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The introduction of flexibility into a road ironwork installation

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This paper describes research undertaken to examine the option of replacing the upper portion of a rigid traditional brick access chamber with a flexible material, so that the system is more compatible with the surrounding flexible (asphalt) pavement construction, and is therefore less likely to exhibit premature failure. It focuses on one example of a suitable material, the influence of the confinement of this material within the surrounding pavement, and the importance of using a compatible backfill that acts as a bridge between the pavement and the ironwork. Full-scale experiments have been undertaken using a laboratory-based rolling-wheel test facility. Results show that flexibility incorporated into a road ironwork chamber can smooth out the step change in stiffness between a flexible pavement and a rigid chamber. Replacement of the upper portion of a chamber with a suitable flexible section results in the structure being more compatible with an asphalt pavement. It was also confirmed that the backfill around the chamber should be well compacted to provide good confinement, and the reinstatement material around the frame is a key element in the overall performance of a flexible chamber installation.

1. INTRODUCTION

The term ‘road ironwork’ refers to covers that are placed over highway installations such as manholes, drainage gullies and water valves, which can be found in virtually all classes of road, especially in urban areas. Highway maintenance engineers have to deal with a high incidence of premature failure in these installations, the annual total costs of which, in the United Kingdom alone, have been estimated to be £207 million.[1]

Previous research resulted in improved ironwork designs and mortar specifications to provide sufficient tensile and compressive strengths and adequate shrinkage resistance.[2,3] Results from field testing using the falling weight deflectometer (FWD) have shown that the vertical stiffness directly over the chamber wall can be much greater than the vertical stiffness of the surrounding pavement structure.[4,5] This mismatch in stiffness is likely to cause high tensile interfacial stresses and strains in the asphaltic material adjacent to the ironwork under traffic loading that will lead to cracking and premature damage, as illustrated in Fig. 1.

This paper describes research undertaken to examine the option of replacing the upper portion of a traditional rigid brick chamber with a flexible construction, so that the resulting structure is more compatible with the surrounding flexible (asphalt) pavement construction. One example of a suitable flexible material has been studied, and the influence of the confinement of this material by the surrounding pavement, and the importance of using a compatible backfill material that acts as a bridge between the pavement and the ironwork, have been investigated. The work was wholly experimental, and the findings are limited to the materials that were used, but it is recognised that there are many other products and methods of installation available to the road ironwork industry. However, it is hoped that the principles of construction used in this work may assist in reducing pavement failures around road ironwork installations.

2. ROAD IRONWORK TEST FACILITY

The road ironwork test facility (RITF) operates over a 4 m × 2·4 m × 1·89 m deep pit in which two manhole chambers were constructed within a three-layer pavement. It can apply a rolling-wheel load or a fixed position plate load to the surface of the construction, as seen in Fig. 2. The wheel-loading equipment was changed from a hydraulic system, as used in the previous research project,[6] to a pneumatic system. The original arrangement comprised a carriage, supporting the wheel, which ran under two hinged beams spanning the width of the pit. A servo-hydraulic actuator was attached to the beams at the opposite end to the hinge and was used to apply a controlled load to the wheel. The actuator end and the hinged end were mounted on bogies, which ran on longitudinal rails bolted to the floor either side of the pit. The carriage was reciprocated by a long-stroke hydraulic actuator, and its position was monitored with a displacement transducer, as it was necessary to know its location under the beams so that a constant wheel load could be maintained. With this system there was potential for overloading the tyre when the wheel was at the hinged end, as this was near the location of maximum leverage. To overcome this problem the loading actuator and the hinge were removed, the two cross-beams were fixed to the bogies, and the lever principle for the wheel loading was transferred to within the carriage. Twin pneumatic actuators were bolted to the carriage and attached to one end of two hinged levers supporting the wheel, and the carriage was moved by a long-stroke pneumatic actuator. The loading capacity of the actuators through the levers could not exceed the maximum tyre load, and the pressure requirement for the actuators was now constant. The latter was previously a variable to compensate for the change in leverage as the carriage

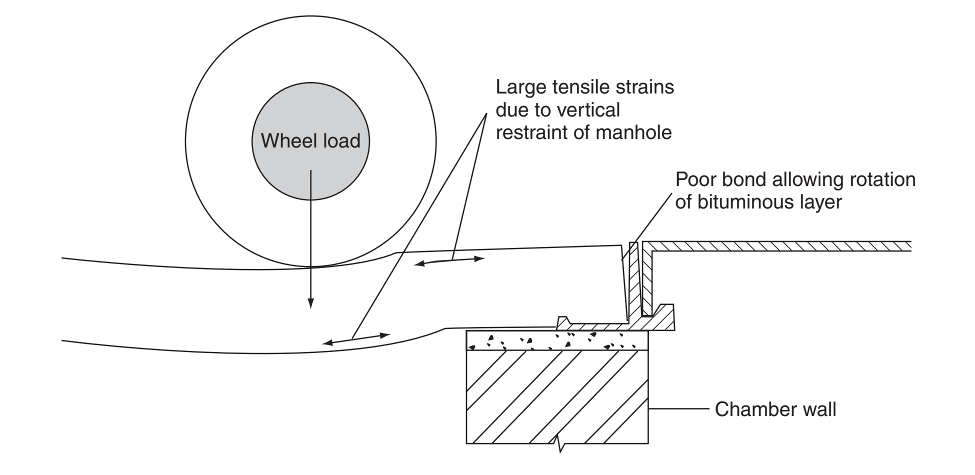

Fig. 1. Cross-section of rigid ironwork installation, illustrating surface deformation

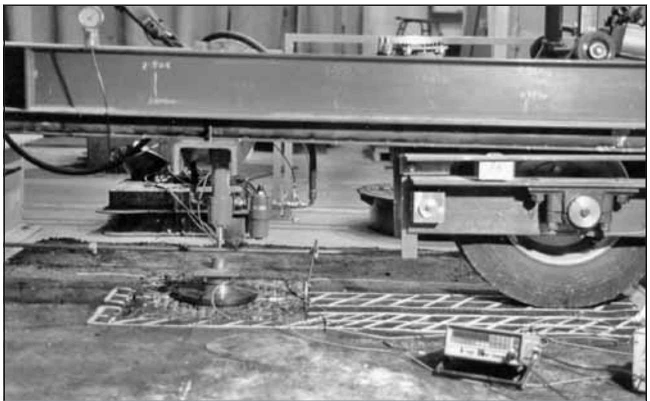
Fig. 2. Wheel loading and plate loading options

moved along the hinged beams. The RITF can apply a wheel load up to 30 kN. The use of a moving wheel produces a realistic three-dimensional stress distribution in the pavement, but, owing to its limited travel, it could only move slowly at speeds up to 3 km/h. Consequently, a plate-loading option was made available that, although positioned at one location, could be cycled at higher loading frequencies (up to 7 Hz) and could also be used in a static test mode.

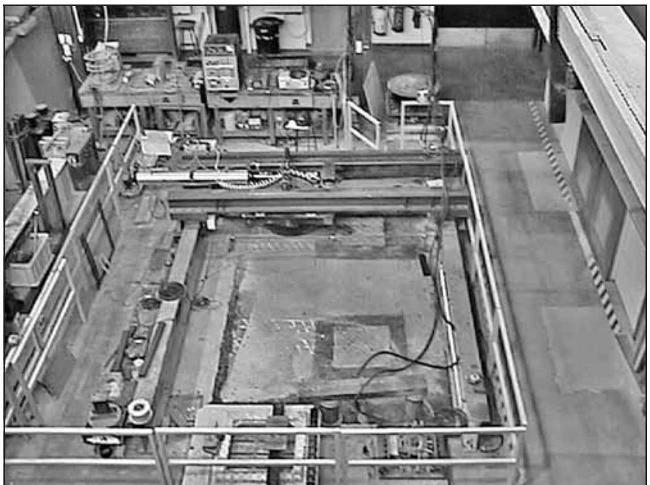
Fig. 3. Plan view of the road ironwork testing facility

A plan view of the test facility is shown in Fig. 3. Two brick manhole chambers were constructed in the pit and were surrounded by a pavement structure (see Fig. 4). At intervals during the testing programme the upper portions of each chamber were changed from brick to an alternative construction, which included a flexible element.

The performance of each alternative chamber construction was assessed on the basis of the transient surface deflections measured on the frame, over the chamber wall and on the surrounding pavement. This was achieved by using a displacement transducer, which could be moved across the pit, next to the wheel path, along a rod suspended from supports that rested on the laboratory floor.

3. MATERIALS

The original rigid chambers, approximately 1·8 m deep, were constructed from engineering bricks arranged to form a single brick (215 mm) wall thickness, increasing to a 317 mm thickness on a layer of rubber above a 150 mm concrete base (Fig. 4). The layer of rubber was introduced to represent the surface of the subgrade soil. Flexibility was achieved in the first chamber by replacing the upper 500 mm with an interlocking twin-wall construction of polymer bricks. In the second chamber it was achieved by replacing a similar depth with precast concrete rings that incorporated a 40 mm thick polymer brick insert placed first under the frame, as this was thought to be a suitable location, and then between the top two concrete rings after consideration of the results from the first test. The polymer brick thickness was chosen as it was one of the thicknesses available from the manufacturer normally used to achieve the correct chamber height for the frame to finish flush with the road surface.
A proprietary mastic surface reinstatement was used to ensure a good bond with the frame and the pavement. This consisted of a mastic screed overlaid with dense asphaltic blocks and then covered with a further mastic screed, which was levelled off to the top of the ironwork frame. The temperature of the mastic mixture was sufficient to bond to the bricks to form a solid fill attached to the frame and pavement. The specific mastic mixture details were not known, but in general a mastic is made up of solid fines and a bitumen binder (about an 8% binder content). This differs from the surrounding HRA pavement material, which would have a lower binder content (typically 5·5%), and would include coarse aggregate.

The flexible brick elements were made from a modified recycled polymer. Fig. 5(a) shows a single element and Fig. 5(b) shows a chamber constructed of interlocking elements. The surrounding pavement comprised a 150 mm deep layer of an HRA to BS 594[7] laid on a 400 mm deep, 20 mm Type 1 compacted granular sub-base[8] over a silty-clay subgrade. Changes to the upper chamber construction required renewal of the asphalt layer and some of the sub-base.

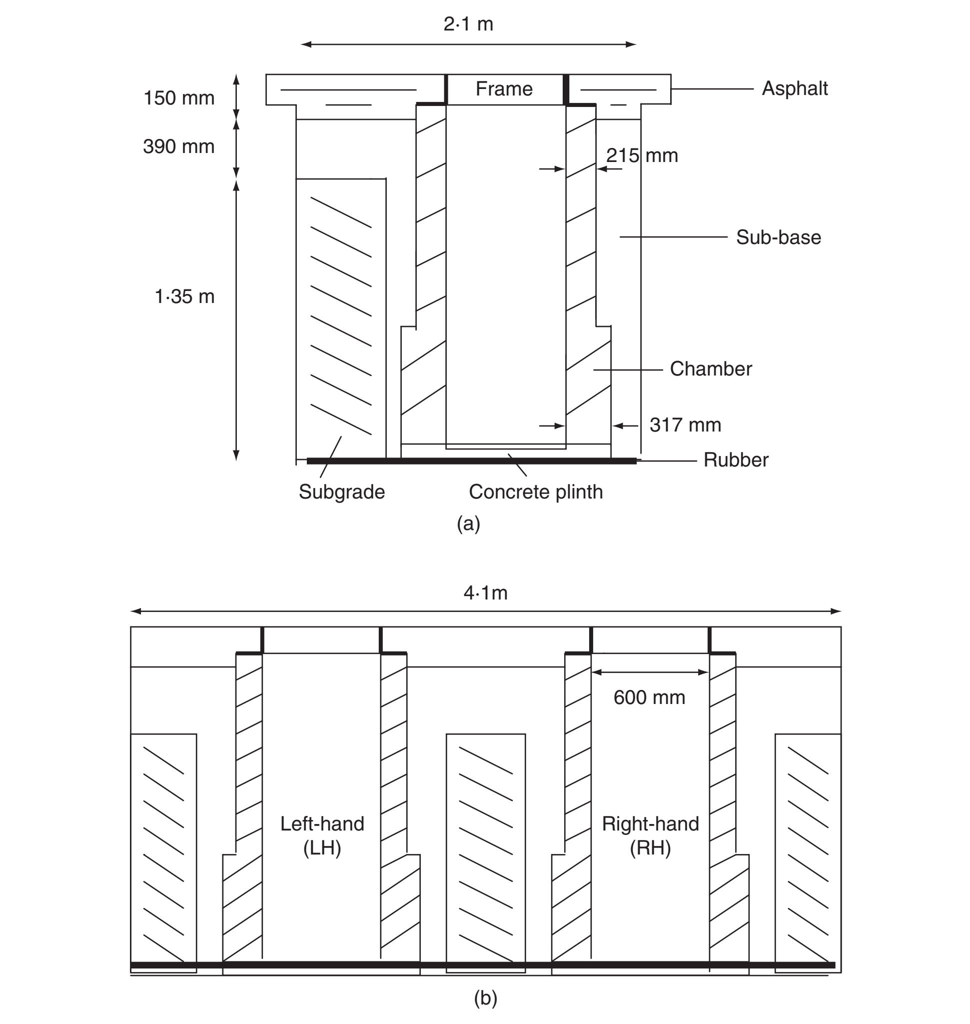

Fig. 4. Cross-section through chambers: (a) transverse section; (b) longitudinal section

chamber confinement and frame stability were also addressed. This was also done on the basis of surface deflection measurements, which would be expected to decrease in response to loading on the frame, as material was compacted around the chamber during the reinstatement process, causing the effective stiffness of the chamber to increase.

5. TEST PROCEDURE

The chambers, as orientated in Fig. 4(b), were designated left hand (LH) and right hand (RH). A summary of the various tests undertaken is given in Table 1 and the accompanying schematic, Fig. 6. The LH chamber was initially tested in its rigid engineering brick form, which can be considered to be a reference (test LH0). The top 500 mm was then reinstated and tested with a combination of three rigid concrete sections (see Fig. 7) and 40 mm thick polymer inserts in a recess under the frame (as shown in Fig. 8) to produce a composite incorporating flexibility. Both 'soft' (test LH1) and 'standard' (test LH2) polymer inserts were used. This was followed by a test with two concentric 'standard' polymer inserts under the first ring (separated by a gap of approximately 20 mm) with the frame sitting directly in the recess and reinstated with the proprietary mastic asphalt system shown in Fig. 9 (test LH3).

The RH chamber was tested with the upper 500 mm of the chamber reinstated with polymer elements of a standard stiffness (test RH1,

4. TESTING OBJECTIVES

The aim was to achieve a chamber stiffness more compatible with that of the surrounding flexible pavement. This was assessed by comparing the surface deflection profiles, during loading, of the constructions incorporating flexible elements in the chamber with the results for the rigid chamber. However, it was considered important that the integrity of the road ironwork/chamber construction should not be compromised, so the importance of

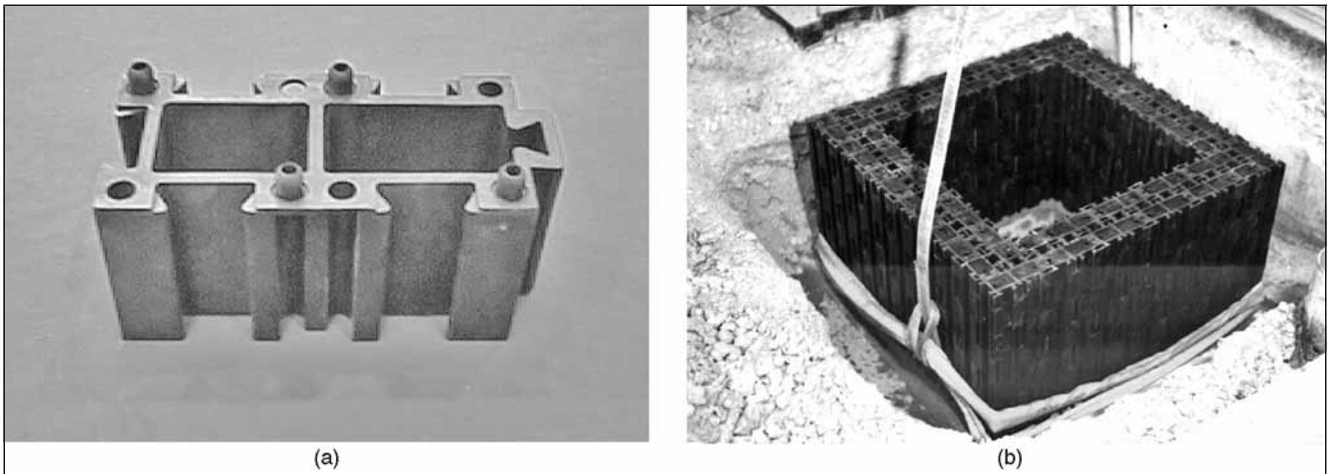

Fig. 5. Polymer bricks construction: (a) 75 mm thick individual polymer brick; (b) chamber constructed of interlocking polymer bricks

Test No.	Chamber reference	
	LH	RH
0	Full-depth masonry bricks	—
1	Three concrete sections + 40 mm 'soft' polymer bricks	500 mm 'standard' polymer bricks
2	Three concrete sections + 40 mm 'standard' polymer bricks	500 mm 'stiff' polymer bricks
3	Two concentric 'standard' polymer bricks under first concrete ring + mastic	500 mm 'stiff' polymer bricks + mastic

Table 1. Summary of tests

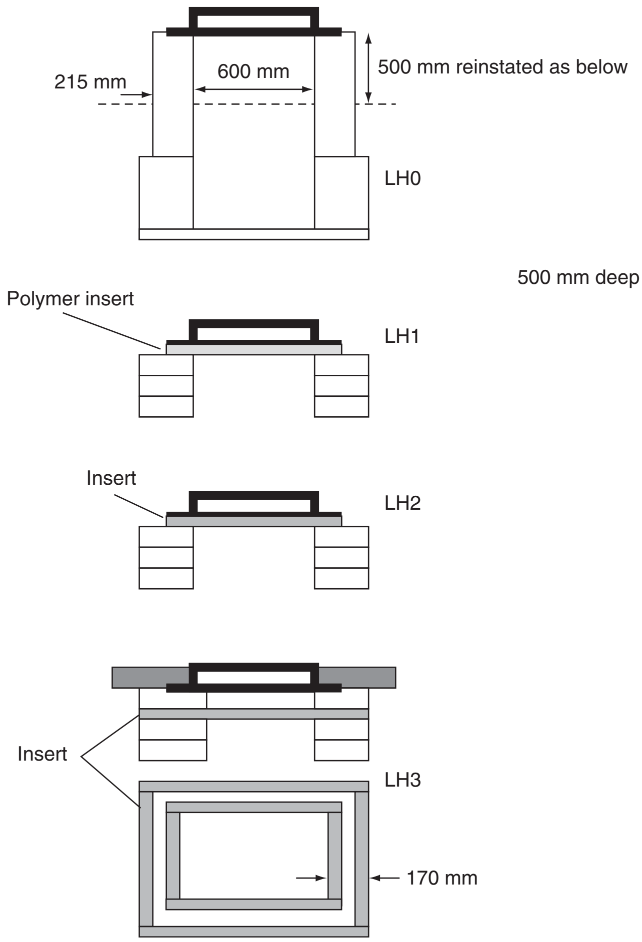

Fig. 6. Schematic of test configurations

Fig. 7. Concrete chamber

Fig. 8. Photograph showing 40 mm thick polymer insert below frame

Fig. 9. Mastic asphalt reinstatement

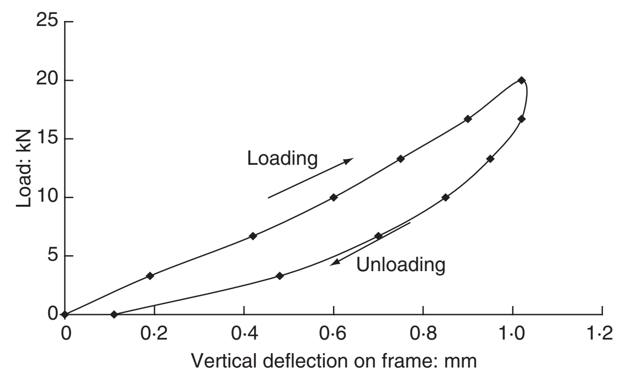

Fig. 10. Plate loading test on stiff polymer brick chamber confined by sub-base

Fig. 5(b)). This chamber section was then reinstated and tested utilising a stiffer grade of polymer element (test RH2). The same test was repeated but with the frame reinstated with the mastic asphalt system (test RH3).

In all cases, the inside of the chamber wall was aligned with the inside of the ironwork frame, providing an opening 600 mm square. For tests LH0, LH1 and LH2 the width of the bricks was 102·5 mm. Engineering bricks (class B) were used, which were 215 mm long, and this was the wall thickness as the bricks were laid in English bond. For test LH3 two concentric polymer inserts, separated by a 20 mm gap, were used, giving an approximate wall thickness of 170 mm at that level. For tests RH1, RH2 and RH3 double-thickness 76 mm wide polymer bricks were used, giving a wall thickness of 152 mm. These configurations are summarised in Fig. 6.

During construction, the effect of confining the polymer brick walls in the chamber with the sub-base, asphalt and mastic asphalt was assessed by loading the chamber cover and measuring the resulting vertical deflection of the frame after the compaction of each layer. With the LH chamber utilising the two combinations of 40 mm polymer bricks and concrete rings (LH1, LH2), only the placement of the surfacing had an influence. Consequently, for the LH chamber, no frame deflection readings were taken for the sub-base confinement.

Tests on the completed constructions were carried out separately with a plate loading system, operating on a 300 mm diameter platen placed over the centre of the ironwork cover, and with a moving loaded wheel running across the construction (wheel tracking). During these operations, vertical surface deflections were measured in three locations: on the frame, over the chamber wall next to the frame, and on the pavement beyond the chamber.

6. RESULTS

6.1. Effect of confinement

Figure 10 shows the response of the RH chamber containing the stiff polymer bricks (RH2) when confined by the surrounding sub-base during the plate loading tests. Increments of load were applied on the centre of the cover up to 20 kN and then decreased back to zero. Vertical deflections on the frame were recorded, and it can be seen that there was significant hysteresis (energy loss) in the load–deflection curves. This is a characteristic of polymeric viscoelastic materials when loaded slowly. Immediately after the load was removed a deformation of 0·1 mm was recorded. However, this deformation was not permanent, and the frame position continued to recover after these readings had been taken. There was also a small seating effect between the layers of polymer bricks and the adjacent surfaces, which was probably due to the initial slightly uneven level of the interlocked inserts.

Figure 11 shows a summary of data from this type of test carried out at various stages of construction and, consequently, confinement. The top two lines are for the RH flexible chamber, confirming that the chamber with the stiff polymer bricks (RH2) was stiffer than the chamber with the standard polymer bricks (RH1) when unconfined, and was not affected as much by the sub-base confinement. There was no influence of the sub-base confinement on the LH chamber when the 40 mm polymer bricks

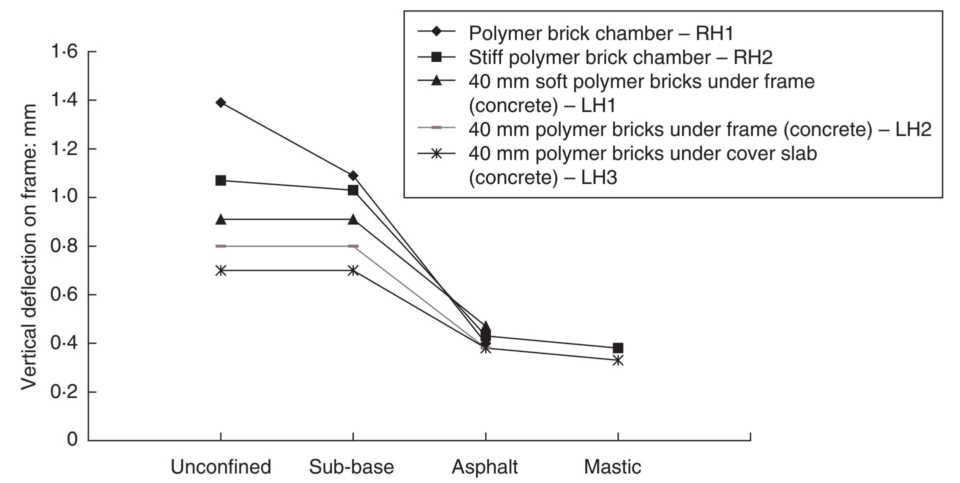

Fig. 11. Surface deflections under various construction conditions for 20 kN load applied on centre of cover

were placed under the ironwork frame with the concrete rings (LH1, LH2), or when they were placed under the top concrete ring (LH3), as they were then level with or above the sub-base. As expected, the softer 40 mm bricks (LH1) gave a greater deflection than the standard bricks (LH2).

Placement of the asphalt surfacing had a significant confinement effect, and the deflections converged to about 0·4 mm for all the tests. The result for the mastic from test RH3 has been added to test RH2, as these were otherwise identical installations. Deflections on the frame are slightly less for the mastic, which may be because a bonding agent was used in this case to ensure good adhesion to the frame and surrounding asphalt. For the chamber containing the standard polymer bricks (RH1) there was a reduction in deflection of 71% from the unconfined condition after the asphalt had been compacted, which is due to the chamber confinement provided by the surrounding materials.

6.2. Surface profiles

Plate load tests were carried out on the chamber with the stiff polymer bricks after paving with HRA (RH2) and then again after reinstating the frame with the mastic asphalt (RH3). The same tests were then repeated on the LH concrete installation with the 40 mm thick insert under the ironwork frame (LH1, LH2) and then again with the two concentric 40 mm inserts under the first concrete ring (LH3) instead of under the frame. Mastic asphalt was used as the surface reinstatement system for the latter test.

The deflection results are summarised in Fig. 12 for a plate load of 20 kN located at the cover centre. Deflections at 300 mm were on the frame flange and were of the same order as those for the asphalt and mastic confinement tests in Fig. 11. The deflections then decreased with distance from the load. These deflections will have been influenced by the flexibility of the chamber, and this is demonstrated by the more gradual reduction of the upper three curves compared with the large step to a low deflection for the bottom curve. In the case where the flexible element was under the frame (LH1, LH2) it deflected independently of the pavement. This was confirmed by carrying out a dynamic loading test of 54 000 cycles, when the frame was seen to detach from the surrounding asphalt. As a result, the load on the cover and frame would not have been transferred to the pavement even above the chamber wall, which was rigid. The same dynamic load test was then repeated for the stiff polymer brick chamber (RH2), and the frame remained integral with the asphalt.

With the 40 mm polymer bricks placed below the top concrete cover slab (LH3), some movement at the asphalt/sub-base interface is possible. This is a less critical location than the surfacing around the frame. Consequently, the frame can transfer part of the load into the asphalt, and the high localised deflection, which occurred with the flexible element directly under the frame, was eliminated. An extra reading at 750 mm from the cover centre was taken for this arrangement, as the concrete chamber wall extends further than the polymer brick chamber wall. This reading represents the pavement construction deflection, and should be similar for the other installations.

6.3. Wheel tracking tests

Figure 13 shows the surface deflections for the LH brick and concrete chamber in response to the loaded wheel as it moved from the centre of the cover onto the pavement. The load was measured by strain gauges on the wheel support lever arms, and was set to 18 kN, but as there was a dead load from the carriage and wheel, the total load was approximately 20 kN.

All the readings converge towards about 0·1 mm deflection on the pavement at the point 700 mm from the cover centre, which indicates that this position is getting beyond the influence of the load on the chamber. The objective was to achieve a deflection profile that is compatible with the deflection of the pavement. This appears to be the case for the rigid brick chamber (LH0), but because the deflection taken over the wall (300 mm from the centre) is effectively zero, the stiffness under the wheel was very high, and represented an abrupt change for a wheel running onto the chamber. The use of the flexible inserts under the frame helped to overcome this effect (LH1, LH2) but, as was seen from the plate loading test, this option caused detachment of the frame from the surrounding pavement. It can also be seen that there was insignificant difference in deflection response between the soft (LH1) and standard (LH2) polymer brick constructions. It would be expected that for the standard polymer brick insert the deflection on the frame would be less than for the softer insert, as seen for the plate loading tests. However, for the wheel tracking tests there may be a seating effect between the frame and the insert as the wheel passes over the frame and onto the cover, producing an additional deflection of a

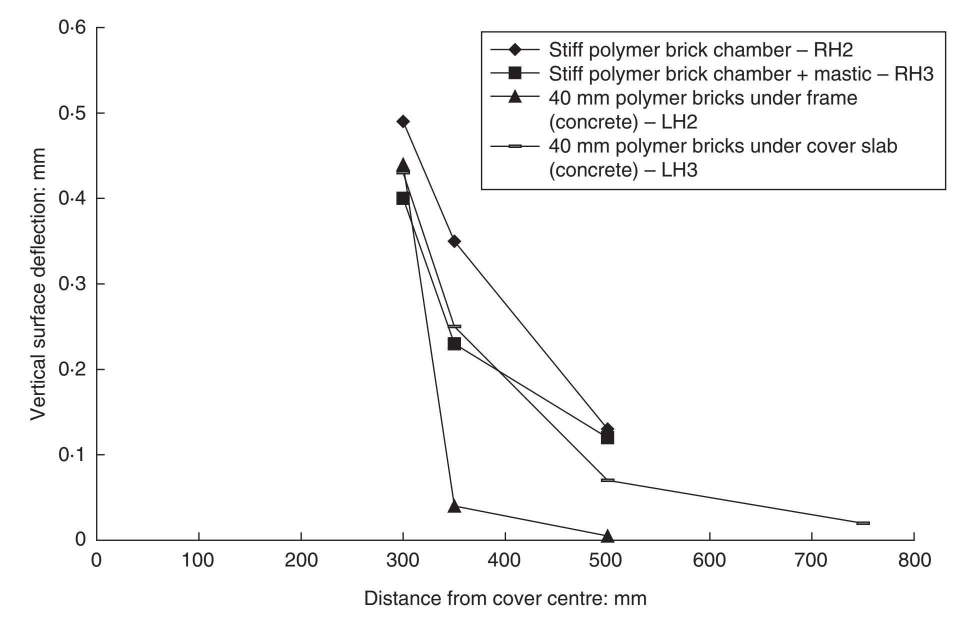

Fig. 12. Plate loading tests on centre of cover for 20 kN applied load

similar magnitude for each type of insert. This seating effect would be overcome for the static test as the load is increased, and the difference in stiffness of the two inserts would have more influence on the frame deflection.

When the flexible insert was used under the cover slab (i.e. lower down in the pavement) the problem of frame detachment was eliminated (LH3). The chamber still had some flexibility, but the deflections decreased slowly compared with the previous two tests (LH1, LH2), in which there was a large change from the frame to the edge of the chamber wall. This smooth transition from the cover and frame to the pavement was probably due to the effective connection of the frame to pavement provided by the mastic interface. During installation of this material great care was taken to ensure a good bond between the mastic, the frame surface and the exposed pavement. The process combined a hot mastic with brick-sized mastic blocks so that a solid homogeneous material was obtained upon completion of the installation.

Figure 14 shows the profiles for the RH 500 mm deep polymer brick chambers (RH1, RH2). These gave higher measured deflections over the chamber wall compared with Fig. 13, but the deflection profiles, on average, decreased more smoothly onto the pavement. There was still a degree of discontinuity directly over the chamber wall for the top two curves, but the introduction of the mastic (RH3) eliminated this. The deflection readings converge at 600 mm from the cover centre compared with 700 mm for the concrete chamber, as the polymer brick chamber is smaller, and its influence on the pavement deflections would not extend as far. The readings then increase

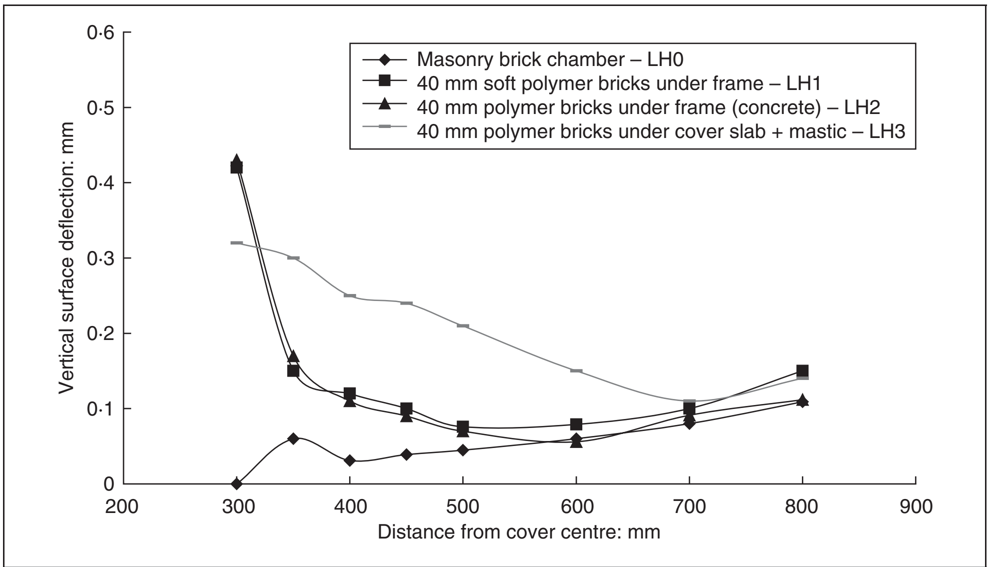

Fig. 13. Wheel tracking tests at 20 kN on brick and concrete chambers

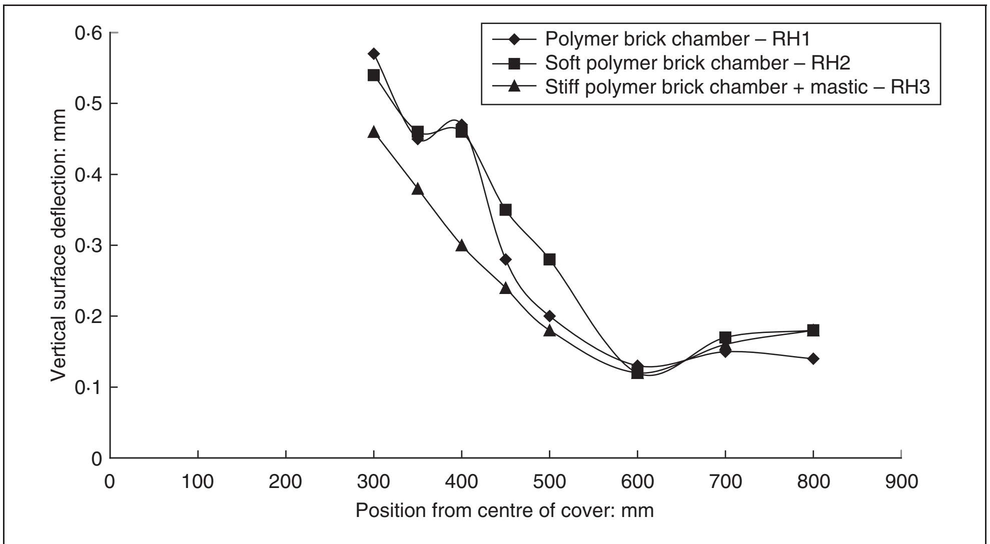

Fig. 14. Wheel tracking tests at 20 kN on polymer brick chambers

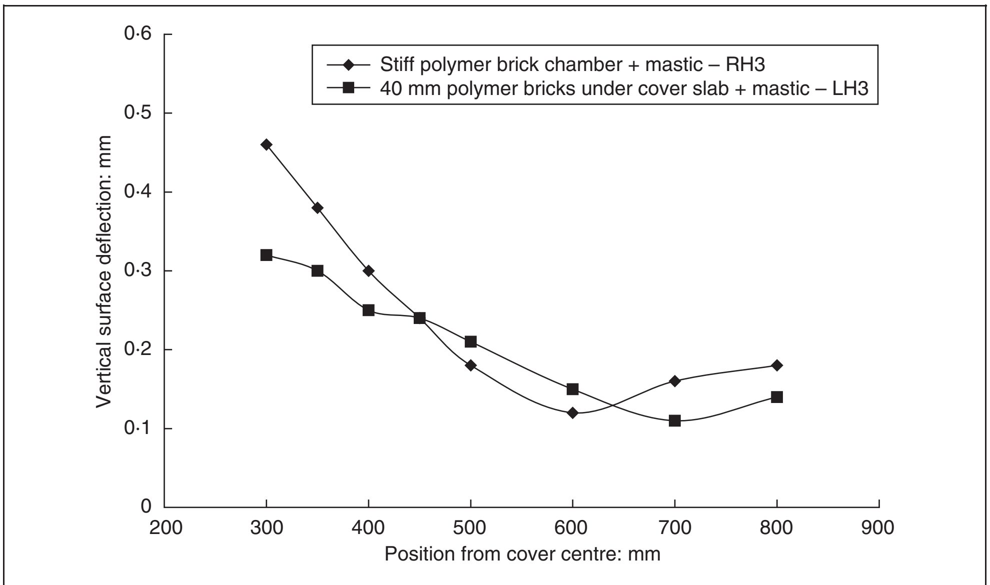

Fig. 15. Wheel tracking tests for chamber constructions LH3 and RH3

slightly, but the trend could not be investigated as measurements were not taken beyond this point.

Deflection data for the two chambers are compared in Fig. 15, which shows that the desired smooth transition of surface deflection under a wheel load from the frame onto the pavement was achieved when the mastic surfacing was used (RH3). As a consequence, tensile strains and shear stresses in the surfacing around the frame should be reduced.

7. DISCUSSION

When a thin flexible element is incorporated in a rigid chamber, the flexibility can occur only at the location of the insert. It has been shown that the element should be positioned below the asphalt/sub-base interface to prevent the frame moving relative to the pavement immediately surrounding it. This makes the role of the reinstatement material critical as it must, in effect, bond the frame to the surrounding pavement, providing a durable interface between the components. The upper portion of the chamber and the reinstatement will then be able to deflect a small amount as a vehicle passes over, and the abrupt step change in stiffness that occurs for a rigid chamber is modified to a smooth transition to a lower stiffness.

The flexibility of the polymer brick chamber is effective over a greater depth, and a proportion of the wheel loading on the cover and frame is transferred into the surrounding pavement/backfill through the mechanism of interlock and confinement: that is, the chamber becomes part of the pavement structure. The mastic asphalt system combined with the polymer brick construction provided a durable bond with the frame and pavement, and had sufficient stiffness to contribute to the transfer of the wheel loading from the ironwork into the pavement, such that there was a slight reduction in the chamber deflection.

It was the intention of this work to investigate the performance of a road ironwork installation as a whole by combining flexible and rigid components to produce a durable construction under trafficking. The time taken for a road ironwork failure to occur after it has been installed or reinstated can be very short. Installations can cost between £1000 and £1500 and a repair can cost in the region of £250. In the introduction it was stated that an estimated £207 million is spent annually on installation and reinstatement work, so considerable savings could be made by extending the life of road ironwork installations.

8. CONCLUSIONS

(*a*) Flexibility incorporated into a road ironwork chamber can smooth out the step change in stiffness between a flexible pavement and a rigid chamber.

(*b*) Flexibility can be introduced into a rigid chamber made up of several concrete rings, by introducing polymer inserts between the rings. They should be placed at or near the asphalt/sub-base interface, where the vertical movement of the polymer insert is more readily accommodated. If it is placed under the frame then there will be differential movement between the frame and the surrounding asphalt, which could cause the frame to detach from the asphalt.

(*c*) Replacement of the upper portion of a chamber with a flexible polymer brick construction introduces a component that is more compatible with an asphalt pavement.

(*d*) It is desirable that the flexible chamber should have sufficient width for vertical stability, provide support for the frame, and have an external profile that can interlock with the surrounding pavement material.

(*e*) Backfill around the chamber should be well compacted to provide good confinement for the polymer brick construction.

(*f*) The surface asphalt reinstatement material around the frame is a key element in the overall performance of the installation. It should have good load-carrying properties, be durable, and bond well to the frame and pavement. A proprietary mastic asphalt system was shown to be effective.

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