EAST RAIL
UNDERFRAME EQUIPMENT MOUNTING CRACKS
ROOT CAUSE INVESTIGATION

FINAL REPORT

1. EXECUTIVE SUMMARY

Following the East Rail Mid-Life Refurbished (MLR) train air compressor mounting bracket incident on 21 December 2005, KCRC took immediate steps to examine all underframe equipment of the MLR trains using non-destructive testing. As more hairline cracks were discovered, the KCRC's crack management scheme was put into operation to ensure the running safety of the MLR trains.

In January 2006, a KCRC in-house team, with the support of specialist consultants and the manufacturer of the MLR trains, began an investigation to identify the root causes of these cracks and to recommend remedial measures. Specialist consultants were also employed to provide an independent assessment of KCRC's train and trackwork maintenance programmes, including benchmarking against international standards, and to provide expert support to the investigation. This final report sets out the findings of the investigation and the remedial measures to solve the cracking problem. These findings and remedial measures have been reviewed and endorsed by the Corporation's Independent Review Panel (IRP) led by Ir. Edmund Leung.

The scope of the investigation has encompassed all possible causes of the cracks, including those arising from vibration, manufacturing, operation, maintenance, the environment and any possible impact from East Rail enhancement projects.

The investigation has involved an extensive testing programme with a total of more than 164 train test runs having been conducted. Strain measurements have been taken at key locations to help in identifying excessive fatigue loading experienced by the underframe equipment mounting brackets, and to trace potential sources of vibration and their transmission paths. Measurement results were analysed and conclusions were validated using VAMPIRE, which is a state-of-the-art computer simulation tool for train-track dynamics.

A comprehensive review has also been carried out on other factors, which include the impacts of new projects, maintenance regimes of trains and tracks, and changes in operational/environmental conditions.

Possible manufacturing-related causes have been investigated to determine the adequacy of the design and the quality of materials and welds. Techniques employed include fatigue life analysis and accelerated life cycle tests. In addition, analysis on each type of crack together with metallurgical examinations on selected mounting brackets have also formed part of the investigation.

The dominant cause of the cracks found in underframe equipment mounting brackets, with the exception of those involving the air compressors and motor-alternators, has been established to be excessive vibration induced by resonance oscillations[1] of the car-body. Based on the results of finite element analysis[2](FEA) conducted by the train manufacturer, the original design and fabrication of the equipment mounting brackets show they would normally be fit for purpose. However, the excessive vibrations measured in the MLR trains have increased the fatigue loading on the mounting brackets by up to twice their design limit. Weld imperfections and stress concentration areas found through metallurgical examinations have also contributed to the cracking of the mounting brackets.

The dominant cause of the cracks in the mounting brackets of air compressors and motor-alternators has been established to be weld imperfections. Vibrations, induced by the moving parts of the air compressors and motor-alternators, and resonance oscillations of the car-body also contributed to the occurrence of the cracks in the brackets for these two types of equipment.

Based on time-domain and frequency-domain analyses[3] of the measurement results and computer simulations, it has been established that the source of the excessive vibrations is due to resonance oscillations

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(1) Every structure possesses natural frequencies of oscillation. When the frequency of an external force exciting the structure matches one of the natural frequencies, the resulting vibration will have large magnitude. An example is how an experienced diver would take advantage of the natural frequency of the springboard by synchronizing his/her stepping rhythm to achieve a maximum jumping height.

(2) A computer-aided modelling and analysis technique to evaluate stress level at various parts of the mounting bracket under prescribed loading conditions.

(3) At each snapshot of time, vibration experienced by the mounting consists of many components, each of which possesses a unique frequency. Time domain analysis looks at the resultant value of all these components, while frequency domain analysis looks at each component individually.

of the car-body resulting from the presence of minute undulations in the form of cyclic patterns on the rail top along many sections of the East Rail alignment. These patterns have a longitudinal pitch[(4)] of around 3 metres and a vertical profile of less than a millimetre. Resonance oscillations of the car-body occur when a train is running with a speed of 70 – 90 km/hour over tracks with such patterns. This speed range coincides with the normal speed of East Rail services.

Findings from tests show a strong correlation between the occurrence of the minute undulations and a batch of rail supplied in 1998 – 1999 for the East Rail track renewal programme, which now makes up 36% of the East Rail tracks. It is not possible to measure by conventional methods the presence of the minute undulation on the rail top, and the rail specifications adopted as industry standards at the time did not eliminate the possibility of minute undulations. The operating limits of track recording machines and rail grinding machines commonly used in the industry for track maintenance likewise cannot measure nor ensure such undulations will be removed. The planned rail replacement programme for East Rail will therefore include the early replacement of this batch of rail at critical sections.

Even though the rail will be replaced, a study report commissioned by the UK Railway Safety and Standard Board in 2004 recognized that there have been changes in the rail operating environment and recommended raising the fatigue loading standard for vertical loads carried by equipment mounting brackets by a factor of three. Although this recommendation has not been adopted as an industry-wide standard, the KCRC has decided to upgrade the fatigue strength of the mounting

(4) Horizontal length of each pattern along the rail.

brackets on the MLR trains in accordance with the UK Railway Safety and Standard Board recommendation, so as to withstand the vibration as currently seen.

Design of the enhanced mounting brackets has now been substantially completed. The physical works are targetted to be completed by mid 2007, by which time all the secondary temporary supporting systems will have been removed.

A third measure is to reduce the resonance oscillation of the car-body by enhancing the suspension system of the MLR trains to resist the transmission of vibrations induced by minute undulation patterns on the rail top. Discussion with the train manufacturer is in progress on the means to achieve this.

The findings of the investigation and independent reviews by specialist consultants show that the KCRC maintenance standards and procedures have not been a contributory factor in the occurrence of cracks in the underframe equipment mounting brackets. However, maintenance procedures for the MLR trains will be further strengthened to support the early detection of mounting bracket cracks. Train-based and track-based instruments will also be installed for continual surveillance of the wheel-rail interaction so that further corrective actions, if needed, can be proactively implemented.

Kowloon-Canton Railway Corporation
3rd May 2006