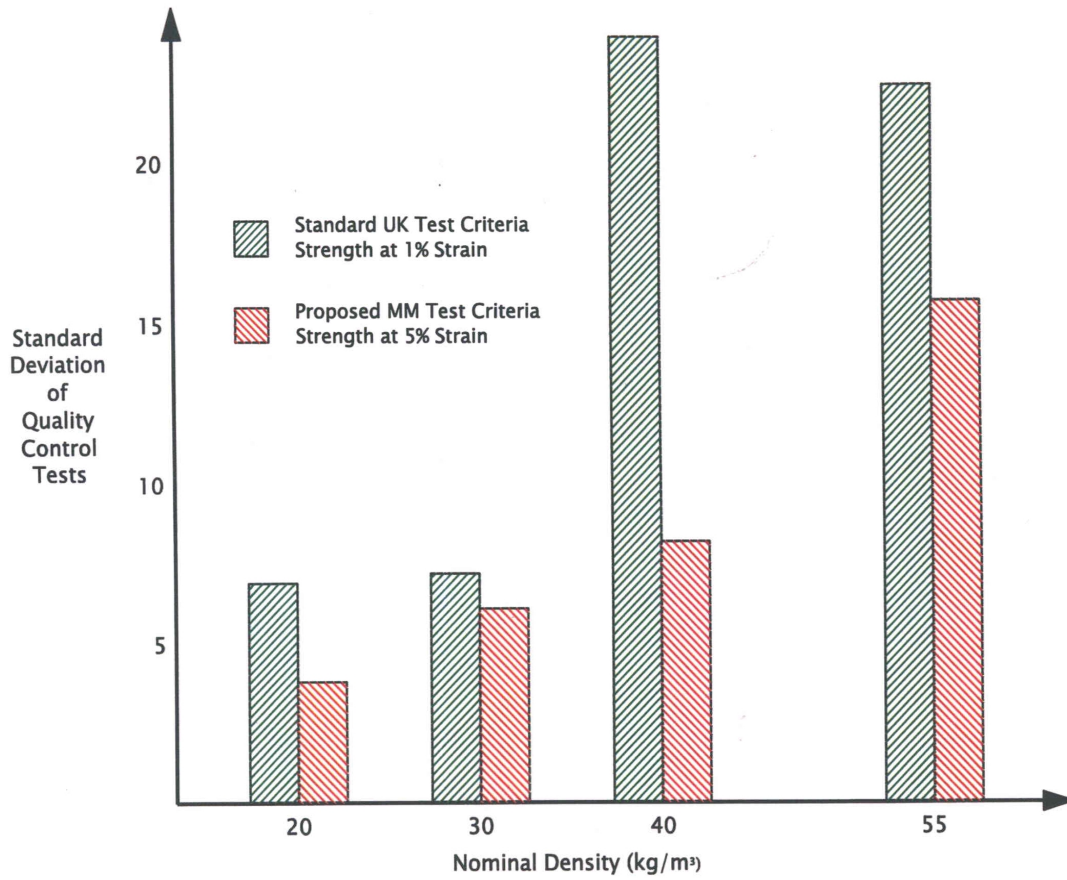


Figure 11. Variability of routine strength data