INVESTIGATIONS OF RAIL FRACTURES AT VIENNA UNDERGROUND AND MEASURES TO REDUCE THEM

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ABSTRACT

At Vienna Underground, fractures of rails have turned up to a high extent, so it was necessary to search for methods to fight them. For this reason a catalogue concerning classification and coding of rail defects in addition to a general map for finding out accumulations of rail defects were drawn up. This special coding system developed in Vienna has been already applied at other Underground networks.

Also load on the underground rail caused by the underground car with regard to frequency and axle load (wheel load) was determined. It has been amazing that the parameter tons/year is nearly in the same range as at normal railways (comparison of a section of the Federal Austrian Railways with the Vienna Underground).

Sudden fractures of rails (fractures in the welded joints are not considered) which turned up because of reasons that were not recognizable at visual controls showed a lack of criteria. Also by means of questionnaires sent to the other metro networks of the world it could not be found out, when a fatigue crack, depending on load and load cycles, has reached a critical extension. This led to the decision to carry out measurements by means of strain gages at a high-loaded spot overrun by trains of the Vienna Underground.

These investigations showed that the knowledge of the K_{Ic}-value of the rail steel and of the specific loads of the rail have made it possible to reduce the frequencies of fractures. If the critical crack length in the rail is known, a safety factor can be determined and the intervals of inspections can be calculated.

INTRODUCTION

All railway companies – underground companies included – endeavour to eliminate rail defects at the very beginning, for these defects influence safety and quality of operation and even increase operating expense.

Rail defects at railways have to be seen from another point of view as at underground networks (metros). Great axle-loads and high speeds are decisive at railways, short headways and high accelerations of trains and therefore intensive alternating stress of rails are determinant for metros. Moreover rail defects at metros may become catastrophic in narrow tunnel areas, trenches, etc.

COMPARISON UNDERGROUND TO RAILWAY

1954296 axles run over a cross-section per annum at the Vienna Underground line U1.This corresponds by assuming a medium axle load of 9.7 tons to a load of 18.96 million tons/year and track. The rail is stressed by 9.47 million tons/year.

Comparing Vienna Underground with Austrian Federal Railways one of the most frequented sections of Austrian Federal Railways (Hütteldorf - Tullnerbach 14 km) will be considered.

The load amounts to 64000 tons/day and track – that means 23.36 million tons/year and track.The medium axle load is 11.85 tons, locomotives have an axle load of 20 tons and the maximum axle load amounts to 22.5 tons. That means that the load of the track at Federal Austrian Railways (23.36 million tons/year and track) is not essentially higher than at Vienna Underground (18.96 million tons/year and track).

The loads at the underground networks of Seoul (54 million tons/year and track) Moscow (59 million tons/year and track), New York (up to 45 million tons/year and track) and Hong Kong (40 million tons/year and track) go far beyond the load of Austrian Federal Railways (comparisons to the railway companies of these countries were not available).

Wear and sensitivity to defects concerning rails do not depend only upon load/year and track and axle-load and speed, but are also dependant on rail material, cross-section of wheels, spring suspensions of cars and further parameters. The form of rail is nearly the same to Federal Austrian Railway and Vienna Underground, but in the last time more and more UIC60 rails have been installed at Federal Austrian Railways.

CLASSIFICATION AND CODING OF DEFECTS OF RAILS

In order to classify and to assign a rail defect the kind of defect, the site of defect (in the rail), the direction of defect and the position of defect in the track must be known.

Actually there exists a "Catalogue of Rail Defects" published by the International Union of Railways (UIC, Union Internationale de Chemin de fer), but this catalogue is very comprehensive and not easily to handle by the permanent way staff, therefore the Vienna Underground (Wiener Linien) developed a new Classification and Coding System where the essential rail defects are indicated on a sheet of standard paper size (DIN A4).

The first number (two digits) describes the kind of defect (e.g. 01 fracture),
the second number (two digits) indicate the site of the defect (e.g. 02 head of rail)
the third number (two digits) refers to the direction of the defect (e.g. 03 declined).
The position in the track is defined by the fourth number (two digits), e.g. 10 area of joint (alumino - thermic welding).

The permanent way staff must fill in a form for every detected rail defect using the above mentioned code numbers. The code numbers are stored in the PC, so a survey on turned up rail defects (especially rail fractures) can be got, conclusions can be drawn and measures can be taken.

APPEARANCE OF RAIL DEFECTS IN LARGE NUMBERS ON SPECIAL SPOTS

For the understanding of the causes of rail defects (especially rail fractures) there are not only the types of rail defect decisive but also the spots where rail defects turn up. It could be found out at Vienna Underground (especially on line U1) that more rail fractures than at other spots turned up in winter at ventilation shafts and emergency exits (drop of cold air). The number of fractures at these spots could be reduced by suitable measures (partly by welding of rail joints at lower temperature).

STATISTICS ON RAIL FRACTURES FROM AN INTERNATIONAL POINT OF VIEW

The underground networks all over the world were asked to deliver statistics on rail fractures in their respective networks (study initiated by Vienna Transport). Thirty companies sent answers. This compilation was worked out in the paper "Statistics on Rail Fracture from an International Point of View and Evaluation of Data" [1].

The maxima of fractures occur in cities with continental climate (hot summers, cold winters) during the winter periods, because low temperature cause a drop of fracture toughness (K_{IC} values) and an increase of tensile stress Fig.1.

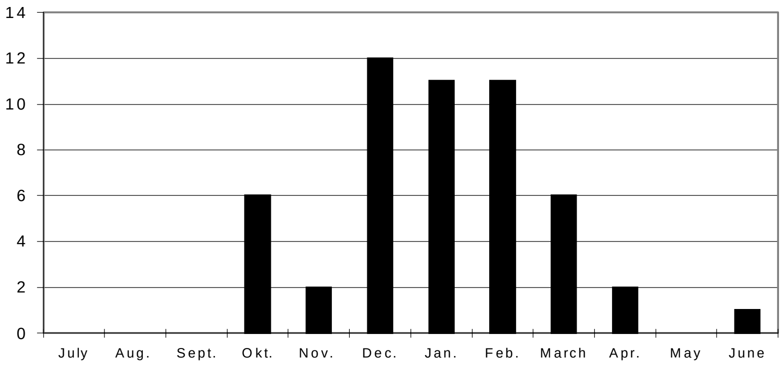


Figure 1: Number of rail fractures 1982 - 1986 on Line U1 (10 km) Vienna Underground

The chart of London shows the typical behaviour for turning up of rail fractures at underground networks in areas with mild winters (and not very warm summers) Fig 2.

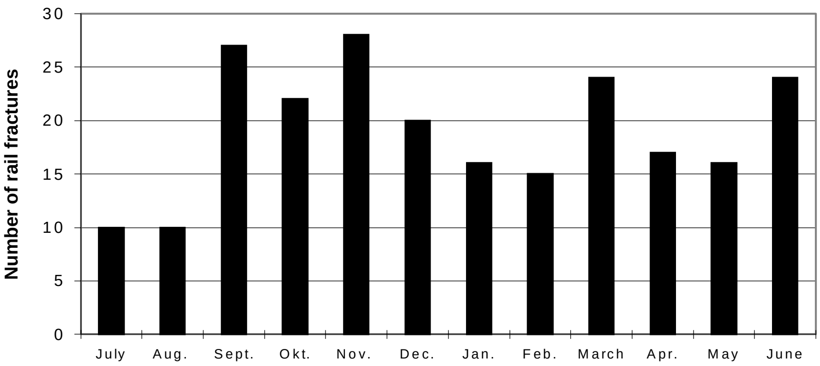


Figure 2: Number of Rails Fractures on all Underground Lines of London, between 1980 and 1988

WEAK SPOT OF RAIL - WELDED JOINT

The frequency of defects was highest at welded joints at all underground networks, but a defect of a welded joint is more easily to discover because it can only turn up every 15 m or 30 m (depending on the length of rail). It was found out in Vienna that frequency of rail fractures was very high at electrically welded rail joints, so where it has been possible nowadays alumino-thermic rail joints have been carried out.

Table 1: Rail fractures in Vienna 1996; 26 rail fractures; 20 quality 900A; 5 quality HSH (Head Special Hardened); 1 not quoted

Coding	Position of defect	Number
00	not quoted	1
01	running rail	1
03	in area of frog	1
06	fish plate joint	7
09	electrically welded joint	12
10	alumino-thermically welded joint	4

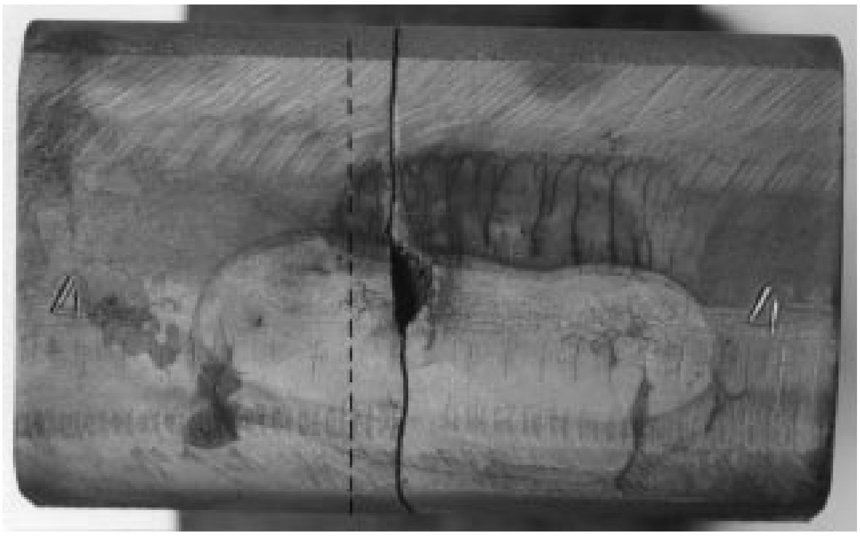
SURVEY ON RAIL FRACTURES AT UNDERGROUND NETWORKS OF THE WORLD

The mean value of rail fractures of 30 underground networks is m = 0,1221 rail fractures/year and track km, the standard deviation was evaluated with 0,10011. That means that with an assumed track length of 100 km at a fictitious underground network the expected mean value amounts to 12 rail fractures per year (Standard deviation ± 10).

EXAMPLES OF RAIL FRACTURES WITH REGARD TO FRACTURE MECHANICS

Wiener Linien (Vienna Underground) examined and documented about 60 rail fractures.
Following data were documented:
The day of production of rail,
the day of laying,
the day when the fracture had happened (if it could be found out),
the air temperature at the time of fracture (rail temperature would be better but is very rarely available),
the position of the track (tunnel, open air)
and the way of laying (ballasted track, ballastless track, guard rail, types of sleepers etc.)

Four typical examples are discussed



Example 1

Figure 3: Fracture of a HSH Rail (Head Special Hardened)

This rail fracture (Fig. 3) occurred two years after laying (track is situated in the open air) at a temperature of –1°C. The fracture was vertically situated (head – web - foot). Fatigue crack band markings could not be discovered, because the fracture was fish-plated after discovery and should have been welded at a later point of time. A sample of this rail containing the fracture was sent to the rail manufacturer and it came out that a welding on the rail surface had been carried out where the fracture had obviously started from (Fig.4).

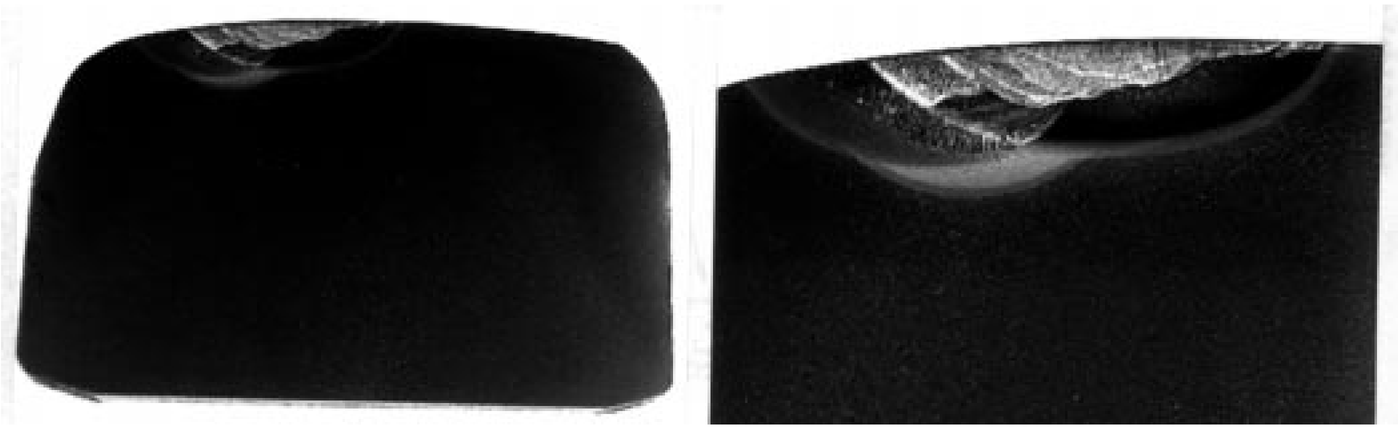


Figure 4: Example 1;The oval zone was etched and appeared as a spot welded in some layers)

Example 2: Wheel-slip mark. This kind of rail defect is usually repaired by surface welding that might cause cracks owing to embrittlement. So these defects although having been repaired are therefore documented by Vienna Underground and are periodically controlled with regard to cracks.

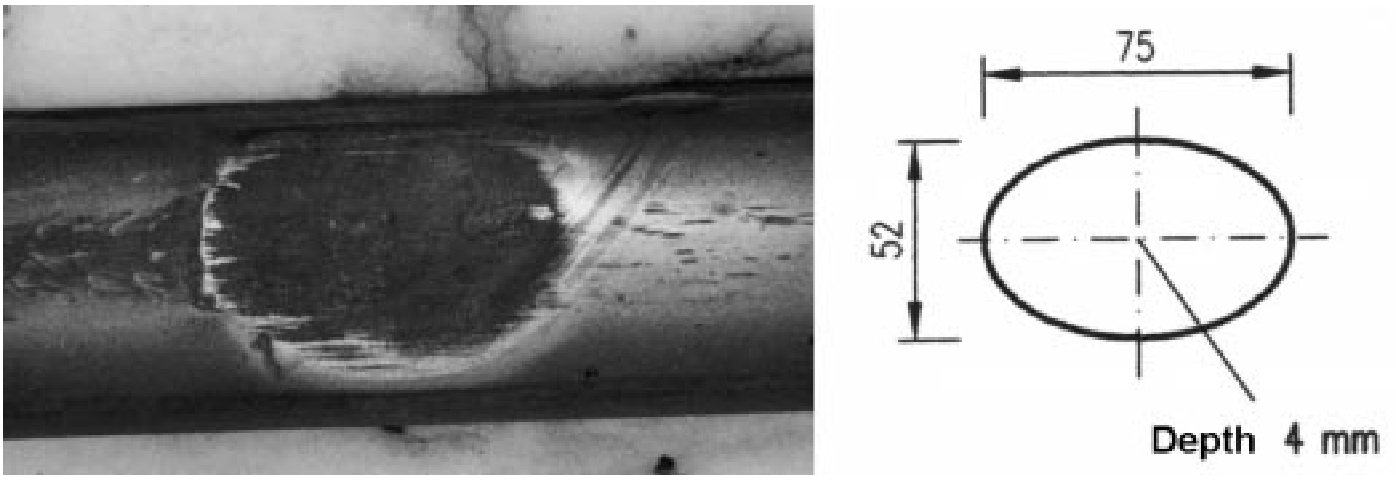


Figure 5: Example 2; Wheel-Slip Mark

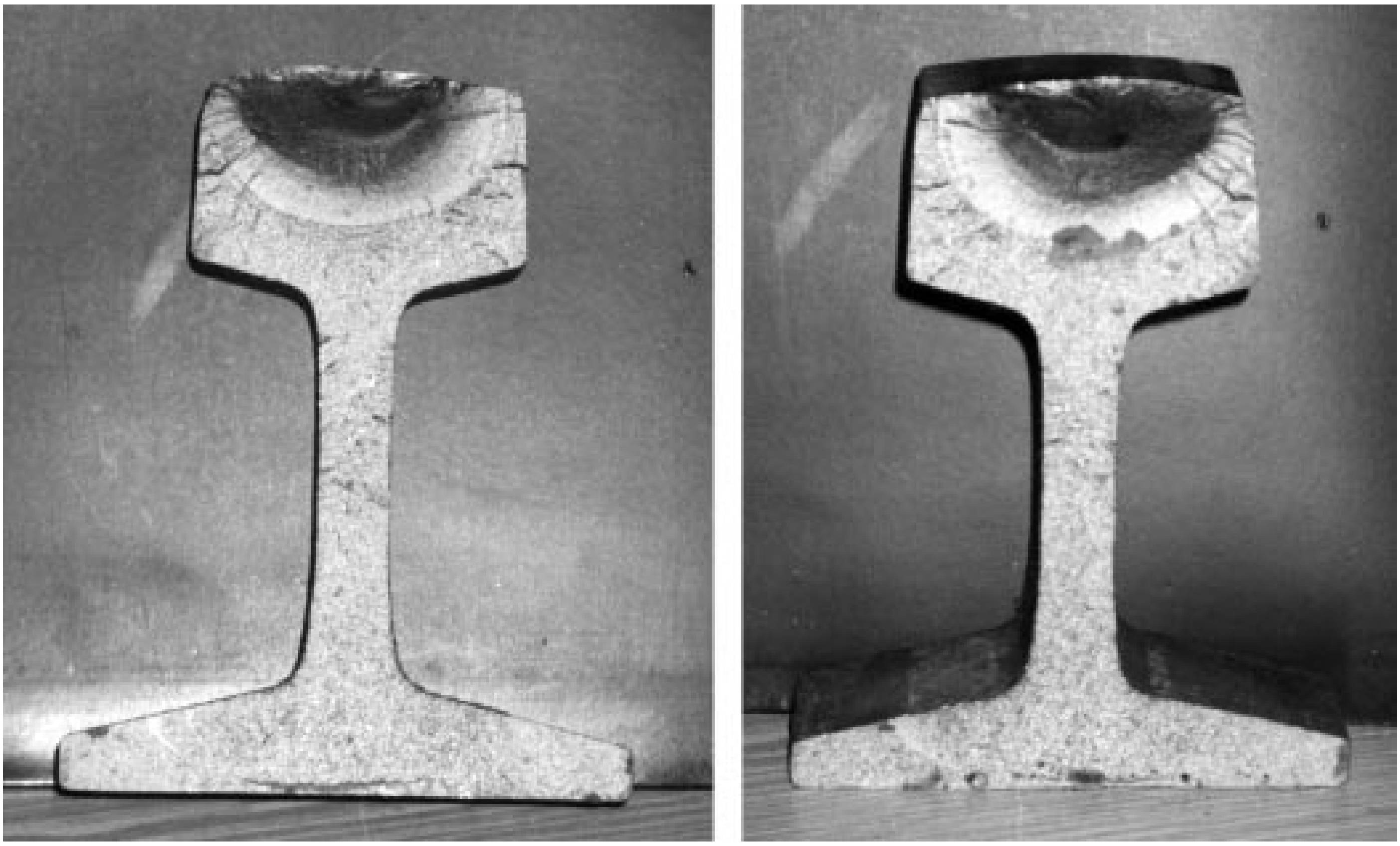
Example 3

Figure 6:; Fracture of Welding (at welded fish-bolt hole)

The rail was laid in 1975, quality 900A.
This fracture occurred on February 1st, 1996 at a temperature of –7°C.
The track is situated in the open air. It appeared that as long as the defect remained an interior defect no fracture occurred. Owing to wear the inclusion got contact to the surface, moreover the tensile stress was increased by sudden coldness.

RAIL FRACTURE (HEAD-WEB-FOOT)

Example 4: The fracture turned up in the tunnel of Line U2 on March 3rd, 1996 Fig. 8. The air temperature was +11°C, so no additional tensile stresses could have turned up. The rail has been laid on April 4th/5th, 1985, so service life in track had been 11 years. Guidance rails are installed at radii below 300m (Regulations of Vienna Underground). Because this rail in question was situated on the inner side of the curve (225m), horizontal forces had been absorbed to a high extent by the installed guide rail.



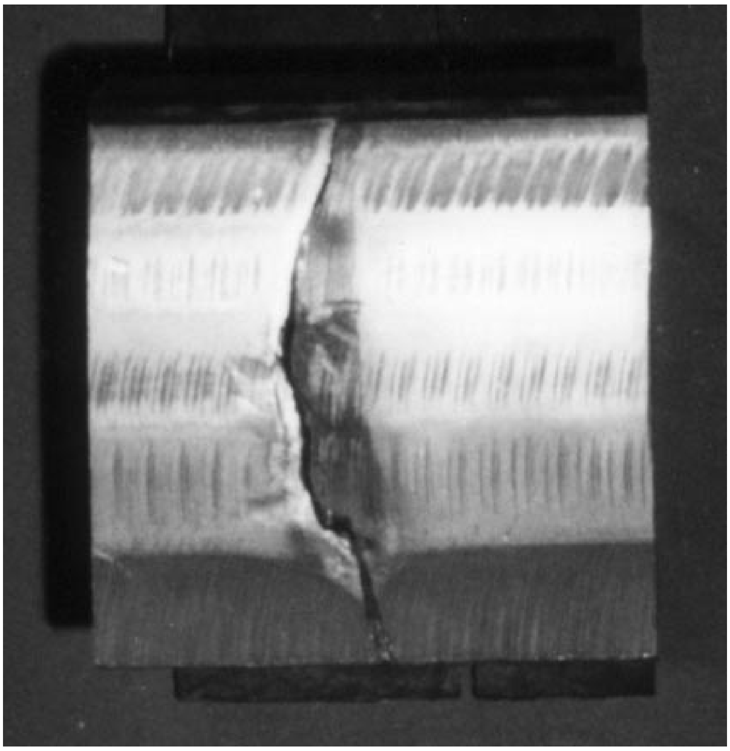


Figure 7: Example 4; Rail fracture (head-web-foot)

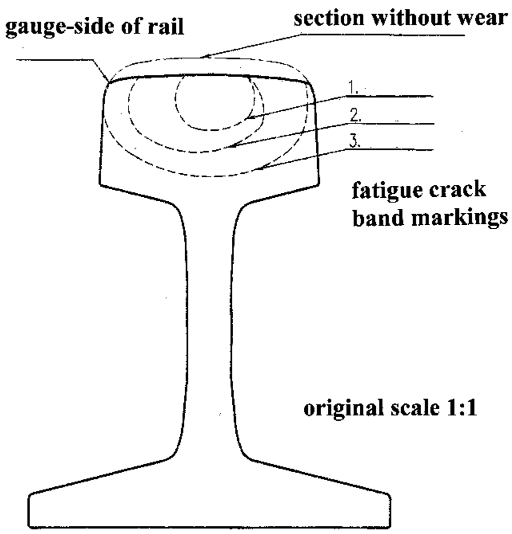


Figure 8: Example 4

The ellipse of the last fatigue crack band marking showed “a” with 32 mm and “2c” with 65 mm. The broken rail was examined at laboratory and thermal influence (martensitic structure) was found at the spot where the fracture had originated from.

APPLICATION OF FRACTURE MECHANICS AT RAILS OF VIENNA UNDERGROUND

Fine fissures on rails may probably originate during production, transport or laying, but also in the course of operation (wheel slip marks).These fissures may also be caused by corrosion. By means of linear elastic fracture mechanics the significance of such failures can be judged with regard to the behaviour of a rail under load in track, if fracture toughness is known as a characteristic value of the rail steel. First trials on sections of rails with fatigue cracks were executed by British Rail. Later on experiments were made in the USA. Engineering fracture mechanics that is based on simplified models results in engineering methods for treating the fracture behaviour of construction parts with cracks.

The K_{IC} - mean value of rails of the Vienna Underground evaluated by tests of the producer and the TVFA TU Vienna lies in the range of 37 MPa√m at -20 °C and 39 MPa√m at room temperature [2]. If the value K_{IC} 38 MPa√m is applied to defect fig. 7 and 8 then the evaluation for the measured crack depth and crack length results in a stress σ_c = 107 N/mm² according to the formula for an edge crack

$$K_{IC} = 1.12 \times \sigma_c \times \sqrt{\pi a_c}$$

This value lies in the range of measured stresses during operation.

An evaluation with the formula used in [3] resulted in higher not realistic values (crack reached the lateral surfaces of the rail head).

$$K_{IC} = M \times \sqrt{\frac{\pi a_c}{Q}} \times \sigma_c$$

$$Q = 1 + 1.464 \times (a_c / c_c)^{1.65}$$

$$M = 1.12 - 0.09 \times (a_c / c_c) \quad \text{Newman, Raju [4].}$$

CONCLUSION

The number of rail fractures /year and track km had risen continuously at Vienna Underground until 1992, so measures had to be taken against. The first step consisted in registrating and recording of these rail defects which was followed by measurements of stresses during operation and simulating of these stresses at laboratory.

These measures resulted in first statements on behaviour of material and structure (behaviour of crack propagation, fracture toughness, residual life) under operating conditions. Knowing the critical fracture toughness of the material it has been possible to indicate the critical margin of defects that must be recorded by non destructive testing to take measures (repair or exchange) at an appropriate time

The fracture mechanics assessment showed that the K_{IC} -value, determined by tests, and the critical size of defects before fracture correspond rather well to the maximum stress that was measured during operation, so it has been possible to indicate critical limits of defects [5].

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