Metro Report
INTERNATIONAL

CAPACITY
Melbourne
Boring more tunnels to relieve existing routes
PAGE 22

INTER-URBAN
Rhein-Ruhr
A premium service for Germany's largest conurbation
PAGE 26

DEMAND
Tokyo
Plans are afoot to increase services in the busy Kanto area
PAGE 30

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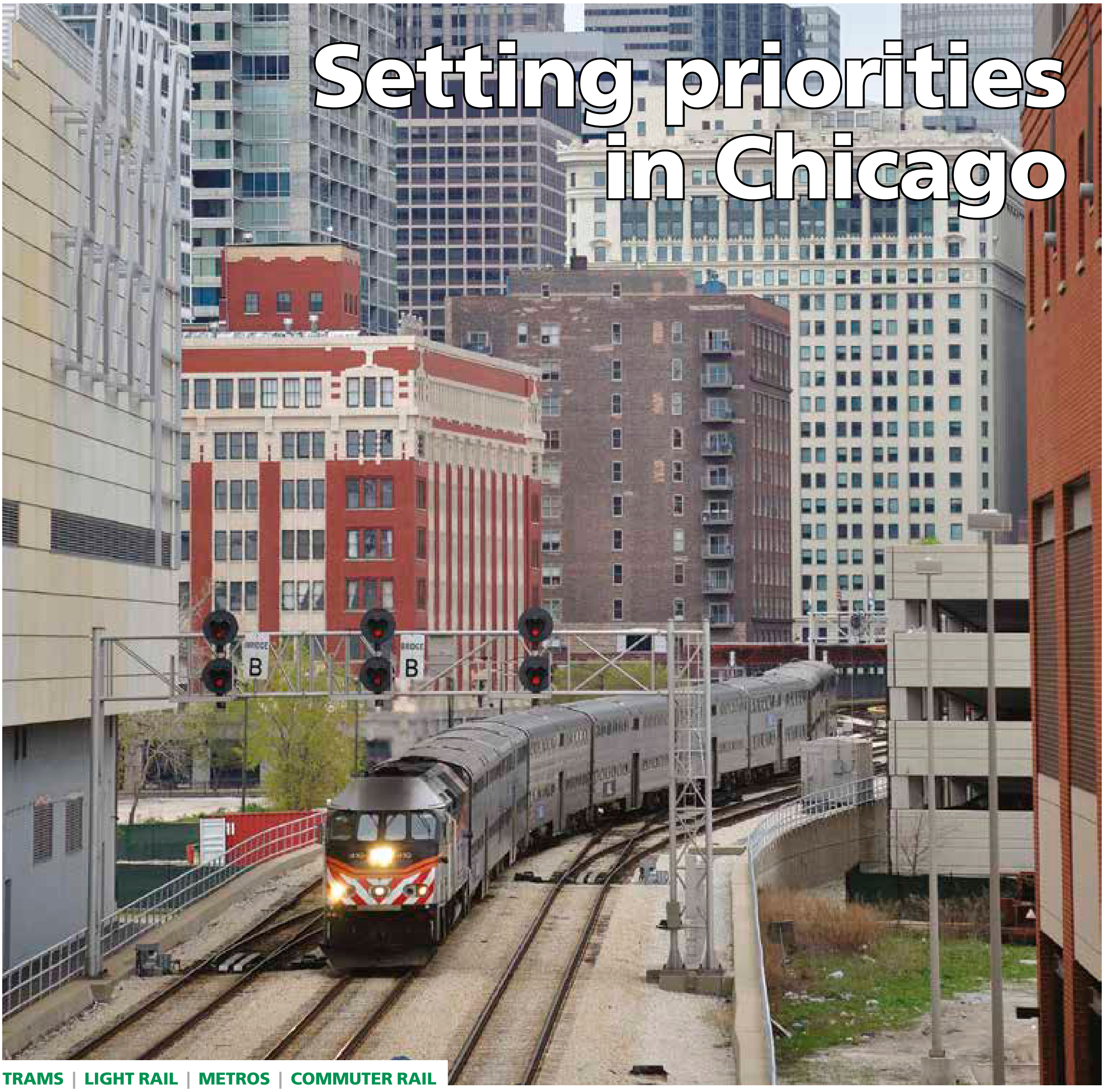
Setting priorities in Chicago



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TECHNOLOGY Superstructure Renewal

Renewing track superstructures

Metro Madrid has developed a renewal method to transform its conventional ballasted track into a mass-spring system to reduce the transmission of vibrations into the ground and adjacent buildings.

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Turnouts are the most maintenance-intensive sections of track in a metro network, with attendant high costs. They are also the most common source of vibrations that may be felt by residents and buildings in the immediate vicinity. One way to reduce the maintenance requirements of turnouts and limit vibration is to replace conventional ballasted track by a mass-spring system. Following positive experience with previous installations, Metro Madrid is replacing six more turnouts this year.

The Madrid metro covers 293 route-km and has around 300 stations. The superstructure to be renewed in the tunnels mainly consists of conventional ballasted track with wooden sleepers and 54E1 rails. The depth of the ballast is generally 250 mm to 400 mm below the bottom of the sleeper, and trains travelling at up to 60 km/h have an axleload of 13 tonnes.

Exposed turnout areas are fitted with supporting tracks, so that the ballast can be extracted.

Track renewals are taking place at night to avoid disrupting operations. The greatest challenge is the short window available for track work, of just 2½ h. This means that around 75 nights are required to replace a 60 m to 80 m turnout section on conventional ballasted track by a ballastless turnout with a mass-spring system. Limited space, poor light and no ventilation make the work more difficult.

Mass-spring systems

Vibrations from trains can cause noise to be heard in nearby buildings, and the problem is exacerbated if services are frequent. Various measures can be taken to reduce the transmission of structure-borne noise, and the correct one will depend on specific technical and economic factors. As a general rule, the requirements are defined by national standards that limit noise and vibration. Installing under-ballast mats is the most common method of reducing vibrations from ballasted track, whereas elastic rail pads or baseplate pads are often favoured for ballastless track.

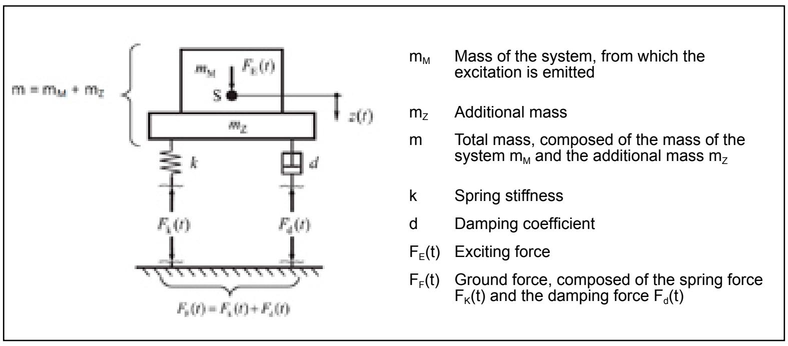
The most effective method, although the most costly, is to install a mass-spring system. This entails the elastic decoupling of the entire slab from the subsoil. As well as reduced vibration emissions, a mass-spring system has several advantages over ballasted track. These include a longer service life with less onerous maintenance requirements and lower life-cycle costs, plus improved track quality — which means a smoother ride.

The vibration-isolating effect of the superstructure is best explained using the single degree of freedom principle (Fig 1)[1]. The theoretical system frequency is derived from the dynamic effective mass of the slab and the train, as well as the dynamic stiffness of the elastic bearing. The mass of the slab is usually predetermined at the planning stage, so the dynamic co-ordination is usually effected through the vibration-related properties of the elastomer.

To ensure the vibration isolation is as effective as possible, the system frequency should be significantly lower than the excitation frequencies. Irrespective of the type of elastic bearing used, the vibration isolating effect is only triggered when the ratio of the excitation frequency to the natural frequency is greater than √2. If this ratio is smaller, the dynamic force is distributed more intensely into the subsoil. The system damping comprises the damping of the elastic bearing and all the other damping mechanisms. The isolating effect is usually expressed as a logarithm of the ratio between the input and output forces.

Getzner Werkstoffe's Sylomer polyurethane elastomer is being used for the elastic base and side mats. The mat is 25 mm thick; with a slab thickness of 400 mm and an unsprung wheelset

Fig 1. The single degree of freedom principles for mass spring systems.



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mass of 15% for trains with a 13 tonne axleload, a natural system frequency of 20 Hz was calculated.

Sylomer and Sylodyn have been used as elastic bearings of footings for over 30 years[2-7]. The mats are supplied either in 1·5 m wide rolls or bespoke plates made in advance, which simplifies their installation in some cases. They bend easily and can be cut to size using conventional knives.

In addition to the horizontal base mats, which are subjected to pressure, the vertical side mats contribute to the overall vertical stiffness because of their shear stress. If this detail is neglected, higher natural frequencies are generated, which reduces the vibration isolation. The mats can be installed as lost shuttering and for additional protection must be fully bonded using adhesive tape partly laid with plastic film to prevent structure-borne noise bridges forming later.

Renewal process

For safety reasons, speed restrictions must be enforced over the section while work is in progress, and the track should be kept under close observation. After a topographic survey, work can begin on removing the turnout and installing a supporting skeleton for both tracks using customised metal isolated sleepers. The ballast can then be extracted, leaving the track skeleton supported with concrete blocks and secured horizontally with wooden wedges or struts. Before installing the elastic bearing, a compensation layer may need to be applied to the tunnel floor.

Installing the elastic bearing involves filling the gaps that are opened up on the tunnel floor with polyurethane elastomer mats. Full functionality of the mass-spring system can only be guaranteed if the elastic isolation layer is fully formed. It is therefore essential that a high level of quality is maintained when forming and working with the elastic isolation to avoid structure-borne noise bridges.

Once the mats have been laid on all the lateral surfaces such as the support structure and the shafts, the reinforcement can be installed and the initial 100 to 200 mm concrete support slab produced. The concrete is poured into the subsoil through air shafts. Next, the turnout sleepers, rail fastenings and remaining components are pre-assembled. Once the shuttering is complete for the longitudinal and lateral dewatering, shafts and signalling devices, the track panel is adjusted and levelled using a track geometry car. To conclude this stage, the concrete support slab is built up to its full height in several phases. At this point, temporarily loosening the fastening system removes stresses between the rails and anchors the concrete slab support.

The shuttering and temporary supporting blocks can then be removed. The gaps created by the supporting blocks are lined with elastomer mats and sealed with concrete. The concrete support slab is now finished and is a uniform 400 mm in height. Welding the rails and final cleaning conclude the work.

Measuring results

The effectiveness of the vibration isolation measure used in a mass-spring system can be estimated accurately using the single degree of freedom principle. Irrespective of the local conditions, the insertion loss is determined only by the natural frequency and system damping. The measure is designed based on the dynamic effective masses, which are usually predetermined, and the choice of elastic bearing. More complex forecasts take into account other conditions, such as the stiffness of the tunnel invert, the tunnel cross-section, the kind of soil above the tunnel, the retroactive effects of the elastic track on the vehicle and the abrupt load generated in turnouts when the train travels over the frog.

In Madrid, vibrations were measured at the street surface immediately above the turnout frog at two different turnouts before and after renovation. Because of the gaps in the rails, abrupt broadband track excitations above the frequency range are to be expected when trains pass over it. Before renovation, maximum vibration velocities of more than 0·2 mm/sec were recorded, whereas measurements taken afterwards show a tenfold decrease.

Vibration velocity reduction of 8 to 16 dB was achieved for the frequency range critical for secondary airborne noise, 40 to 160 Hz, equating to a vibration-damping efficiency of 60% to 84%.

In the meantime, five 60 m to 80 m turnouts in tunnel areas of the Metro Madrid ballasted track have been converted into vibration-reducing mass-spring systems with no interruption to services. Four further turnouts have been converted but these required train services to be interrupted. Due to the extremely positive experiences, another four turnouts in the Madrid metro network are being converted this year, and Metro Madrid expects to continue this renewal schedule in the coming years. ■

The vibration-suppressing mats bend easily and can be cut using conventional knives, making them simple to install.

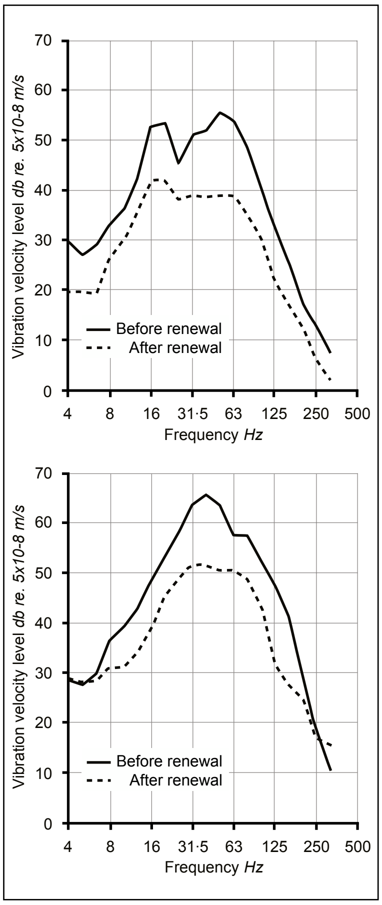

Fig 2. The 1/3-octave band spectra of vibration velocity levels were measured before and after turnouts were replaced at two locations.

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