

TESTING THE NEXT GENERATION OF TRAMWAY TRACKS

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SUMMARY

Since the late 19th century the design of tramway tracks in streets has remained remarkably static. A mass concrete foundation supports grooved girder rails bolted together with gauge bars. The highway pavement is made up with setts, concrete or blacktop. With new tramways being proposed in many places, that track design has a number of limitations: the need to reduce: under street utility plant relocation, stray currents, ground borne vibrations and long possession periods needed to reconstruct the street and install the tracks. Over the years variations of this theme have been tried, with shallower rails, thinner foundations and encapsulating the rails. None has removed all the limitations.

The new LR55 track design has a top suspended rail, bonded with an elastomeric polymer into pre-cast concrete foundation troughs, which are only 180mm deep and 380mm wide. Trenches in the highway pavement are 400mm wide and 200mm deep to take the LR55 foundation troughs and minimise the need to relocate under street plant. The bearing pressure on the base of the troughs is low, and does not require any further pavement strengthening. The paper will report on the testing, both cyclic and to destructive of the LR55 tramway track form, which attempts to address the limitations of existing designs. As well as laboratory testing, field trials have also been completed and these will be reported.

INTRODUCTION

One of the reasons for the development of street tramways and railways in the 19th century (first in New York 1832) was the very poor state of city streets and the rough ride provided in wheeled vehicles. Streets were little better than dirt tracks, or in wet weather mud baths.

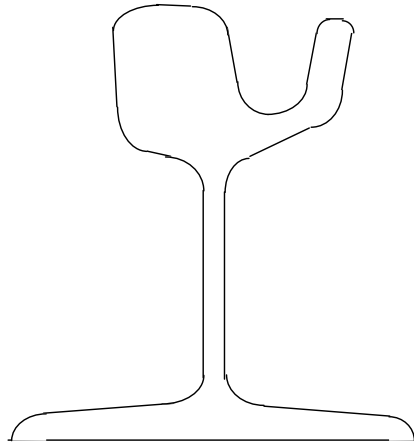
In order to support the rails, that give tramcars and light rail vehicles smooth riding, substantial foundations, usually a mass concrete slab, are laid, on which the rails are placed with tie bars to give gauge assurance. In the middle of the 19th century, tramways were almost the first utility to occupy urban highways. In many towns, tramways often provided the first permanent durable road surface.

Over the following century, a complex utility infrastructure has been installed under streets, including sewers, water and gas supply pipes, power and telecommunications cables etc.. Road pavements have also been developed as permanent load bearing structures, able to support 44 tonne heavy goods vehicles (HGV) and buses that can have up to 13 tonne axle loads. A strong pavement is needed to give a long life road and to protect the under street utility plant.

PRESENT TRAMWAY TRACK SYSTEMS

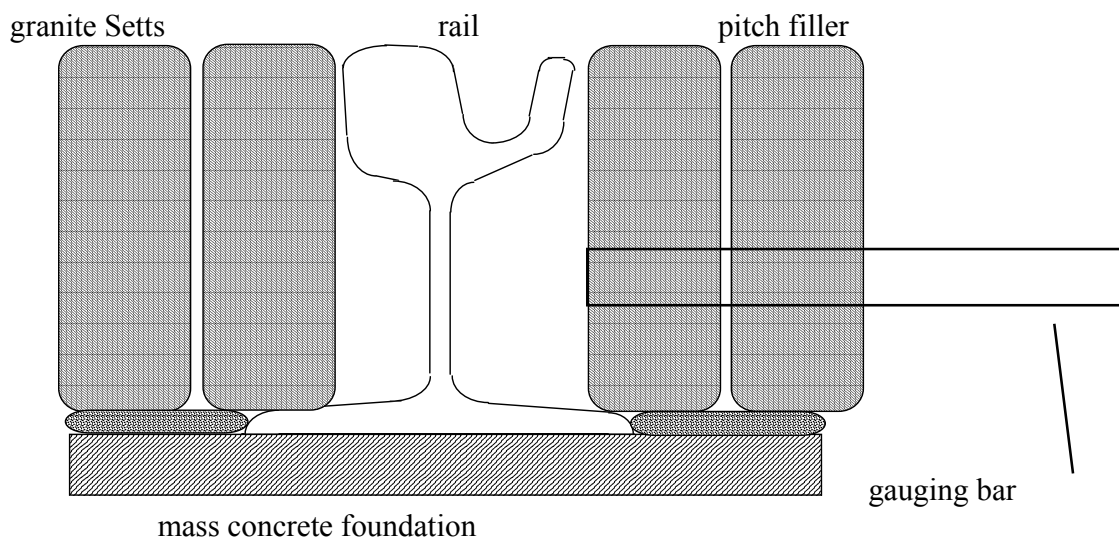
Currently installed tramway tracks have developed incrementally from 19th century designs. All use mass foundations up to 500mm deep, either as a continuous in situ slab, or in France by the use of prefabricated concrete railway sleepers. The space required for this foundation can only be achieved by the removal of existing under street utility plant. In any case access to that plant for repair or maintenance would be impossible once tram tracks are installed on concrete foundations. Grooved girder rails (eg. Ri60 180mm high) (fig. 1) are then fixed to the foundation (fig. 2).

Fig. 1 Grooved girder rail cross section



Finally the carriageway is remade, up around the rails but structurally separate from the tram tracks

Fig. 2. Typical 20th Century construction with grooved girder rail

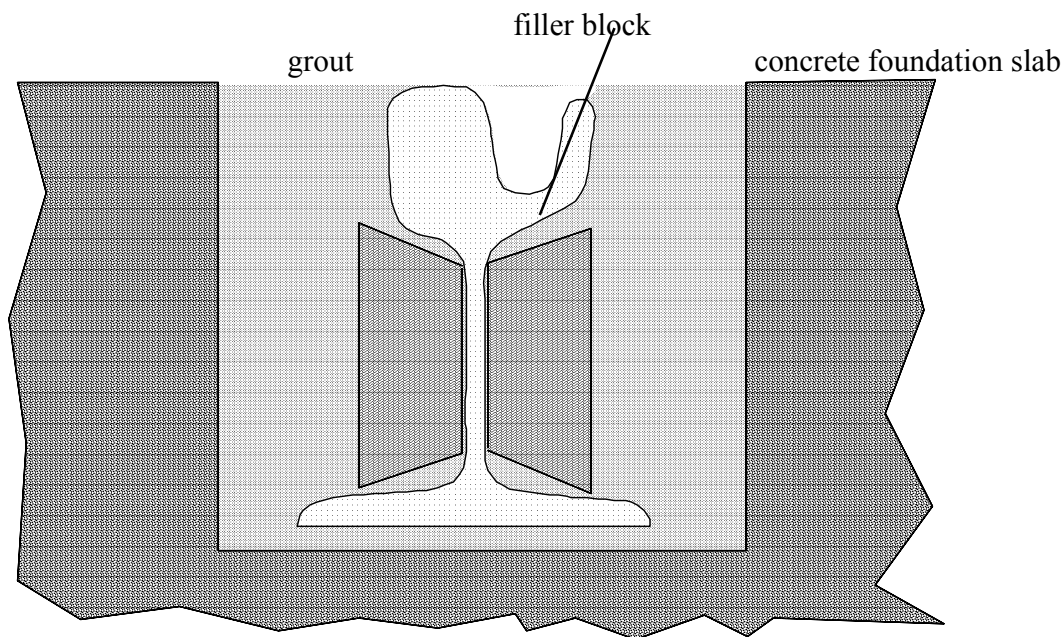


There have been instances of recently installed tracks failing, due to poor design or installation. Attempts to reduce the costs of grooved girder railed street tracks have been made, starting in the mid 1930's when the Brooklyn and Queens Transit Corporation experimented with a grooved girder rail only 150mm high to reduce the construction depth and therefore cost. More recently a similar system

was used for the Downtown Tourist Streetcar Line in Portland. In both cases a mass concrete foundation some 2500mm wide is needed for each track, sterilising the under carriageway space.

In the UK different street track designs (eg. fig. 3) have been used in each of the recent installations: Manchester, Sheffield, Birmingham, Croydon and Nottingham. Little pre installation testing was undertaken and notable failures have occurred, due to intrinsic design faults, sometimes coupled with the difficulty of insuring that installation was undertaken properly. These show that there is little scope to address the fundamental problems with tramways based on grooved girder rail. This paper describes the testing of a tramway track which is based on different principles

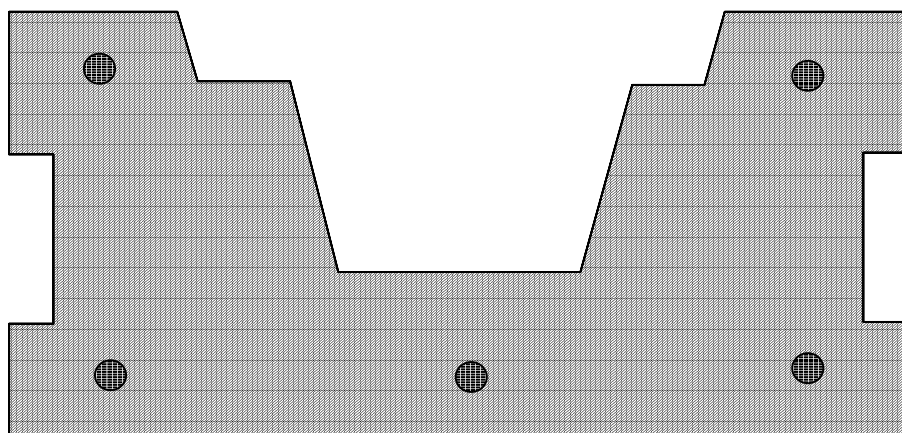
Fig. 3 More recent applications of grooved girder rails



LR55 SYSTEM

Most existing UK highway pavements are capable of carrying 40 tonne gross weight vehicles, with up to 13 tonne axle loads, even though the UK legal maximum is 10.5 tonnes, capable of repeated loadings over 5 MPa. The LR55 system uses the existing pavement as a structural element by inserting shallow pre-cast concrete foundation troughs 180mm high and 380mm wide (fig. 4) (Lesley 1991). This is similar to drainage gullies, kerbs and other highway furniture of similar size. The LR55 trough becomes an integral part of the highway pavement, carrying both road vehicles and tramcar loads (Lesley 1997).

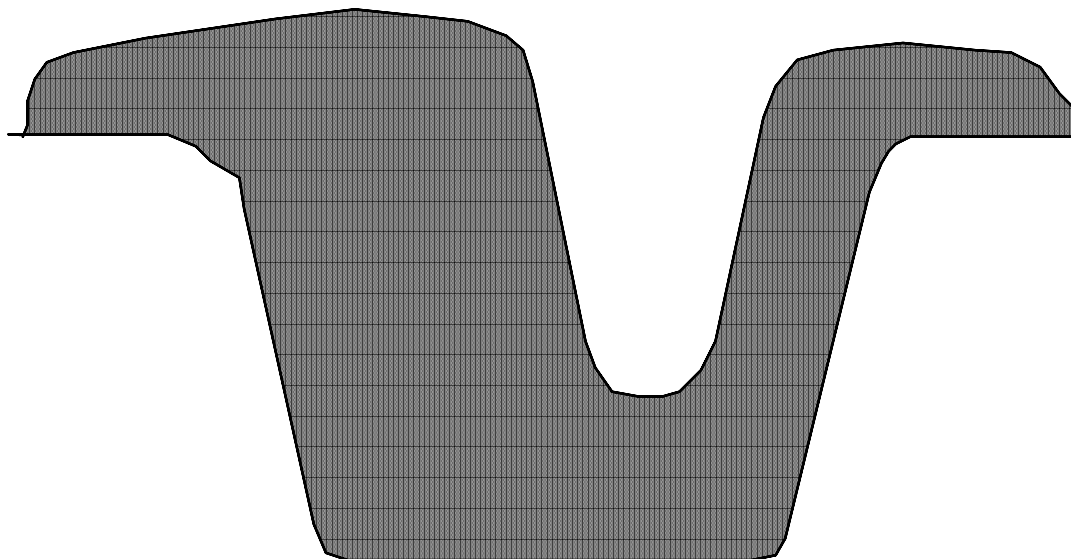
Fig. 4 LR55 concrete foundation trough with reinforcing tendons



(scale: third full size)

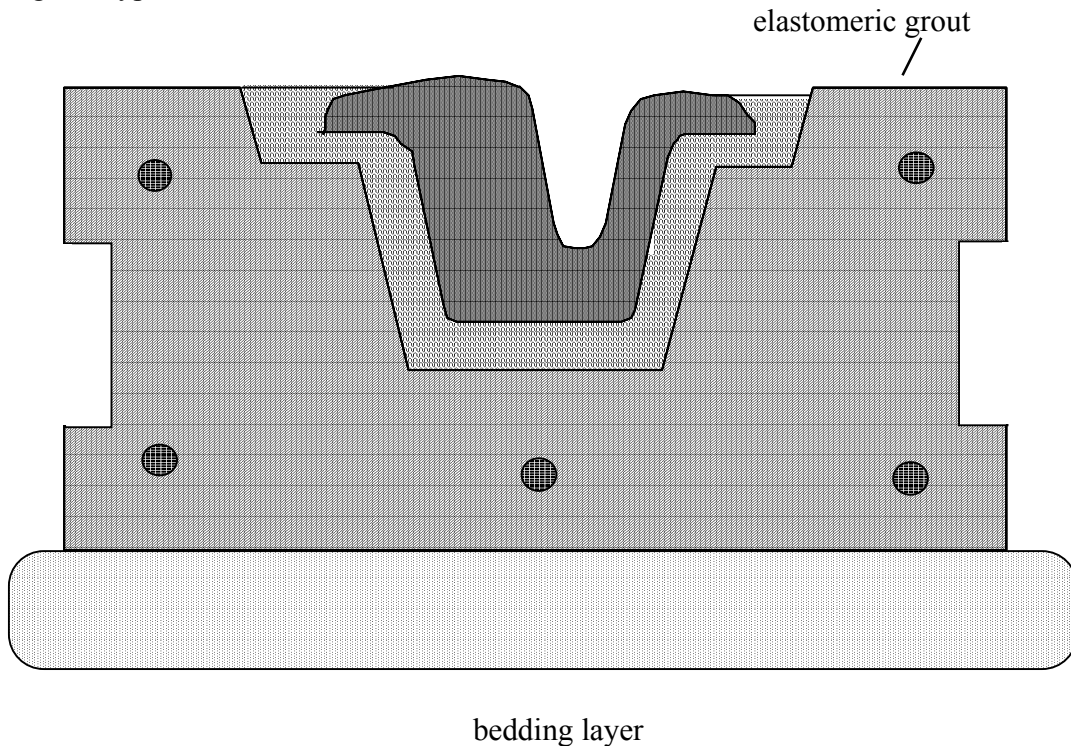
The LR55 rail is a new section only 80mm high.

Fig.5 LR55 rail section full size



The rail is supported by and bonded into the LR55 trough by an elastomeric grout.

Fig. 6 Typical installation detail of LR55 track



The high stress about 160,000 MPa at the rail/wheel interface is transmitted to the upper part of the LR55 trough by rail flanges in line with the rail head. From here the stress is dispersed across the full width of the trough and over a metre in front and behind the wheel along the trough. This means that the pressure at the base of the LR55 trough is low typically averaging 65 kPa and peaking immediately below the wheel contact point at below 200kPa. Being top supported the rail is also very stable with very little turning moments or rocking associated with bottom supported girder rails 180mm high. This also reduces damage to the highway pavement, which is further reduced by the track structure acting monolithically with the carriageway pavement.

TESTING THE LR55 TRACK SYSTEM

Numerical simulation

Several numerical models were constructed, including the use of 1, 2 and 3 dimensional beam and finite element analyses (eg. Mohammad et al 1996, Al-Nageim et al 1997). These replicate the behaviour of the LR55 track system under road and rail vehicle loadings. All numerical simulations were undertaken assuming 25 tonne axle loads (mainline railway), compared to typical tramway maxima of 10 tonnes. Using these models under a series of different assumptions; the transmission of wheel loads, pressure, bending moments and rail and trough displacements were calculated. Further models were constructed to determine noise and vibration transmission.

Laboratory tests

Samples of rail were cast in rail grade steel with heights of 60, 70 and 80 mm. Tests were undertaken for static and dynamic loadings in a hydraulic rig at the LJMU Structures Laboratory (Al-Nageim et al 1996). Cyclic testing was undertaken with 25 tonne axle loads (Lesley 2001). Samples of rail were also tested submerged in water to identify the mechanisms of penetration and debonding. Two rail samples were tested to their limits for pull out and void failure. Finally a 6 m long sample was tested to validate the finite element model. (Lesley et al. 1997). Tests were carried out with the LR55 track supported on compacted sand to replicate the road bearing course.

Field Tests

Two field tests were undertaken . The first in the access road of Rotherham Bus Station during 1993-5, where 2500 buses per day arrive, shunt, turn and manoeuvre. The access road had a flexible pavement laid over made up ground of a former waste tip. The second field test was installed on a single track section of the South Yorkshire Supertramway in March 1996. This replaced 80 lb conventional girder rail that had failed after only a year of operation. Whilst a 6 year warranty was given, this LR55 section was adopted in September 1996, and continues to give excellent performance, after 6 years of accelerated testing on a critical section of the Supertramway.

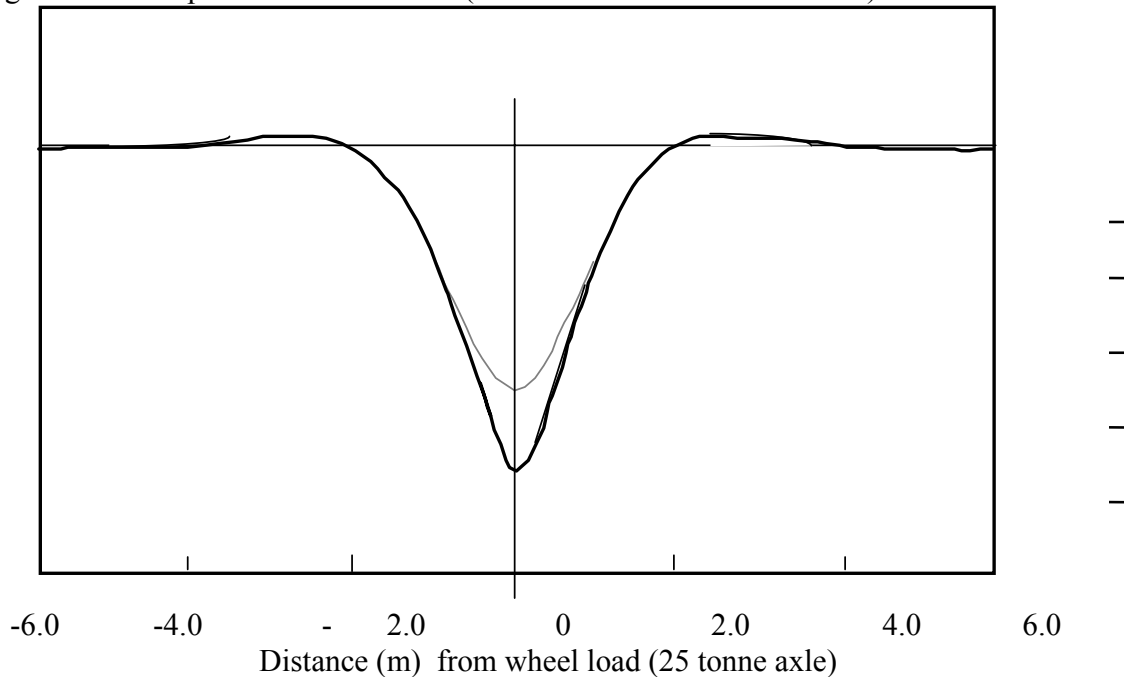
RESULTS OF LR55 TESTING

Laboratory

LR55 samples were tested up to 80 tonne axle loads, without failure. After over 100 million cyclic tests at 25 tonne axle loads and 15Hz (equivalent to operating speed of 100km/hr) , LR55 track samples showed no evidence of failure. No samples failed due to water penetration or debonding. Two different elastomeric grouts were tested (ALH System 6 and SIKA KC330), which showed similar mechanical and other properties. Indeed the tests in the LJMU Structures laboratory on KC330 replicated earlier tests undertaken in the Civil Engineering Department of the University of Calgary, prior to the use of KC330 in the Calgary light rail system.

One track sample was tested to destruction as a simply supported beam over a void 1 m wide. The sample failed at a 58 tonne axle load. The trough failed in tension but the bond between grout, rail and trough remained intact. A second sample 1 m long rail was subjected to pull out. The sample failed at a 36kN pull out force. Again the trough failed in tension. There was no failure of the elastomer grout to either the rail or trough. Examples of some results are shown: fig. 6 rail and trough displacement under load, fig.7 track pressures, fig. 8 bending moments.

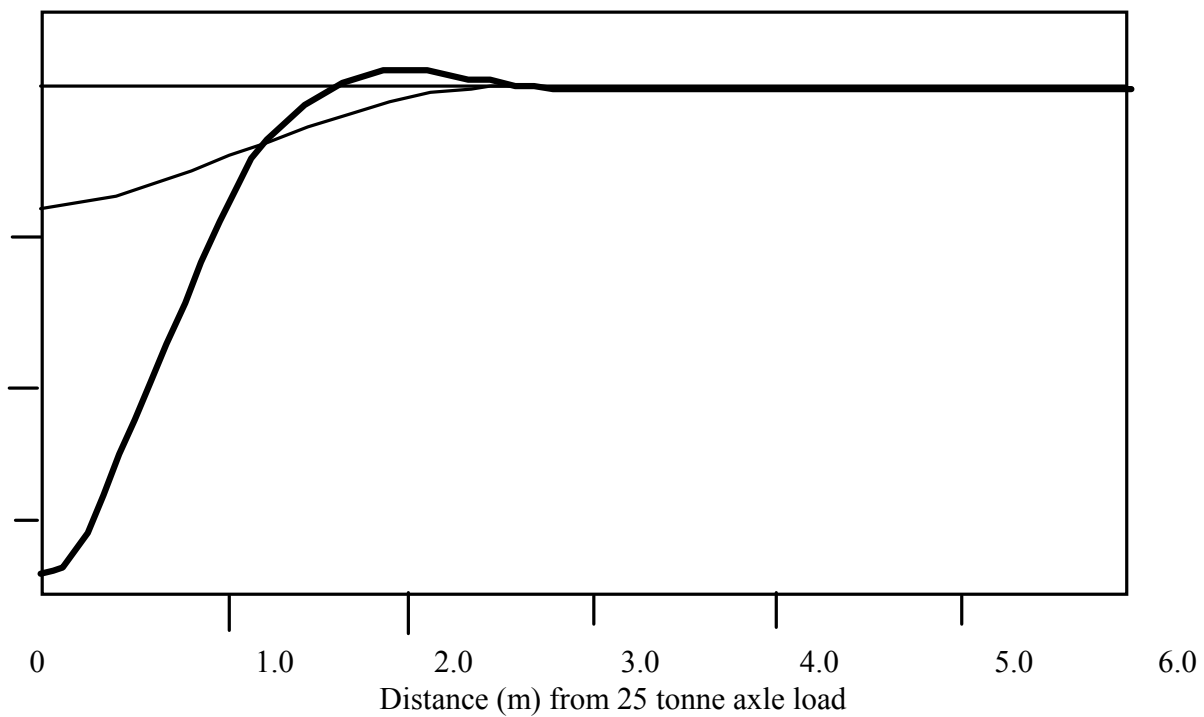
Fig.6 LR55 displacement under load (vertical axis = 1mm increments)



Maximum displacement. LR55 rail = 4.5mm LR55 trough = 3.3mm

Fig. 7 Pressures through the LR55 track system

vertical axis = pressure in 200 kPa increments



Thick line = pressure in elastomeric grout. Thin line = pressure at base of LR55 trough

Fig. 8 Bending moments in LR55 track system.

vertical axis = bending moment in 4kN.m increments

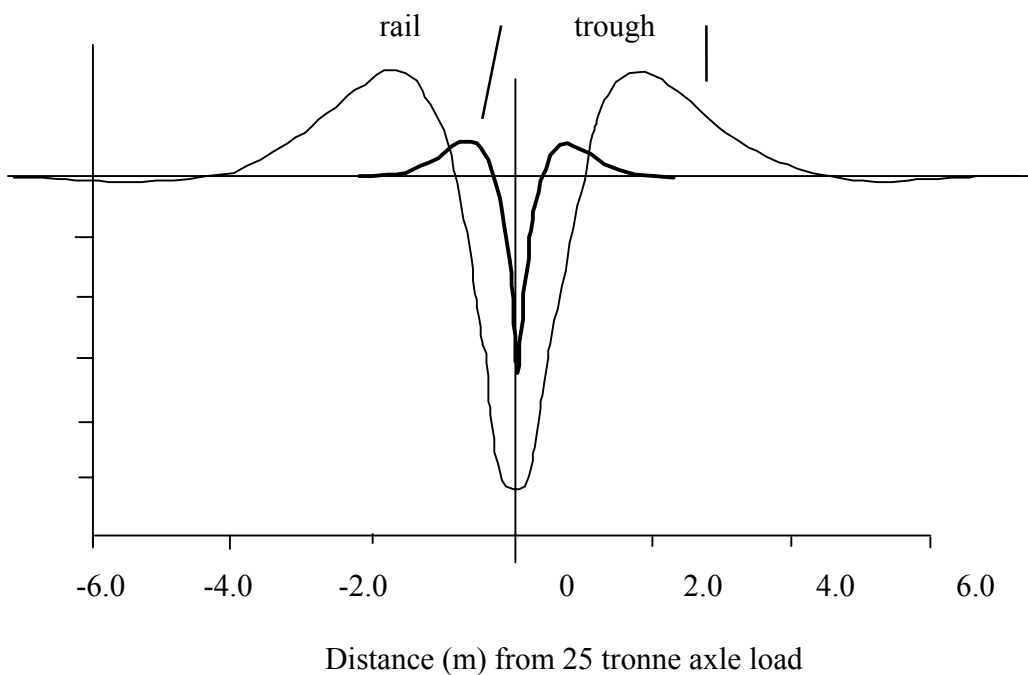
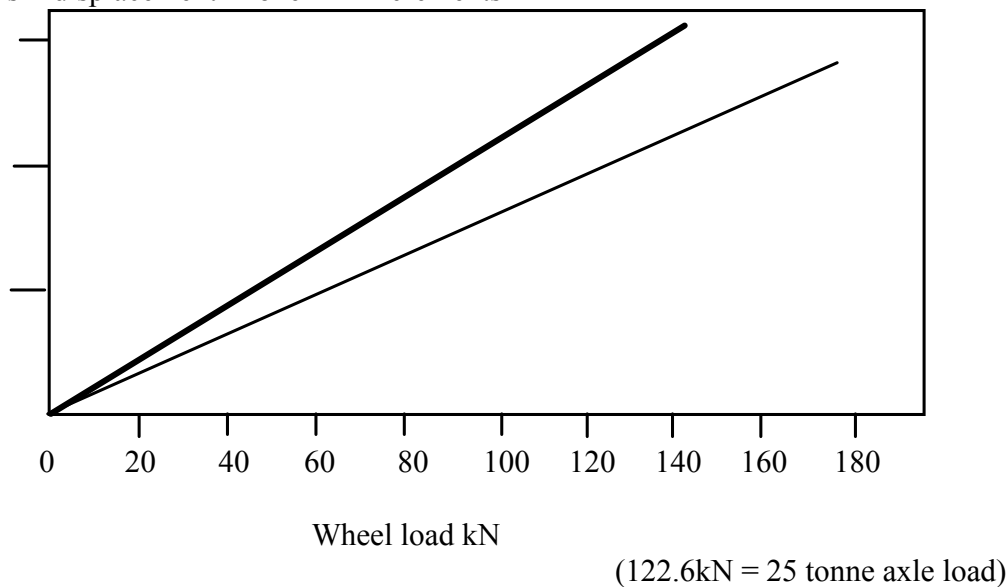


Fig. 9 Temperature effects on LR55 track system

vertical axis = displacement in one mm increments



Thick Line = LR55 track at 60oC

Thin Line = LR55 track at -5oC

A LR55 track sample was subjected to cyclic testing in a controlled temperature environment. Temperatures were varied from -5oC to +60oC. No failures were recorded and as expected from other work on elastomers the track was only a little less elastic at the lower temperature compared to the higher temperature. The lateral pressure at the sides of LR55 troughs are very low, typically less than 20 kPa and therefore can be absorbed by the pavement without deformation. This means that unless the pavement is particularly weak, LR55 tracks do not need to be gauge barred. This is like the kerb guided bus rails which are two independent concrete strips that maintain gauge by the lateral resistance of the ground. Highway pavements are much stiffer than the ground in which many busways have been laid. For areas of the LR55 track where gauging is an issue, eg. short radius curves, a simple stainless steel stop clamps the LR55 troughs to gauge. There are heavy rail locations where rails are not gauged in track, eg. in London tube stations. The "suicide pit" means that there are no sleepers between rails.

Field tests

Rotherham Bus Station

A 12 m length of LR55 rail was installed in the entrance to Rotherham Bus station, and instrumented with strain gauges to record the movement of the concrete trough and rail. The gauges were linked to a data logger which sampled the readings. After one year most of the gauges had exceeded their design life but no permanent changes in the rail or trough were recorded. In Sept. 1996 a trench was dug under the track and representatives of the statutory undertakers and HMRI were invited to inspect the installation, the shallow depth of construction and the stability of the track, as buses passed over and along the track.

South Yorkshire Supertramway

A site on the single track access to Meadowhall station was selected at Alsing Road, which is the only access to a major industrial complex with about 100 HGV movements per day. The site has about 400 tramcars per day. After 6 years of satisfactory operation there is no obvious wear either of the rail head or groove side.

Other Tests

Noise

With the LR55 rail having no rigid connection to the foundation, and configured as a mass (rail)-spring (grout) -mass (foundation trough) -spring (sub soil) structure, groundborne noise attenuation is good. This is further helped by the rail having no web to resonate. The LR55 track structure has a natural resonance of about 800Hz (Lesley 1996). This is well above the frequency levels which transmit through the ground. Indeed the LR55 track compared to girder rail tracks will attenuate noise in the 0 - 20Hz range by up to 30dB, and in the 20 - 100 Hz range by 50dB. Buildings have low natural frequencies, and therefore LR55 tramway tracks are expected to transmit no annoying vibrations in adjacent buildings or fixtures.

Electrical Resistivity

The elastomeric grouts recommended for use in LR55 track have very high electrical resistance. The LR55 rail, including crossings and switches, is surrounded by grout providing a high level of electrical resistivity, measured at better than $1000\Omega \text{ km}$. In dry weather therefore the LR55 track will produce very low stray currents, typically less than 2 milliamps on starting. In wet weather, or when the road is under water, strays are uncontrollable. Most continental tramways have no general measures to prevent stray currents but apply site specification solutions when strays are detected to cause problems. Stray currents can be further moderated by the periodic reversal of polarity, and the use of unearthed systems, with rails bonded at close intervals to an insulated return. By these measures the achievement of a 7volt rail to earth maximum is easily achieved. In installation LR55 tracks have achieved resistivities of $10,000\Omega \text{ km}$.

CONCLUSION.

The LR55 tramway track system has been comprehensively tested at over mainline axle loads. By distributing vertical and lateral loads over a large section of the LR55 trough, pressures into the highway pavement are low. This means that tramway tracks can be laid into existing road pavements with a minimum of reconstruction, usually only a new wearing course to provide the right profile into which the troughs are installed. Indeed LR55 tracks can tolerate voids under the trough of about 1m length in the pavement without failure. This is a benefit to utilities being able to trench under LR55 tracks, without special track support. It also means that the lateral stiffness of the pavement is sufficient to maintain track gauge without the need for gauging bars.

POSTSCRIPT

The LR55 track offers a economic solution to convert busy bus routes to tramway operation. Where the peak bus frequency is more than 10 per hour, then LR55 track can offer a commercially viable alternative to bus operation, and attract car commuters who presently will not use buses. The speed with which LR55 tracks can be installed at over 100m per week, means that the social, communal and economic disruption is minimised which is associated with existing track forms

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