SETTLEMENT BEHIND BRIDGE ABUTMENTS
The performance of a medium-clay fill used to form the approach embankments to a bridge on the M.1 motorway
by
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SETTLEMENT BEHIND BRIDGE ABUTMENTS

The performance of a medium-clay fill used to form the approach embankments to a bridge on the M. 1 motorway

ABSTRACT

This Report describes an investigation in which a medium-clay fill was used to complete the construction of approach embankments to a bridge on the M. 1 Motorway in Leicestershire. Observations made during the placing of the fill behind the bridge abutments indicated that the state of compaction and moisture content of the medium-clay fill closely conformed to the existing M. O. T. specification.

Settlement measurements made on the subsoil beneath the embankments and on the completed road surface after a period of about two years showed that only very small movements of the order of 1/8 inch, have occurred within the fill material after the road was completed.

These embankments have performed as well as a number of bridge approaches investigated on the M. 4 Motorway (Maidenhead-By-pass) where good quality hoggin and sandy-gravel fills were used and found to be satisfactory.

The investigation has shown that a medium-clay soil can readily be employed as a satisfactory fill material for constructing approach embankments behind bridge abutments.

The likely costs involved (including extra compaction costs) when placing common fill behind bridge abutments have been examined, and are shown to be small in relation to the substantial expense which would be incurred by importing special fill materials for use in these areas.

1. INTRODUCTION

As part of a study into the problem of the serious differential settlement which frequently occurs between bridges and their approach embankments a series of investigations is being made of the performance of different materials when used for filling behind bridge abutments.

This Report describes an investigation in which a medium-clay fill was used to complete the construction of approach embankments to a bridge on the M. 1 Motorway. Settlement measurements were made on the subsoil beneath the approach embankments and on the final road surface to assess the magnitude of any settlement which resulted from movements occurring within the fill material, after the road was completed. Observations were also made during the placing of the fill to determine how closely the state of compaction

and moisture content of the medium clay conformed to the requirements of the Ministry of Transport Specification for road and bridge works.  

2. DETAILS OF THE SITE

The site of the investigation was the southern underbridge of the M1/A46 interchange at Enderby, Leicestershire. This interchange provides Leicester's main southern connection with the M1 Motorway. The construction formed part of Contract G of the M1 extension from Crick to Leeds.

2.1 Bridge abutments

The underbridge was of precast concrete portal construction having solid abutments (Plate 1). The abutments walls were constructed in mass concrete and piled to a depth of approximately 35 feet below ground level. Floating transition slabs of reinforced concrete 16-feet long and 1ft-2in thick were cast in situ after the embankment construction was completed (Fig. 1).

2.2 Subsoil conditions

The subsoil at the site consisted of a firm-to-hard red silty clay (Keuper Marl) which existed to a depth of at least 60 feet. Overlying the marl were deposits of recent and glacial origin composed of silty and sandy clays, sand, and gravel, which varied in thickness between 5 and 10 feet.

2.3 Fill material

The type of material used to fill the 20-to 22-feet deep wedges left behind the bridge abutments was Midland boulder clay. The boulder clay generally consisted of a medium-clay soil and contained only a small proportion of stones.

Material for filling the wedge behind the north abutment had been stockpiled to a mean height of between 10 and 12 feet on a 250 feet length of the main embankment between the two underbridges forming the interchange when the bridges were being constructed. The stockpile consisted of a fairly uniform reddish-brown clay having a liquid limit of 41 per cent and a plastic limit of 17 per cent.

For filling the wedge behind the south abutment, material was freshly excavated from an area just north of the site where the motorway was being carried through cut. This material was similar to that used behind the north abutment but was sometimes mixed with a heavy grey clay (liquid limit 72, plastic limit 24). Surplus sandy clay material removed from the adjacent main embankment, which has previously been placed 6 inches higher than formation level, was also used to provide a 4-feet thickness of fill. This material was sandwiched beneath a further 3-feet thickness of freshly excavated clay brought in to complete the wedge filling.

The mean particle-size distribution and properties of the different
soils that comprised the fill material are given in Fig. 2.

3. DETAILS OF CONSTRUCTION

The earthworks involved the placing of a total of 18,000 yd\(^3\) of compacted fill to complete the wedges left behind the bridge abutments. This work was carried out between March and May, 1964.

The motorway pavement had a lean-concrete base surfaced with rolled asphalt. The wearing course was laid on the west (northbound) carriageway in June 1964 but it was not until 4 months later, in October, that the east (south-bound) carriageway was surfaced.

The motorway extension was opened to traffic in January 1965.

3.1 Wedge filling

In the first instance, to provide working space for the construction of the bridge, the approach embankments had been constructed to within 15 feet of the north abutment and to within 60 feet of the south abutment as shown in Fig. 1. The procedure for filling the wedge behind the north abutment, where the fill material was stockpiled on the adjacent approach embankment, was to doze material into the wedge from a series of benches cut into the face of the approach embankment. This process was continued until the gradient of the face had been sufficiently reduced to allow material from the top of the stockpile to be dozed directly into the wedge. Softened material in the stockpile was pushed over the side of the embankment and subsequently removed to spoil. Prior to the placing of freshly excavated clay fill in the wedge behind the south abutment, the end of the older approach embankment was cut back to remove any uncompacted material.

The filling in both wedges was compacted by 8-ton smooth-wheeled rollers. It had been estimated that four passes would be sufficient to meet the M. O. T. specification\(^1\) which required that the filling be compacted to a dry density corresponding to a maximum air content of 10 per cent in the main bulk of the fill and a maximum air content of 5 per cent in the top 2 ft below formation level. It also required that the moisture content at which the filling is compacted should not be greater than 2 per cent above the plastic limit.

3.2 Flexible pavement

Details of the thickness and composition of the flexible pavement, which was constructed in accordance with the M. O. T. Specification for Road and Bridge Works\(^1\) are given in Table 1.
### TABLE 1
Details of flexible pavement constructed

<table>
<thead>
<tr>
<th>Pavement structure</th>
<th>Thickness</th>
<th>Material</th>
</tr>
</thead>
</table>
| Sub-base           | 6 in on 6 in | Type 1 aggregate (granite) (upper layer)  
Type 2 aggregate (granite) (lower layer) |
| Base               | 7 in      | Lean concrete - 5% cement; 1½ in nominal max. size granite aggregate |
| Upper Base         | 3 in      | Dense bitumen macadam, 1½ in nominal size granite aggregate.  
Binder 4.0 - 5.0 per cent. |
| Basecourse         | 2½ in     | Rolled asphalt ; 65% stone cement  
(Table 7B, Schedule 12) B.S. 594:  
Binder: Table 1, Col. 1.) 1961 |
| Wearing Course     | 1½ in     | Rolled asphalt - 30% stone cement.  
Table 7B, Schedule 2) B.S. 594:  
Binder: Table 1, Col. 1) 1961  
⅜ in chippings rolled into surface. |

### 4. EXPERIMENTAL PROCEDURE

The experimental procedure involved observations on the compaction of the clay fill and measurements of the settlement of the subsoil and of the road surface. These measurements enables the settlement occurring within the fill, after construction was completed, to be evaluated.

#### 4.1 Compaction observations

The state of compaction of the fill was measured as work proceeded by determining the dry density using the B.S. core-cutter method. Routine measurements were carried out by the Consulting Engineers' control team but additional tests were also made by the RRL observers using the same method. The results of the dry-density test also provided a check on the moisture content of the fill. To relate the moisture content of the fill to the specified maximum moisture content, plastic-limit determinations were made on selected samples of soil from each batch of dry-density tests carried out by the Consulting Engineers' control team.

In the wedge behind the north abutment, 81 dry-density samples were taken giving a mean rate of testing of 1 test per 90 yd³ of compacted fill placed. At the south abutment, 88 density samples were taken and the mean rate of testing was 1 test per 100 yd³ of compacted fill placed. During one phase of the earthworks behind the south abutment, when the RRL observers reported that the rate of filling appeared to be greater than the possible
output of the compaction plant, 23 extra test-samples were obtained from two trail pits; these have not been included in the assessment of the mean rate of testing.

4.2 Settlement of subsoil

Settlement gauges were installed on the surface of the subsoil a few feet clear of the abutment walls as shown in Fig. 1. At the south abutment a multi-point mercury-filled settlement gauge was used equipped with three measuring points which were located beneath the mid-point of each carriageway and at an intermediate point beneath the central reserve. The settlement of these points was measured relative to a datum plate which together with the gauge indicator unit was housed in a cast-iron box situated just in front of the south-east wing-wall (Plate 1). The level of the datum plate was checked periodically against a permanent datum installed well clear of any influence from the earthworks.

At the north abutment the multi-point type of gauge could not be employed as approximately 9-ft of fill had already been placed in the wedge before the investigation could be started. In this circumstance it was decided to use a rod-type of gauge to measure the settlement of the subsoil at one point located beneath the central reserve. A 6-inch-diameter borehole was therefore augered through the compacted fill and the rod-gauge installed at a depth corresponding to the original ground level. This gauge consisted of a solid steel rod \( \frac{3}{4} \) inch in diameter which was set into a core of concrete 1-foot thick placed at the bottom of the borehole. The rod was made up of screwed sections 3 feet in length and was isolated from the surrounding soil by an outer sleeve of 2\( \frac{1}{4} \)-inch-diameter rigid P.V.C. pipe. As the height of the fill was increased, the rod and outer sleeve were extended and on completion of the earthworks were protected by a cast-iron inspection box built into the top of the embankment. The settlement of the rod was measured relative to the permanent datum to an accuracy of \( \pm \) 0.05 inch by optical levelling.

4.3 Settlement of road surface

The movement of the road surface was recorded by levelling on metal studs which were driven into the asphalt wearing course before it had hardened. The stud pattern employed behind each abutment is shown in Fig. 3 and was the same for both northbound and southbound carriageways. To provide an estimate of any settlement which resulted from compaction under traffic of the two-course surfacing, transverse rows of studs were also placed in the surfaced area on the bridge deck. The studs were levelled in relation to temporary bench marks which were established on the parapets at the four corners of the bridge. The levels of these bench marks were checked periodically against the permanent datum.

5. RESULTS

5.1 Compaction observations

The results of the dry-density tests carried out during the filling of each
abutment are given in Fig. 4. Air contents were calculated using a specific gravity of 2.75 for the fill which was considered to be representative of the main bulk.

The proportion of dry-density samples which had less than 10 per cent air voids was 92 per cent at the south abutment and 90 per cent at the north abutment, thus indicating that the compaction in the bulk of the fill just complied with the requirements of the specification. The mean air contents of the samples tested were 5½ and 6 per cent respectively for the south and north abutments.

Compaction was achieved in the normal manner using two rollers in the abutment area. The mean output of compacted soil obtained was about 100 yd$^3$ per hour per roller. This was well within the maximum output of 240 yd$^3$ per hour which would have been expected if the roller had been operating under ideal conditions. However, the calculated maximum output could not have been achieved because of the restrictions on roller operation imposed by working in the abutment area. Although occasionally high rates of filling occurred, the majority of the material was placed at a rate well within the capacity of the rollers employed. At the south abutment, where on one occasion the rate of filling appeared to exceed the possible output of the compaction plant, extra dry-density tests carried out to a depth of 5 feet in two trial pits confirmed that the state of compaction was within specification. The results of dry-density tests in the top 2-feet of fill do not indicate that a lower air content was obtained in this zone despite the fact that at this stage of the earthworks the rate of placing fill was low in comparison with the compactive effort employed. Failure to obtain the specified lower air content was primarily caused by the fill having dried. Nonetheless, as can be seen in Fig. 4, the dry-density was generally at least as high as that at lower levels.

The mean moisture contents of dry-density samples taken in the different layers of compacted fill are compared in Fig. 5 with the plastic-limit determinations on selected soil from each batch of samples. The moisture content at which the medium-clay fill was placed behind each abutment is shown to have seldom exceeded the specification limit of P. L. + 2%. A comparison of the results obtained from individual samples of the fill for which representative plastic-limit values were determined showed that between 85 and 90 per cent of the samples tested at both abutments were within the moisture-content specification limit. In general the moisture content of the medium-clay fill ranged between 12 and 19 per cent. The plastic-limit tests however confirm that the fill placed behind the south abutment (P. L. range: 13 to 27 per cent) was more variable than the fill placed at the north abutment (P. L. range: 13 to 18 per cent). This would account for the wider overall variation in the moisture content of the south-abutment fill where individual moisture contents of up to 30 per cent were measured.

5.2 Settlement measurements

A summary of the settlements measured in the subsoil and on the road surface up to August 1966 is given in Table 2. Assuming that no compression
of the pavement materials other than the surfacing has occurred, the results show that only small settlements of about 1/8 in have occurred within the fill material since paving was completed.

TABLE 2
Summary of settlement measurements - (inches) - up to Aug. 66
(To nearest 0.05 inch)

<table>
<thead>
<tr>
<th></th>
<th>North abutment</th>
<th>South abutment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>West C'way</td>
<td>East C'way</td>
</tr>
<tr>
<td><strong>Road surface</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max. total settlement in Wedge area.</td>
<td>0.75</td>
<td>0.60</td>
</tr>
<tr>
<td>Mean total settlement over subsoil gauge.</td>
<td>0.50</td>
<td>0.55</td>
</tr>
<tr>
<td>Compaction of surfacing on bridge</td>
<td>0.10</td>
<td>0</td>
</tr>
<tr>
<td><strong>Subsoil</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Before paving</td>
<td>1.80</td>
<td>1.80</td>
</tr>
<tr>
<td>After paving</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Total</td>
<td>2.10</td>
<td>2.10</td>
</tr>
<tr>
<td><strong>Within fill</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean over subsoil gauge since paving.</td>
<td>0.10</td>
<td>0.25</td>
</tr>
</tbody>
</table>

The settlement records obtained from the foundation gauages installed beneath the abutments (Figs. 6, 7) indicated that in the wedge areas the settlement of the subsoil was more or less uniform. The compression of the subsoil resulting from the imposition of the embankment was approximately 2 inches and practically all of this movement is shown to have taken place before the road was opened to traffic.

The settlement of the four corners of the bridge, as indicated by the change in levels of the temporary bench marks with respect to the permanent datum, varied between 0.10 and 0.20 inch.

5.2.1 Rate of settlement

The rate of settlement of the subsoil since paving is compared in Figs. 8, 9 with the rate of settlement of the road surface at positions on each of the four approach carriageways in the vicinity of the foundation gauages. The
results show that the settlement of the subsoil and the road surface is continuing at a rate of about 0.10 inch per year and that the settlement within the fill was largely completed within the first 6 to 8 months after paving.

5.2.2 Distribution of settlement on road surface.

The distribution of settlement along each section of carriageway immediately behind the bridge abutments is given in Fig. 10; settlement relative to the bridge structure is shown. The results given are the mean settlements of the three longitudinal profiles of studs installed in the road surface at each approach carriageway.

Approximately 2 years after observations were commenced only small differential settlements have occurred at the approaches to the bridge. Maximum differential settlements of less than $\frac{1}{4}$ inch have occurred to date and these settlements are distributed over a minimum distance of 30 feet.

At the approaches to the north abutment the removal of the 10-to-12-foot-high stockpile has caused the road surface on the main embankment to rise by about $\frac{1}{2}$ inch. This has created a maximum differential movement of about one inch on the west (northbound) carriageway but this movement is distributed over a distance of 70 feet and has not noticeably affected the riding quality of the road.

Measurements on transverse rows of studs installed in the road surface showed that settlement across the width of the carriageway was practically uniform, the settlements recorded being generally within the range of $\pm 0.05$ inch of the mean settlement in each transverse profile. This suggests that the traffic loading has had little influence on the settlement of the fill.

5.3 Cost of Earthworks

In an attempt to eliminate differential settlement at bridges specially imported high quality granular material is often specified as fill behind bridge abutments. The high cost of this process is not always recognised and to illustrate this point, the cost relative than would have been incurred by using it at this site is now considered.

The contract rate for placing common fill on this project was 4s. 11d. per yd$^3$ and the rate for providing imported granular fill was 20s. 0d. per yd$^3$. Therefore if imported granular fill had been employed it would have resulted in a total extra cost of £13,500 for this bridge.

Although the state of compaction produced in the fill material behind the abutments at this site was no higher than normally required for mass earthworks it might be argued that it was more costly to achieve this result with the clay fill than it would have been with granular material which is easier to place and compact and generally requires less supervision. If one assumes an outside figure for the cost of compacting the clay as double that for the granular material and that a full-time inspector is required the extra cost of this would only amount to about 6d per yd$^3$, i.e. a total increase in cost of £450. Even allowing for additional compaction and supervision the
total extra cost of using imported granular fill at this bridge would still have amounted to more than £13,000. Thus it can be seen that the use of specially imported fill would have been a very uneconomic and highly unnecessary procedure at this site.

6. CONCLUSIONS

The settlements which have occurred within the fill behind the bridge abutments since the completion of the road pavement have been small: of the order of 1/8 inch. The compression of the subsoil, caused by construction of the embankments, was largely completed before the road was surfaced and this has resulted in only a small amount of settlement at the approaches to the bridge; this has had no appreciable affect on the riding quality of the road.

These embankments, which were well compacted in accordance with the requirements of the M.O.T. Specification, have performed as well as a number of bridge approaches investigated on the M.4 motorway (Maidenhead By-pass) where good quality hoggin and sandy-gravel fills were used and found to be satisfactory.

The investigation has shown that a medium-clay soil can readily be employed as a satisfactory fill material for constructing approach embankments behind bridge abutments. The likely costs including extra costs of compaction involved when placing common fill behind bridge abutments have been examined, and are shown to be small in relation to the substantial expense which would be incurred by importing special fill materials for use in these areas.

7. ACKNOWLEDGEMENTS

Thanks are due to the Resident Engineer and site staff of the Consulting Engineers, Sir Owen Williams and Partners, for their co-operation during the work described in this Report. The investigation was carried out under the direction of W.A. Lewis and G. Margason in the Earthworks and Foundation Section of the Laboratory, and the author was assisted by J.E.Cross.

8. REFERENCES


View of bridge during construction of final approach embankments showing position of the indicator unit for the mercury-filled settlement gauge

PLATE 1
Fig. 2. MEAN GRADINGS AND OTHER PROPERTIES OF THE SOILS PLACED BEHIND THE BRIDGE ABUTMENTS
Fig. 3. ARRANGEMENT OF SURFACE LEVELLING STUDS ON THE TWO SECTIONS OF NORTHBOUND CARRIAGeway ON THE BRIDGE APPROACHES (REPEATED ON SOUTHBOUND CARRIAGeway)
Fig. 4. Results of dry density tests carried out during the filling of the wedges behind each abutment.
Fig. 5. Comparison of the mean moisture content of dry-density samples taken in the different layers of compacted fill with the plastic limit determinations on selected soil from each batch of samples.
Fig. 6. SETTLEMENT OF THE SUBSOIL BEHIND THE NORTH ABUTMENT RESULTING FROM THE IMPOSITION OF THE FINAL APPROACH EMBANKMENT

Fig. 7. SETTLEMENT OF THE SUBSOIL BEHIND THE SOUTH ABUTMENT RESULTING FROM THE IMPOSITION OF THE FINAL APPROACH EMBANKMENT
FIG. 8. SETTLEMENT / TIME RELATIONS FOR THE ROAD SURFACE AND SUBSOIL AT THE NORTH ABUTMENT

FIG. 9. SETTLEMENT / TIME RELATIONS FOR THE ROAD SURFACE AND SUBSOIL AT THE SOUTH ABUTMENT
Fig. 10. LONGITUDINAL DISTRIBUTION OF THE SETTLEMENT OF THE ROAD SURFACE RELATIVE TO THE BRIDGE STRUCTURE (AFTER 720 DAYS ON WEST CARRIAGEWAY AND 650 DAYS ON EAST CARRIAGEWAY)