Settlement of a Bridge Footing Supported on Reclaimed Asphalt Pavement Backfill

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ABSTRACT
This paper describes the greater-than-expected settlement of a perched bridge abutment footing supported on a mechanically stabilized earth (MSE) wall. A possible reason advanced for the greater than expected settlement was the presence of reclaimed asphalt pavement (RAP) material in the MSE backfill. This possibility was assessed by reviewing the published literature, and conducting a limited laboratory test program comparing the settlement potential of RAP to conventional MSE backfill. The published literature shows that RAP settlement depends on asphalt cement binder content and performance grade, asphalt age, and aggregate characteristics, and generally cautions against the use of RAP because of concerns regarding creep deformations. The laboratory tests showed settlement increased as both asphalt cement and moisture content increased, and led to the conclusion that the observed settlement may have resulted from the use of RAP backfill.

RÉSUMÉ
Cet article décrit un tassement supérieur à la prévision de conception ayant eu lieu au niveau de la fondation d'une semelle de culée d'un pont, supportée par un mur en terre stabilisé mécaniquement (MSE). Une des causes avancées pour expliquer ce tassement est l'utilisation de matériau d'asphalte recyclé (RAP) comme matériau de remblai pour un mur en terre stabilisé. Cette hypothèse est, ici, documentée par une revue de littérature et par un programme d'essais de laboratoire visant à comparer le tassement d'un remblai conventionnel avec un remblai constitué de matériau RAP. La littérature a montré que le tassement d'un remblai avec RAP était fonction de la teneur et du grade de bitume, de l'âge du revêtement et des propriétés des granulats. La littérature met généralement en garde l'utilisation des RAP comme remblai, car le matériau est sensible aux déformations par fluage. Les essais de laboratoire montrent que le tassement augmente lorsque la teneur en bitume et la teneur en eau du matériau augmentent. L'étude conclut que les mesures importantes de tassement au niveau du pont peuvent résulter de l'utilisation de RAP dans le remblai.

1 INTRODUCTION

This paper describes the greater-than-expected settlement of a bridge abutment footing supported on reinforced backfill of a mechanically stabilized earth (MSE) wall. The bridge, which crosses a major highway, consists of a 30.8 m single span structure with perched abutment footings (Figure 1). The field assessments were conducted in July through December 2012, about 2 years after completion of the bridge.

The feature of the settlement was that south abutment footing settled more than the north abutment footing. A possible reason advanced for the greater-than-expected settlement of the south footing compared to the north footing was the presence of reclaimed asphalt pavement (RAP) in the south reinforced backfill but not in the north reinforced backfill.

RAP is a bituminous/asphaltic concrete material removed and/or reprocessed from existing asphalt concrete pavements undergoing reconstruction or resurfacing. Reclaiming the asphalt concrete pavement may involve cold milling a portion of the existing asphalt pavement, or full depth removal and crushing.

To assess the possibility of whether or not the greater than expected settlement was caused by the presence of RAP, a review of available case histories in which RAP had been used as structural fill was undertaken, and a limited laboratory test program conducted comparing the settlement potential of RAP to similarly graded aggregate without asphalt.

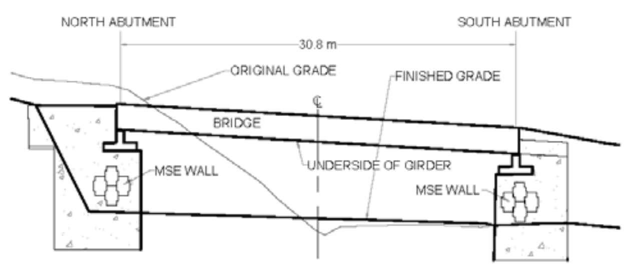

Figure 1. General view of bridge and MSE abutments

This paper does not consider the potential leaching of pollutants from RAP. Available research studies such as Townsend and Brantley (1998), and Shedivy and Meier (2012), show that pollutant leaching concentrations are typically low for heavy metals and polycyclic aromatic hydrocarbons, however if RAP is to be used, the potential for leaching should be assessed by project-specific testing.

2 CASE HISTORY: SETTLEMENT OF A PERCHED BRIDGE ABUTMENT FOOTING

2.1 Construction Details and Performance

Footing loads and dimensions were similar for both abutments (Figure 2), but the construction methodology and backfill varied as described in the following sections:

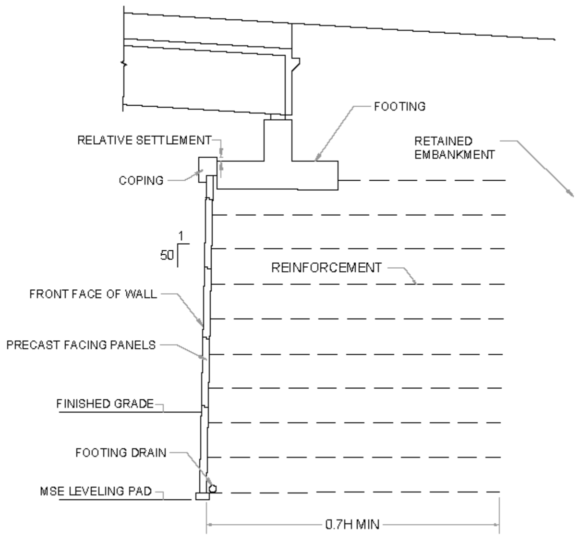

Figure 2. Typical abutment footing supported on MSE backfill

2.1.1 South Abutment (with RAP)

- Straight MSE wall; steel MSE reinforcing mesh does not overlap.
- Wall founded on dense, silty gravel over thinly bedded slate bedrock.
- RAP/crushed rock backfill placed in layers and compacted using a vibratory compactor.
- Levelling pad installed April 2010, MSE wall completed May 2010, and bridge deck placed in December 2010.

2.1.2 North Abutment (no RAP)

- Box-type abutment resulting in overlapping of the steel MSE reinforcing mesh at the corners.
- Wall founded on thinly bedded slate bedrock.
- Crushed rock backfill placed using a rock slinger and compacted using a plate compactor because of limited access, and confined work area.
- Similar construction schedule as south abutment.

2.1.3 Construction Details and Performance

Table 1 summarizes abutment details and performance of the abutment footings, as well as the performance of the connection between the MSE reinforcing mesh and precast concrete facing panels.

Table 1: Abutment Details and Performance

Item	South Abutment	North Abutment
Maximum wall height	10.2 m	11.1 m
MSE fill thickness below footing	6.4 m	7.6 m
Footing dimensions	2.6 m x 8.3 m	
Serviceability Limit States bearing pressures	310 kPa toe, 200 kPa average	
Backfill type	RAP/crushed rock mixture	Crushed rock
Footing settlement relative to MSE wall coping (see Figure 2)	104 mm in 2 years	8 to 17 mm in 2 years
Connection between reinforcing mesh and precast facing panels	Broken directly below footing	Not broken

Footing settlement in Table 1 is the settlement of the footing relative to the MSE wall coping (see Figure 2). Therefore, it represents backfill settlement only, as the contribution of the foundation soils to settlement is the same for both the MSE wall facing (and coping) and bridge abutment footing.

The integrity of the reinforcing mesh/facing panel connections was directly assessed by excavating test holes through the precast facing panels at various locations. Only the holes excavated through the south MSE wall facing panels encountered broken connections.

In general, the results show the south abutment footing supported on RAP/crushed rock settled more than the north abutment footing, and the connection between the MSE reinforcing mesh and the precast concrete facing panel was only broken on the south abutment.

2.2 Visual Observations

Visual observations on both abutments showed the following:

- No visually discernible signs of bulging, distorting or spalling of the MSE wall precast facing panels or coping.
- The footings appeared to rotate inwards, about the longitudinal axis (parallel to the roadway), towards the roadway.
- Drainage appeared to be effective at both abutments, and there were no signs of seepage, or wet discolouration on the facing panels.

2.3 Backfill Properties

2.3.1 Gradation

Figures 3 and 4 show that the gradation of the south abutment RAP/crushed rock was very similar to the north abutment crushed rock. Both gradations generally met BC Ministry of Transportation and Infrastructure 2006 Specification requirements (BC MOT 2006) for Bridge End Fill.

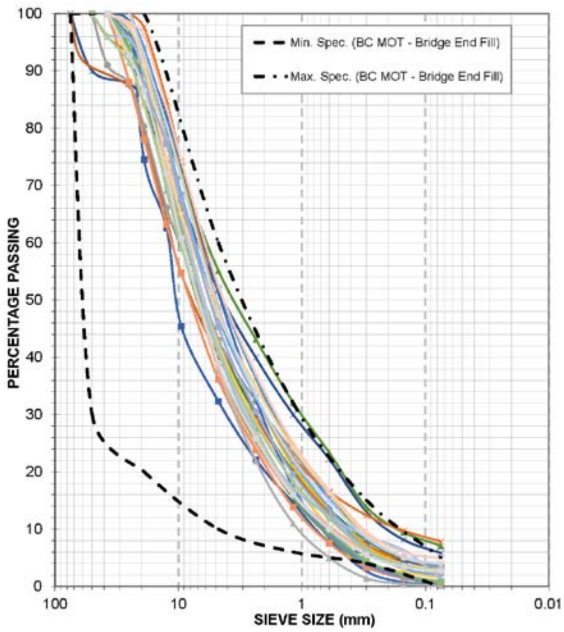

Figure 3. South abutment RAP/crushed rock grading

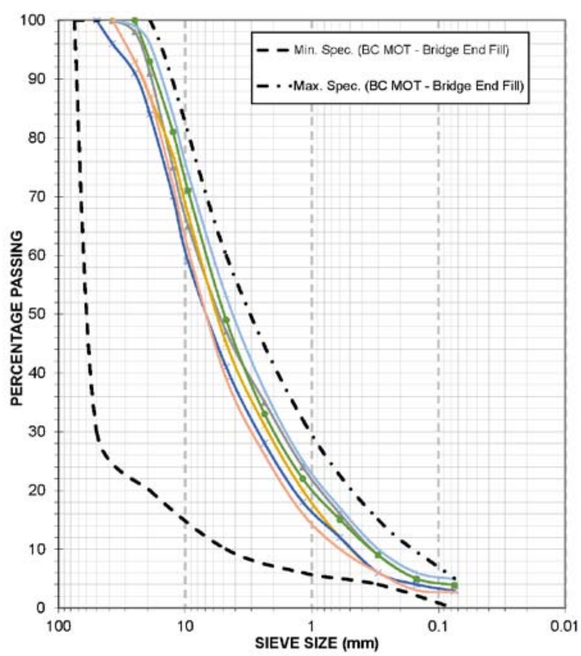

Figure 4. North abutment crushed rock grading

2.3.2 Backfill Type and Compaction Data

Table 2 summarizes material and compaction data for the two different backfill types and together with Figures 5 and 6 show the following:

- The specified compaction was achieved for both backfill types, but there was more scatter in the RAP results.
- Compaction was undertaken dry of the optimum moisture content.

Table 2: Backfill Type and Compaction Data

Item	South Abutment	North Abutment
Backfill type	RAP/crushed rock mixture	Crushed rock
RAP content	53% to 75% (64% mean)	None
Average asphalt cement content	2.67%	None
Specified minimum compaction (ASTM D698)	100%	
Maximum Dry Density (ASTM D698)	2160 kg/m^3	2349 kg/m^3
% Standard Proctor Compaction achieved	97% to >100%	95% to >100%
Optimum Moisture Content	7.2%	5.9%
Field Moisture Content	Up to 4.8% dry of OMC	Up to 2.8% dry of OMC
Compactor used in main MSE zone	Vibratory 10,852 kg static weight	Plate 465 kg static weight
Compactor used within 0.9 m of the MSE facing panels	Plate compactor	
Average compacted lift thickness	300 mm	250 mm

Comparative testing was also undertaken on RAP backfill obtained from a nearby bridge of similar layout and loading, which had been built at about the same time. Compaction records for the RAP/crushed rock backfill at this bridge were similar to the results given above, and compaction was likewise conducted at up to 4% dry of optimum moisture content. For this second bridge, the average asphalt cement binder content of the RAP/crushed rock mixture was 1.33%. The resulting abutment footing settlement amounted to between 56 mm and 66 mm relative to the coping wall. In Tables 3 and 4 this material is designated as MSE 2.

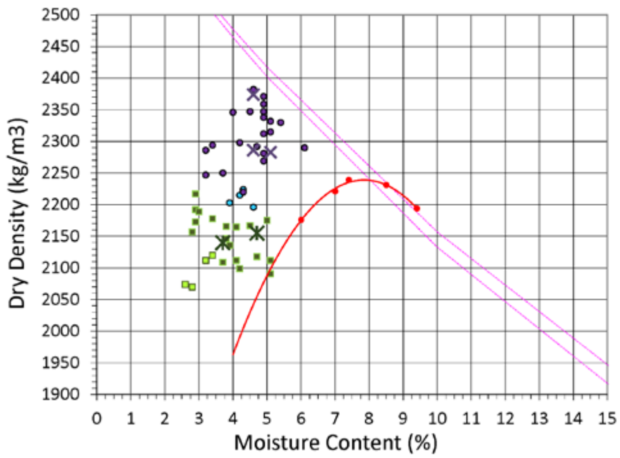

Figure 5. South abutment, RAP/crushed rock compaction

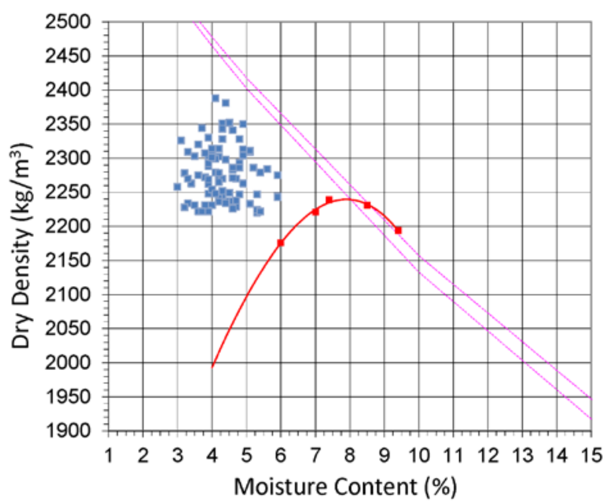

Figure 6. North abutment, crushed rock compaction

2.3.3 Control Test Strip

RAP can cause inaccuracies in nuclear density testing because the asphalt cement binder influences the moisture readings. Therefore, prior to the original construction, control strip tests were undertaken to verify the in-place density. These showed that after 6 passes of a Dynapac CC501, 2.1 m drum compactor a maximum dry density of 2190 kg/m^3 was achieved. This value is slightly higher than the dry density of 2160 kg/m^3 achieved in laboratory test (see Table 2).

2.4 Postulated Reasons for Greater-than-Expected Settlement

The following were postulated as possible reasons for the greater-than-expected footing settlement on the south abutment compared to the north abutment:

- The foundation soil below the south abutment was more compressible than that below the north abutment.
- Thawing of frozen backfill zones.
- Connection failure between MSE reinforcing and facing panel caused lateral and vertical displacements of the footing.
- Partly overlapping reinforcing mesh in the corners of the box-type north abutment reduced settlement potential.
- Pullout/creep issues between RAP and the reinforcing mesh.
- The north backfill was more settlement resistant than the southl because it was more uniformly compacted
- Poor compactibility of RAP resulted in more compressible backfill, possibly aggravated by saturation settlement.
- RAP more predisposed to settlement than crushed rock.

The available construction records, drawings, and the field observations were able to reasonably discount the contribution to settlement from compressible foundation soils, inadequate compaction, presence of frozen layers, and pullout/creep issues between RAP/reinforcing mesh..

This paper considers the settlement potential of RAP/crushed rock. The assessment of connection failure is outside the scope of this paper.

3 REVIEW OF AVAILABLE LITERATURE

3.1 Pavements

3.1.1 Specifications

Pavement research shows that premature rutting occurs at high RAP addition rates and, as a result, transportation agencies typically limit overall RAP addition rates to between 20% and 40%, with 50% being the highest allowable addition rate. A few agencies instead limit asphalt cement binder content directly, usually to less than about 2% of total mass. Transportation agencies also require RAP, irrespective of the addition rate, to satisfy the same physical property requirements as for granular materials without RAP.

3.1.2 Local Experience

Our firm's experience (Johnston A 2014, Chief Technologist – Tetra Tech EBA) with the use of RAP in pavement projects is that performance is susceptible to moisture conditions, for example:

- On a major roadway reconstruction project in Alberta, sub-base consisting of 40% RAP mixed with crushed rock softened and rutted severely under traffic when placed at above optimum moisture content.

- RAP in temporary surfacing experiences shoving, softening and rutting with increasing moisture content.
- When RAP gets wet it is very difficult to dry-out. It is typically more cost-effective to remove and replace wet RAP with dry material than to try and dry it out on site.

3.2 Structural Fills and MSE Backfills

There is little guidance available on the use of RAP in structural fills and MSE wall backfill. FHWA (FHWA 2009), cautions, "*Use of salvaged materials such as asphaltic concrete millings or Portland Cement Concrete rubble is not recommended. Recycled asphalt is prone to creep resulting in both wall deformation and reinforcement pullout*".

Research by Rathje (Rathje et al. 2006) showed that creep depends on the asphalt cement binder content and asphalt performance grade, aging and aggregate characteristics. Her team concluded that although some MSE walls constructed with RAP had performed well, the use of RAP is not recommended. They concluded that RAP *"displays a significant potential for creep deformation, and these creep deformations may lead to excessive deformations in a MSE wall. Additionally corrosion testing indicated that RAP caused more corrosion than CC (crushed concrete) or CFM (conventional fill material). Based on these results, RAP is not recommended for use as backfill for MSE walls".*

4 LIMITED LABORATORY ASSESSMENT

4.1 Material Properties

Laboratory testing was undertaken on RAP obtained from the south abutment MSE wall (designated as MSE 1), and from another nearby MSE wall (designated as MSE 2 – see Section 2.3.2). The results were then compared to tests on a manufactured sample with higher asphalt cement binder content (designated as Stockpile sample).

The Stockpile sample was manufactured by blending RAP obtained from three separate stockpiles at a local paving contractor's yard. The stockpiles consisted of minus 19 mm, 12.5 mm and 9.5 mm RAP with asphalt cement binder contents of 2.52%, 3.58% and 4.34%, respectively (determined using ASTM D2172 Method A).

The stockpile material was blended to produce a grading (Figure 7) which was similar to (though on the fine side) of the MSE 1 gradations in Figure 3.

Compaction data of the materials used in the laboratory loading test are summarized in Table 3:

Table 3: Compaction Data of Loading Test Samples

Item	Stock-pile	MSE 1	MSE 2	Stock-pile
Description	RAP/crushed rock			Clean
Asphalt Cement Content	3.6%	2.67%	1.33%	0%
MDD kg/m^3	1960	2160	2215	2280
OMC	6.2%	7.2%	6.4%	5.5%

MDD = Maximum dry density (ASTM D698)
OMC = Optimum Moisture Content (ASTM D698)

These results show that as the asphalt cement content increases, the laboratory maximum dry density decreases and the optimum moisture content increases. Soleimanbeigi and Edil (2015) note that the lower dry density may partly reflect the lower specific gravity of the asphalt cement compared to granular aggregates. However, we consider that the reduction is greater than would result from the lower specific gravity. The reason for the increase in optimum moisture content is unclear.

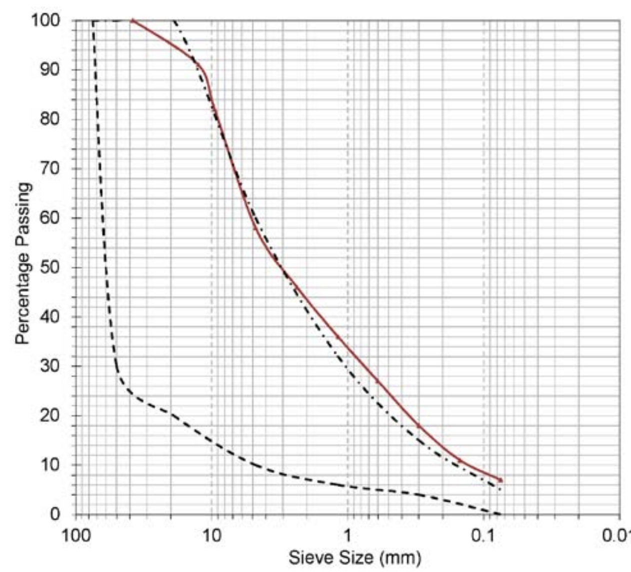

Figure 7. Gradation of Stockpile sample

4.2 One-Dimensional Loading Test

The loading test consisted of the following steps:

- Moisture condition the samples to between 2% and 3% dry of OMC by adding water and leaving to stand for 3 days prior to testing. Contrary to previous Tetra Tech EBA pavement experiences, the nature of the RAP was such that water was not readily absorbed and quickly drained from the samples.

- Compact the samples in a California Bearing Ratio (CBR) mould (118 mm high by 150 mm diameter) using a Standard Proctor hammer and 5 lifts of either 45 blows/layer or 56 blows/layer to provide a range of dry densities.
- Load the samples in a CBR loading frame, by applying load through a 62 mm thick rigid loading platen covering the full top surface of the sample.
- Increase load to 300 kPa which is representative of the nominal abutment footing load, and maintain the load.
- Measure settlement using two dial gauges installed on diametrically opposite sides of the loading platen.
- Maintain the load until the settlement becomes imperceptible, typically after about 24 hours.
- Remove samples from the loading frame, soak for a further 4 days, and then again load to 300 kPa, until settlement becomes imperceptible.
- Extract the asphalt cement binder from one sample of Stockpile material to provide a "clean" sample with no RAP. Repeat test on this sample to benchmark the tests conducted on RAP.

Potential sources of error in the laboratory test are:

- The CBR mould is not ideal for settlement testing because the aspect ratio (sample height/sample diameter) of 0.78 is high. This value is much greater than that of a conventional consolidometer test which has an aspect ratio of about 0.30. A higher aspect ratio results in greater side friction acting to limit the settlement magnitude. This was somewhat mitigated by heavily lubricating the inside surfaces of the mould.
- Temperature was not varied or controlled in the tests. The ambient temperature in the laboratory was between 23°C and 28°C during the day and from 21°C to 24°C overnight. No additional heat was applied to the samples to simulate the effect of sunlight on the samples.
- Water was able to drain from the samples during testing. Ideally the testing should have been undertaken with the sample flooded as is the case in a conventional consolidometer test.

4.3 Loading Test Results

The results obtained from the loading test are summarized in Table 4, and plotted in Figures 8 and 9.

In Table 4, vertical total strain is the total settlement normalized to sample height and expressed as a percentage. Likewise vertical creep strain is the settlement which occurred following immediate settlement normalized to sample height and similarly expressed as a percentage.

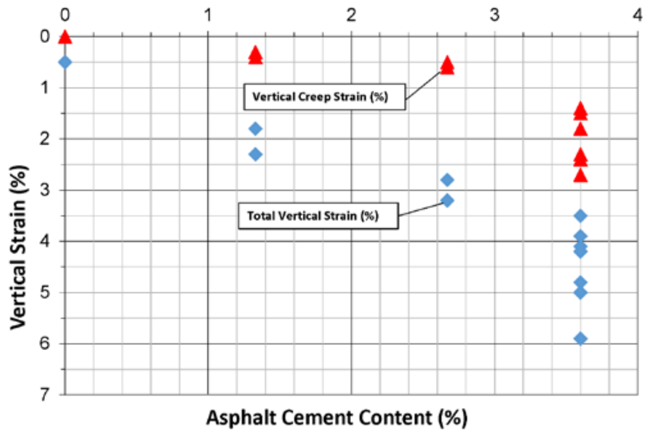

Figure 8. Asphalt cement content versus vertical total and creep strain

Figure 8 shows that vertical strain (both total and creep) increases as asphalt cement content increases. In addition, strain generally increases as the moisture content increases for a given asphalt cement content.

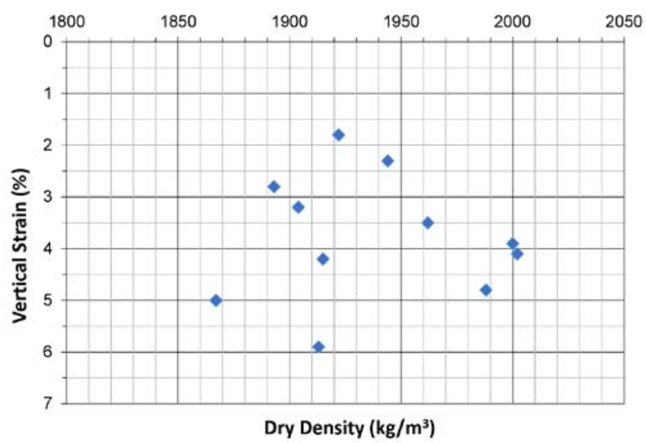

Figure 9. Vertical strain versus dry density

Figure 9 shows that there is little relationship between vertical strain and dry density.

Table 4: Simulated Loading Test Results

Test No	Asphalt Cement Content (%)	Dry Density (kg/m^3)	Moisture Content (%)	Proctor Density (%)	Total Settlement (mm)	Initial Settlement (mm)	Vertical Total Strain (%)	Vertical Creep Strain (%)
Stockpile RAP								
1	3.6	2002	4.6	102.0	4.83	3.15	4.1	1.4
2	3.6	1988	5.1	101.4	5.68	2.54	4.8	2.7
3	3.6	2000	4.0	102.0	4.65	2.92	3.9	1.5
4	3.6	1913	4.3	97.6	6.92	4.18	5.9	2.3
5	3.6	1962	7.2	100.1	4.13	2.06	3.5	1.8
7	3.6	1867	7.4	95.3	5.93	3.07	5.0	2.4
8	3.6	1915	7.6	97.7	5.95	4.22	4.2	1.5
MSE 1 RAP (South Abutment MSE)								
9	2.67	1893	2.8	87.6	3.30	2.56	2.8	0.6
10	2.67	1904	8.9	88.1	3.77	3.22	3.2	0.5
MSE 2 RAP (Nearby MSE Bridge Abutment)								
11	1.33	1922	3.3	87.8	2.17	1.68	1.8	0.4
12	1.33	1944	7.7	90.0	2.66	2.31	2.3	0.3
“Clean” Stockpile Material with Asphalt Cement Binder Extracted								
6	0	2288	5.0	100.0	0.55	0.55	0.5	0

4.4 Discussion

The benchmark “clean RAP” Stockpile sample (Test No. 6 Stockpile sample with asphalt extracted) showed minimal total settlement (vertical strain about 0.5%) and no measurable creep strain compared to the tests with RAP.

Table 5 summarizes average settlement and effective elastic moduli from the RAP samples during loading.

Table 5: Average Results from Loading Tests

Average Parameter	Stockpile	MSE 1	MSE 2
Asphalt Cement Content	3.6%	2.67%	1.33%
Dry Density (kg/m^3)	1950	1899	1933
Total Strain (%)	4.5	3.0	2.1
Creep Strain (%)	1.9	0.55	0.35
Effective Elastic Modulus (MPa)	6.7	10.0	14.3

The results were used to estimate the settlement of the south abutment footing using both conventional settlement analyses methods and finite element analysis methods (the program PLAXIS 2D version 2011 was used). These analyses resulted in estimated settlements varying between about 100 mm and 160 mm which is of similar order of magnitude as the observed settlement. In contrast similar settlement estimates conducted on the north abutment footing showed settlement of 20 mm to 30 mm.

It could be argued that the south footing settlement occurred because the heavy footing load bearing directly on the connection between the reinforcing mesh and the precast concrete facing, caused the connection to break. While this mechanism could be correct, it does not explain why the connections at the north abutment which were subject to similar foundation loads did not break.

5 CONCLUSIONS

The following conclusions were made:

- The simple one-dimensional loading test show, that up to 5.9% total vertical strain could occur under a 300 kPa applied load on compacted RAP fill. This settlement magnitude is greater than the approximately 0.5% settlement which was measured on “clean RAP” after the asphalt cement binder had been extracted.
- The greater-than-expected settlement could be explained by the presence of RAP in the MSE backfill.

- The limited testing conducted indicates that settlement of RAP is a function of asphalt binder content, and to a lesser extent, of moisture content.
- In our opinion there is a place for using RAP in structural fills, but its potential for creep settlement, and its moisture susceptibility, must be considered.

ACKNOWLEDGEMENTS

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