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How to cite this thesis
INSULATED RAIL JOINTS

by

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Dissertation submitted in compliance with the requirements for the Masters Diploma in Technology in the School of Civil Engineering at the Technicon Witwatersrand Johannesburg

December 1991
Declaration

I hereby declare that the dissertation submitted herewith to the Technicon Witwatersrand in compliance with the requirements for the Masters Diploma in Technology in the School of Civil Engineering is my own work, except where assistance has been acknowledged. It has not previously been submitted to any institution to obtain any qualification.
This dissertation is dedicated to
the late Mr Desmond W. Hoffmann,
who first introduced me
to insulated rail joints
and who, through his dedication,
encouragement and keen sense of humour,
did much to develop insulated rail joints
to the level that we know them today
on Spoornet track.
SUMMARY

In this treatise the insulated rail joint is discussed from a largely practical perspective.

The various components of the joint, problems experienced with joints under operating conditions, and the resulting developments, are described. General maintenance procedures and the measures taken to overcome weaknesses and problems arising in track, are discussed.

The forces acting on the joint are discussed from a theoretical point of view and an example calculated to enable the designer to have a better understanding of the joint and the forces to be designed for.

Various types of field and laboratory tests, past and present, are discussed, as well as the development of a new laboratory test which endeavours to come closer to actual track conditions than previous tests. Attention is also given to a Spoornet field evaluation done on ten different types of joints and strain gauge tests done under track conditions to determine actual stresses under various conditions. The results of all these tests initiated various improvements in design and maintenance procedures, the most important being that it should be ensured that the joint is always well tamped, as a slack
under the joint dramatically increases the stresses in the joint.

This scientific base, combining practical experience with the knowledge gained through the study of theoretical principles, has found application in the proposed specification for insulated rail joints as set out in chapter 13.

However, development on insulated joints is continuing and the last word has definitely not been written on this subject.
OPSOMMING

In hierdie verhandeling word die geïsoleerde spoorstaaflas merendeels vanuit 'n praktiese oogpunt bespreek.

Die onderskeie onderdele van die las, probleme wat onder baantoestande met die lasse ondervind word, sowel as nuwe ontwikkelings, word beskryf. Algemene instandhoudingswerkwyses en stappe wat gedoen word om probleme wat in die baan bestaan, te oorkom, word bespreek.

Die kragte wat op die las inwerk, word vanuit 'n teoretiese oogpunt bespreek en 'n voorbeeld is uitgewerk om die ontwerper 'n beter begrip te gee van die las en kragte waarvoor ontwerp moet word.

Verskeie laboratorium- en baantoetse word bespreek, sowel as die ontwikkeling van 'n nuwe laboratoriumtoets wat poog om baantoestande beter na te boots as vorige toetse. Aandag is ook geskenk aan 'n Spoornet baanevaluasie van tien tipes geïsoleerde lasse en inbaan toetse om die werklike spannings in die lasse te bepaal onder verskeie toestande. Die resultate van al hierdie onderskeie toetse het verskeie verbeterings in ontwerp en instandhoudingswerkwyses teweeggebring, die belangrikste waarvan is dat verseker moet word dat die las te alle tye goed onderstop moet /......
moet wees aangesien 'n slapte onder die las die spannings in die las grootliks laat toeneem.

Hierdie wetenskaplike grondslag, wat die praktiese toepaslikheid en die verworwe teoretiese kennis verenig, is in 'n nuwe voorgestelde spesifikasie vir die aankoop van geïsoleerde lasse saamgevat in hoofstuk 13.

Ontwikkeling van geïsoleerde lasse gaan steeds voort en daar sal in die toekoms nog veel gesê word oor hierdie onderwerp.
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CHAPTER 1  INTRODUCTION

1.1 History

The track structure, crowned by the rail, is essentially a supportive roadway for the train. The first railroads were built quite early in the European countries. A narrow gauge railroad in the mines at Leberthal, Alsace, was illustrated in "Cosmographiae Universalis" by Sebastian Münster in 1550. (Britannica Vol 15, p 478)

A mining wagon with flanged wooden wheels and track was used in the gold mines of northwestern Transylvania in the mid 16th century and can be seen in a transport museum in Berlin.

Plateways or flanged rail systems were widely used because the wagons did not require flanged wheels and could be used on the rail and on ordinary roads, as long as the wheels had the correct gauge to fit the flanged rails. The flanged rail gave way to the flanged wheel, at least partly, because of the difficulty of devising a workable switch or turnout for the flanged rail. (Britannica Vol 15, p 479)

In England routes for coal transport were lined with wood in the 17th century, providing an all weather tram road.
In 1767 Reynolds covered planks with cast iron plates to reduce wear. These plates had a slightly lateral elevation in order to guide the wheels. In 1789 Jessops developed the mushroom rail, eliminating the longitudinal planks. Bending stresses caused cracks, resulting in transverse ruptures. Thus fishbellied rails, bellying out on the underside, were developed in 1822 by Berkin Shaw. These were used for the Stockton to Darlington railway that was opened in 1825. The rails were rolled 4.57 metres (15 feet) long with a mass of 14 kg/m (30 lbs/yard).

(Fastenrath, 1977, p 10-11)

The first public freight-carrying railroad in Britain was the Surrey Iron Railway, opened from Wandsworth to Croydon on July 26, 1803. (Britannica Vol 15, p 478)

The real railroad era began with the opening of the Liverpool and Manchester Railway on September 15, 1830. It incorporated all the features of modern public railroads. It was a public carrier of both passengers and freight, with all business handled directly by the company itself. It used mechanical traction for all traffic.

(Britannica Vol 15, p 479)

An English engineer, Charles Vignoles, is credited with the invention of the broadbased rail in the 1830s.
A similar design was also developed by Robert L. Stevens, president of the Camden and Amboy Railroad in the United States. (Britannica Vol 15, p 488) It was the need for stability at the rail fastening, together with the problem of high bending stresses, that led to the development of the broadbased rail by the above mentioned Stevens. (Fastenrath, 1977, p 11) This flat bottom rail is often called the "Vignol" rail by manufacturers. (Fastenrath, 1977, p 5)

The first railway line in South Africa was the 3 km Durban to Point line, opened in June 1860. In 1862 a 34 km line was opened between Cape Town and Eerste River. Both these lines were built to the European standard gauge of 1 435 mm. The gauge on all railway lines in South Africa was changed to 3' 6" (1 067 mm) by 1882. The discovery of gold and diamonds prompted the construction of a number of long distance lines. The Cape Town - Johannesburg line was completed in 1892 and the NZASM line to the east coast by 1895. In 1910 all railway lines were put under the central administration of the South African Railways. Electrification of lines started in 1925 and in 1958 diesel traction was introduced. (Ebersohn, 1990, p 1.1-2)
There are two main types of rail joints, suspended and supported joints. Supported joints join the rail on top of the sleepers or rail ties and are carried by special chairs. The suspended joints are suspended between the sleepers. (Heeler, 1979, p 31) The suspended joints are generally used on most railways and are also used in South Africa for insulated rail joints.

In a normal joint, steel fishplates are used and steel to steel contact occurs. An electrical current would therefore be carried over the joint. Modern colour light signalling requires the use of isolated track circuits and therefore the insulated joint became a standard track item the world over.

1.2 Background

The insulated rail joint consists of two rails cut squarely at the ends, separated by an end post and physically joined and held together by two fishplates, one on each side of the rail, and four or six fishbolts.

The end post is an insulating distance piece required to keep the two rails apart when the rails are in compression due to high temperature. It is also needed to fill the gap between the two rails and, in doing so, keeps foreign matter /.....
matter from falling into this gap causing damage or electrical failure. The end post is usually from 4 to 6 mm thick and can be used singly or in multiples.

**Fig. 1** The component parts of the insulated rail joint.
The plates connecting the two rails are called fishplates, after the fishbellied rails developed by Shaw. These plates keep the rail ends in alignment in the horizontal, vertical and lateral planes. To achieve this, the plates must be true-fitting and held very tightly into the web profile of the rail. The surfaces under the rail crown and on the bottom flange where the fishplates come into contact with the rail, are wedge-shaped to facilitate tight fitting and are called the fishing surfaces. The fishbolts are used to keep this assembly together and protrude through the bolt holes in the rail and the fishplates. These bolts are to be kept well tightened, as a loose assembly can cause excessive wear and damage, not only to the joint, but also to the track structure.

As the two rails are to be electrically insulated, the one from the other, the above mentioned parts are either to be manufactured from insulating material or insulated by other means. Therefore a host of different designs exist, each with its own, mostly patented, ingenious insulating arrangement.

On jointed track the longitudinal forces in the rail are relatively small and hardwood fishplates were used with success for some years. When the technology was developed to make laminated, compressed wooden fishplates, these were /......
were used instead. Spoornet still uses some of these as there are quite a number still in stock.

The first continuously welded rails were introduced in Europe in the twenties. The first tests on continuously welded rail by the old S. A. Railways were conducted on a one mile section in 1938. Since the late fifties it has been standard practice to continuously weld rail where possible. Continuously welded rail presently constitutes more than 10 500 km of track or more than 30% of Spoornet track. (Wildenboer, 1983) This figure is growing since the minimum radius of curve that can be continuously welded has been reduced to 200 metres during 1991 in a letter, reference S.I.(W)2/4/1/5/2, dated the 12th of February. The use of continuously welded rail is restricted by sleeper type, rail mass and the radius of track curvature.

The advent of higher axle loads and continuously welded track necessitated the development of stronger joints. Along the lines of the laminated wooden joint, a laminated fibre-glass or glass reinforced plastic joint was developed and this is used with great success worldwide.

Steel encapsulated joints have proved to be of greater strength and are used for high axle load and heavy haul lines /......
lines. Various encapsulating insulating materials have been used with varying degrees of success. Steel joints bonded to the rail by some insulating system, such as epoxy or glue impregnated fabrics, are favoured internationally on heavy haul lines.

The Spoornet Signalling Department has tested electronic devices in place of insulated joints with some degree of success. These were found to be prone to damage by lightning and also not suitable for use on points and crossings.

In 1985 it was decided that insulated rail joints will be controlled and purchased by the Civil Department. There are approximately 50 000 joints in track, 20 000 in continuously welded rail. The replacement costs, material only, amount to approximately R1,5 - 2 million annually. It is projected that a 20% longer track life will save approximately R300 000 annually on material purchases for joints.

Development on insulated joints is continuing and the last word has definitely not been written on this subject.

1.3 /......
1.3 Terminology

A certain measure of disagreement exists as to the use of the words insulate and isolate in terms of the insulated rail joint. The meanings of the two words as given by the Oxford Dictionary (fourth edition) are:

insulate - Make into an island; isolate, esp by non-conductors, insulation, insulator.

isolate - Place apart or alone; quarantine;
(electr.) insulate, isolation, isolator.

Regarding rail joints, the word "insulate" is generally used. Insulated rail joints are also referred to as "block joints".

The term "slack" is often used referring to railway track and can loosely be defined as a place in the track structure where the vertical alignment has been disturbed because the ballast bed does not give adequate support to the overlying sleepers and rails and the rail surface seems to sag. Localized vertical movement takes place under traffic load as there are voids under the sleepers where the supporting ballast has moved away. A "blind slack" is not visible to the naked eye.

MGT means million gross tons, the measure of traffic carried on railway lines.
CHAPTER 2  INSULATION REQUIREMENTS OF THE JOINT

The railway signalling system has two aims:

- To move traffic safely on a line by allowing safe
distance between trains travelling in the same
direction, and allowing safe crossing of trains
moving in opposite directions.

- To move the maximum number of trains safely on a line
during peak periods.

To achieve this, the human element must be eliminated and
a fail-safe system designed. If the system fails, it must
fail to safety. This means that, if a rail breaks or any
malfunction occurs, the signal must show the track to be
occupied.

The rail acts as a low-resistance conductor and track
circuits are isolated by means of discontinuity in the
rail. Thus the two rail ends have to be joined physically
for continuity of the track, and isolated electrically for
signalling purposes.

The joint isolates two track circuits. The one rail is
common to both circuits. The steel wheel and axle of the
train connect the one rail to the other electrically and,
as the train passes over the insulated joint, it passes to

a /.......
a new track circuit. When this happens, the track relay drops and the signal changes back to red. When there is a short circuit in the insulated joint or over the two rails, the signal will change back to red. The signal cannot be changed away from red until the short circuit has been removed.

The question arises as to what degree of insulation is required. Esveld (1989, p 101) states that on the Netherlands Railways "the electrical resistance (impedance) must be at least 10 Ω at 100 kHz".

For the purpose of this investigation the author inquired from the Spoornet Signalling Department what their requirements were. Their letter S+T/W.2/12.86, dated 3-12-86, stated as follows:

"That all pre-assembled insulated rail joints manufactured in workshops should have a resistance of at least 100 Meg Ω (100 million ohms) measured with a 500 volt megger".

This high standard was set to ensure that the electrical failure of joints in track is kept to a minimum. The rationale behind this philosophy is that the joint should be totally insulating. If the joint is manufactured to this high standard, other factors contributing to failure would /....
would stand less of a chance to actually cause failure of the joint once it is in track. It was found that field conditions tend to lead to contamination of the joint by brake dust and sand. The main culprit, however, is steel dust build-up over the joint emanating from wear between the wheels and rails. This could lead to stray currents and electrical failure of the joint in track. To solve this problem the joint is painted with a special anti-static rubberized paint before contamination can take place.

In the letter from the Signalling Department mentioned earlier (S+T/W.2/12/86) it is stated that under wet conditions the insulating material should not absorb moisture and no moisture should accumulate in the joint. To achieve this, it was decided to build all workshop assembled joints with epoxy, eliminating the possibility of moisture build-up. The completed joints are then painted with an anti-static paint, effectively sealing the joint in its dry condition and eliminating the possibility of any contamination. This decision was taken in a joint committee meeting where the Signalling, Mechanical and Civil Departments were represented. Since the acceptance of this modus operandi, no complaints about electrical failure of workshop assembled joints have been reported to Head Office staff.

To / .......
To achieve the high standard of insulation, all components of the joint separately and the completed joint as a whole must conform to the 100 Meg Ω standard. Each joint is tested to this standard before it is allowed to leave the workshop. (Admittedly this standard is very high and in practice joints with a lower resistance are put in track. This is done on the responsibility of the local signalling personnel and is found to work satisfactorily.) This insulation standard is considered necessary to achieve a high level of safety where human life is at stake. It is not considered excessive in the light of the fact that these high values can easily be achieved at little or no extra cost with the technology available.

A very high standard of insulation is also maintained between the rail and the sleeper on all the fastening systems on Spoornet track. Problems regarding insulation that could be traced back to the fastening systems have not been reported over the last five or more years. This can largely be attributed to pristine development work done in the late seventies by the Track Development Section of Spoornet on the insulation qualities of concrete sleeper fastening systems.
Insulated joints are also used by the Electrical Department to insulate other railway lines from electrified lines for safety reasons, e.g. oil sidings where petroleum and other flammables are handled. It is also used to insulate lines so that electrolytical corrosion of underground services can be restricted. It is stated in letter CEE/W20/133/6/4, dated 1986-09-08, that the joint must be able to withstand 700 volts for 0,1 second and 65 volts for a prolonged period of time. This is the standard required by the Electrical Department.
CHAPTER 3 DIMENSIONAL CONSTRAINTS

To design a joint, or any part thereof, certain dimensional constraints have to be considered. By discussing the joint part by part these constraints will be covered as, dimensionally, the joint is the sum of its parts.

3.1 End post

The end post has to keep the two rail ends apart and, if possible, help prevent the build-up of iron filings over this gap. These iron filings build up at the end of the rail due to the electromagnetic peripheral effect and the build-up eventually bridges the gap, causing electrical failure. This happens mainly at the bottom rail flange extremities. The electromagnetic effect is probably caused by a combination of the effects of the handling of the rails with electromagnetic cranes, the induction effect of the overhead high voltage electrical wires and the high voltage induction motors on the electric locomotives.

The logical solution to this problem would be to have the end post protruding around the edges of the rail. This, however, is not practical on prefabricated joints, as the joints are handled on skids and rollers during the process of manufacturing and this would cause the end posts to break /...
break. Breakage can also occur due to handling after manufacturing when the joints are loaded onto railway trucks for transport to the installation sites. The only areas where the protrusion would therefore be effective would be above the rail between the extremities of the rail and the fishplates.

![Protrusion Diagram]

Fig. 2 Protrusion of the end post beyond the dimensions of the rail.

As this area is where the biggest build-up of iron filings takes place, the end post is manufactured to protrude approximately 2 mm here. No protrusion is necessary on the sides of the rail crown, as iron filings generally do not build up here. Because of the proximity of the wheels, the wind blows the iron filings away when the train passes at speed, resulting in the build-up on the bottom flange. The action of the train wheels over the rail...
rail running surface also precludes any protrusion above the rail crown. Protrusion to the sides of the rail web is possible where the fishplate does not fit snugly into the rail profile at the web, as in the dry joints that rely on a wedge action to fit into the rail. On the epoxied joints, however, this would be a problem if the protrusion is any bigger than the dimension allowed for the epoxy. A maximum of 1,8 mm is allowed in this regard on each side of the rail.

The thickness of the end post is governed by the design philosophy of the designer. The signal engineer’s philosophy is to have as big a gap as possible to overcome possible electrical failure, whereas the track engineer wants as small a gap as possible to have the minimum hammering action from the passing wheels. With the use of chrome manganese and head-hardened rails, the metal flow in the joint area is largely reduced and a six or even four millimetre gap has become a practical reality.

The dimensions of the end post therefore have to conform to that of the rail, except above the bottom rail flange as shown in figure 2.

3.2 Bolts or studs, washers and nuts

The two governing dimensions here are the thickness and the length of the bolt.

3.2.1 /......
3.2.1 Thickness of the bolt

The standard hole size for fishbolt holes in 48 kg rail is 32 mm, with 30 mm x 175 mm bolts. Rail drills are bought in 24, 28, 32 and 36 mm sizes.

On dry joints, the difference in size between the bolt and the hole is taken up when the rail shrinks due to low temperature, causing the joint to pull open. In the past holes of 32 mm with 24 mm bolts were common in track. Such a joint can pull open by eight to twelve millimetres, depending on the accuracy with which the holes were drilled. The hammering action of wheels passing over this large gap induces extra stress in the joint. This results in extra maintenance effort as well as possible premature failure of the fishplate. To minimize this, the bolt and hole sizes should be as close as possible.

On epoxied joints, both workshop and field assembled, the epoxy fills the gap between the bolt and hole. The epoxy also glues the fishplate to the rail so that no relative movement is possible. It follows that, as long as the bolt and hole sizes are /......
are within practical limits, the sizes are not of importance.

However, three other cases need to be looked at. The first is when the epoxied joint is near the end of its service life and the epoxy loses its bond to the steel. When this happens the joint acts as a dry joint and relative movement between the rail and the fishplate becomes possible. In this case the bolts again need to be tight-fitting in the holes to allow the minimum movement.

The second case is when the joint is cut at an angle and the bolts have to take up any wedge forces when the joint is in compression due to high temperature. In this case the bolts must be as thick as possible to give maximum resistance to the wedge forces.

From the above it can be concluded that the bolts should be of maximum thickness and the bolt size should be as close to the hole size as is practically possible. Practical experience has taught that the hole diameter should be about 0.3 mm bigger than that of the bolt. If the bolt is 30 mm thick, the hole should be 30.3 mm diameter.
to allow for wear on the drill bit used to drill the holes in the rails, as well as the manufacturing tolerances on the bolt.

The third case concerns the fishplate. The thicker the bolt, the bigger the holes have to be in the fishplate to accommodate the bolts. The bigger the holes in the fishplate, the weaker the section of the fishplate over the bolt holes. As experience shows that the fishplate often breaks in service towards the middle bolt holes, it is advisable that the holes in the fishplate should be as small as possible. Breakages through the holes usually occur in the dry type of joint where the hole is bigger to allow for insulation inside the hole, insulating the bolt from the fishplate. Both the phenolic insulated joints and the nylon encapsulated joints occasionally break through these holes under service conditions.

Very few breaks through the holes were experienced on the epoxied joints with relatively small holes. As the general trend is to move towards epoxied joints, it is not foreseen that breakages through the holes will be a major problem in future.

3.2.2 /......
3.2.2 Length of the bolts

The length of the bolts is governed by possible damage during transport and damage by tamping machines once the joint is in track.

After workshop assembly, the joints are loaded onto railway trucks for transport to the districts of destination. During the shunting process the joints tend to move lengthwise relative to one another. In the past, when the bolts or studs protruded beyond the extremity of the rail flange, damage to the bolts and nuts used to occur. Wooden spacer blocks are now placed between the joints in the trucks to space them wider apart and damage to the bolts and nuts are minimized.

If the bolts protrude too far from the centre of the rail profile, they can be damaged by the tines on the tamping machines during regular tamping of the track. Figure 3 shows a safe zone of 196 mm with a maximum of 216 mm. As there are no other constraints on the length of the bolts, the maximum length should be 190 mm. The bolts should not protrude any more than 95 mm from the centre line of the rail on either side.

Fig. 3 /......
Fig. 3 Position of tamping machine tines showing free zones around the rail.

3.2.3 Nuts and washers

Any practical washers and nuts can be used with the bolts or studs, provided two threads on the bolt protrude beyond the end of the nut when tightened. (Hay, 1982, p 574) The nuts should not show a tendency to become loose in track.
3.3 Fishplates

There are five dimensions to be considered when the fishplate is designed.

3.3.1 Length of the fishplate

The length of the fishplate has for years been a bone of contention. As the length of the fishplate is determined by the number and spacing of the holes, this issue needs careful consideration. The four hole joint is more economical. As this joint requires a shorter piece of material (steel) for manufacturing, as well as only four instead of six bolts, the joint should cost about 30% less than its six hole counterpart.

The six hole joint looks stronger and more solid. Longer fishplates decrease the vertical movement between the rail and the end of the fishplate, but not at the joint or rail ends. A series of tests conducted on the American Pennsylvania and Santa Fe Railways indicated that the longer fishplates have a substantially longer service life, measured in million gross tons carried, than the short four hole fishplates. (Hay, 1982, p 567)
It used to be the practice on Spoornet track that six hole joints were used in open track, and four hole joints in points and crossings due to the difficulty of fitting the fastenings correctly. However, it was decided in 1990 that all insulated joints on the heavy haul Richards Bay Coal Line were to be six hole joints. Subsequent inspections showed that four hole test joints did not perform well under heavy haul conditions.

The steel clip fastening mechanism for wooden sleepers can be accommodated comfortably in the 85 - 90 mm gap between the bolts of the six hole joint. On concrete sleepers the standard Spoornet Pandrol clip can just be fitted between the outer two bolts on the six hole joint. There is no problem using a standard Spoornet Fist fastening on insulated rail joints. Care must however be taken that the Fist clip does not touch the steel fish-plate as this could lead to electrical failure of the joint.

It was found in strain gauge field tests that the four hole joint showed 12% higher stresses than the six hole joint. This can probably be attributed to the length of the six hole joint.

Fig. 4 /......
Fig. 4 Four and six hole fishplates in relation to sleeper spacing.

The fishplates of the six hole joint continue over the gap between sleepers to "rest" on the sleeper, whereas the four hole joint does not rest on the sleeper, causing the fishplate to carry the total load when the train passes over it. In-track evaluation of four and six hole joints on the Spoornet heavy haul lines proved conclusively that the six hole joints are superior to the four hole joints of similar manufacture. On the epoxied joints the longer six hole joints provide more adhesive area for the epoxy adhesive to cling to, resulting in a stronger joint. For these reasons six hole fishplates should be used in stead of the shorter four hole fishplates wherever practical.

3.3.2 /......
of this the forces are carried over the gap by the fishplate. The fishplate has to be strong enough to take the shear force at the joint but, in bending, the joint acts as a complete unit. The section of the epoxied joint either side of the gap is considerably more stiff and does not bend as easily as the rest of the rail. The dry joints, however, allow movement of the rail relative to the fishplate and more bending therefore takes place in the fishplate, necessitating a heavier design.

Fishplates should be designed for maximum thickness to facilitate maximum fatigue life in the joint. This would be the maximum length of the bolt, i.e. 190 mm, minus the thickness of the bolt head, washers and the nut. In the case of studs being used instead of bolts, it would be the 190 mm minus the thickness of two nuts and washers.

Care should be taken when the fishplate is designed not to have sharp surface radii and recesses that can lead to stress risers. A design that proved problematic in this regard was used on Spoornet track some years ago. A recess was cut into the fishplate to accommodate the standard Flat sleeper fastening, ending in a 13 mm radius close to the bottom / ........
bottom of the two centre holes. Many of these fishplates broke in service, the crack emitting from this stress riser. It was ascertained by the use of photoelasticity that this was the cause of the breakages. The use of this type of fishplate has since been discontinued. The photoelastic test is discussed in chapter 10.

3.3.3 Hole sizes and spacing

As mentioned under the bolt size discussion, the holes should be small, as the fishplates tend to break through the bolt holes when the holes are big. It would therefore be correct to say that the holes should be kept as small as possible.

Adequate allowance should be made for the fishplate to be able to withstand the longitudinal forces exerted on the joint. As the weakest point in the fishplate longitudinally is where the cross section is at its minimum, i.e. at the holes, it must be designed to take the maximum force that the joint is expected to carry. This force is around 120 tonne for an S60 rail. Esveld (1989, page 75) gives the maximum stresses in rails to be 60 N/mm² due to residual stresses, 100 N/mm² due to temperature change and 50 N/mm² due to bending.
The fishplate should be designed to allow for the temperature and the bending stress indicated by Esveld.

As a rule of thumb, to withstand these forces there should be a minimum of 2 000 square millimetres cross sectional area, i.e. 40 x 50 mm of steel, to each fishplate. This was calculated by using the yield strength of En8 steel, namely 280 N/mm².

The hole sizes should allow for the bolt as well as insulation around the bolt or on the inside of the hole. Some designs allow for insulation on the bolt where other designs have insulation around the inside diameter of the hole.

The spacing of the holes differ from one design to another. It is determined by the standards of the railroad concerned and the design philosophy of the designer. On Spoornet track a standard spacing for all fishplate holes, insulated or non-insulated, is used. The two centre holes are spaced 140 mm apart, the next two (outwards) 100 mm from the centre holes and the outside holes of the six hole joint a further 140 mm outwards, as shown in diagram Z 2181, figure 8, page 39.
Some European manufacturers and railroads prefer to have the centre two holes closer, e.g. 100 mm. It is presumed that the rationale behind this is to have maximum clamping and therefore wedging force close to the joint. However, the closer to the joint or rail end, the higher the stresses in the fishplate, and the higher the probability of the fishplate breaking into the hole when fatigue cracking develops.

Studies were done at the University of Illinois Experiment Station on the effects of bolt hole spacing on rail web stresses. (Hay, 1982, p 499) These tests indicated that "high intensities of tensile stress in a vertical direction are produced at the bolt holes and in the upper and lower fillets at the rail end when the track bolts are tightened to tension approaching the upper range of that used in track." When the distance between the joint or rail end and the first bolt hole is increased, the stress intensities in the web are decreased. "A wider spacing between bolt holes and rail ends reduces maximum tensile stress and the possibility of fatigue failures. Inadequate bolt tension / ......
tension severely increases the stress range in the upper and lower fillets and bolt hole areas." (Hay, 1982, p 499)

The distance between the last hole and the end of the fishplate is governed by the strength of the material from which the fishplate is manufactured. On the glass reinforced plastic fishplates it is found that the bolt sometimes pulls through the end hole when the joint is subjected to excessive stress due to temperature forces. It must therefore be ensured that there is enough material to prevent this type of failure from occurring. A distance of between 50 and 60 mm is usually allowed between the centre line of the hole and the end of the fishplate and this seems to work in practice.

Usually the end of the fishplate is square in design. The latest local glass reinforced plastic fishplate, however, has round ends. This is due to the manufacturing process where the glass strands are wound around a mandrel, producing round ends.

3.3.4 The top angle

The fishplate usually protrudes past the side of the rail crown. On a worn rail, this protrusion can /......
can be knocked by a worn train wheel. Therefore the fishplate is cut away at an angle or at a radius. Spoornet drawing diagram Z 2191 shows a 30 mm radius here, but no point of reference. As the wheel has a curved profile, the cut allows for the fishplate to fit even when the wheel protrudes past the bottom of the rail crown.

Fig. 5 Theoretical position of a worn wheel on a worn rail in relation to the insulated fishplate for maximum crown wear.
The maximum flange height allowed by Spoornet is 35 mm, and the maximum wheel tread wear allowed 6 mm. (Transnet Code of Practice No 2, 1990, p 2-12)

The maximum crown wear allowed on Spoornet rails is 16.6 mm on 560 rails, 16.3 mm on 57 kg rails and 13.8 mm on 48 kg rails. (Permanent Way Instructions, 1984, p. 75)

Rails worn to maximum crown wear is very rarely encountered in track. As the insulated joint constitutes a weak spot in the track structure, the joint has a limited life and is replaced before the rail reaches considerable crown or side wear. The extreme case of wear as shown in figure 5 should therefore very rarely occur in track.

When the joint is in a curve it is exposed to side wear. Because of the nature of the side wear process, little crown wear occurs. As the side wear progresses into the rail, some metal at the bottom of the rail crown is forced down by the action of the wheels. This metal protects the fishplate against damage from wheels but at the same / ......
same time results in metal flow and consequently electrical failure takes place. It should be ensured that the wear of the curved rail is taken into account when the joint is replaced. If at all possible, insulated joints should not be installed on sharp curves. In practice signals are placed for maximum visibility and therefore signals and the accompanying insulated joints are only placed on sharp curves in exceptional cases.

3.3.5 The bottom angle

The fishplate is designed with an angle in the bottom face below the fish bolts to allow for the fastening systems holding the rail to the sleeper. Extracts from Spoornet drawings showing these dimensions are illustrated herewith.

When the design of any of the joints presently used on Spoornet track is compared to these drawings, it is immediately evident that the joints all foul both the standard Fist and Pandrol fastening systems. These fastening systems are both used widely on Spoornet track with concrete sleepers and unreported problems are therefore probably experienced by maintenance staff under track conditions.
Fig. 6  Extract from Spoornet drawing D.O.C. 347 SHT 1 showing clearances for the design of insulated fishplates on S60 Pandrol PY sleepers.

Fig. 7  Extract from Spoornet drawing D.O.C. 347 SHT 2 showing clearances for the design of insulated fishplates on S60 Fisit FY sleepers.

With /......
With the glass reinforced joints and the nylon encapsulated joints there is no danger of electrical failure should the fastening system be in contact with the joint. However, on the uncovered joints with steel fishplates used extensively on the Richards Bay Coal Line, a real danger of electrical failure exists should the fishplate touch the fist rail fastening on both rails, as direct electrical contact will result.

Problems in this regard have not been reported to the Rail Technology Section of Spoornet for the last five years or more. This, however, does not mean that field staff do not experience problems. It merely indicates that it is not considered a major problem, or alternatively, that somehow they make do.

This anomaly was taken up with the fastening and fishplate suppliers in an effort to find a satisfactory solution. For the Fist fastening it is intended that a small glass filled nylon "glove" will be designed to fit over the ends of the fastening, insulating it from any possible contact with the fishplate. A solution is still being sought for the Pandrol fastening.
3.4 Insulation

The position, thickness and nature of the insulation are determined largely by the type of insulation used, the design philosophy of the designer and the standards set by the using railroad company.

Spoornet used to have a rule of thumb that there should always be at least half an inch (12.5 mm) of insulation between adjoining steel surfaces. However, this did not apply over the joint gap. The reason for this was to make it difficult or impossible for stray currents to cross contaminated and dirty insulation. Since the whole prefabricated joint is now painted with a thick, highbuild chlorinated rubber non-static paint when the joint is manufactured, the necessity for this rule has lapsed. However, dry field assembled joints are usually installed without this paint. Therefore a similar clause was written into the tender specification for insulated fishplates, stating that "on exposed surfaces at least 10 mm of insulation must separate one conductive surface from the next...." Chapter 13, clause 13.2.4.

The thickness of the epoxy on the new generation joints is determined by the strength of the epoxy and the probability of failure due to poor construction techniques. If the /.....
the layer is too thin, unevenness in the rail and fishplate could cause electrical failure. If it is too thick, it could cause wastage of expensive epoxy and a structural weakening of the joint. A practical compromise was struck and a 1.5 - 2 mm layer of epoxy is used in the finished product on the locally developed joint. The glass reinforced plastic spacers used in the construction of the joints are designed to allow for some 0.5 mm flattening due to the pressure applied to them when the studs are torqued up, giving a final 2 mm epoxy coat.

The thickness of other products like polyurethane, nylon and phenolic resin is determined largely by the physical properties of the material, the manufacturing process and the possibility of wear in the joint area. The thickness for each design therefore is different.

Spoornet Diagram Z 2181 gives maximum dimensions for insulated rail joints, as well as manufacturing tolerances. It has been used extensively over the last seven or eight years as a guide to prospective manufacturers of insulated rail joints, and it was attempted to keep to these dimensions when the specifications were reviewed.
LASPLAAT MOET ONTEWERP WORD OM FIST BEVESTIGING TE AKOMMODEER.
FISHPLATE TO BE DESIGNED TO ACCOMMODATE FIST FASTENING.

<table>
<thead>
<tr>
<th>SPOORSTAAP RAIL</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>48 kg</td>
<td>34</td>
<td>47</td>
<td>35</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>57 kg</td>
<td>36,8</td>
<td>47</td>
<td>46</td>
<td>70</td>
<td>32</td>
</tr>
<tr>
<td>5-60</td>
<td>37,7</td>
<td>47</td>
<td>47</td>
<td>70</td>
<td>32</td>
</tr>
</tbody>
</table>

**Fig. 8** Spoor net Diagram Z 2181, giving maximum dimensions for insulated rail joints.
CHAPTER 4  END POSTS

The end post fills the gap between the two rail ends in the joint, keeping the rail ends apart and acting as an electrical insulator. It is in the form of the rail profile and is generally four to six millimetres thick.

Weathering, delamination and general degeneration of the old compressed fibre type end post occurred under field conditions. This caused costly delays as the fishplates had to be removed to replace the end posts.

4.1 Nylon end posts

It was decided around 1976 to use nylon end posts. The white nylon end post did not delaminate and was a great improvement on the fibre type. However, the nylon was susceptible to embrittlement from ultra violet rays and the end post deformed due to pressure from the rail ends when the rails were under compression.

After consultation with the manufacturer it was decided to add carbon black to the nylon to prevent ultra violet rays from penetrating the nylon. Chopped glass fibre was added to harden the end post, thus preventing deformation under compression.

Fig. 9 /......
Fig. 9 Deformation in the nylon end post.

Industrial type MARANYL NYLON 6.6 (black), reinforced with 33% glass fibre was tested and found to perform satisfactorily under field conditions. The material has a water absorption of 0.8% in 24 hours and a shore hardness of 80 on the D scale.

About 60 000 of these end posts have been ordered since and are used all over South Africa. This figure was supplied by Spoornet Track Material Office during 1991.
Various glass reinforced plastic (hard fibre-glass) end posts, and end posts made from black polyurethane or high density polyethylene were also tested. The results were reported as follows:

"Many of the end posts used in the test joints were too hard and brittle, causing breakages. At the other extreme some were too soft and could not withstand the high compressive forces, causing electrical failure. The black glass filled nylon type proved to be a success as it is both hard and durable." (Hoffmann and De Koker, 1987, p 15)

4.2 Clip-on end posts

An end post was also needed to replace broken or damaged end posts quickly and economically under track conditions without having to take the fishplates off the rail. At first the idea of pouring polyurethane into the joint was considered. A suitable joint was selected in track and all openings closed up with masking tape. A cable jointing pack of polyurethane was mixed and poured into the joint. The polyurethane leaked past the masking tape and, as it was a cold day, took a very long time to coagulate (gel). This method could still be made to work if a more suitable sealing agent such as putty or prestik were /......
were used. However, it was abandoned because of the long setting time and the high cost of polyurethane.

Two nylon end posts were then taken and cut out with a hack saw so that the pieces clipped into each other. The regular manufacturer of end posts was then approached to make a few samples out of black glass filled nylon. These were put in track but were found to be too high, due to the fact that the specific rail crown was worn by about three millimetres. It was also found that, during the night, when the joint pulled open, the bottom piece would fall out as a result of the vibrations caused by passing trains. It was then decided to put a groove into the clip-in section of the end post. A small bulge was added to the bottom piece as it was found to break in the middle. A trial run of this upgraded end post was manufactured and it proved to be a success. These end posts are now used throughout South Africa and orders for some 27 000 were received by the middle of 1991. No reports of problems with these end posts have been received from maintenance staff. Personnel from the Signalling Department are very positive about the use of this type of end post.

Fig. 10 /........
Fig. 10  Front view of the clip-on end post with a section through the clip.
CHAPTER 5  THE SIZE OF THE END POST GAP

Although the gap between the two rails is the major weak point in the joint, hardly any literature could be found on this aspect. Everyone seems to accept the gap as a necessary evil.

5.1 Eliminating the joint

The firm manufacturing thermit weld portions was approached to investigate the possibility of developing a thermit weld with resistance high enough to act as an "insulated joint" in place of the present type of joint. It was theorized that, if an acceptable resistance could be achieved over a thermit weld, technology could be developed in collaboration with the Signalling Department to make it work. It was found that this idea was not viable, for the following reasons:

All high resistance metals are very brittle. This would render the completed joint susceptible to breakage in track.

The resistance of a conductor is directly proportional to its length and inversely proportional to its cross-sectional area. It increases with increasing /......
increasing temperature for steel. (Britannica Vol 8, p 523) The cross-sectional area of a 48 kg rail is 60.8 cm² and that of a 57 kg rail is 73.2 cm², rendering them practically useless as resistors.

The cost implications of making a joint out of high resistance metal would probably make it uneconomical. The firm concerned also did not consider it a viable proposition, so the scheme was dropped.

5.2 Cutting the joint at an angle

Various suggestions have been received over the years from permanent way staff in the field regarding the angled cutting of joints, the most common being to cut the joint at 45°. In practice this leads to a very dangerous situation where the two rails, when in compression, tend to move past each other with the nylon end post acting as a lubricating distance piece. The rails cause a wedge action and exert a very high force on the bolts. This can be calculated.
Fig. 11 Schematic presentation of the wedging forces in the joint.

Where

- \( W \) = compressive force in the rail
- \( F \) = reaction force in the bolt
- \( T \) = force exerted by the bolts
- \( \mu_1 \) = coefficient of friction between the rail and the fishplate
- \( \mu_2 \) = coefficient of friction between the rail and the end post
- \( \theta \) = angle of cut in the rail

As motion impends, these forces add to zero, and it follows that:

\[
F + T = W \left( \mu_1 + \frac{\mu_2 + \tan \theta}{1 - \mu_2 \tan \theta} \right)
\]

(Branson, 1970, p 115)
The following coefficients of friction can be used to calculate the values if the friction is taken into consideration:

<table>
<thead>
<tr>
<th>Surface Combination</th>
<th>Coefficient of Friction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminated plastic on steel</td>
<td>0.35 (dry, sliding)</td>
</tr>
<tr>
<td>Mild steel on mild steel</td>
<td>0.74 (dry, static)</td>
</tr>
<tr>
<td>Mild steel on mild steel</td>
<td>0.57 (dry, sliding)</td>
</tr>
<tr>
<td>Teflon on steel</td>
<td>0.04 (dry, static)</td>
</tr>
</tbody>
</table>

(From CRC Handbook on Lubrication, volume II, Table 2)

To calculate the theoretical reaction force F to be a maximum, the force exerted on the joint by the bolts, as well as the friction forces, must be zero. It then follows that:

\[ F = W \tan \theta \]

If \( W = 100 \) tonne, F is as follows:

- for \( \theta = 20^\circ \)  
  \[ F = 274.63 \text{ tonne} \]
- for \( \theta = 30^\circ \)  
  \[ F = 173.12 \text{ tonne} \]
- for \( \theta = 45^\circ \)  
  \[ F = 100.00 \text{ tonne} \]
- for \( \theta = 60^\circ \)  
  \[ F = 57.68 \text{ tonne} \]
- for \( \theta = 70^\circ \)  
  \[ F = 36.34 \text{ tonne} \]
- for \( \theta = 80^\circ \)  
  \[ F = 17.57 \text{ tonne} \]
- for \( \theta = 90^\circ \)  
  \[ F = 0.00 \text{ tonne} \]

These forces would be transferred to the bolts.
GRAPH 1 Wedge forces depicted graphically.

The tensile strength of 8,8 grade high tensile steel bolts is calculated as follows:

Stress under proof load for grade 8,8 steel

\[ S = 571 \text{ N/mm}^2 \text{ (industrial steel tables)} \]

Tensile strength of bolt in tonne T

\[ T = \frac{S \times \text{tensile stress area of bolt} \times A}{1000 \times 9.81} \]

For /......
For 24 mm diameter bolt $A = 353 \text{ mm}^2$

$$T = \frac{571 \times 353}{1000 \times 9.81} \quad T = 20.54 \text{ tonne}$$

For 27 mm diameter bolt $A = 459 \text{ mm}^2 \quad T = 26.70 \text{ tonne}$

For 30 mm diameter bolt $A = 561 \text{ mm}^2 \quad T = 32.65 \text{ tonne}$

In practice the difference in hole and bolt size, and friction and tolerances on the bolt, hole and rail would all reduce the effect of the wedge action. However, to achieve the probable worst situation in track, these reducing factors are ignored and a joint is accepted to have only two bolts to withstand these forces. For a 45° cut the forces transferred to the bolt will be equal to the compressive force in the rail ($F=W$). This force will result from braking force from the train, temperature forces and other possible contributors. For a 70° cut it will be only 0.36 times the longitudinal force and each of the two bolts will carry half the load.

At a 45° cut the bolts will each be able to withstand:

- 24 mm bolts: 20.5 tonne
- 27 mm bolts: 26.7 tonne
- 30 mm bolts: 32.6 tonne.

GRAPH 2 /......
GRAPH 2 Wedge forces exerted on the bolts increasing as the wedge angle becomes more acute.

At a 70° cut, the longitudinal forces of \(1 / ,36 = 2,7778\) times the forces of a 45° cut can be withstood, that is

- 113,9 tonne for 24 mm bolts
- 148,3 tonne for 27 mm bolts
- 181,1 tonne for 30 mm bolts

This means that a 70° cut can be used in practice with 30 mm diameter bolts, with a fair margin of safety as compressive forces in the rail rarely exceed 120 tonne.

A number of these joints were built and put in track. After roughly two years in track, reports from maintenance personnel / .....
personnel were very favourable and it was decided to manufacture all workshop assembled joints to this standard from 1991 onwards.

Apart from the fact that this decision was based on the above mentioned calculations, no quantifiable data is available as to how much maintenance effort is saved by this concept. The decision was verified by the subjective judgement of field staff and the author's own field observations. The reluctance of maintenance personnel to keep and supply actual maintenance figures, resulted in a decision to accept this subjective judgement.

5.3 The "Kimberley" joint

As a result of the high forces induced into the bolts by the 45° cut, it was suggested by Mr C. Gentle of Kimberley that a joint be manufactured with a 45° cut in the crown of the rail and the usual 90° cut in the rest of the rail. The bottom section of the rail would then absorb the compressive forces and the wedge action would effectively be neutralized. The idea was put into practice and a number of joints were built accordingly.

The idea worked well in practice and the people concerned reported a sharp drop in maintenance effort to the joints, again a subjective judgement. After some months in track
a number of these joints were inspected and it was clear that a much better rolling action of the wheel over the joint had been achieved.

However, the sharp point in the joint on the gauge side of the rail showed considerable signs of metal flow and yield. The yield takes place because the sharp point has to take the full wheel load during one stage of the transition of the wheel while it is not adequately supported. This is especially true when a new wheel, with little wear on the "throat" radius, traverses the joint.

Because of this problem it was decided not to adopt the procedure as country-wide standard.

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**Fig. 12** Plan view of the rail cut for the "Kimberley" joint.
5.4 Running of the wheel over the 70° joint

When the 70° cut was considered, it was decided to examine the path of traverse of the wheel over the joint in order to be sure that a sufficient contact band is available for the wheel over the joint. The thickness of the end post was taken as 6 mm.

Fig. 13 The 70° cut with a 6 mm gap.

Fig. 14 Calculation of the contact band.
To calculate the contact band for an effective available running surface of 40 mm:

\[
\cos \, abc = \frac{6}{cb} = \cos 70^\circ
\]

\[
cb = \frac{6}{\cos 70^\circ} = \frac{6}{0.34202} = 17.54 \text{ mm}
\]

contact band: \quad 40 \text{ mm} - 17.54 \text{ mm} = 22.46 \text{ mm}

For a 4 mm end post gap, \( cb = 11.70 \text{ mm} \) and the available width for the contact band increases to 28.3 mm.

Fastenrath (1977, p 51) gives the actual contact band width as 12 mm. Therefore it is concluded that the 70° cut allows ample space to relocate the contact band.

5.5 The width of the gap

Particular effort was made to determine the effect of the width of the gap between the two rail ends forming the joint, on the stresses in the joint. Two joints in the field test were specially prepared for this, one four hole and one six hole joint. (See chapter 10 for general comment on the layout of the test and the test procedure). The holes on the one side of both these joints were elongated to allow opening of the joints. Readings were taken at 0 mm, 2 mm, 4 mm, 8 mm, 12 mm and 20 mm openings.
GRAPH 3 The effect of widening of the gap on stresses in the joint.

On the graph very little was shown of the expected jump in values after the joint was opened from 0 mm to 2 mm and 4 mm. However, on the one joint a jump in values occurred between 8 mm and 12 mm, whereafter the values returned to a flatter curve again. This has no significance as this particular joint had been disturbed and then repacked by track maintenance personnel after the 8 mm tests were recorded. The other joint did not show any such increase in values.

The standard gap used for insulated joints was reduced on Spoornet over the last ten years from 10 mm to 8 mm and then /......
then to 6 mm, and strong consideration was given to reduce the gap to 4 mm. The use of chrome manganese rails in building the joints enabled this reduction since the chrome manganese rails are not so prone to metal flow in the joint area as the old UICA and HCDB type rails. The Signalling Department favours a big gap as the bigger gap is not so easily bridged by dirt, metal filings and metal flow as the smaller gap. However, the Civil Department favours a small gap as this reduces hammering as well as preventative maintenance on the joint. The Spoornet "Permanent Way Instructions", clause 528.4, page 109 (1984) prescribes a 6 mm gap.

From the results of the field tests it was calculated that the stresses are 10.07% higher in the case of an 8 mm gap than for a 4 mm gap. It can thus be assumed that the difference would only be around 5% between a 4 mm and a 6 mm gap. It would therefore not lead to a dramatic increase in joint life should the 4 mm gap be accepted as the standard. It must also be borne in mind that the 4 mm gap, being 33% smaller, would be in danger to short out electrically much sooner because of metal flow than the 6 mm gap. This is demonstrated on points and crossings where the rail stands directly upright and not at the usual 1:20 inclination. High contact stresses occur /......
occur on the rail-wheel interface, resulting in heavy metal flow in joints on points and crossings. This is clearly noticeable on the heavy haul lines where many joints are in track on chrome manganese rails in points and crossings, carrying high volumes of heavy axle load traffic. The gaps on these joints are ground regularly to remove the metal flow.

If the 4 mm gap is used with the 70° angled cut across the rail, where the hammering action of the wheels are replaced by a rolling action, the metal flow problem will be significantly reduced. It is therefore suggested that a 4 mm end post be used with the 70° angled joint and the 6 mm standard be upheld for the 90° joint.
CHAPTER 6  THE USE OF STRUCTURAL ADHESIVES AND COMPOSITES

6.1 Structural adhesives

Structural adhesives are used widely in industry and are put to innovative new applications daily. In insulated rail joints they are applied as adhesives and insulators. They are also applied in composite materials such as glass reinforced plastics for fishplates and insulators.

The nine main types of structural adhesives are each discussed briefly. The materials are all thermoset or thermoplastic adhesives, meaning that heat plays a major role in the curing process. This is a general discussion and it should be kept in mind that there are new products developed daily that do not submit to the wider general guidelines as discussed here.

6.1.1 "Hot melts"

These are thermoplastic resins with no solvents. They become soft or liquid when sufficient heat is applied and solidify again when cooled off. These products are widely used in the packaging industry and are available to the public as hot melt glues in glue guns.
The advantages of these products are that they are fast setting and economic. They have good moisture and solvent resistance and give rigidity to flexible bonds. The low heat resistance could be advantageous or disadvantageous, depending on the application. Their major disadvantages are their poor creep resistance, low adhesion and poor wetting out qualities. Special dispensing equipment is generally needed to apply these products.

6.1.2 Solution or dispersion adhesives

These are thermoplastic resins containing only 20-50% solids. These resins are usually manufactured from natural or synthetic rubber dispersed in some solvent. These products usually have a long shelf life and are easy to apply. They possess excellent wetting out qualities and no special equipment is needed for application. They can be applied to both solid and porous surfaces. Unfortunately they have low strength under load, poor creep resistance and poor heat, solvent and moisture resistance. These adhesives are well known and are used as contact adhesives in most households /......
households and are also used in the wood industry for the manufacture of chipboard.

6.1.3 Silicones

These adhesives usually do not contain solvents and are thermoset adhesives, i.e. once cured or set, the curing process cannot be reversed. They are generally used in the home as silicone bathtub or motor-car sealants. These products have a good heat resistance between 40° and 200°C and have good chemical and solvent resistance. They do not usually need special dispensing equipment. However, they have a short shelf life and are not very economical. They can take up to five days to cure, depending on the type of product, and can be applied to most surfaces. They have high impact strength and high peel strength.

6.1.4 Cyanoacrylates

This is commonly known as "wonder glue" because it sets within seconds and has a good tensile strength. It is a thermoset adhesive containing 100% solids and no solvents, although in liquid form. It is very easy to apply as it has good wetting out characteristics and no special application /...
application equipment is needed. It has a short shelf life and poor solvent resistance. It does not bond permeable materials and has poor shock and impact resistance. It should not be handled with bare hands.

6.1.5 Modified acrylics

These are PVA adhesives and are usually in liquid or paste form. They are thermoset adhesives and are 100% reactive. The PVA adhesives are widely used in the wood industry and are known under the trade names Ponal, Henkel and Alcolin. They are fast curing and can bond to "dirty" surfaces. They have good peel and shear strength. Special equipment is usually required for high volume applications. These adhesives have to be kept closed as they dry out when left in the open. They are moisture sensitive and mostly have an unpleasant odour.

6.1.6 Amino resins

These are also known as formaldehydes and are thermoset resins known for their excellent adhesion characteristics. They have high tensile strengths, a long shelf life, and are easy to apply. They have /.......
have good wetting and penetration characteristics and are available at fairly low cost. These resins are widely used in the construction wood industry where high tensile strengths are required and laminated wooden beams are usually manufactured with these adhesives. They are also used in wooden finger joints where very high strength is required. In the railway industry they are used to manufacture laminated softwood sleepers used locally as a substitute for hardwood sleepers. These adhesives are prone to shrinkage due to moisture loss during curing and tend to be brittle.

6.1.7 Polyurethanes

These adhesives contain no solvents and are thermoset adhesives. They bond to both permeable and impermeable surfaces and will even stick to glass. They can be obtained as both one or two component adhesives and are used extensively in decorative laminates such as in caravans. They are highly sensitive to moisture and need special mixing and dispensing equipment. They are also very toxic, but the new moccafree types are not toxic. Unfortunately these new types are very expensive.
6.1.8 Anearobics

These are thermoset adhesives that come in liquid form. It is usually a one component adhesive with good cohesive strength and is easy to apply, usually by putting a drop of the adhesive on the work piece. It is excellent for use with static joints and nuts and bolts that are to be kept from vibrating loose and is generally known under the trade name Locktite. It has low adhesive strength and requires a primer on many materials. It causes crazing in certain plastics and will only cure when no air is present.

6.1.9 Epoxy adhesives

These adhesives are also classified as thermoset adhesives containing no solvents. They come in a variety of forms: powders, liquid, pastes, films, tapes and rods. They are very versatile and are used in a myriad of applications in industry. Epoxy compounds are available in a wide variety of formulations. They have a variable pot life depending on formulation, a long shelf life, good chemical resistance, low creep value, and shrinkage is generally negligible.
The bond formed by an epoxy adhesive is very rigid and the curing dependent on temperature. As the epoxy usually causes the temperature within itself to rise during curing, care must be taken not to mix too much epoxy at any given time. Epoxy adhesives are used extensively in the manufacture of boats, aeroplanes and motor-cars because they achieve high bond strengths with most other materials used in the manufacture of these items. As they achieve a high bond strength with steel they are well suited to use in insulated rail joints.

6.2 The use of epoxy in insulated joints

One has to distinguish between two types of insulated joints: The "frozen" joint where the epoxy is an integral part of the joint and the "dry" joint where no epoxy is used. In the frozen joint the epoxy is used both to strengthen and insulate the joint.

In a dry joint, relative movement between the rail and the component parts of the joint causes wear, especially on the fishing surfaces. This happens mainly as a result of the bending of the joint under load, e.g. when a train passes over it, and because of movement of the rails caused /.....
caused by temperature forces acting on it. The wear, in turn, allows more movement to take place, resulting in a snowball effect. This is further aggravated by the formation of voids under the sleepers due to the increased movement.

To stop this relative movement, epoxy is used both as a filler material and as an adhesive. The adhesive quality of the epoxy is used to bond the fishplates to the rails. The epoxy must be strong enough to withstand the shear forces in the joint-rail interface.

Two epoxies were first laboratory and then field tested for this application: Ciba Geigy Araldite AV 138 / HV 998 with a lap shear strength of 16,6 MPa, and Elite Chemicals FR977A, with a lap shear strength of 9,9 MPa. The lap shear strength was tested according to test DIN 53283. Both the epoxies were found to be acceptable and the Elite FR977A was used, as the price was approximately one third that of the Araldite.

The Elite epoxy is a locally manufactured product filled with asbestos and glass chopstrand and has a 30 minute pot life, making it very easy to use under field conditions. About 17 000 portions of this epoxy has been purchased and distributed to all Spoornet Track Maintenance districts up
to the middle of 1991, according to the Spoornet Track Material Control Office.

As mentioned above, the epoxy also acts as a filler material. The standard holes drilled in 48 kg rails are drilled to 32 mm diameter. The holes in the fishplates are also drilled to 32 mm diameter and 28 or 30 mm bolts are used in track. If 28 mm bolts are used, the possible movement in the horizontal direction is 8 mm on each side of the joint, adding up to 16 mm. This enables the joint to pull open on a cold night. The epoxy takes up this space and acts as a filler that is pressed into all openings during assembly. The quantity of epoxy is calculated to be 20% more than actually needed to achieve this filling action. When the joint is assembled, all the excess epoxy is put onto the fishplate so that it can be pressed into the holes and fill up all the voids. The area between the fishplate and the web of the rail is also filled with epoxy. This prevents water and dirt from accumulating behind the fishplate and causing possible electrical failure or corrosion of the joint.

The combined effect of all the above is a joint where all relative movement has been eliminated. The joint now reacts as a unit and less maintenance is needed as a slack /......
slack does not form so easily under the joint. This improvement could not be quantified as the maintenance districts were unable to assist in this regard.

Laboratory and field strain gauge tests, however, bore this improvement out. An epoxied glass reinforced plastic joint was tested in the CSIR tensile test and an improvement of 24% (1 370 kN against 1 103 kN over a similar dry joint) was measured. See graph 4.

In the field strain gauge tests described in chapter 10, an epoxied joint was compared to an unepoxied joint, both 6 hole joints. In the bottom tension and top compression strain gauge modes, the stresses in the unepoxied joint were 19% and 30% higher than for the epoxied joint, thus an average of 24.5%. This can be seen as a significant improvement, and on the strength of this, it was decided to make better use of epoxied joints.

The type of joint where the epoxy doubles as insulator is widely used internationally. On the local heavy haul lines, i.e. the Richards Bay Coal Line and the Sishen - Saldanha Iron Ore Line, it was found that these joints perform superior to the other types, not so much in actual million gross tons traffic carried, but rather in the amount of maintenance effort required to keep the joint in good shape. (Hoffmann and De Koker, 1987, p 12 and 18)
GRAPH 4 Comparison between epoxied and unepoxied joints.

It was found that both the frozen epoxied type joint and the nylon encapsulated unepoxied dry joint last around 350 million gross tons before failure. The nylon joint, however, required considerably more maintenance effort because of plastic flow of the nylon insulating material. (Hoffmann and De Koker, 1987, p 13 and 17) As a result approximately 5 000 nylon encapsulated joints were taken out of the Coal Line stock and the nylon machined down so that the joints could fit the smaller 57 kg rail profile. These joints were distributed to all the main lines across the country where maintenance personnel reported /......
reported most favourably on the use of these joints. The nylon encapsulated joints perform well under the less strenuous conditions found in the general main lines and in the moist, coastal areas. (Hoffmann and De Koker, 1987, p 11) Epoxy was used to reinforce these joints.

During the 1970's an epoxied joint known as the "Glued Permali" was in general use on S.A. Railways track. In the assembly of this joint, spacers were used to keep the steel fishplate and the rails apart. Once the epoxy had been applied to the fishplates, these spacers slipped out of position and electrical failure of the joints resulted.

To counter this problem a phenolic encapsulated steel joint was developed locally. This proved to be a very good joint, but the brittle phenolic cracked and wore away in the fishing areas adjacent to the end post. (Hoffmann and De Koker, 1987, p 11) When the Sishen-Saldanha Line was built by ISCOR, heat-cured joints were imported, pre-assembled, from Germany. These joints gave such good service that they are now used extensively on both the Saldanha Line and the Richards Bay Coal Line. (Hoffmann and De Koker, 1987, p 12) Because of the high cost of these joints (in 1990 around R1 300 per set of components excluding the rail, after delivery in South Africa) it was decided to attempt to build a similar joint locally. However, the expected cost savings could not
not be realized and this project was abandoned.

The joint consists of two steel fishplates of high quality steel, similar to normalized En8 steel, six insulated studs and a fibre-glass insulating jacket impregnated with a heat-curing phenolic powder. The joint assembly is heated with a propane gas burner to approximately 150°C and then assembled. The studs are torqued to 1 030 Nm torque and the joint left to cool. It is then tested electrically and released for use in track.

However, a batch of about 100 of these joints were overheated in the manufacturing process, leading to electrical failure. These joints were stripped and cleaned and, because of the high cost of the heat-curing insulation, it was decided to rebuild the joints using epoxy and special spacers. The spacers were manufactured out of glass filled nylon (MARANYL NYLON 6.6) with 33% glass. This same material is used to manufacture end posts for insulated rail joints and is known not to deform too readily. The spacer was designed to fit around the stud like a washer, with a little flat vertical "tail" going upwards and downwards from the washer to fit along the whole cross-section of the fishplate. It was also decided to use one of the stronger epoxies available on the market, namely Araldite AV 138 / HV 998 mentioned earlier in this chapter, for this joint. As this epoxy has /......
has a setting time of 8 hours at 20°C, the joint can only be built in a workshop or under field conditions where no trains will pass over the joint for at least 8 to 10 hours. This was done as a joint development between Spoornet and the firms Ciba Geigy and BTR Rubber and Wheel. The spacer was patented by BTR. The epoxy was supplied by Ciba Geigy.

The joints mentioned were rebuilt according to this technique and have been in use under normal operating conditions on the Richards Bay Coal Line for about two years. The track personnel accepted these joints as equal to the heat-cured joint in performance and no extra maintenance has been reported on the joints. Inspection showed no difference in performance after the joints had been in track for about 100 million gross tons.

On the strength of this evidence it was decided to use this type of joint on a country-wide basis, in 6 hole configuration for 57 kg rails and 4 hole configuration for 48 kg rails. A contract has been entered into with BTR for the manufacturing of 1 500 of these joints for use during the 1991 - 1992 financial year. It was decided to call the joint the Dunlop High Tensile Joint, or DHJ for short. The joint costs approximately 60% of the price of the imported joint.

It /.....
It was calculated that the 48 kg rail has an effective fishplate area of 71 136 mm$^2$ available for epoxy. This multiplied with the 16,56 MPa lap shear strength of the epoxy gives 1 178 kN needed to break the adhesive in shear. For the 57 kg rail the figure comes to 2 376 kN. This leaves a fair margin of safety as 900 kN are required for a 48 kg joint and 1 000 kN for a 57 kg joint.

It can be said that this joint was developed partly from experience gained in the work done for this research project. The saving effected hereby during the first year of use amounts to around R700 000 if the cost of the DHJ joints is subtracted from that of the imported joints.

6.3 The use of glass reinforced plastic fishplates

Glass reinforced plastic, commonly known as fibre-glass, has advantages over steel in certain applications.

- It is electrically non-conductive.
- It is non-corrosive.
- It is lower in mass for equal volume.
- It is superior in fatigue strength.
- It can be formed before curing.

The major disadvantages of fibre-glass are that it elongates more than steel under equal load, it is a carcinogenic material and it is difficult to work and machine /......
machine once it is cured. Steel is superior under high tensile and compressive applications.

The reason for using glass reinforced plastic in insulated rail joints is the electrical non-conductivity and the superior fatigue performance of the product.

The glass can be cast in either polyester or epoxy. Polyester is generally a more economic product. Epoxy generally gives higher physical values and is favoured in insulated rail joints as it is a better adhesive.

Theoretically glass fibre has a tensile strength of around 3 000 N/mm² against En8 steel with tensile strength of 540 N/mm². In practice, however, this cannot be met because of the circular shape of the glass strands, the inability to pack the strands close enough, covering the strands in epoxy or polyester, and the inclusion of air in the product. All these factors combine to space the glass strands further apart, resulting in less fibres per square millimetre and a practical tensile strength in the final product of around 1 kN/mm². Where steel can only be utilized in tensile up to the yield strength, glass reinforced plastic can be utilized up to very close to its full tensile strength. The composite material remains elastic virtually up to break point.
The composite material is strongest in the longitudinal direction of the glass strands and does not show high strength across the strands. Fishplates are usually manufactured from glass mats, woven to give 10-30% glass in the vertical and the balance in the horizontal direction. The mats are then stacked in layers in a container and sprayed with epoxy. The air is extracted by vacuum and the excess epoxy removed by placing the mats under high pressure. In this way approximately 70% glass content by mass is achieved. After curing, the slab of glass is cut into sections, machined to the right size and the holes are drilled. This is usually done with diamond tipped tools under water spray as the dust is highly carcinogenic. A 48 kg joint of this type failed at the bolt holes at 978 kN under the tensile test. The joint showed no defects after 2 million cycles in a dynamic fatigue test. (Hoffmann, 1985)

Another type of glass reinforced joint is manufactured in similar fashion but the woven mats are replaced by chopstrand mats with glass fibre arranged in a haphazard way, facing in all directions. This joint was put to the tensile test and only failed at 1 512 kN. The joint was imported from France and it is suspected that a superior type of epoxy was used in the manufacturing of the joint.
A local manufacturer of epoxied products developed a joint manufactured by winding continuous strands of glass fibre on a mandrel after wetting the fibre in an epoxy bath. Glass content in excess of 70% is achieved in this way. The fishplate is then cured in a mould. The end product needs a minimum of finishing. The laboratory testing of this joint is discussed in chapter 10. The joint withstood 5 million cycles in the dynamic fatigue test without failure. However, it pulled open by 24 mm and showed very high vertical movement during the course of the test. This was to be expected as glass reinforced plastic shows about 2.5% elongation at high stress before breaking. The glass under stress over the 500 mm effective length of the fishplate, should give about 12 mm elongation. The joint had a 6 mm end post gap. The rail and fishplates allowed another 0 to 4 mm opening, depending on how accurately the holes were drilled. As the bolts tend to bend under stress, another 4 to 5 mm movement was possible, bringing the total calculated opening to between 22 and 27 mm. This correlates well with the 24 mm measured, as the glass was not stressed to its maximum.

As the glass in this joint is wound around the ends, it is superior to all other glass reinforced joints regarding pull-out through the end holes. In the CSIR tensile test the /......
the bolts bent and this caused the glass to delaminate. The bolts were standard 30 mm fishbolts. The true tensile strength of the joint is still to be determined.

The joint shows very good results in day to day field use. The theory behind this joint is borne out by a European patent application, number 86100803.5, where it is stated categorically that the glass fibres must be arranged parallel to the direction of the tensile stress. It also mentions that perpendicularly inserted fibres transfer no compressive stress at all, so that this type of insertion is without effect, and that winding fibres in the form of a figure eight around the holes achieves very little, as the fibres are no longer co-axially under stress.

The glass reinforced plastic is sensitive to breakdown of the epoxy or polyester material by weathering, especially by the ultra violet rays of the sun. The manufacturers of some types of joints add a protective layer to the joint in the final stage. The local joint is manufactured with a dark pigment added to the epoxy to minimize the effect of the ultra violet radiation.

The use of carbon fibre and aramid fibre (Kevlar) have been discussed at length with the manufacturer but these have not been used in joints tested locally. The carbon fibres are electrically conducting and both these types of fibres /......
fibres are so expensive that it wipes out the price advantage of the glass reinforced plastic joint. The glass joint costs about 60% of the price of a steel encapsulated joint. This price advantage, coupled with its low mass, high strength and superior fatigue performance makes the glass reinforced plastic joint the ideal joint for use in jointed track applications. It also performs satisfactorily in continuously welded track but is not considered very suitable for heavy haul lines because of the elasticity of the fishplates under tensile conditions.
CHAPTER 7  THE USE OF STEEL IN THE JOINT

7.1 Background

Steel is a logical choice as material for the insulated rail joint fishplate. It can withstand the high tensile, compressive and bending forces exerted on the joint and is economical to use. It can be rolled, forged or machined into any required shape. The only impediment of steel is its electrical conductivity. However, this can be overcome by proper insulation, usually by the use of some type of durable plastic covering like polyurethane, nylon or phenolic resin. Epoxy is also widely used as filler, insulator and bonding agent with steel fishplates.

In most cases ordinary mild steel gives sufficient strength for use in the insulated joint, but the use of specialized steel allows for a less bulky product and more allowance can be made for restrictive dimensions.

Heat treatment and alloying can change the physical properties of steel significantly. The controlled addition of foreign metals to steel changes the physical properties such as tensile and yield strength, corrosive properties and workability. In the absence of foreign metals, the carbon content is one of the most significant factors controlling the properties of steel. Different
temperatures and cooling rates lead to varying grain size and different rates of diffusion of carbon causing different thicknesses of the cementite lamellae in the microstructure of the steel. These differences largely govern the mechanical properties in pearlitic steels. As the lamellar thickness decreases, yield point and tensile strength increase. A similar effect can be achieved by alloying of the steel and thereby controlling the diffusion rate. (Esveld, 1989, p 152)

7.2 The use of En8 steel

During World Wars 1 and 2 a number of special alloy steels were developed that required reduced levels of alloying elements to obtain the desired properties. (Britannica Vol 17, p 642) In Britain certain "Emergency Numbers" were awarded to specific types of steel during the war and these steels are still commonly known under these numbers. Emergency Number Eight steel is thus still known as En8.

En8 steel is used where the expense of an alloy steel is not justified but where better properties than ordinary mild steel are required. It is used for engineering parts and forgings not subjected to very high stresses or severe wear, e.g. railway couplings, motor shafts, bolts, crankshafts and fishplates. As the improvement in mechanical /......
mechanical properties is usually not sufficient to justify the extra cost, the use of En8 steel in the hardened or tempered condition is mostly not recommended. (Woolman and Mottram, 1964, p 103)

7.3 Properties of En8 steel

The specific gravity of En8 steel at 20°C is 7.828 and the Brinell hardness number for normalized En8 is 152/207. The machinability of En8 in the normalized condition is 72% of that of mild steel, also called En3 steel. The following hot working and heat treatment temperatures apply to En8 steel:

- **Forging, Rolling**: 1 200°C finish above 850°C
- **Annealing**: 830°- 860°C furnace cool
- **Normalizing**: 830°- 860°C air cool
- **Hardening**: 830°- 860°C quenched
- **Tempering**: 550°- 660°C air cool

The tensile strength is 35 tons/sq.in (540 N/mm²) (minimum), the yield stress 18 tons/sq.in (280 N/mm²) (Woolman and Mottram, 1964, p 104). A comparison in the chemical properties of En8 and other fishplate steels shows very little difference in the quantities of the main elements used. The minor elements were omitted in the comparative table on page 82 (Table 1).
TABLE 1  Comparison in chemical composition of steel used in the manufacturing of fishplates

<table>
<thead>
<tr>
<th>Element</th>
<th>Spoornet Fishplate</th>
<th>Imported Fishplate</th>
<th>En8 steel 080 M40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0,42-0,52</td>
<td>0,49</td>
<td>0,36-0,44</td>
</tr>
<tr>
<td>Manganese</td>
<td>1,15-1,40</td>
<td>0,77</td>
<td>0,60-1,00</td>
</tr>
<tr>
<td>Silicon</td>
<td>0,10-0,35</td>
<td>0,32</td>
<td>0,10-0,40</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0,04 max</td>
<td>0,014</td>
<td>0,05 max</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0,05 max</td>
<td>0,038</td>
<td>0,05 max</td>
</tr>
</tbody>
</table>

Each of the elements mentioned in TABLE 1 contributes certain characteristics to the steel:

- **Carbon** - adds hardness
- **Manganese** - gives toughness and strength
- **Silicon** - aids in removing gasses during the pouring and rolling process due to its high affinity to oxygen
- **Phosphorus** - causes steel to be brittle and inclined to break under impact
- **Sulphur** - causes breaks during the rolling process

(Hay, 1982, p. 485)

The En number system is still used widely in South Africa amongst steel merchants and users alike. However, new, more...
more up to date specifications came into being over the years. The BS 970 (1955, 1970/2 and 1985) specification is probably the most widely used. The BS 970 equivalent for En8 is 080 M40 steel (BS 970 Part 1, 1983, p 91). The American SAE equivalent is SAE 1038 and 1039, as is the Swedish SIS 14.1650. In the BS 970 the 080 M40 refers to an average of 0.80% manganese and 0.40% carbon.

7.4 The use of En8 steel in fishplates

En8 steel is easily obtainable and well suited for use in insulated rail joints as it forges easily and can be machined with relative ease. It is also used by other manufacturers for fishplates, as was found when an imported fishplate was analysed by the Transnet Metallurgical Laboratory.

Fishplates locally manufactured with En8 steel were found to be full of scale marks. This was ascribed to poor quality control as the fishplates were the last batch from a regular supplier that was in the process of closing down his forging shop. Another forging shop produced samples of a better quality. The process involved heating the round billets in a furnace and dropforging the red hot steel to the required shape. After each blow the workpiece was cleaned by blowing the scale off the hot steel /......
steel with compressed air. After cropping and normalizing, however, the fishplates still had scale marks.

The furnace was found to be fired with low calorific gas produced from oil that was fed into the furnace together with air by hand operated valve. No oxygen control was installed. Excess oxygen was leaching the carbon to the surface of the steel, causing the steel to scale.

To forge En8, the steel needs to be heated in an inert or neutral, oxygen depleted atmosphere. This is best achieved by induction heating. A forging shop with ample experience in the forging of En8 steel was found. This shop has an induction heating furnace as well as larger forging hammers better suited to the forging of fishplates. Although minor scale marks still occur on the fishplates, it is well within the specification.

7.5 Induction heating

As a result of changes in the relative costs of various metal heating techniques, combined with significant advances in technology, industry is increasingly turning to induction heating. Many of the major components of induction heaters are now manufactured locally.

In forging, the induction method of heating billets achieves /......
achieves consistent heating as the correct amount of heat is applied constantly for the exact period of time. Power is only used when heating is taking place and it is an easily controllable and uniformly accurate technique. This facilitates easier quality control and saves forging time. Heat losses are minimized as only the workpiece is heated. Heating is very rapid and because of the lack of oxygen there is very little time for surface oxidation and scale formation to occur, ensuring that the forging has a good surface finish.

7.6 Problems with fishplates

Quite an interesting way was devised by the supplier to check the fishplates for correct width between the fishing surfaces. These surfaces are at an angle, as in a wedge, and the correct width can therefore not be checked easily. However, the fishplate is placed on a flat surface and two round steel bars of known diameter placed either side of it to touch the sides tangentially at predetermined height. The distance between the outside tangents of the bars is then measured as shown in figure 16.

Most problems encountered with steel fishplates can be attributed to human or design error, two recent examples of which are highlighted.
On one of the locally manufactured joints a groove was forged into the bottom of the fishplate to allow for the rail fastening. The groove ended in a sharp 13 mm radius close to the centre holes. Many joints broke in service with a crack emitting from this radius to the hole. The sharp radius acted as a stress riser and caused the fractures as was seen in the photoelastic analysis of the joint discussed in chapter 10. This problem was not foreseen during the design of the joint.

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**Fig. 16** Measuring the wedging sides on a fishplate.

A contract for the delivery of joint material was entered into where the fishplates supplied, fitted correctly into the /...
the rail profile. In 1988 identical material was ordered from the same supplier. The fishplates supplied did not fit correctly. This misfit caused the fishplate to press through the insulation when the joints were assembled and caused electrical failure only when the joints were placed in track. The fishplates had to be machined and the joints rebuilt to fit the required rail profile.

Figure 17 below is a photograph of a cross section through the joint, clearly showing the lack of conformity between the rail and fishplate profiles.

Fig. 17 Lack of conformity between rail and fishplate profiles.
7.7 Rail breaks in the joint area

The most common rail breaks are associated with the joint area as the joint usually manifests as an uneven place in the running surface with resultant higher stresses in the rail. Rail breaks are always dangerous, as a break can lead to the derailment of a train with subsequent loss of life or income and damage to property.

In open, continuously welded track, rail breaks usually emanate from some impurity or stress riser in the rail. The chrome manganese rails used on heavy haul lines are fairly brittle and are known to break from stress risers such as hammer blows on the flange or a spot where a welder struck an arc on the rail. Kidney fractures, emanating from hydrogen inclusions in the rail steel, also cause breaks. The kidney fractures are detected ultrasonically and can be cut out. Most Spoornet lines are tested ultrasonically at least once a year.

Bolt hole fractures are generally the result of overstressing the edges of the bolt holes. The star fracture is a dangerous type of defect characterized by cracks radiating from the fishbolt holes, generally at an angle of about 45°. (Esveld, 1989, p 184) Such a fracture occurred during the latter half of 1990 on the Orange River - Kimberley section and caused a derailment.

The /......
The joint was removed and sent to the Spoornet Metallurgical Laboratory at Koedoespoort and formed the basis for Report No MD 149 dated 19-12-1990.

A fatigue crack formed in the horizontal plane through the bolt holes of the joint. Further cracks emanated in star fashion from the holes and broke through to the running surface of the rail, resulting in a piece of rail between two holes falling out. This, together with a slack that developed under the joint, caused a section of train to derail. These star cracks form in bolt holes because of the high contact stresses between the bolt and the hole caused by repeated temperature changes in the rail. These in turn deform the bolts and the holes, also mentioned in the report. Because the sharp edges of the holes are deformed, cracks start and propagate from there.

The accepted way to prevent these cracks from forming, is to chamfer the edges of the holes during the assembling process. It is usually done to a depth of about 1 mm and at a 45° angle. In the case of the joint mentioned above, the edges of the holes had not been chamfered and the failure can be attributed to this fact. The chamfering of all holes drilled in the Spoornet workshop for the manufacturing of pre-assembled insulated rail joints is mandatory and care is taken that this code of practice /......
practice is adhered to. See the Annexure, Procedure for workshop assembly of insulated rail joints, point 1.2.3.

During the manufacturing process, fishplate holes are chamfered after drilling. Subsequent shot-blasting acts as further stress reliever and removes stress risers from the fishplate surfaces. This procedure precludes the formation of star fractures from the fishplate holes.
CHAPTER 8  CORROSION IN THE INSULATED RAIL JOINT

8.1 Background

According to literature, corrosion in insulated rail joints seems to be a major problem overseas. It is only reported occasionally in South Africa and cannot be seen as a major problem. This can probably be attributed to the low rainfall and arid nature of large areas of the country. The joints seem to dry out before corrosion can do much damage, but the low incidence of problems with corrosion in insulated joints can also be attributed to proper precautions taken during the manufacturing process and subsequent storage of the joints. It is necessary for the technologist to understand the mechanisms of the different types of corrosion to be able to take the required precautions in the design and manufacture of the insulated joints.

Corrosion can be defined as the deterioration or destruction of a material because of reaction with its environment. (Fontana, 1987, p 4)

Most environments are corrosive to some degree. The various environments where the insulated rail joint is manufactured, stored and used, each causes some degree of corrosion. The task of the technologist is to control and manipulate /......
manipulate this environment to minimize corrosion to acceptable levels.

Corrosion can be classified in various ways, but the preferred classification for most practical uses is wet and dry corrosion. (Fontana, 1987, p 9) Wet corrosion occurs when a liquid is present, usually an aqueous solution or electrolyte. Dry corrosion occurs in the absence of liquid where vapours and gasses are usually the corrodennts.

Liquid corrosion accounts for the greatest amount of corrosion in the present day industrial environment. The presence of small amounts of moisture can change the corrosion process completely, e.g. dry chlorine is practically non-corrosive to ordinary steel, but moist chlorine is extremely corrosive and attacks most common metals and alloys.

Oxygen and heat are two other factors that greatly influence the rate of corrosion in our everyday environment and must be controlled to arrest corrosion. Thermodynamics and electrochemistry can be used to explain and control most types of corrosion. Complete corrosion resistance can be achieved in most media by the use of platinum or glass, but the application of these materials is not always practical.
8.2 Forms of corrosion

Fontana defines eight forms of corrosion in his book "Corrosion Engineering" (1987). These are:

1. Uniform or general attack corrosion
2. Galvanic or metal corrosion
3. Crevice corrosion
4. Pitting corrosion
5. Intergranular corrosion
6. Selective leaching or parting
7. Erosion corrosion
8. Stress corrosion

This listing is arbitrary but covers practically all corrosion problems and failures. Most of these forms of corrosion affect insulated rail joints to a larger or lesser degree and will be discussed briefly.

8.2.1 Uniform attack corrosion

This is the most common form of corrosion and is characterized by chemical or electrochemical reaction over a large area or the entire exposed area. The metal is usually oxidized under normal atmospheric conditions and becomes thinner and eventually fails.
The insulated rail joint is generally not affected by this form of corrosion, as the thickness of the steel plate remains practically unaffected by some overall loss of metal. In coastal areas the joint is usually painted to counteract the corrosion. The paint also serves as an anti-static agent to prevent the build-up of iron filings over the end post that can cause electrical failure.

The only time when this form of corrosion poses a problem is in the assembly stage of the epoxied joint when the steel surface has to be free of dirt, oil or corrosion products. The steel fishplates are usually shot-blasted or wheel-abraded within twenty four hours before the joint is assembled so that the steel is still shiny when the epoxy is applied. The fishplates are stored under cover if they are to lie overnight before assembly. The manufacturer usually packs the fishplates in paper and seals the plates in plastic or shrinkwrap to ensure that the plates arrive at the workshop relatively free of corrosion.

8.2.2 Galvanic corrosion

This form of corrosion does not usually pose a
problem for insulated rail joints. It is also known as two-metal corrosion. An electrical potential difference is created between two dissimilar metals when they are immersed in a conductive solution or otherwise electrically connected. This produces an electron flow between them, similar to a dry cell battery. As all metals are electrically insulated in the insulated rail joint, this electron flow and subsequent galvanic corrosion, cannot take place.

8.2.3 Crevice corrosion

Intensive localized corrosion occurs with shielded areas and crevices on metal surfaces exposed to corrosives. Contact between metallic and non-metallic surfaces causes crevice corrosion as in the case of a gasket. Plastics and other material can cause this problem.

To function as a corrosion site, the crevice must be wide enough to allow liquid entry, but sufficiently narrow to maintain a stagnant zone, i.e. fractions of a millimetre wide.

Popular belief held that differences in metal ion and oxygen concentration between the crevice and its /.....
its surroundings caused the corrosion, hence the term concentration cell corrosion. Recent studies (Fontana, 1987, p 53) have shown that an oxygen reduction reaction is the cause of the problem.

The metal oxidizes thus: \[ M \rightarrow M^+ + e \]

Reduction: \[ O_2 + 2H_2O + 4e \rightarrow 4OH^- \]

Every electron produced during the formation of a metal ion is immediately consumed by the oxygen reduction reaction, rapidly depleting the oxygen within the crevice. This has an important indirect influence becoming more pronounced with increased exposure. When the oxygen is depleted, an excess of positive metal (\( M^+ \)) is formed by dissolution, producing an excessive positive charge which is necessarily balanced by the migration of chloride ions into the crevice, especially in saline or marine environments. This results in an increased concentration of metal chloride within the crevice. An aqueous solution of metal chloride dissociates into an insoluble hydroxide and free acid, both of which accelerate the dissolution rates of most metals, resulting in a very severe and rapid corrosion of the metal within the crevice.
As the rate of oxygen reduction increases, the oxygen reduction on adjacent surfaces also increases, cathodically protecting the surrounding areas and causing localized corrosion in the crevice. This type of attack occurs in many mediums but is very severe in mediums containing chlorides or ordinary salt. There is often a long incubation period associated with crevice attack - six to twelve months is common - but once started, it proceeds at an ever increasing rate.

The crevice width is also very important. All materials are susceptible to crevice corrosion, provided the crevice is narrow enough, i.e 1 micrometre or less. (Fontana, 1987, p 58)

Insulated rail joints are particularly susceptible to crevice corrosion, especially in coastal areas. Joints with plastic encapsulated steel fishplates form crevices between the back of the fishplate and the rail where rainwater accumulates. Epoxied joints form small cracks in the joint area due to bending of the joint during unloading, also acting as corrosion crevices. However, when the joint is in track the pumping action caused by the passing trains causes the solution to be pumped out of the crevice /...
crevice and enhances oxidation, nullifying the crevice effect. It also causes the solution to dry out before the incubation period is completed. When the joint is stored in the open, there is no movement and moisture penetrates the joint at the end post and severe crevice corrosion can result. A directive, letter CCE M24/5/7 dated 86-05-29, was sent out to Spoornet track maintenance districts that prescribes the storage of insulated joints under cover before installation in track.

8.2.4 Pitting corrosion

Pitting is a localized form of corrosive attack resulting in holes in the surface of the metal. Generally the surface diameter is equal or less than the depth of the hole. This type of corrosion is generally seen in rails lying along the track for long periods of time before they are installed for use. It usually takes several months to show up. Pits usually grow in the direction of gravity and tend to undercut the surface as they grow. (Fontana, 1987, p 64) It is a unique type of anodic reaction where the pit and its contents act as the anode and the surrounding metal as the cathode, explaining the relative absence of corrosion on the surrounding surfaces.

This /......
This form of corrosion generally does not occur on insulated rail joints unless they are left unprotected in moist conditions. Basic protection as for crevice corrosion suffices in this case.

8.2.5 Intergranular corrosion

This form of corrosion usually attacks steel alloys by localized attack at and adjacent to grain boundaries. Grains break loose and fall out and the member loses its structural strength. When stainless steel, generally containing more than 10% chrome, is heated to 950°C - 1450°C, it is sensitized to intergranular corrosion. A widely accepted theory holds that this type of corrosion is caused by chromium depletion in the grain boundary area. (Fontana, 1987, p 74) As high chrome alloys are not generally used for insulated rail joint fishplates, this type of corrosion is not generally found in these joints. Intergranular corrosion is also usually associated with weld decay due to the heat sensitizing process. Chrome manganese rail is not considered a high chrome alloy as it contains a maximum of 1.3% of chrome.
8.2.6 Types 6 & 7 - Selective leaching and erosion corrosion

Selective leaching is the removal of one element from a solid alloy by corrosion processes, e.g. dezincification of brass alloys. (Fontana, 1987, p 86) As this is also confined to alloys, it will not be discussed. It has never been reported in South Africa on insulated rail joints. The same applies to erosion corrosion, which is the increased rate of deterioration of a metal due to the relative movement between a corrosive fluid and the metal surface. Erosion corrosion usually occurs in pumps and flow systems, also due to turbulence. Fretting corrosion is a special case of erosion occurring at the contact area between materials under load subjected to vibration and slip. (Fontana, 1987, p 105) Fontana reports that "a classic case of fretting occurs at bolted tie plates on railroad rails." (p 105)

Theoretically this form of corrosion should also occur with insulated tieplates or fishplates. However, the insulation on the plates generally precludes fretting corrosion as it usually occurs between materials of similar hardness and composition.
composition. The plastic insulation is so much softer than the rail steel that fretting does not happen. On the glass reinforced plastic joints a process that can be described as fretting corrosion (or erosion) takes place at the interface between the fishplate and the rail in the joint area. This has never been investigated closely and is generally accepted as a wear phenomenon, especially since the glass fibre is worn away and the steel does not wear. The use of epoxy in insulated joints causes the whole joint to act as a complete unit and no relative movement takes place between the rail and the fishplate. This effectively precludes the problem of wear or fretting corrosion on the fishing surfaces.

8.2.7 Stress corrosion

This refers to cracking caused by the simultaneous presence of tensile stress - as found in the insulated joint fishplate - and a specific corrosive medium. (Fontana, 1987, p 109) The coating of the fishplate with insulating material, epoxy or paint precludes the presence of a corrosive medium, and therefore it follows that this type of corrosion does not occur with insulated joints under normal circumstances.
8.3 Conclusion

Although corrosion can cause damage to insulated joints, and the products of corrosion could cause electrical failure of the joint, problems with corrosion can be excluded from insulated rail joints with the use of the correct products such as coatings and insulating materials. The joint is therefore painted upon completion of the workshop assembly with Polyvinyl Chloride Copolymer Highbuild Midgrey paint, specification no. CSS 183/18.10/G25, modulus item number 9/024752. Furthermore, the correct procedures to remove all corrosion products before assembly of the joint would preclude most problems in the joint once it is in use. These precautions are described in the Annexure, Procedure for workshop assembly of insulated rail joints. A sound knowledge and understanding of the various corrosion processes by the technologist ensures the correct application of measures to combat and preclude corrosion and its effects on the product.
CHAPTER 9 MAINTENANCE PROCEDURES ON SPOORNET TRACK

9.1 Background

The action of traffic on the track causes deflection to take place, causing a slight wave motion in the track. The more uniform the wave motion, the smoother the traffic movement on the track. This smooth running is disturbed when a joint is encountered, and the disturbance is drastically increased when the joint is worn. This is the result of disturbed track conditions like slack track, worn fishplates, rail end batter and metal flow in the joint area. This action is progressive and will result in serious damage to the joint unless remedial action is taken timeously. (Heeler, 1979, p 33) It was found that the dynamic load on the joint doubles when a bad slack develops under a joint. Permanent deformation and bending of the rail ends occur, resulting in extraordinary maintenance, usually culminating in the replacement of the joint.

Maintenance procedures differ widely from one region and district to the next. The local track manager and permanent way inspector have the last say in what is done and what not. However, certain regulations have to be adhered to. The most important are the instructions prescribed in the "Permanent Way Instructions" of 1984, published /......
published in-house by Spoornet and its predecessor, the S. A. Transport Services. Two clauses need to be emphasized. Clause 529.1.2, page 109, states that "The permanent way staff are responsible for the renewal of block joints (insulated rail joints). A technician (signals) should, if possible, be in attendance. Clause 528.11, page 111, concerns an important safety aspect and reads: "The installation of insulating joints on open lines involves breaking the track. On electrified lines, jumper cables must be applied before breaking the track." The role of the Rail Technology Section and Head Office is but an advisory one, and also one of education as to what is considered to be good maintenance practice.

It is generally accepted that maintenance has to be done on insulated rail joints on either a cyclical preventative basis, or in a corrective way only when necessary. Various maintenance procedures and rectification measures are discussed in this chapter.

9.2 Metal flow

When metal flow occurs on a joint, the joint will eventually fail electrically as the metal flow will cause an electrical connection to form across the gap. The aim of corrective procedures would therefore be to remove the offending metal. This is usually done by cold chisel or cutting /......
cutting with a hack saw. Care should be taken in these instances that the metal particles produced do not fall into the gap of the joint where it will cause electrical failure. It is safer to use an angle grinder and grind the metal flow away. As the particles are shot away from the work piece, there is usually very little danger of contamination by the particles.

Fig. 18 Metal flow in the end post area of the joint.

9.3 Battered rail ends

Battered rail ends are caused by the action of the wheel over the joint. When the wheel approaches the joint, the rail under load moves down relative to the other rail end. The wheel strikes this unloaded end, causing wear and metal flow at the rail end. The wheel then jumps a small distance because of this blow and lands some distance ahead /.....
ahead of the joint, causing further wear, and the battered rail end. (Heeler, 1979, p 35) This is borne out by the plots done by the FAST test program. (Moyar and Cruse, 1982, p 29) The plots in their report, labelled as "Characteristic joint surface profile features", are reproduced here.

Fig. 19 "Characteristic Joint Surface Profile Features" produced by the FAST test programme.
Joints with a section modulus for the fishplates close to that of the rail will cause excessive batter, as opposed to joints with a combined fishplate section modulus of around 33% of that of the rail. (Swart, 1979)

Rail end batter is accelerated by "heavy wheel loads, wide joint openings, soft rail steel ..... the condition of car and locomotive springs, small wheels ..... poor joint support and poor maintenance ..... The seriousness of the problem has increased with higher axle loads and speeds." (Hay, 1982, p 500) Batter causes shock to rolling stock as well as to the track structure, resulting in increased maintenance. Ballast and sleepers are damaged by the action of the train over the battered joint and eventually have to be replaced. The rate of development of rail end batter can be reduced by frequent tamping of the joint as well as tight fitting, well tightened fishplates on the joint. End-hardening of the rails also retard the growth of rail end batter. (Hay, 1982, p 500)

Work-hardening chrome manganese rails were introduced in 1985 to be used in Spoornet insulated joints, both to reduce metal flow and to retard the growth of rail end batter. However, there are thousands of joints still in track with softer UICA and HCOB rails, suffering from severe rail end batter. This is rectified by "welding the joint up". The metal is ground to approximately 3 - 4 mm deep /
deep for 70 - 80 mm either side of the joint. This is done to remove all work-hardened metal from the joint area. The joint is now welded up with special welding rods resulting in a hard-faced or work-hardening surface. After welding, the joint is ground down to a smooth surface and the gap also ground to the correct profile. This method is described in an information circular sent out by the now defunct Department of the Chief Civil Engineer of S.A. Transport Services. (Procedure for Repairing Insulated Rail Joints in Track, 1987) This was initiated by the Interdepartmental Committee for Insulated Rail Joints.

9.4 Worn and broken fishplates

Generally, insulated fishplates are not maintained. When worn or broken, they are replaced on Spoornet track mainly for three reasons:

- Breaking of the steel core due to fatigue or stress risers.
- Worn insulation causing excessive movement and sag in the joint.
- Breaking of non-steel fishplates because of excessive longitudinal forces in the rails.

In the past, the insulation was an integral part of the fishplate and could not be replaced. A replacement phenolic/......
phenolic insulating piece was developed for the phenolic joint, but this was discontinued. The fishplate joint had sharp stress risers built into it, causing many breakages in track, resulting in the use of this type of joint being discontinued. The new epoxied joints can be reclaimed and the fishplates cleaned and re-used. This course of action is presently being implemented as enough second-hand fishplates are becoming available on the Richards Bay Coal Line.

Fishplates crack from the top or the bottom. If the crack originates from the bottom, it suggests that the sleepers are not well tamped and a slack exists under the joint, or alternatively, that the sleepers are spaced too far apart. If the crack originates on top in the centre section of the fishplate, the sleepers are usually not packed evenly and the sleepers on one side of the joint are very slack. (Heeler, 1979, p 242)

It appears that the six hole fishplates last longer than the shorter four hole fishplates under the same traffic conditions. (Heeler, 1979, p 31) The standard Spoornet hole configuration is such that a four hole fishplate can be installed in the same holes as the six hole fishplate. A worn fishplate can therefore be replaced temporarily without modification due to hole spacing.
It is generally accepted that the best long-term answer is to design a better fishplate or joint, rather than to have a concerted maintenance drive on substandard joints.

9.5 End posts

(See chapter 4 for more information on end posts.) End posts get damaged by metal flow and the metal flow removal procedures. Damage is also done on the older types of end post by crushing when the rails expand due to heat. Ultra violet rays embrittle the white nylon types, causing breakages. The glass reinforced plastic type of end post is also prone to brittle fracture.

The only end post not showing signs of environmental decay is the black glass filled nylon type. (Hoffmann and De Koker, 1987, page 15) Because of the success of the black glass filled end post and the fact that the fishplates have to be removed from the joint to replace the end post, the two-piece clip-on type was developed. The old end post is removed and this new two-piece end post slid in from the top and bottom and clipped into each other. For a complete description of this design see chapter 4, page 42. This design simplified the maintenance on end posts to a large extent.

Because of crown wear, end posts that are replaced must be filed /....../.
filed or cut to match the crown of the rail. (Permanent Way Instructions, 1984, p 111, clause 529.3.4)

9.6 Bolts and studs

Bolts and studs are replaced when broken. Breakages usually only occur on the dry or friction type joints and are mostly caused by the extreme pressures exerted on them. The bolts are bent to and fro due to the expansion and shrinkage of the rail caused by temperature variations, resulting in the breakages.

On the friction type joints, tests and experience have shown that repeated traffic loading "draws the (fishplate) more closely into the fishing surface, with loss of bolt tension. Important reductions have been recorded with the passing of a single train." (Hay, 1982, p 569) In such cases the bolts have to be torqued up or, as usually happens, the bolts are fastened with a large spanner as torque wrenches are not always readily available. Shifting spanners are commonly used as there are different types of joints in track, each with its own nut size. However, as joints are being standardized, the old joints will be replaced and this problem should then be solved. "The Permanent Way Instructions" (1984, clause 529.3.3) also states that "fishbolts on block joints must be checked periodically and kept tight."
Studs are generally only used on epoxied or frozen joints. On friction or dry joints it is found that, if the studs become loose due to vibration, two spanners are needed to fasten the loose stud. (Hoffmann and De Koker, 1987, p 14) Generally the one nut has a marginally higher coefficient of friction due to roughness on the thread than the other. The one nut tends to turn deeper into the stud, causing the stud-nut combination to turn out of the other nut. To combat this, many maintenance men weld the one nut to the stud, especially on the nylon encapsulated type joints. The other nut is then fastened like an ordinary bolt-nut combination.

9.7 Worn insulation

The insulation wears according to the physical properties of the insulating material. On all types of joints, wear usually takes place on the interface of the rail crown and the fishplate, that is on the top fishing surface of the fishplate. Wear on the bottom fishing surface is usually less severe. The wear is more severe closer to the rail ends and usually leaves a wedge shaped worn section, with the thick end of the wedge at the rail end. As the wear continues, "the joint becomes less rigid and the blow as each wheel strikes the running-on rail becomes the more harmful". (Heeler, 1979, p 240)
On the phenolic encapsulated joints, most of the wear takes place in the high stress contact area between the rail and the insulated fishplate, on both the top and bottom fishing surfaces either side of the rail joints. Due to the high compressive resistance of the phenolic, no problems are experienced in the holes as with the nylon. Wear similar to that of the phenolic on the fishing surface is experienced with the glass reinforced plastic joints, causing added maintenance in both cases. This wear seems to be a fretting erosion where the particles bite into the mother material, accelerating the wear action.

On the epoxied joints, the epoxy usually shows a minute crack along the joint next to the end post. After some time in track the epoxy tends to crack in the high stress areas on the fishing surfaces because of overstressing. These cracks grow, eventually causing complete failure of the epoxy bond between the whole length of the fishplate and the rail.

On the encapsulated joints, the nylon insulating material was found to show cold flow characteristics under high rail temperature and pressure. The end post deformed, the insulation in the holes deformed under pressure and tension, and the material flowed in the high stress contact /.....
contact areas close to the joint on the fishing surfaces. The studs also tended to work loose because of the cold flow of the nylon under the washers where the studs were torqued up to the specified 980 Nm. (Hoffmann and De Koker, 1987, p 11) The deformation in the holes in some cases led to the bolt crushing through the insulation. This caused electrical contact between the fishplate and the rail via the bolts on both sides of the joint, resulting in electrical failure of the joint. The cold flow on the fishing surfaces caused the joint to deflect more under traffic, also allowing more lateral movement. This added movement and deflection increased the necessity for maintenance of the joint. The joint needed to be tamped more frequently, increasing maintenance expenditure.

In all the cases mentioned above there is very little that can be done to alleviate the situation and the joint has to be replaced when the maintenance effort and expenditure becomes excessive.

About 5 000 S60 profile Nylon insulated joints became redundant when the Richards Bay Coal Line staff decided to standardize on the imported type of frozen joint. The nylon insulation on the fishplates was fairly thick, up to 8 or 10 mm. This was reduced by machining about 1.5 mm off each fishing surface, taking the relative position of the /......
the hole into account. This enabled the productive use of the fishplates on 57 kg rail during 1988 to 1990.

9.8 Rounding of ballast and sleepers

Due to the continual tamping, as well as the effect of the traffic over the joint, the stone ballast and the sleepers tend to wear and become round as shown in figure 20. This rounding of the corners cause the sleepers to lose "grip" on the ballast, and also reduces the bearing surface drastically. The ballast also wears away, resulting in rounded corners. The ballast loses its interlocking and load bearing ability. The effect is like applying pressure on a heap of marbles: the marbles move away and show no load bearing characteristics.

Fig. 20 The rounding effect of wear due to traffic and tamping of the joint.
9.9 Rectification procedures

All the wear phenomena described above tend to develop due to the effect of traffic on the joint. The more traffic passing over the joint, the more severe the maintenance expenditure to keep the joint in good repair. On Spoornet track, when this maintenance effort and accompanying regression in the physical condition of the joint became excessive, the joint used to be replaced. The replacement of a complete joint is always an expensive exercise. In continuously welded track the whole six metre length of joint is cut out and scrapped. A new pre-assembled joint is then brought in and welded into track. The costs involved run into thousands of rands. The figures quoted below only hold for 1991 prices, but will give an indication of the expense involved.

6 Metres of 57 Cr Mn rail at R166/m R 996
2 Thermit weld portions 290
1 Insulated rail joint kit (DHJ) 760
1 Portion of epoxy 54
Transport from factory to site 736
Manufacturing labour costs 2190
Installation labour costs 974

TOTAL R 6 000

Because /......
Because of this high capital outlay, it was decided to investigate the possibility of in-track rectification of the joint. This had been tried a number of times in the past, but the process could never be perfected to work without hitch in practice. The main problem experienced in the past was that, as soon as the old fishplates were removed, the joint would either close up or pull open due to changing temperature, resulting in the bolts not being able to go back into the holes and therefore the fishplate could not be replaced. The old rail would mostly still be serviceable, apart from the batter at the joint. The late Mr D.W. Hoffmann, Chief Engineering Technician, however, showed his practical mettle and perfected the process which is widely used on Spoornet today to rectify the worn insulated joints in track.

When a joint is identified to be rectified, the first step is to cut through a thermit weld close to the joint to relieve the tension in the track. If the joint is dipped badly and the rails bent, the joint is bent straight with a vertical jim-crow. The old fishplates are inspected for possible re-use. If not re-usable, they are left in place and the batter on the rail surface is ground out with a grinding machine until all work-hardened metal has been removed, usually 3 to 4 mm deep. The joint is then welded up with special hardwearing welding rods. The running

surface /......
surface on the joint is ground with a rail grinding
machine to conform to the rest of the rail surface. The
old fishplates are used to keep the rail in alignment.

After the gap has been cut clean with an angle grinder,
the fishplates are removed and the joint area cleaned.
All dirt, oil and rust are removed. It is best to clean
the rail to a shiny surface by grinding. The epoxy, a two
part rapid hardening type, is then mixed thoroughly and
applied to the new fishplates as well as the rail surface.
The end post is inserted, the rail pulled up to close the
gap and aligned. The fishplates are then put on and the
bolts hand-tightened. The bolts are now tightened with a
spanner, the inside ones first and then the outer ones.
Finally the bolts are tightened with a torque wrench, also
from the inside out. The joint is then painted with an
anti-static, rubberized paint. As soon as the epoxy has
set, the rail is thermit welded to restore the track to
its continuously welded status. Care must be taken to
weld the rail within the correct welding temperature
envelope. (Procedure for Repairing Insulated Rail Joints
in Track, 1987)

This process is practical and can be completed during a
two hour occupation of the track, with a saving of the
rail, one thermit weld portion and the transport and

manufacturing /......
manufacturing costs of a new joint. This amounts to R4 067 per joint. It was calculated that at least 25% of joints replaced annually could be done this way, resulting in a saving of one thousand joints.

Apart from the rectification process of the joint itself, the track also has to be upgraded, both when a new joint is installed or an old joint rectified. The ballast has to be replaced for at least 1,5 metres each side of the joint and the concrete sleepers inspected. If these need replacement due to rounding of the bearing surface, this must be done. It is also suggested that the standard 700 mm sleeper spacing on main lines be reduced by inserting one more sleeper, reducing spacing to 500 mm either side of the joint. This ensures better bearing of the joint on the ballast and a more even spread of the load around the joint. This is borne out by work done on other railway systems. "British Railway Track" (Heeler, 1979, p 31) reads: "It is standard practice, in order to give greater support at the joints, for the sleepers at and near the joints to be spaced closer together."

American experience seems to be similar. Hay states: "The much-to-be-desired stiffness of joint may be obtained in part by closer spacing of joint ties (sleepers). Because the joint is less stiff than the full rail section /......
section, a heavier demand is made on the rail support. The closer spacing should be spread in equal increments over adjacent ties". (Hay, 1982, p 571) This work is usually done a day or two before the joint is rectified and is not done under occupation conditions. It ensures that the new joint is immediately placed on a sound new track formation. It must be ensured that the sleeper spacing either side of the joint is equal to achieve equal bearing and support on both sides.

9.10 Sleeper Spacing

Various experiments were done over many years by Rail Technology as well as maintenance staff on sleeper spacing and configuration. A few cases are mentioned here:

"The Permanent Way Instructions" (1984, clause 528.7) reads: "Where two insulating joints are situated opposite each other, wooden sleepers must be inserted under the insulating joints and a reinforcing rail at least 6 m long provided on the track centre." This rail reinforces the whole track structure in an attempt to provide an even running surface where the two joints create discontinuity. As a result of the above mentioned instruction, many track inspectors believe that the life of a single insulated joint can be prolonged and the maintenance on the joint reduced /........
reduced by inserting this third rail in the track structure. The rail is installed between the existing two rails or on the side, next to the insulated joint. This technique has the merit of helping to spread the impact load over more sleepers, as well as providing a stiffer track structure, largely eliminating the bending caused by the joint, and has the advantage that the joint does not have to be tamped so often. The introduction of wooden sleepers in the continuous concrete sleepered track changes the riding quality and characteristics over that short section, but this change is less severe than that of a badly maintained joint.

The insertion of two wooden sleepers, immediately alongside each other and each under the rail end in the joint, used to be common practice. The theory was that one would achieve double the amount of support with the two sleepers under the joint. In practice this did not work very well because the two sleepers could not be tamped properly. During the tamping operation, half the sleeper is tamped longitudinally from either side, resulting in the two sleepers both being half tamped. This in turn leads to a bad slack developing under the joint, causing a dipped and bent joint. The double sleeper under the joint "slows the output of the tamping machine and raises some
technical difficulties with this type of mechanical maintenance". (Heeler, 1979, p 31) This defeats the object of the exercise and the practice was discontinued.

Attempts have been made to install a sleeper directly under the joint, as this is theoretically a sound place to support the joint. It can only be done on the Pandrol fastening system, as the Fist fastening would cause electrical failure. The gauge plate insulator of the Pandrol fastening covers the joint at the toe of the rail and seals off contamination. This method has not won favour with track staff and it can therefore be assumed that very little benefit, if any, is achieved by the use of it.

The use of heavy 560 concrete sleepers under the joint instead of standard ones, is encouraged. When they are placed at 500 mm centres under the joint the tamping machine can easily tamp the joint. These sleepers have the added advantage of bigger bearing area on the underlying ballast. Unfortunately they are not available everywhere but, where available, are used with success.

9.11 Tamping cycles

To ensure that a slack does not develop under the joint, the joint should be re-aligned and tamped regularly. Some districts /......
districts do this on a regular preventative cycle. It was found in Spoornet strain gauge tests that the presence of a slack in the track structure under the joint causes the stresses in the fishplate to double under load. Adequate support for the joint must be maintained and the only way to obtain this is to tamp the joint regularly. The FAST test programme in the USA bears this out. They report that "adequate support is necessary to prevent .... deflections. A moderate amount of tamping is needed on a regular basis to keep the joint surface profile within maintenance limits". (Moyar and Cruse, 1982, p 32)

There is an interactive relationship between joint stiffness, sleeper support and performance of the joint. Locally it is felt that a joint should be spot-tamped after approximately every 2 - 2.5 million gross tons (MGT) of traffic. This is usually done by a team dedicated to preventative tamping and maintenance of insulated joints and points and crossings.

9.12 Further observations regarding the FAST test.

The FAST report also makes a few other points relevant to joint maintenance that bear repeating:

The median structural life of an insulated joint based on statistical analysis of their tests is around 425 MGT. (Moyar and Cruse, 1982, p 43) No accurate life figures are /......
are available locally, although the author once calculated the life of joints on the heavy haul lines to be in excess of 300 MGT for both nylon encapsulated and epoxied joints. The local 1 065 mm gauge between rails, "narrow" according to American and Continental standards, against their "standard" 1 435 mm renders direct comparison of joint life unrealistic. Our local 300 - 350 MGT life may well compare favourably with their 450 MGT. The Richards Bay Coal Line personnel reported that the nylon encapsulated joint required substantially more maintenance effort due to the effects of the cold flow of the nylon in comparison to the epoxied joint. However, no figures were available to back up this claim statistically.

FAST also reports that the electrical resistance drops markedly after about 250 MGT of traffic. (Moyar and Cruse, 1982, p 43) This figure could not be substantiated locally as the joint would have to be taken out of track to enable measurement of the resistance. If measurement of the resistance is attempted in track, it is found that the combined resistance of the rest of the track circuit in the signalling system is measured and not the resistance over the joint. This insulation measurement of the joint is only possible under test conditions where track signalling equipment is absent, like on the FAST test track.
Locally the joint is only removed and considered to have failed electrically if it physically passes current over the joint. Since the joint only fails electrically once the resistance falls below approximately 10 Ω, the FAST test drop below 100 000 Ω cannot be used for comparative purposes, neither does it have much practical value. However, it is significant to note at what tonnage the electrical resistance was observed to drop, namely at around 250 MGT. They concede that the insulation limit of 100 000 Ω for the experiment was somewhat arbitrarily defined. (Moyar and Cruse, 1982, p 35)

The FAST team also recorded the vertical deflection. This is reported to be on average 0.37 inches (9.4 mm) under a dynamic wheel load of a 100 ton rail truck, i.e. a 26 ton axle load, similar to our heavy haul lines. The range observed was 0.23 inches (5.84 mm) to 0.55 inches (13.97 mm). They report, "No definitive trend with life or correlation with joint stiffness was observed." (Moyar and Cruse, 1982, p 43)

It is difficult to evaluate these results, as the report does not state what sleeper spacing was used. From their sketches and photographs it seems as if a 20 inch, that is 500 mm, spacing was used. The rail size is also not given in the report and, without this information, no comparison can /.......

can be made to local joints. Their wider track gauge also invalidates many direct comparisons.

9.13 Conclusion

In conclusion it can be said that the best maintenance is a soundly designed and well built joint. It is the philosophy of the Richards Bay Coal Line maintenance engineers not to buy an inferior, low cost joint. Their experience has proved that the extra money spent on a good joint is recovered many times over in reduced maintenance on the joints. This philosophy, combined with a programme of preventative maintenance in the form of regular tamping of joints, has gone a long way towards minimizing problems on insulated joints on this heavy haul line. This attitude is now encouraged on other lines throughout the country.
CHAPTER 10  TESTS DONE ON INSULATED RAIL JOINTS

Various standard and special tests were investigated and done on insulated rail joints during the course of this investigation.

10.1 Standard electrical test

As the primary function of the insulated rail joint is simultaneously to join and insulate two rail ends, the most important test of qualification is to quantify the insulation or measure the resistance over the joint.

On the Netherlands Railways an "electrical resistance (impedance) of at least 10 $\Omega$ at 100 kHz" is required. (Esveld, 1989, p 101) Locally it was decided by the Interdepartmental Committee for Insulated Rail Joints in their sixth meeting held on the 13th September, 1985, that the qualifying level for workshop manufactured joints should be 100 million ohms (100 Meg $\Omega$) measured across the joint with a 500 volt megger. This standard is achieved relatively easily in practice and is strictly adhered to. Lower standards are sometimes applied under field conditions.

10.2 Static tensile test

The aim of this test is to determine the performance of the joint under tensile load: elongation of the joint, performance /......
performance of the various joint components and ultimate failure under tensile load.

This test is done in the laboratory of the CSIR Mine Equipment Research Unit at Cottesloe in Johannesburg. The joint is installed to the manufacturer's specifications onto two short lengths of rail that are machined down at the ends to be accommodated in the clamps of the testing machine.

The test piece is clamped into the 5 000 kN Mohr and Federhaff tensile testing machine. At a preload of 98 kN a suitable gauge length is marked across the joint. The joint is then loaded at a rate of 80 kN/minute to a maximum of 800 kN. The load is then released and again applied at a rate of 100 kN/minute until failure occurs. At random loads, the load is maintained and the gauge length is measured and noted. Failure could occur when the bolts break or the fishplate shears through the bolt holes. The test is usually terminated around 1 500 kN if no untoward elongation or cracks are noted.

Although not adhered to rigidly, the joint should not pull open by more than 10 - 15 mm. When the joint opens up the reason for the elongation is sought. It is then determined whether this is a permanent set and whether this set will be detrimental to the functioning of the joint /......
joint. Each case is judged on its own merit.

A load elongation diagram and a short report are supplied by CSIR for each test.

Fig. 21 Example of a load elongation diagram for the CSIR tensile test.

The / .......
The acceptance levels for joints in the tensile test were adjusted upwards because it was found that joints that had passed the test by close margins did not perform well in subsequent track tests. The old and new acceptance levels compare as follows:

- **48 kg/m rail joints**
  - Old: 800 kN
  - New: 900 kN
- **57 kg/m rail joints**
  - Old: 950 kN
  - New: 1 000 kN
- **60 kg/m rail joints**
  - Old: 1 000 kN
  - New: 1 200 kN

The 20% jump in the acceptance value for the 60 kg joints resulted because these joints are used under heavy axle load conditions on the heavy haul lines. The figures were derived from the 1982 and 1990 tender documents for the supply of insulated joints to Spoornet. The 1980 specification gave the tensile strength requirement as 600 kN.

10.3 Photoelastic tests

10.3.1 Description of photoelasticity

Photoelastic stress analysis was chosen to analyse the stresses in the fishplate because it is the only visual method to show the stress pattern in a test piece. It is a non-destructive and very instructive test method and it provides a quick qualitative...
qualitative analysis of the stress distribution within a test piece.

Photoelasticity can be loosely defined as "the property of some transparent materials, such as glass or plastic, while under stress, to become doubly refracting (i.e. a ray of light will split into two rays at entry). When photoelastic materials are subjected to pressure, internal strains develop that can be observed in polarized light". (Encyclopaedia Britannica Vol VII, p 967)

Materials such as plastics behave optically anisotropic when stressed. The change in the index of refraction is a function of the stress applied. When these photoelastic materials are subjected to load and viewed with polarized light, colourful patterns are seen which are directly proportional to the stresses and strains in the material. The photoelastic colour sequence observed with increasing stress is: black - zero stress - yellow, red, blue-green, yellow, red, green repeating the yellow, red, green sequence. The transition line between the red to green colours is defined as a "fringe". As the stress increases, the number of fringes increase proportionally /.......
When the colour bands are closely spaced, the stress gradient is steep. The appearance of a uniform colour represents a uniformly stressed area. Interpretation of the stress patterns observed under the reflection polariscope leads to an evaluation and understanding of the entire stress field under observation and permits measurement of the magnitude of the stresses present. (Measurements Group Inc. Bulletin SFC – 300A, 1987)

![Schematic presentation of the photoelastic observation process from Measurements Group Inc. Technical Note TN 702.](image)

**Fig. 22** Schematic presentation of the photoelastic observation process from Measurements Group Inc. Technical Note TN 702.

### 10.3.2 Test procedure

In the case of the insulated rail joint, a specially formulated plastic coating was bonded to the fishplate with a special reflective bonding agent /......
agent. The joint was assembled onto two short pieces of rail and the assembled joint was put in a rolling load machine. This machine has a wheel that runs to and fro under load on the test piece. The wheel can be moved slowly or even stopped in one position if necessary. The load on the wheel is adjustable so that various axle loads can be simulated on the test piece. The supports were adjusted to 700 mm centres, equal to the standard sleeper spacing in track. The load on the wheel was increased to 9 tons, equal to an 18 ton axle load. No recordable change was observed through the reflection polariscope. The load was increased to 26 ton axle load and still very little was seen through the polariscope. The results were disappointing at the operating axle loads and gross overload had to be reverted to to see significant results. The load was increased incrementally until the equivalent of 62.5 ton axle load, that is 31.25 ton wheel load, was reached. Photographs were taken at no load, and at the equivalent of 32.8; 42.7; 50.0; 56.0 and 62.5 ton axle load. The significant pictures are included and discussed herewith. It must be noted that the photographs were taken through the lens of /......
of the reflection polariscope and the quality of the photos is therefore not of a high standard. The corners are blackened and blurred and the light conditions could not be enhanced by means of a flashlight. Two fishplates were tested: an imported fishplate from one of the joints used on the heavy haul lines, and a locally manufactured phenolic encapsulated steel fishplate.

The wheel on the rolling load machine was advanced until the most significant results were achieved, namely when the wheel was just about to advance from the one rail over the end post to the other rail, i.e. when the wheel was at the end of the one rail.

As the results in this test were only achieved on high loads well above the operating loads for fishplates, no attempt was made to quantify the results and colours obtained in this test. It should be mentioned that it is possible to quantify the stresses in a test piece as the stress within every colour area is equal. In this case it was not done as the calibration process is cumbersome and the results would not be applicable in practice.
10.3.3 Results of the test

10.3.3.1 Sleeper spacing

It was hoped that appreciable changes would be observed as the sleeper spacing was changed from 700 mm to 500 mm. However, at the operating axle loads of 18,5 and 26 tons no real quantifiable change could be seen, as the fishplates did not show any quantifiable signs of stress at these loads. The photoelastic colour change did not go beyond a barely discernible pale red. This is in line with subsequent calculations which show that the high stress area under this load is on the fishing area itself.

10.3.3.2 Bending stress

With the phenolic encapsulated joint a fair indication of high stress in bending was achieved around 50 ton axle load, i.e. double the load used on the heavy haul lines.

In figure 23, showing the test piece under no load, no red/brown or blue can be seen, except for some internal stresses in the photoelastic coating.
In figure 24 an area of blue and brown/red and even yellow can be seen in the bottom section of the fishplate between the bolts and adjoining the bottom flange of the rail. This was achieved with the wheel load centrally on both the rail ends. This means that the bending stress is present in this area, with the maximum vertically below the load in the section of the fishplate furthest away from the load. The stress is evenly distributed and decreases evenly towards the middle of the fishplate.

Fig. 23 Photoelastic stress test: no load on locally manufactured joint.

Fig. 24 / ......
10.3.3.3 Stress risers

The phenolic encapsulated insulated joint has a groove forged into the bottom of the fishplate to accommodate the Fish rail-to-sleeper fastening. This groove terminates close to the centre bolt holes in a round termination with a radius of about 12 mm.

In figure 23 some discolouration can be seen at the end of the groove when the test piece is at rest (no load). These were internal stresses in the /.../...
the photoelastic coating. Figure 24 shows a small pronounced blue area on the edge of the radius, radiating upwards. This indicates a sharp stress riser at the termination of the groove in the bottom of the fishplate. This is borne out by numerous breaks of this type of fishplate in track. The breaks would usually start at this termination and break towards the centre bolt hole or quite often towards the hole between the second and third bolt hole, just above it. This is a locating hole made in the fishplate to facilitate the manufacturing process when the phenolic insulation is moulded onto the fishplate.

10.3.3.4 Shear forces

The second joint, the imported joint used on heavy haul lines, showed the shear forces and their effects the best. Figure 25 shows the joint under no load. Figure 26 shows the joint under a load of 32,8 ton axle or 16,4 ton wheel load. Figure 27 shows the joint under 50 ton axle or 25 ton wheel load. Figure 28 shows the joint with a load of 56 ton axle load or 28 ton wheel load. The load or wheel was on the right-hand rail just before moving onto the left rail.

Fig. 25 /......
Fig. 25 Photoelastic stress test: no load, imported joint.

Fig. 26 Photoelastic stress test: wheel load 16.4 ton or axle load of 32.8 ton, imported joint.
There is a stressed area clearly visible just under the rail crown on the top section of the fishplate to the right of the end post, showing brown on the photograph. A further brown stress area is visible in the centre of the fishplate and to the bottom left of the centre area. On the photograph, figure 28, a faint blue stress field is shown on the centre bottom section of the fishplate just to the left of the end post line. The bottom angle of the fishplate just below the vertical plane seems to show up as a stress riser as this also shows a thin blue line. (Fig. 27 & 28) The stress area on the top right side of the fishplate is due to the compressive stress from the wheel transferred through the rail onto the fishplate via the fishing area. The bottom stress area across the fishplate is due to the bending stress induced here by the load. The stress area is more pronounced on the left due to the upward reaction force exerted there by the left-hand rail.

In the centre of the fishplate there is an upward spiked stress field right over the end post line. This shows orange / brown in colour on figures 26, 27 and 28. This stress field is due to the high /......
high shear force exerted here. This was seen to reach a maximum just before the wheel passed over from the one rail to the next. This field increased as the force from the wheel load increased, but the reflection from the light source onto the surface of the photoelastic material at the top of the vertical plane on the fishplate caused it not to show up very well on this area of the photograph. The increase can be seen as the load increased from figure 26 to figure 27 and finally to figure 28. The little field of blue shown on the left of the end post line at the bottom of the fishplate on figure 28 indicates the high reaction force exerted by the left hand rail just before the wheel passed over to it.

10.3.3.5 Maximum stresses

The maximum stresses predictably occur at the extremities of the fishplate over the joint area, i.e. at the top and bottom of the fishplate on the end post line. To quantify these stresses under actual operating conditions, strain gauge measurements were taken. These are described under "Strain gauge tests", section 10.4, page 144.

Fig. 27 /......
Fig. 27 Photoelastic stress test: wheel load of 25 ton or axle load of 50 ton on imported joint.

Fig. 28 Photoelastic stress test: wheel load 28 ton or axle load of 56 ton, imported joint.
10.3.3.6 Other observations

As the load increased, a small area could be seen developing above the bolt hole on the left of the picture, indicating that the hole was stressed. The bottom of the hole could also be seen to take an increasing load towards the right of the hole on figures 27 and 28. This indicates that the holes should be spaced further apart as stress in this area would ultimately lead to fatigue failure towards the bolt hole. This was borne out by a subsequent fatigue test where the fishplate broke through the bolt hole after a phenomenal 8,12 million cycles. The test was conducted to ascertain whether a 10 million cycle fatigue test for heavy haul joints would be practical, and was done in conjunction with staff of the Spoornet Track Testing Centre at George Goch. (Meyer, 1991, p 16)

It was not possible to determine the negative bending (uplifting) effect of the wheel on the joint when the wheel was over the first sleeper as the test jig did not allow for sufficient movement of the supports and adequate travel of the loading wheel.
10.3.3.6 Other observations

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10.4 Strain gauge tests

10.4.1 Background

A first series of in-track strain gauge tests on insulated joints were done during July 1986 by the Track Testing Centre. The shortcomings of the first tests were that the data was collected under normal operating conditions and the same trains did not traverse each joint. The speed of the traffic could not be controlled, special joints were not inserted and not enough variables tested. These tests are referred to by M.D. Tomas, in his report "In situ tests on block joints." (1986)

The data was not considered sufficient after the field evaluation of joints under Mr Hoffmann and it was decided to do further, more comprehensive, strain gauge tests. This was done to obtain scientific and comparative data for this project, and to obtain data to enable the Spoornet Track Testing Centre to develop a laboratory test. The laboratory test was to be used for the comparison and evaluation of insulated rail joints in the adjudication of tenders.

In depth discussions were held with the Track Testing Centre staff regarding the aim and detail
of the tests. It was decided that the author would obtain and ready the joints for the tests and that the Testing Centre staff would do the actual strain gauge tests. The Testing Centre has a pantechnicon and all the necessary equipment with which this type of test is regularly done on railway track related problems. The pantechnicon is parked at a test site anywhere along the track, the test site is readied, the strain gauges bonded to the rail or test piece and the instruments calibrated. Stresses and strains are then measured under traffic or special conditions and the data recorded. Because highly trained and experienced specialists were available, the author did not attempt to get involved in the bonding of the strain gauges and recording of data.

This second series of tests was done during November 1988. Upon receipt of approximately 3 000 readings on the ten joints under test, the author analysed these and drew the conclusions as presented in this document.

A report on the development of a laboratory test for insulated joints was written by Mr J. Meyer, Senior Engineering Technician at the Track Testing Centre, under the title of "Toetsmetode vir die toets /....."
toets van bloklasse" (Testing method for the testing of insulated rail joints). It is available as report no 24.833/04/91 under reference no 12/4/3/5, dated April 1991, and is referred to in the list of references. Meyer consulted the author on some of the points in writing the report.

10.4.2 The joints

Ten joints were chosen for this test:
(All the joints, except the first one, were for 57 kg rail)

1. UIC 60 heavy haul joint, imported, 6 hole, 4 mm end post.
2. Phenolic encapsulated, epoxied, 6 hole, 6 mm end post.
3. Phenolic encapsulated, dry (not epoxied), 6 hole, 6 mm end post.
4. Phenolic encapsulated, dry, 4 hole, 6 mm end post.
5. Phenolic encapsulated, dry, 6 hole, joint cut at 45°, with 4 mm end post.
6. Phenolic encapsulated, dry, 6 hole, joint cut at 45°, with 6 mm end post.

7. /......
7. Phenolic encapsulated, dry, 6 hole, joint cut at 65°, with 4 mm end post.
8. Phenolic encapsulated, dry, 6 hole, joint cut at 65°, with 6 mm and post.
9. Phenolic encapsulated, 6 hole, variable gap.
10. Phenolic encapsulated, 4 hole, variable gap.

The joints were chosen with the view to determine the effects on the stresses in the joint caused by:

- four and six hole joints
- epoxied and dry joints
- standard and angled end post gaps
- variable end post gaps

It was also attempted to compare the effect of rubber pads to the standard HDPE pads under the joint. The effect of changing the sleeper spacing on the stresses in the joint was measured, as well as the effect of a slack under the joint. The heavy haul joint was included because it could give an interesting comparison to the standard joints.
10.4.3 The test site

A test site was chosen where extended occupation time could be obtained. Suitable 57 kg track in good condition was a prerequisite. The site had to be accessible to the pantechnicon with the measuring equipment, as well as within easy reach of the Johannesburg Spoornet offices and Track Testing Centre. A District Engineer had to be found who would be willing to assist with the work involved in setting the test up, providing the necessary labour and carrying the track costs for the test.

A suitable test site was found at 29,5 km on the Kaydale - Nigel section near Heidelberg. The joints were assembled at the Elandsfontein Mechanical Workshops in six metre lengths and welded into track on the one leg of the line, each with a six metre closure between them, effectively leaving twelve metres between joints. The last two joints were installed with fishplated joints so that the end post gap could be changed during the course of the test.
The strain gauges were bonded to the joints, four per joint: one each side at the top of the fishplate on the end post line, i.e. on the top gauge side and top field side, as well as on the bottom gauge and field side, all in the centre of the fishplate on the end post line.

On the opposite leg of the rail, right across from the joint, strain gauges were placed to measure the wheel load. With the axle load of the locomotive measured, the measured wheel load could be subtracted from the axle load and the wheel load on the joint obtained. The gauges were calibrated by means of a hydraulic jack before the test commenced.

HBM strain gauges were used, with 120 Ω resistance, known gauge factors (around 2.05) and 95 ppm/K temperature coefficient of gauge factor. A 6E1 locomotive was used for the test and the test was completed in three days. Readings were taken in the up and down direction at speeds of 5 km/h to simulate static loading, and then at 10, 20, 30, 40, 50 and 60 km/h.

Fig. 29 /......
Fig. 29  The positions of the strain gauges on the joints, placed to measure maximum stress.

10.4.4 Results of the strain gauge tests

The tensile and compressive stresses in the fishplate were measured and recorded. It can be illustrated graphically in figure 30, page 152. This data was digitized, averaged out and then made available on diskette. A printout of the data for one joint is shown in figure 31. This data was processed and graphs drawn. The results are /......
are discussed under the appropriate sections and a summary of relevant results are given herewith.

It must be noted that the statistician has to be very careful when he processes this data. Dubious deductions can very easily be made. It was found that different answers can very easily be arrived at if the problem is approached from a slightly different angle. It was therefore attempted to process the maximum amount of data in every case to average out all unknown factors. The influence of unstable track conditions on the joint is so great that, in relation thereto, most other factors diminish in importance.

The biggest lesson learnt from these tests was that preventative maintenance to keep the underlying track in peak condition is the most important and rewarding act to be performed on insulated joints. Without proper preventative maintenance even the best and most excellently designed joint will end up in premature replacement.

Fig. 30 /......
10.4.4.1 The effect of speed on the joint

An attempt was made to determine whether the speed of the traffic has any influence on the stresses in the joint. To this end approximately fifty graphs drawn from the test data were studied. On some graphs the stresses increased or decreased as the speed increased. On other graphs the scatter was very wide. On some graphs the maximum stresses occurred around 30 km/h. Percentage increase or decrease of up to forty percent was observed on some graphs.
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The graphs on the next few pages can be viewed as examples. In his report Meyer noted an increase in stress due to speed of between 0 and 17% and the dynamic effect of the traffic to be around 18%. (Meyer, 1991, p 3) The data was then processed and all the values for the top and bottom compression readings averaged out. The top and bottom values varied by about 6% in both cases but there was no clear trend to be noticed.

<table>
<thead>
<tr>
<th>DESCRIPTION WHEEL-LOAD</th>
<th>GAGE TOP</th>
<th>GAGE BOTTOM</th>
<th>FIELD TOP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>COM- PRESSION SION STRESS</td>
<td>TEN AVE</td>
<td>COM- PRESSION SION STRESS</td>
</tr>
<tr>
<td>5 KM/H DOWN 10.9</td>
<td>-136.4</td>
<td>51.1</td>
<td>377.7</td>
</tr>
<tr>
<td>10 KM/H DOWN 10.8</td>
<td>-138.9</td>
<td>50.7</td>
<td>382.1</td>
</tr>
<tr>
<td>20 KM/H DOWN 11.2</td>
<td>-141.1</td>
<td>50.5</td>
<td>386.6</td>
</tr>
<tr>
<td>30 KM/H DOWN 10.7</td>
<td>-135.8</td>
<td>43.0</td>
<td>390.8</td>
</tr>
<tr>
<td>40 KM/H DOWN 11.4</td>
<td>-138.2</td>
<td>47.2</td>
<td>400.3</td>
</tr>
<tr>
<td>50 KM/H DOWN 10.9</td>
<td>-136.0</td>
<td>38.8</td>
<td>399.7</td>
</tr>
<tr>
<td>60 KM/H DOWN 11.4</td>
<td>-142.3</td>
<td>46.1</td>
<td>403.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5 KM/H UP 11.1</td>
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<td></td>
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<td>10 KM/H UP 11.1</td>
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<td>50 KM/H UP 10.9</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>60 KM/H UP 11.7</td>
</tr>
</tbody>
</table>

Fig. 31 Data in microstrain obtained from the field strain gauge tests.
In the case of the top compression gauges the readings increased from 5 to 20 km/h by 1.4% and then declined by 6.1% to 60 km/h. In this specific case there was no significant effect on the stresses in the joint when the traffic speed changed, although theory prescribes an increase in stress due to the dynamic effect of increased speed on the joint. It can therefore be concluded that there were other factors shielding the effect of speed on the joints.

10.4.4.2 Width of the end post gap

This is discussed in detail in chapter 5 page 55. An increase of 10.07% in stress was recorded between a 4 mm and an 8 mm gap. Therefore the gap should not be increased unless for some very well founded reason. However, one millimetre smaller or wider would not make that much difference to the stresses and the resultant fatigue life of the joint. The size of the gap could make a marked difference to the rate of formation of the batter on the rail surface at the joint. There is very little scientific data available on this aspect and it could be an interesting subject for further research.
10.4.4.3 Effect of a slack under the joint

A slack will induce high stresses in the fishplate and this in turn could lead to premature failure due to metal fatigue in the joint.

Meyer reported increases of 80% in the stresses in the fishplate due to a slack under the joint. (Meyer, 1991, p 6) It was found that the increase of stress in different components vary. Stresses can vary up to 150% within the two fishplates of the same joint. Approximately 80 readings on two joints were averaged out and 40% (39.76%) higher stress was found in the fishplates under slack conditions compared to after repair of the slacks. (See graph 5)

However, scrutiny of the data suggests that the stresses could be as much as 280% higher in extreme cases measured! The difference could lie in the magnitude of the slack under the joint. The less the support, the higher the stresses in the fishplates. It is important to know what the magnitude of the extreme values is and to have an indication what the average values would be for design purposes. The factor accepted /......
accepted by Meyer for the laboratory test, namely 1.4 for a moderate and 1.8 for a bad slack, seems very reasonable.

GRAPH 5  The effect of a slack in the track under the joint.

10.4.4.4 Sleeper spacing

The laws of structural design stipulate that the closer the support (sleeper spacing) the less the stress would be in the fishplate. It was hoped that this could be ratified in practice, but the uneven support conditions made these test results unreliable. On these joints slacks were unexpectedly found, nullifying the results...

Meyer /....
Meyer also reports that the results were not consistent. (Meyer, 1991, p 7)

10.4.4.5 Four hole and six hole fishplates

Joints number 3 (six hole) and 4 (four hole) were included in the test especially to quantify the difference between a four hole and a six hole joint. Careful scrutiny of the data suggests that the stresses in the six hole joint are lower than that for the four hole joint but the data is not very consistent and a suitable graph could not be drawn from it. Joints 9 (six hole) and 10 (four hole) were then considered since these two joints were used to test the influence of the width of the gap on the joint and data was recorded for every gap opening from 0 to 20 mm. Some 240 readings were averaged out and graph 6 was drawn from this data. The final analysis shows that the stresses in the four hole joint were 12% higher than that for the six hole joint.

On the strength of this, as well as practical experience on the heavy haul lines, it is recommended that six hole joints be used in track and not four hole joints.

GRAPH 6 /........
10.4.4.6 Rubber pads under the joints

The six hole unepoxied joint was fitted with rubber pads on the rail-sleeper interface and the high density polyethylene pads removed. Graph 7 shows the stresses measured by the top compression gauges in this joint. Because the rubber is much softer than the HDPE pads, the graph / ......
graph seems to be faulty as it could be reasoned that the rubber should allow more bending than the HDPE pads. This would be true if there were no shock effect caused by the joint. However, a study of the stress curve as measured over the joints in this test, shown in graph 10 (p 167), shows that the stresses recorded are the maximum stresses as at point C on the curve. The

GRAPH 7  Stresses in the joint with HDPE and rubber pads on the sleepers.
rubber, however, attenuates or dampens the peak caused by the shock of the wheel going over the joint gap, much as a car with soft tyres would give a smoother ride on a gravel road than a car with hard tyres. According to the data recorded, rubber rail pads under the joint reduce the stresses in the fishplates by approximately 30% and would therefore play a major role in reducing fatigue in, and maintenance on, the joint.

10.4.4.7 Epoxied joints

Epoxy is used in the building of the insulated rail joint to make the joint electrically safer and to enhance the structural strength of the joint as discussed in chapter 6, page 64 onwards. This is borne out by the data from the strain gauge measurements. Both the top compression and bottom tension gauges showed a significant difference in the two joints - the epoxied joint and the non-epoxied or dry joint. See graph 8. The non-epoxied joint showed 19% and 30% higher stress than the epoxied joint. The difference in the top and bottom measurements can be attributed to the fact that
the epoxy had taken up some of the stresses and proves that the epoxy does the job that it is meant to do. The fact that the graphs move closer to each other as the train speed increases can probably be attributed to the dynamic effect of the train speed.

**GRAPH 8** Stresses measured in epoxied and non-epoxied (dry) joints.
10.4.4.8 The UIC 60 Joint

The UIC 60 imported joint was included in the test to see whether any informative deductions could be made from the data obtained.

The joint performed much better than the other joints. This was to be expected as it is a heavier joint fitted on a heavier UIC 60 profile rail. The joint was manufactured with a unique heat induced bonding process, having glass fibre reinforcing in the insulation layer.

The results were compared with the six hole local phenolic insulated joint, which was fitted with epoxy. All the gauge readings were between 130% and 300% better on the UIC 60 joint, except the bottom tension readings, which were only 22% better.

It must be taken into account that the moment of inertia of the UIC 60 rail (Ixx) is only 15.3% higher than that for the 57 kg rail. From the large differences in the data, it can be concluded therefore that the design of the UIC 60 joint is superior to that of the phenolic joint. It is borne out by field experience of the two joints. This fact has contributed largely /....
largely to the development of a local bonded or epoxied joint where a design similar to an old glued type joint is used, but with a superior epoxy and a unique distance piece or spacer between the rail and fishplate. This spacer keeps the conductive surfaces apart until the epoxy has set. This joint was found to give service comparable to that of the UIC 60 joints in comparative track tests on the Richards Bay Coal Line.

10.4.4.9 Angled joint cut

As discussed in chapter 5 page 46 onwards, the cut at the joint interface of the two rails can be made at an angle. It is theorized that a rolling motion would be achieved at the joint and the hammering action on the joint would be minimized. If this is true, it should show in the strain gauge readings. The readings for joint no 8, cut at 65° were compared in graph 9 to those obtained from joint no 3, cut at 90°. It was found that the readings on the square joint were 30% higher than those on the angled joint. Although a larger difference was expected, the 30% can be considered substantial and an indication that the theory is confirmed by /........
by the track measurements. Similar to the rubber pads, the angled cut serves to attenuate the impact stress caused by the wheel travelling over the square cut gap on the joint.

GRAPH 9  Comparison of a joint cut at an angle to a joint cut squarely.

10.4.4.10 Other observations

Scrutiny of the data revealed some peculiarities that justify discussion.
In some cases the data from the down run and the up run differed by a substantial margin, even as much as thirty percent. This could mean that the sleeper on the far side of the joint was not as well packed as the opposite sleeper. The "loose" sleeper would tend to cause recording of higher values when it was on the far side of the joint. When the traffic approached from the side of the "loose" sleeper it did not record the high loads as the load was taken up in a gradual way and not as a shock, as in the first case.

In some cases it was found that the data improved on a specific joint as the tests progressed from the lower to the higher speeds. This could be attributed to the sleepers at the joint being packed unevenly or packed high on one side only. As the test progressed the sleepers would then bed in properly and better readings would be obtained.

It was observed that the values obtained were very sensitive to the track quality. To obtain truly comparable readings, the tests should be done on a track slab where all the track parameters /...
parameters can be controlled and where there are no variable support situations.

Graph 10 shows an enlarged typical curve of the stresses recorded as the wheel goes over the joint. The theoretical curve of a wheel over a smooth joint should follow the dotted line from A to E. The reduction in stress between A and B is when the wheel traverses the gap and therefore momentarily reduces the stress on the joint. When the wheel hits the rail on the other side of the joint, the stress increases due to the impact load, to C. This impact stress is usually very close to double the measured wheel load. (Tomas, 1986, p 13) The section CD of the graph represents the reaction of the wheel to the impact and it now "jumps" and hits the joint rail a little further along, usually about 20 mm from the joint. The impact here is recorded in D - E on the graph. This jump and the resultant impact cause the well known batter that is discussed in chapter 9, page 105. It is a wear phenomenon that is caused by the energy dispersed when the wheel hits the rail. The batter on the other rail can be seen in the slight discontinuity in the graph /.....
graph at point Z. The wheel now continues along the rail and the stress in the joint diminishes along the line E - F.

GRAPH 10 Typical stress pattern of a wheel traversing an insulated joint.

It has been reported that flat wheels as well as skid marks on rails can add another 30% to the stresses measured in the joint. (Tomas, 1986, p 13)

The stresses recorded in the joints are not high and are in the order of 150 MPa, well within the yield stress of 280 MPa for En8 steel. (Tomas, 1986, p 15)
10.5 Laboratory test

The laboratory test was developed from the field strain gauge tests. This was documented by J. Meyer in his report "Toetsmetode vir die toets van bloklasse." (1991) The test was developed entirely by the Track Testing Centre staff and the only input from the Rail Technology Section was to state requirements and to recommend certain limits from practical experience.

10.5.1 Previous tests

In the past rolling load tests and dynamic fatigue tests were done in the old track laboratory. The rolling load test is still available and the apparatus was used in the photoelastic test described under 10.3. It consists of a machine frame holding the loading wheel and a jig where the test piece is clamped. The wheel is mounted to rotate in a fixed position in the frame and is loaded by compressed air. The test piece is moved to and fro on bearings under the wheel by an arm and wheel arrangement similar to the driving wheel on a steam locomotive. The test piece would be run in this machine for a predetermined number of "passes" of the wheel in an attempt to simulate the action of the wheels of passing traffic on the test /......
test piece. This test is very slow and the dynamic effect of the traffic cannot be simulated. It can also not simulate the lifting curve created by traffic on open track.

The dynamic fatigue test was done in an old "Mori" testing machine. The test was similar to tests done today in that the test piece was clamped and then loaded vertically with predetermined loads and the test piece fatigued. Tension and compressive forces of 73 kN and 216 kN were applied respectively for 2 million cycles at 330 cycles per minute (5.5 Hz). The supports were 500 mm apart under the test piece. The machine did not have space or facilities to have a horizontal load applied to the test piece. This machine gave very good service but was eventually replaced by new, technologically superior equipment.

10.5.2 The new fatigue test

The test was developed to be done on a load frame which is part of the computer controlled servo hydraulic testing equipment in the Track Testing Centre at George Goch, Johannesburg.
First strain gauge tests are done in a test pit in the Track Testing Centre, consisting of a pit with a standard track built in it, including rails, fastenings, sleepers and ballast. Under a load of 130 kN a stress of 380 micro m/m was measured, against 392 micro m/m in the field, a correlation of within 3.5%. From these results it was decided that the test pit evaluation was adequate. For laboratory testing, new joints can now be tested in the test pit and field testing for determining the traffic induced stresses would therefore not be necessary. As the stresses in each type of joint are different for the same wheel load, the appropriate stresses must be determined for each type of joint individually. The maximum positive and negative stresses are determined and reduced to stress per ton wheel load. (Meyer, 1991, p 11) This stress is then multiplied by the appropriate wheel load for the different rail size joints, namely 14 tons for 60 kg rails and 11 tons for 48 and 57 kg rails.

Before installation of the joint in the test frame, the electrical resistance is measured with a 500 volt megger. The joint is then cut to 2.5 metres and installed in the frame on 2.2 metre centre /......
centre supports. This is done so that a smaller load can be used to induce the same stress in the joint fishplates as would be done by the train wheels in track on standard sleeper spacing. A horizontal tensile force of 60 tons simulating temperature induced forces in track is applied to the joint. (Meyer, 1991, p 13) The joint is now ready to start the fatigue test.

From the field strain gauge tests a series of factors was derived for adjusting the load in the new test. These were: speed 1.17; size of end post gap 1.15; dynamic effect of trains 1.18 and effect of a slack in the track 1.80. (Meyer, 1991, p 8)

For the first 60% of the test the piece is run for "good track condition" and the wheel load adjusted only for the speed, dynamic effect and gap width factors, i.e. $1 \times 1.17 \times 1.18 \times 1.15 = 1.6$ times the static wheel load. For the next 20% of the test it is run for "slight slack condition", multiplying the 1.6 by another 1.4 for a slight slack, giving a factor of 2.24 times the static wheel load. For the last 20% of the test the joint is run for "bad slack condition", i.e. $1.6 \times 1.8 = 2.86$ times the static wheel load.

The /......
The 1,8 is applied to simulate a bad slack. The 60% and 20% values were taken as estimated times that the "average" joint in the field would be under those conditions. In practice this would be different for every joint. (Meyer, 1991, p 12)

The test joint is loaded by the adjusted wheel load stress "F" downwards and a stress of 0,3 x F upwards to simulate the uplifting curve in track that gives a stress of 30% of the wheel load. (Tomas, 1986, p 5) The test is run at a frequency of about 5,5 Hertz for 5 million cycles each for 48 kg and 57 kg joints and 10 million cycles for the 60 kg heavy haul line joints. Upon completion of the test the electrical resistance is measured again. (Meyer, 1991, p 13)

Of the joints tested under these conditions, only one joint completed the test, namely a locally manufactured glass reinforced plastic joint, discussed in chapter 6, page 76. This joint pulled open under the horizontal 60 ton force and showed considerable vertical movement during the test. However, it completed the full 5 million cycles. A 60 kg heavy haul line joint was tested and it broke under the "bad slack" condition after a total of 8,12 million cycles. An imported 57 kg nylon /......
nylon encapsulated joint broke after about 1.5 million cycles. This was attributed to some metallurgical defect in the steel insert. A glass filled nylon encapsulated joint broke after just more than 1 million cycles due to a stress riser on the steel insert, classified as a manufacturing defect.

Although a very stringent test, this test can be used most effectively to compare joints and to test joints for adjudication of tenders. If, in the long term, it should be found that the standards set in the test are too high, the Track Testing Centre staff have indicated that the standards can be revised. (Meyer, 1991, p 17)

Nowhere in the literature surveyed was a test of this nature mentioned, but it is considered the most stringent test done on insulated rail joints.

10.5.3 Overseas tests

The German Federal Railways are reported to have done tests on insulated joints running for 2 million cycles at 9 Hertz with a 10 kN upward and 150 kN downward force and a horizontal force of 20 tons alternating from tension to compression four times /.......
times an hour. Thereafter the horizontal force is increased to 40 tons for another 0.5 million cycles. Their electrical resistance test has a pass limit of 30 000 Ω.

In 1985 the Association of American Railroads reportedly acquired three joints from a manufacturer to test, one for a rolling load machine test and two for shear tests.

Another test that is done by some railroads is to cut the joint at the end post and then to apply pressure on the rail and fishplates in opposite directions with the aim to measure failure or displacement between the fishplate and the rail. The load is applied in increments of 25 000 lbs (11 338 kg) until failure or a load of 600 000 lbs (272 tons) is reached. Movement of the rail with respect to the fishplate is measured after each load increment to the nearest 0.001 of an inch (0.0245 mm) by means of dial gauges. This was done by Mr Amir N Hanna, Principal Engineer, Track Structures, Transportation Development Department, Construction Technology Laboratories, Illinois. The report was not dated. In the same report it is mentioned that electrical resistance is measured.
measured by applying a 500 volt direct current to the rail on one side of the joint for three minutes. Current flow is measured and the resistance calculated. An electrical impedance test is done by supporting the joint on non-conducting material. A 50 volt alternating current is applied to the rail and the current flow for frequencies between 20 Hz and 10 kHz is measured. The impedance is then calculated.

10.6 Track tests

In 1982 the Rail Technology Section (Chief Civil Engineer's Office) of Spoornet, then S.A. Transport Services, decided to do an extended field evaluation of some of the best joints available on the market, under leadership of Mr D.W. Hoffmann. Tenders were invited and, of the fourteen types offered, ten types of joints were selected and bought for use on 48 kg, 57 kg and 60 kg rails. Of one type of joint only 16 were bought while of the other types mostly 64 and 56 of each were bought. (Hoffmann and De Koker, 1987, p 3-4)

It was decided to test the joints on four regions in South Africa to be able to encompass all traffic and weather conditions:

- Natal /.......
- Natal for high rainfall and high general traffic.
- Kimberley for dry, arid conditions with high summer and low winter temperatures.
- the Richards Bay Coal Line for high axle load heavy haul conditions.
- Southern Transvaal for high general traffic and suburban lines.

Each one of these regions and districts was visited to acquire cooperation for the test. The details of what would be required were explained carefully and followed up by a letter under reference CCE/M 24/5/7 dated 1984-03-30. The importance of the requirement to record accurate and complete maintenance figures for every joint was emphasized, as the success of the test hinged on this factor. The Rail Technology Section acquired additional personnel to cope with the extra work load. A short summary of the letter mentioned above will explain how the tests were to be performed:

The aim of the test was to evaluate the available joints to find the types most suitable for local conditions. Each district would receive four of each type of joint, numbered and marked clearly with a colour code for easy identification. Personnel from Rail Technology would assist with the first installations to ensure that the joints were installed in a satisfactory manner. All the joints /......
joints were to be installed on Fist sleepers with 500 mm sleeper spacing, one of the four joints in a welded-up set of points and crossings and the remaining three in open track. The joints were to be evaluated monthly by a competent person of the district, with Rail Technology personnel inspecting the joints on a three monthly basis. Joints that failed in track — physically or electrically — were to be kept for inspection and the date and reason for failure noted. An inspection form was designed to record the monthly and three-monthly measurements. The following items of equipment were used:

- a track thermometer calibrated in degrees centigrade
- a tapered feeler gauge
- a one metre insulated straight-edge
- a 300 mm steel ruler
- a camera
- a torque wrench with all the necessary sockets

One inspection form had to be filled in for each joint. The following details were required:

- track data and location
- rail mass
- joint type and number
- bolt torque
- sleeper type and spacing
  - ballast /......
The following physical measurements had to be taken and recordings made:

- inspection date and inspector's name
- rail temperature and time
- end post gap as measured
- length and depth of dipped (battered) joint
- bolts loose or tight
- fishplate cracked, rusted, worn or distorted
- fastenings (on the joint) broken, missing, loose or damaged
- condition of the end post
- quality of the ballast under the joint
- maintenance done on the joint in man hours
- tonnage the joint had carried
- any other relevant remarks

The key information needed to determine the estimated life of the joint was the man hours spent on the joint in maintenance and the total tonnage carried on the line since the installation of the joint.

Signalling staff had to be informed of the test joints, their positions and their significance.
The joints were workshop assembled under supervision of Rail Technology staff. The manufacturer or agent for each type of joint was invited to attend the assembling process to ensure that the joints were assembled correctly. The joints were numbered, colour coded, checked and sent out to the various districts. Apart from a few small problems, the joints were installed correctly and the evaluation process could begin.

The following types of joints were acquired:

- Solid glass reinforced types:
  - Permali
  - Marshall (Bosse)
  - Three M (3M)
  - Röchling

- Encapsulated steel types:
  - Benkler with Hardomid insulation
  - Portee, coated with epoxy resin insulation
  - BTR with three types of locally developed joints:
    - phenolic insulating
    - polyurethane insulating
    - composite phenolic and polyurethane

- Steel fishplates with impregnated fibre-glass insulating heatbonded jacket: Klöckner

During 1987 a report was written covering the test and evaluation, discussing each joint and making conclusions and......
and recommendations. The report was written by Messrs D.W. Hoffmann and J.J. de Koker and is referred to in the list of references.

In practice the monthly and three-monthly inspections were found to be excessive and six-monthly joint inspections were subsequently carried out. A short summary of the most pertinent findings and discussions from the report follows herewith.

A table of results for each region is given in the report. Table 2 herewith summarizes these results.

**TABLE 2 RESULTS FROM FIELD EVALUATION OF VARIOUS TYPES OF INSULATED RAIL JOINTS**

<table>
<thead>
<tr>
<th>Type of joint</th>
<th>Number installed</th>
<th>Percent. failed</th>
<th>Ave. MGT carried</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permali</td>
<td>15</td>
<td>20%</td>
<td>33</td>
<td>good</td>
</tr>
<tr>
<td>Three M</td>
<td>56</td>
<td>2%</td>
<td>51</td>
<td>good</td>
</tr>
<tr>
<td>Bosse (Marshall)</td>
<td>47</td>
<td>0%</td>
<td>50</td>
<td>good</td>
</tr>
<tr>
<td>Röchling</td>
<td>45</td>
<td>7%</td>
<td>56</td>
<td>ave/good</td>
</tr>
<tr>
<td>Benkler</td>
<td>44</td>
<td>2%</td>
<td>45</td>
<td>average</td>
</tr>
<tr>
<td>BTR Phenolic</td>
<td>37</td>
<td>8%</td>
<td>53</td>
<td>average</td>
</tr>
<tr>
<td>BTR Polyurethane</td>
<td>57</td>
<td>0%</td>
<td>67</td>
<td>average</td>
</tr>
<tr>
<td>BTR Composite</td>
<td>49</td>
<td>20%</td>
<td>44</td>
<td>poor/fair</td>
</tr>
<tr>
<td>Portec</td>
<td>49</td>
<td>39%</td>
<td>45</td>
<td>poor</td>
</tr>
<tr>
<td>Klockner</td>
<td>53</td>
<td>0%</td>
<td>71</td>
<td>excellent</td>
</tr>
</tbody>
</table>
As can be seen from the table, only two types were found unsuitable, namely the Portec and the composite phenolic/polyurethane joints. Subsequently an improved Portec joint was tested, unfortunately also with substandard results. The Klöckner joint proved to be superior to all the other joints, particularly under heavy haul conditions.

The tests showed that laminated wooden fishplates are superseded by technologically superior types such as glass reinforced plastic. These have proved to be successful for light and medium class lines, and even under continuously welded track conditions. They are robust, economical and freely available. Encapsulated steel fishplates showed plastic flow and dipped joints under heavy haul conditions but gave fair service under general conditions. The test did not run long enough to show any difference between four and six hole fishplates. (Hoffmann and De Koker, 1987, p 12, 13)

Bolts were found to be more practical than studs in cases where loosening of the fasteners occurred. For frozen joints, studs posed no problem. The black glass filled nylon end post proved very successful as it is both hard and durable. (Hoffmann and De Koker, 1987, p 15)

Metal flow caused concern where UICA rail was used, but
the chrome manganese rails proved superior in this very vexing maintenance problem area. Sleeper spacing of 500 mm was successful and the best results were obtained where sleepers were the same for the joint and the rest of the track. Joints should be tamped every 4 - 5 million gross tons. Where joints have battered ends, the cycle should be shortened. "The life of an insulated joint is equally dependent on good original installation and well planned systematic maintenance". (Hoffmann and De Koker, 1987, p 19) It is concluded on pages 21 and 22 of this report that most of the joints are suitable for general Spoornet track with less than 20 ton axle loads and that the introduction of technologically superior joints will reduce the quantities of joints purchased in future.

It was recommended on pages 22 and 23 of the report that all joints be assembled onto chrome manganese rails with 30 mm bolts in 32 mm holes and 4 mm black glass filled nylon end posts. Joints are all to be assembled with epoxy and the norm of electrical resistance for a pre-assembled joint should be a minimum of 100 Meg Ω. When a joint is installed or replaced, all the ballast under the joint should be replaced with clean, angular ballast under both sleepers either side of the joint. Either four or six hole joints were recommended, but four hole joints are to be used in points and crossings.
The one shortcoming in the test and evaluation process was that the field maintenance staff did not keep accurate maintenance figures for the joints as had been agreed upon at the outset. This was not realized until too far into the project to rectify the problem. It came about because of the high turnover of maintenance staff in control of the joints in the field, due to them moving or being promoted or transferred. This lead to reduced practical applicability of the final report. Should a similar programme be instituted in future, mechanisms must be designed to make absolutely sure that the actual maintenance figures for all joints are obtained. This data is of great importance for the success of an evaluation project on insulated rail joints.

This evaluation process gave the supervisory staff a very good foundation regarding the manufacture, maintenance and problems associated with insulated rail joints.

10.7 Subsequent tests

Since the end of the evaluation programme discussed under the previous subsection, very few tests have been done. However, some of these need to be mentioned as they could have bearing on the future development of insulated joints on Spoornet track.
A glass reinforced plastic joint was developed locally. This joint is discussed in chapter 6, page 76 and under the laboratory test section. It withstood the 5 million cycles specified by the test. This joint is manufactured by dipping continuous glass strand into resin and winding the glass on a mandrel to the required thickness. It is then oven-cured in a mould. This produces a joint superior in tensile strength as the bolts do not pull through the ends of the fishplate under low temperature. The joint has shown to be very elastic under the laboratory fatigue test and there was difficulty achieving the 60 ton longitudinal force since the joint kept stretching, eventually leaving a 30 mm gap between the rail ends. The joint proved to be very flexible in the vertical direction when the wheel load was applied to it.

Only one joint was reported to have given problems in track and this is still under investigation. However, the manufacturer is presently investigating the possibility of changing his design to counter the problems foreseen. If the joint is applied in continuous track under poor support conditions, like rounded ballast, large gaps can cause heavy batter and excessive vertical movement under traffic. However, if the maintenance staff install and maintain the joint according to acceptable standards, no problems should arise.

After /.....
After the failure of the locally developed composite joint in the joint evaluation programme, it was suggested that a steel fishplate covered with glass reinforced nylon be manufactured. One sample was laboratory tested and broke under test due to a manufacturing defect. Another sample was track tested and was lost because of a derailment. For the six months that this joint was in track, however, the joint gave excellent service and it is envisaged that this design could still be used on the major portion of general lines that do not carry high axle loading.

The success of the heat bonded joint on heavy haul lines prompted Rail Technology and a local supplier to try and improve on designs for epoxy bonded joints that were used with a fair measure of success in the past. The problem experienced with these designs was that poor assembly procedures caused electrical failure of joints. A way had to be devised to keep the steel fishplates away from the rail during the assembly process until the epoxy had set.

A spacer washer was designed that fits over the stud between the fishplate and rail like a washer and has a "tail" to both the top and bottom side of the fishplate, maintaining the minimum distance required between the fishplate and the rail. It was also decided to use a high strength epoxy to assemble the joint and a reputable company /......
company was invited to supply one of their superior products. Three of these joints were built in four hole configuration and have been tested successfully in the heavy haul Coal Line now for at least two years. Some two thousand of this type of joint are presently being assembled in four hole configuration for 48 kg track and six hole for 57 kg track. This joint will in future be used in a six hole configuration under heavy haul conditions.

If the quantity of joints purchased are reduced by about 25% on the medium to long term, these new designs will be considered successful. The results of better maintenance procedures can already be seen in reduced orders for joints.
CHAPTER 11  CONTINUOUSLY WELDED RAIL

11.1 Continuously welded rail

The insulated rail joint is primarily subject to temperature induced forces in the horizontal plane along the length of the rail. In jointed track the rail expands due to increase in temperature and is therefore free of temperature induced stresses. Insulated joints used in jointed track are usually of the bolted on type and the construction of these joints allows for movement to take place in the joint so that the rail can move relative to the fishplate. Generally the holes in the rails and insulated fishplates are larger than the bolts used and that allows for this movement. Due to technological advances it has become common railway practice to weld jointed track into continuously welded sections of several kilometres long where no movement is allowed for and where the resulting forces are of such magnitude that they have to be accounted for.

The first continuously welded rail was introduced in Europe in the twenties. The first tests on continuously welded rail on the South African Railways were conducted on a one mile (1,6 km) section in 1938 and since the late fifties it has been standard practice on Spoornet to continuously /......
continuously weld rail where possible. Continuously welded rail presently constitutes more than 10 300 km of track, i.e. about 30% of Spoornet track. (Wildenboer, 1983, p 6) All main lines are continuously welded where possible.

The use of continuously welded rail is restricted by sleeper type, rail mass and radius of track curvature. Special insulated rail joints that can withstand the temperature induced stresses and strains are used in continuously welded track. On the 860 km Sishen - Saldanha railway line, the only joints in track, apart from welded joints, are insulated rail joints.

11.2 Temperature

Because of the inhibition of longitudinal movement by continuous welding, temperature induced movement is converted to stress in the rail: compressive stress for rise in temperature above the destressing temperature; tensile stress due to temperature lower than the destressing temperature. The destressing temperature is the temperature envelope at which the rail was welded.

Slip resistance between the rail and the sleeper also influences the movement and stresses in the rail. This should be 9 to 10 kN per support point (sleeper). Even with /......
with a vibrating load effect, it provides a safety margin either way of the destressing temperature. Large slip resistance counteracts displacement of the rail. (Fastenrath, 1977, p 37). Added to this there is the bed resistance between the sleeper and the ballast bed, as well as track resistance caused by ballast between sleepers. To overcome this the sleeper has to push ballast ahead of it. This happens when the rail surface is corrugated and a vibratory motion is induced by the passing train. The lifting effect of the train also counteracts the bed resistance, causing momentary loss of approximately one third of the bed resistance. To obtain maximum values, the slip resistance, bed resistance and track resistance are not taken into account in the calculations.

11.2.1 Destressing temperature

Destressing temperature ranges are used to control the temperature at which rails are welded into long lengths. These ranges are planned so that the maximum possible rise in rail temperature does not exceed 40°C and the maximum possible fall in rail temperature does not exceed 50°C. (Lombard, 1972, p 67)
There is a direct relationship between rail and air temperature. It was found that the extreme temperatures are the most critical and the following figures are used:

\[ Y_{\text{max}} = X_{\text{max}} + 23^\circ C \]
\[ Y_{\text{min}} = X_{\text{min}} - 4^\circ C \]

where \( y = \) rail temperature
\( x = \) air temperature

The highest \( X_{\text{max}} \) (air temperature) recorded near a railway line in South Africa was 47.7°C at Komatipoort in 1947, and the lowest \( X_{\text{min}} \) was -13.3°C in Belfast in 1926. This gives an absolute rail temperature \( Y_{\text{max}} \) of 71°C and \( Y_{\text{min}} \) of -17.3°C. The expected daily average change in temperature is around 25°C. (Lombard, 1972, p 67)

11.3 Calculation of temperature forces

The following equation is used to calculate the temperature induced stress: (Fastenrath, 1977, p 38)

\[ \sigma = \alpha . \Delta T . E \]

where \( \sigma = \) stress
\( \alpha = \) heat expansion coefficient of steel
\[ = 1.2 \times 10^{-5}/^\circ C \]

\( T = /..... \)
\[ \Delta T = \text{change in temperature in } ^\circ\text{C} \]

\[ E = \text{modulus of elasticity of rail steel} \]

\[ = 210 \times 10^6 \text{ N/mm}^2 \]

To determine the compressive or tensile force

\[ P \text{ or } Z = \sigma \times A \]

where \( P \) = compressive force

\( Z \) = tensile force

\( \sigma \) = stress

\( A \) = cross-sectional area of the rail

From this, for every \( 10^\circ\text{C} \) change in temperature,

\[ P \text{ or } Z = 1,2 \times 10^{-5} \times 210 \times 10^6 \times 10 \times A \]

\[ = 25,2(A) \text{ kN} \]

For continuously welded track only 48 kg/m, 57 kg/m and 560 kg/m rail are considered. The following areas \( (A) \) apply:

48 kg/m rail = 6018 mm\(^2\)

57 kg/m rail = 7324 mm\(^2\)

560 kg/m rail = 7702 mm\(^2\)

From this the values in table 3 and graph 11 were calculated.

\[ \text{TABLE 3} / \ldots \]
FORCE IN RAIL WITH 10°C STEPS TEMPERATURE CHANGE (Tonne)

<table>
<thead>
<tr>
<th>Rail type</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10°C</td>
</tr>
<tr>
<td>48 kg/m</td>
<td>15.46</td>
</tr>
<tr>
<td>57 kg/m</td>
<td>18.81</td>
</tr>
<tr>
<td>60 kg/m</td>
<td>19.78</td>
</tr>
</tbody>
</table>

TABLE 3 Force in rail with 10°C steps temperature change (Tonne).

Temperature induced forces in the rail

GRAPH 11 Forces induced in rails with change in temperature. (Kilo Newton)
CHAPTER 12  FORCES ACTING ON THE JOINT

To be able to design the fishplated joint, the design of the track structure needs to be understood. A reasonable background is needed of the operation of the track as a structure, as well as of the stresses that occur in the track and especially in the rail. This chapter discusses in some detail the design of the track structure with the emphasis on the rail.

12.1 Design criteria

The track structure and all its components are designed to resist the quantity and magnitude of the loads applied to it for a reasonable period without needing an excessive maintenance effort, and then to still be in an acceptable standard of operating safety. Presently the practice of design of conventional railway track prescribes that the parameters of strength of the various components should not be exceeded. (Ebersöhn, 1990, p 4.1)

12.1.1 Track design

Under the train the track acts as an elastic roadway consisting of six components:

- The rail provides an even guiding surface for the train wheels. It devolutes the loading from the wheels down to the rail chairs on the sleepers.
It also has to resist the lateral forces transferred from the wheels, and it also acts as an electrical conductor.

- The sleeper fastenings must provide a sturdy connection between the sleeper and the rail and prevent longitudinal and lateral movement of the rail relative to the sleeper.

- The sole plates provide a damping effect between the rail and sleeper (up to 35%) of all vibrations, and act as an electrical insulator.

- The sleeper ensures that the track gauge is kept, that inclination is given to the rail and that the load from the train is transferred and spread over a larger area.

- The ballast dampens the loads applied through the sleepers and transfers them over a larger area to the formation below. It also acts as a drainage layer and provides longitudinal and lateral stability to the overlying track structure.

- The formation is divided into two layers:
  a. A sub-ballast layer that keeps the ballast stone from penetrating the foundation layers and assists in further spreading of the load.
b. A foundation layer that supports and provides a firm base for the total track structure.

To design a railway track or, as in this case, a section of line including an insulated rail joint, the following information is needed:

- The track geometry and the type of rail.
- The influence of the environment, i.e. the temperature induced stresses.
- The loading on the track, i.e. the geometric outlay of the rolling stock traversing the joint, maximum axle loads and maximum operating speed on the line.

The static axle load, to which the dynamic increment is added, essentially prescribes the required strength of the track structure. Deterioration is measured in the accumulated tonnage carried by the track structure. (Esveld, 1989, p 29)

12.1.2 Track stresses

Stress is load (P) divided by the area (A) over which it is applied, i.e. Stress = P/A and is measured in MPa.
The following stresses are induced into the track structure:

- Vertical bending stress, caused by the vertical components of wheel loads causing deflection.

- Lateral bending stress, caused by the lateral components of wheel loads, hunting, thermal forces and brake action.

- Shear stress, caused by the vertical and lateral components of wheel loads, causing damage to the metallic structure of the rail.

- Longitudinal stress, caused by thermal forces and the wave action of passing traffic.

- Torsional or twisting stress, caused by the eccentricity of loads applied, lateral flexibility and the tendency of the rail to rotate around its points of physical restraint.

- Contact stress which is a concentration of local shearing and bending stresses on the rail surface and immediately below the point of load application. (Hay, 1982, p 241,2)

12.2 The dynamic factor

The moving rolling stock causes impact and vibratory loads on /......
on the track structure. To allow for this, the static force is to be adjusted by a dynamic factor.

When a static wheel load with a value $P$ moves over the track structure at a velocity $V$, it is felt as a load $Q$, differing from point to point. It can be smaller or bigger than $P$, and the point of application varies in eccentricity. (Ebersohn, 1990, p 4.11)

An empiric value for the dynamic factor was found that is dependent on the velocity of the moving rolling stock and the condition of the track.

Converting the static to a dynamic load is done by multiplying the static load $P$ with the dynamic factor $\phi$.

$$ Q = \phi P \text{ (kN)} $$

where $\phi = 1 + q \cdot s \cdot t'$

$$ q = \begin{cases} 0.1 & \text{for very good running surface condition} \\ 0.2 & \text{for good to average running surface condition} \\ 0.3 & \text{for poor running surface condition} \end{cases} $$

$s$ is the speed adjustment

$$ s = \frac{1 + (V - 60)}{140} \quad \text{for } 60 < V < 200 \text{ km/h} $$

$$ = 1 \quad \text{for } V < 60 \text{ km/h} $$

$v = /.....
V = operating speed of the track section

t' is the required statistical accuracy:

- t' = 1 for statistical upper limits of 84.1%
- t' = 2 for statistical upper limits of 97.7%
- t' = 3 for statistical upper limits of 99.9%

(Ebersohn, 1990, p 4.13)

Spoornet also uses the "Bridge Formula" that was developed from research done on the dynamic increment on bridges.

\[ \phi = 1 + 0.005 \frac{V}{D} \]

where \( \phi \) = dynamic factor

V = speed of rolling stock in km/h

D = maximum wheel diameter of the rolling stock

12.3 Condition of support

The support condition is defined with the aid of two properties, namely the foundation modulus and the track modulus.

The foundation modulus C is defined as the force per unit surface (stress) that will cause a unit deflection of the ballast and underlying track formation. (N/m²/m)

It is influenced by various factors, namely:

- How /......
- How the ballast is packed under the sleeper.
- The quality and depth of ballast under the sleeper.
- The condition of the underlying foundation including the presence of water therein.

Typical values used for Spoornet track:

\[
\begin{align*}
C &= 20 \text{ MPa/m} - \text{very bad clay formation and bad ballast} \\
C &= 50 \text{ MPa/m} - \text{bad to reasonable formation and ballast conditions} \\
C &= 100 \text{ MPa/m} - \text{good formation and ballast conditions} \\
C &> 100 \text{ MPa/m} - \text{excellent formation and ballast conditions}
\end{align*}
\]

(Ebersöhn, 1990, p 4.14)

Track modulus \( U \): it is the force per length-unit resulting in a unit deflection of the whole track structure.

This track modulus depends on:

- The foundation modulus \( C \)
- The dimensions of the sleepers
- The bending stiffness (EI) of the sleepers
- Sleeper spacing
- Rail size
- Track gauge
To be able to view the rail as resting on a hypothetical continuous foundation, it was found that half the length of the sleeper can be transposed to an equal surface area in the direction of the rail, directly under the rail, as in fig. 32. From this it follows that the track modulus

\[ U = b_t \ C \]  

where \( b_t \) = the transposed sleeper width for the continuous foundation (0.46 for Coal Line sleepers)

In practice it is found that, because of the tamping of the ballast under the sleepers, the support under the sleepers is not necessarily equal and continuous. The differences tend to even out and do not have a significant effect on the stresses in the rail. For the purpose of calculation it will be taken as a constant, continuous support under the sleeper.

Fig. 32 /......
12.4 Available structural components

The value of the Track Modulus is influenced by the rail characteristics, the type and spacing of the sleepers:

Wooden sleepers are generally 2 100 mm long, 250 mm wide and 130 mm thick. Non-standard sized sleepers are used in points and crossings but will not be considered in this context.

Concrete /......
Concrete sleepers can be represented by a beam 2 200 mm long, 273 mm wide and 220 mm thick.

Rails are classified in mass of steel per metre length, i.e. 48 kg/m, 57 kg/m and 60 kg/m. The following characteristics are for rails with different steel types used on Spoornet track. (Ebersohn, 1990, p 4.17)

<table>
<thead>
<tr>
<th>ELEMENT</th>
<th>HCDD Steel</th>
<th>UIC-A Steel</th>
<th>UIC-B Steel</th>
<th>CrMn Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon</td>
<td>0,55-0,68%</td>
<td>0,6-0,8%</td>
<td>0,5-0,7%</td>
<td>0,65-0,8%</td>
</tr>
<tr>
<td>Manganese</td>
<td>0,70-0,90%</td>
<td>0,8-1,3%</td>
<td>1,3-1,7%</td>
<td>0,80-1,3%</td>
</tr>
<tr>
<td>Chrome</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0,70-1,3%</td>
</tr>
<tr>
<td>Silicon</td>
<td>0,10-0,35%</td>
<td>0,1-0,5%</td>
<td>0,1-0,5%</td>
<td>0,30-0,9%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0,06% max</td>
<td>0,05% max</td>
<td>0,05% max</td>
<td>0,03%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0,06% max</td>
<td>0,05% max</td>
<td>0,05% max</td>
<td>0,03%</td>
</tr>
<tr>
<td>Hardness (Brinell)</td>
<td>240</td>
<td>280</td>
<td>300</td>
<td>340</td>
</tr>
<tr>
<td>Yield strength</td>
<td>410 MPa</td>
<td>449 MPa</td>
<td>440 Mpa</td>
<td>600 Mpa</td>
</tr>
<tr>
<td>Ultimate strength</td>
<td>880 MPa</td>
<td>885 MPa</td>
<td>885 MPa</td>
<td>1 080 MPa</td>
</tr>
</tbody>
</table>

TABLE 4 Rail steel elements and characteristics.

12.5 Stresses in rails

To determine the maximum bending stresses in the rail, the theory of a beam of infinite length resting on an elastic base /.....
base is used. This theory was proposed by Timoshenko and was confirmed by measurements in track.

This is only true if four of the sleepers (supports) fall within the half wavelength π of the system, as stated by Hetenyi, i.e.

\[ 4a < \frac{\pi}{\lambda} \]

where \( a \) = sleeper spacing (650 mm for Coal Line and 700 mm for general Spoornet main lines)

\[ = \sqrt[4]{\frac{U}{4EI}} \]

\[ = \text{characteristic length of system} \]

The profile and yield strength of the rail for any specific application is determined by the stress pattern and fatigue life. The contact stresses determine the yield strength but do not influence the choice of profile of the rail. In track the rail steel must conform to the high standards of purity and homogeneousness needed to perform satisfactorily for the full design period.

In the design of rails it is important to ensure that the rail can withstand the bending stresses caused by applied loads, stresses induced by temperature changes, as well as the contact stresses at the rail-wheel interface. The critical stress points in the rail are illustrated herewith.

Fig. 33 /......
When a rail is subjected to high axle loads, care must be taken that the combined bending and torsional stresses do not exceed the fatigue limit. This fatigue limit based on laboratory tests and borne out by practical observations is around 230 - 240 MPa. (Ebersohn, 1990, p 4.21)

The variable effect of the quality of the steel and the diameter of the wheel are not included in this calculation because they are constant under normal Spoornet conditions.

The loads exerted on the rail can be represented as follows:

Fig. 33 The critical stress points in the rail.
Lateral dynamic forces \( (Y) \) are applied by wheels that are influenced by guiding forces caused by track misalignments and the sway of the rolling stock on the rail. Shear forces are only of importance in the contact stress area and will not be discussed.

For the purpose of analysis the loading can be divided into four cases as follows:

**Fig. 34** Graphic representation of loading of a rail.

**Fig. 35** Graphic representation of the four load cases used for calculation purposes.
These four cases can each be considered on its own.

**Case 1**: Pure vertical bending

This case represents pure vertical bending. The stress in the rail flange is determined from bending theory, namely

\[ \sigma_{y} = \frac{M}{Z} \]

where \( \sigma_{y} \) = bending stress
\( Z \) = section modulus
\( M \) = bending moment calculated from the beam on elastic support

\[ M = \frac{Q}{4\lambda Z^\eta} \]

\[ \lambda = 4\sqrt{\frac{U}{4EI}} \]

\[ \eta = \text{influence factor of other wheels} \]

\[ = e^{-\lambda x} \left( \cos \lambda x - \sin \lambda x \right) \]

When the influence line of a wheel or set of wheels is viewed, it can be seen that the stresses change from tensile to compressive stress at all points with the passing of each wheel, resulting in continuous bending and eventual bending fatigue of the rail.

The deflection, bending moments and shear forces can now be calculated. The deflection of the beam (rail) is given by /......
by the formula:

$$y = \frac{\rho\lambda}{2U} e^{-\lambda x} (\cos \lambda x + \sin \lambda x) - - - (5)$$

This gives the deflection curve to the right-hand (positive) side of a beam of infinite length on an elastic foundation. The formula does not hold for negative values of $x$. (Ebersohn, 1990, p 4.5)

Differentiating (5), the gradient of the deflected structure is obtained by:

$$V_i = \frac{\rho X^2}{k} e^{-\lambda x} (\sin \lambda x) - - - - - (6)$$

Differentiating (6), in turn, gives the bending moment formula:

$$M = \frac{P}{4\lambda} e^{-\lambda x} (\cos \lambda x - \sin \lambda x) - - - (7)$$

Differentiating yet again, the shear force can be obtained by

$$T = -P / 2 \cdot e^{-\lambda x} (\cos \lambda x) - - - - - - (8)$$

The following sign convention is applied:

Positive is accepted as
- downward load $P$
- downward deflection $y$
- upward shear force directly to the left of the point load
- bending / .......
- bending moment directly to the left of the point of loading in the direction of the positive shear force

From experimental observation of the stresses in rails it was found that the stresses in the top and bottom of the rail crown do not agree with the aforementioned calculations. It is explained that, even if the rail were supported over the entire length by a 100% rigid foundation, stresses will still develop in the rail crown due to the vertical distortion of the web of the rail. The vertical web-modulus can be analysed by observing the rail crown as a beam resting on a continuous elastic support, namely the web. (Ebersohn, 1990, p 4.221)

A more precise theory based on plate theory, states that the web modulus \( k_w \) is given by

\[
k_w = \frac{t_w E}{2.3 a_w \log(a_c/a_w)}
\]

where \( k_w \) = web modulus
\( t_w \) = thickness of the web
\( a_w \) = depth of the rail crown
\( a_c \) = distance from the top of the rail crown to the centre of gravity of the rail

The /........
The stress at the top and bottom of the rail is given by:

$$\sigma_1 = \frac{Q}{4 \lambda' Z_k} \cdot \eta$$

$$\sigma_2 = \frac{Q}{4 \lambda Z_k} \cdot \eta$$

(10)

where

$$\lambda' = \sqrt{k_1/4EI_k}$$

and

$$Z_k = \text{section modulus of the rail crown}$$

$$I_k = \text{moment of inertia of the rail crown}$$

The total stress in the rail at $x = 0$ resulting from the centric loading is calculated as follows:

Top of the rail crown:

$$\sigma_1 + \sigma_2 = \frac{Q}{4 \lambda Z_k} \cdot \eta + \frac{Q}{4 \lambda' Z_k} \cdot \eta$$

(11)

Below the rail flange:

$$\sigma_2 = \frac{Q}{4 \lambda Z_f} \cdot \eta$$

(12)

where $Z_f = \text{section modulus of the rail flange}$

The stress distribution in the rail resulting from the centric loading is graphically depicted herewith:

Fig. 36 /......
Fig. 36 The stress distribution in the rail resulting from the centric loading.

Cases 2 and 4 : Torsion

Case 4 depicts the moment at the centre of gravity resulting from the eccentricity of the vertical loading, while Case 2 depicts the moment also at the centre of gravity resulting from the eccentricity of the lateral loading.

These moments cause a torsional moment in the rail. As the same principle applies in both cases, these two cases are treated simultaneously. (Ebersohn, 1990, p 4.24)

When a prismatic beam like a rail is subjected to pure torsion where all sections of the rail are free to distort, a condition of pure torsion results where only shear . . . . .
shear forces occur. It is called Saint Venant's torsion and can be depicted graphically as follows:

![Diagram of torsion moments in the rail]

Fig. 37 Torsion moments in the rail.

The torsion moment is given by

\[ T = c \cdot G \phi \]

(13)

where \( T = \) torsion moment
\( c = \) torsion constant
\( = \frac{A^4}{40J} \)
\( A = \) section area of rail
\( J = \) polar moment of inertia
\( G = \) shear modulus
\( = \frac{E}{2(1+\nu)} \)
\( \nu = \) Poisson's ratio for steel = 0.3
\( cG = \) torsion rigidity = \( c \)
\( \phi = \) torque per unit length

In practice the rail is clamped at the sleepers and a torsion / ......
torsion moment is applied in the centre between the sleepers. This occurs at the joint area and must be taken into consideration as such. Because of the symmetry, the plane where the torsion is applied cannot distort. A condition of non-uniform torque arises in conjunction with bending of the flange and crown of the rail. This causes stresses in the longitudinal direction that can be supplementary to the stresses in Case 1. (Ebersohn, 1990, p 4.25)

The torque per unit length is now given by

\[ \frac{d\theta}{dx} = \text{rate of torque} \]

The torque moment over any section can now be given by

\[ T = T_1 + T_2 \]

where \( T \) = torsion moment in the rail

\[ T_1 = \text{Saint Venant's pure torsion} \]

\[ = c_1 \frac{d\theta}{dx} \]

\( T_2 \) = the non-uniform part of the torsion in conjunction with the bending of the rail crown and flange

\[ = -c_2 \frac{d^2\theta}{dx^2} \]

\( c_2 = Dh^2 \)

\( D = E \cdot I_1 \cdot I_2 / (I_1 + I_2) \)

\[ I = / \ldots \ldots \]
I_c = moment of inertia of the rail crown around the vertical axis
I_f = moment of inertia of the rail flange around the vertical axis
T_x = Dh^2 \cdot d^3\phi / dx^3

with h_c being the distance between the centre of the rail crown to the centre of gravity of the rail and h_f being the distance between the centre of gravity and the centre of the rail flange. (Ebersöhn, 1990, p 4.26)

From the equations above the following differential equations can be deduced:

\[ T = C_1 \cdot \frac{d\phi}{dx} - Dh^2 \frac{d^3\phi}{dx^3} \]

For a long rail the solution to this equation is given by

\[ \frac{d\phi}{dx} = \frac{T}{C_1} \bigg(1 - e^{\gamma x}\bigg) \quad (13.1) \]

where

\[ C = \frac{A^4G}{40 I_c} \]

\[ \gamma = \sqrt{\frac{C_1}{Dh^2}} \]

\[ T = \frac{Y \cdot n - Q \cdot e}{2} \]

where

Y = lateral load (kN)
n = eccentricity of Y (m)
Q = vertical load (kN)
e = eccentricity of Q (m)
From this it follows that
\[ T_1 = T (1 - e^{-\gamma x}) \]
\[ T_2 = T e^{-\gamma x} \]

It can be theorized that this equation cannot be applied to the rail because it only applies to a beam of infinite length clamped only at its ends. It does not consider the fact that the full torsion moments are taken up within a few sleeper spaces as stresses in the rail fastenings.

It can be proved that the maximum bending stress will be obtained in the rail crown and flange when the torsion load acts on the rail at the point halfway between the two sleepers.

When the value for \( T \) is determined, it will be seen that it is absorbed virtually within a distance equal to half the sleeper spacing, although it only becomes zero when \( x \) tends towards infinity. \( T \) can be ignored as it only causes shear forces. This is borne out by Spoornet in track measurements.

Therefore \( T_2 = T \) in the equation 13:4
\[ \frac{d\phi}{dx} = \frac{T}{C_1} (1 - e^{-\gamma x}) \]

The bending stress as a result of the torsion is:
\[ M = EI_1 h_1 (\frac{d^3\phi}{dx^4}) \]

By /......
By differentiating \( \frac{d\varphi}{dx} \) above, it follows that

\[ M = EI_1 h_1 \left( \frac{T}{C_i} \right) \varphi e^{\gamma x} \]

This will be a maximum when \( x = 0 \), i.e.

\[ M = EI_1 h_1 \left( \frac{T}{C_i} \right) \gamma \]

Similarly for the rail flange

\[ M = EI_2 h_1 \left( \frac{T}{C_i} \right) \gamma \]

The bending stresses in the crown of the rail due to the torsion moments are given by:

Above the rail crown:

\[ \sigma = \text{bending stress due to } Y_n \]
\[ = (E I_1 h_1 / I_k) \times \left( Y_n \gamma / 2 C_i \right) \quad - - - - (14) \]

\[ \sigma = \text{bending stress due to } Q_e \]
\[ \sigma = (E I_1 h_1 / I_k) \times \left( Q e \gamma / 2 C_i \right) \quad - - - - (15) \]

Below the rail flange:

\[ \sigma = \text{bending stress due to } Y_n \]
\[ \sigma = (E I_2 h_2 / I_k) \times \left( Y_n \gamma / 2 C_i \right) \quad - - - - (16) \]

\[ \sigma = \text{bending stress due to } Q_e \]
\[ \sigma = -(E I_2 h_2 / I_k) \times \left( Q e \gamma / 2 C_i \right) \quad - - - - (17) \]

These stresses can be depicted graphically as follows:

Fig. 38 / ......
Case 3: Horizontal bending.

In this case only a lateral force is applied on the centre of gravity of the rail. Pure lateral bending will occur without any torsion and the maximum bending moment in the rail will be given by

\[ M = \frac{V.a}{r} \]

where
- \( M \) = bending moment (kNm)
- \( V \) = lateral force (kN)
- \( a \) = sleeper spacing (metre)
- \( r \) = constant
The constant follows from the fact that the maximum bending moment for a single span simply supported beam

\[ M = \frac{Y_a}{4} \]

and for a single span encased beam \( M = \frac{Y_a}{8} \)

The rail fastened on sleepers will be in a condition somewhere between the above two cases. Therefore the constant should be between 4 and 8. When a lateral force is applied to the rail, the rail is simultaneously pressed firmly down onto the sleepers. It can be reasonably assumed that no lateral movement of the supports (sleepers) takes place relative to the rail.

When the three moment theorem of Clapeyron is applied, it follows that \( r = 5.86 \). From this theorem it also follows that the influence of the adjacent wheels can be left out as it has no bearing on the wheel under consideration.

Because the lateral force fluctuates considerably and small lateral deflections of the support points relative to the rail will lessen the maximum bending moment, it was found that \( r = 6.00 \). (Ebersöhn, 1990, p 4.29)

The maximum bending stresses in the rail are therefore given by:

\[ \sigma_1 \text{ above the rail crown and } \sigma_2 \text{ below the rail flange.} \]

\[ \sigma_1 = \frac{Y_a}{6Z_1} \quad \text{and} \quad \sigma_2 = \frac{Y_a}{6Z_2} \quad - \quad (18) \]

where /......
where \( Z = \frac{I_{xx}}{0.5 b} \), and \( Z_0 = \frac{I_{xx}}{0.5 b} \) (19)

\( b \) = width of the rail head

\( b \) = width of the rail flange

The bending stresses due to the lateral loading on the centre of gravity can thus be pictured graphically as in figure 39.

![Diagram of bending stresses due to lateral loading on the centre of gravity of the rail.]

Fig. 39 Bending stresses due to lateral loading on the centre of gravity of the rail.

The total stress distribution in the rail because of all four cases can be calculated by adding all the practical combinations of these forces. It must be noted that the value of \( e \) can fluctuate and can be a positive or negative /......
negative value. It is only possible when the eccentricity (e) is on the field side of the rail. (Ebersohn, 1990, p 4.30)

12.5.1 Contact Stresses

Contact stresses are caused by pressure of one elastic object on another elastic object with a confined contact area.

Investigations into the stress components of the rail crown showed that the main stresses are very high immediately around the contact area between the wheel and the rail. The stresses are equal in the main, secondary and depth directions of stress. \[ \sigma_1 = \sigma_2 = \sigma_3 \]

Although the extreme values of the compressive stress exceed the yield stress of the steel, the steel does not yield because the shear stresses disappear at the surface, i.e.

\[ \tau_1 = \tau_2 = \tau_3 = 0 \]

The compressive stresses cause work-hardening of the rail steel in the uppermost zones of the rail crown. Deeper under the rail surface the primary stress \( \sigma \) decreases slowly in the direction of the /...
the applied stress while the secondary stresses $\sigma_1$ and $\sigma_3$ decrease very rapidly. Because of this stress differential, the maximum shear stress is found at a depth of half of the contact length. The magnitude of this shear stress is approximately 30% of the contact compressive stress.

It is accepted that the contact compressive stress is spread evenly over the contact area. The wheel and rail are represented as a cylinder running on a flat surface. The contact length $2a$, is derived from the Herzian theory and is given as

$$2a = 3.04R \sqrt{Q \cdot 10^3 \over 2b \cdot E}$$

where $Q =$ vertical wheel load (kN)

$R =$ wheel radius (mm)

$E =$ Young's modulus for rail steel (MPa)

$2b =$ width of contact area, assume 12 mm

the contact stress $\sigma_c$ can be calculated from the equation

$$\sigma = F / A$$

$$\sigma_c = Q \cdot 10^3 \over 2a \cdot 2b$$

It /.......

It was found that if
\[
\frac{\text{dynamic contact stress}}{\text{yield stress}} < 2
\]
the life of the rail will be determined by wear only. If this ratio is equal or bigger than three, plastic deformation occurs (discounting work-hardening of the steel). The allowable contact stress from a fatigue point of view should not be more than half the ultimate strength for rail steel, i.e.

\[
0.5 \times 885 \text{ MPa} = 442.5 \text{ MPa} \text{ for UICA rail steel} \\
0.5 \times 1080 \text{ MPa} = 540.0 \text{ MPa} \text{ for Cr Mn rail steel}
\]

When the allowable shear stress in the rail is exceeded, fatigue yield will take place and sections of the rail steel will break out. This type of rail defect is commonly seen in track and manifests as head checks and shelling of the gauge corner, especially on the heavy haul lines, i.e. the Richards Bay Coal Line and the Sishen - Saldanha Iron Ore Line. This problem can be overcome by lowering the axle and wheel load, enlarging the wheel diameter, or using a rail steel with higher yield strength.

12.5.2 Other stresses
12.5.2.1 Residual stresses

After rolling, the hot rails are left to cool. Because the volume to surface ratio for the rail head and base is different, the rail will bend in the vertical plane while cooling. After the rails have cooled to below 60°C, they are straightened on roller straightening machines. At the ISCOR Pretoria works a group of nine rollers is used. The rail is bent cold beyond its elastic limit, introducing residual stresses into the rail of the order of 100 to 300 N/mm² (Esveld, 1989, page 144) The stresses tend to diminish during in-track use of the rail with the stresses in the head showing the biggest change due to the rolling out effect of the wheel-rail forces.

Some French rail manufacturer has done tests with stretch straightening of rails attempting to produce rails free of residual stresses. However, the system uses very expensive equipment and it is an inherently dangerous operation that might never be used on a production scale.

12.5.2.2 /......
12.5.2.2 Braking and accelerating forces

Forces retarding the train are from three sources: brake shoe pressure, grade and curve resistance and train resistance. Ascending grades aid retardation and descending grades reduce retardation. (Hay, 1982, p 167)

Brake shoe pressure does not introduce any extra force into the rail and can be disregarded. The grade, curve and train resistance are factors influenced by the rolling resistance of the train and the friction between the rail and wheel flanges. The maximum braking is achieved when the brake shoes exert enough pressure to retard the train but the wheels do not slip and are just kept in rolling motion. The maximum force is exerted on the rail when the train wheels skid due to incorrect braking. The force exerted on the rail is equal to the wheel load multiplied by the coefficient of dry sliding friction for steel on steel. For a 26 ton axle load it should be: $13 \times 0.57 = 7.41$ tonne.

Esveld gives the force as 25% of the mass of the train, or $\pm 20$ kN/m and gives the accelerating force as around 33 kN/m over 30 metres or 40% of the train mass.

12.5.2.3 /......
12.5.2.3 Stresses caused by flat wheels

Flat spots on the circumference of the wheel tread are caused by dragging the wheels during braking of the train. The incidence of these flat spots is quite high and can be found on approximately 5% of all wheels. The chance of the joint being hit by a flat wheel is fairly high and has to be catered for. Flat spots of between 1 and 2 mm deep will cause additional stresses of approximately 40 MPa in the flange of the rail. (Lombard, 1972, p 68)

12.5.2.4 Stresses caused by skid marks

Skid marks on the rail are usually caused by the locomotive spinning its wheels in an effort to pull away under load. The skid marks vary in depth but the most common size is around 3 mm deep. Skid marks will cause additional stresses of about 30% of that caused by the wheel load in the fishplates. (Tomas, 1986, p 10)
12.6 Calculated example

All the forces acting on the rail and therefore on the joint, can now be calculated. To indicate the magnitude of the forces involved, an example is calculated and included. Poor track conditions are chosen to obtain maximum stresses.

12.6.1 Calculation of stresses for $560$ heavy haul track on poor track and foundation conditions

The maximum axle load on the track is an $11E$ locomotive with $30$ tonne axle load and $3 \times 2 \, 200$ mm wheelbase. The wheel load $P = 30 / 2 = 15$ tonne. The wheel diameter is $1220$ mm and the operating speed on the line is $70 \, \text{km/h}$.

The dynamic load is calculated from (1):

$$Q = q \cdot P = (1 + q_s \cdot t') \cdot P$$

The track constant $q = 0.3$ for poor track.

For an operating speed of $V = 70 \, \text{km/h}$ the speed adjustment

$$S = 1 + \left( \frac{V - 60}{140} \right)$$

$$= 1.07$$

For the required statistical upper limit of $99.9\%$, $t' = 3$

$$Q = (1 + 0.3 \times 1.0714 \times 3) \times 15$$

$$= 29.46 \text{ for poor track } (19.8 \text{ for good track})$$

The / .......
12.6 Calculated example

All the forces acting on the rail and therefore on the joint, can now be calculated. To indicate the magnitude of the forces involved, an example is calculated and included. Poor track conditions are chosen to obtain maximum stresses.

12.6.1 Calculation of stresses for S60 heavy haul track on poor track and foundation conditions

The maximum axle load on the track is an 11E locomotive with 30 tonne axle load and 3 x 2 200 mm wheelbase. The wheel load \( P = 30 / 2 = 15 \) tonne. The wheel diameter is 1 220 mm and the operating speed on the line is 70 km/h.

The dynamic load is calculated from (1):
\[
Q = \varnothing P = (1 + q.s.t').P
\]

The track constant \( q = 0.3 \) for poor track.

For an operating speed of \( V = 70 \) km/h the speed adjustment
\[
S = 1 + (V - 60) / 140 - - - \text{ from (2).}
\]
\[
= 1.07
\]

For the required statistical upper limit of 99.9\%, \( t' = 3 \)
\[
Q = (1 + 0.3 \times 1.0714 \times 3) \times 15
\]
\[
= 29.46 \text{ for poor track ( 19.8 for good track )}
\]

The /...
The foundation modulus $C$ is given as:

$$C = 20 \text{ MPa} / \text{m} \quad \text{for very poor track}$$

The transposed sleeper width for coal line sleepers for a continuous foundation: $b_* = 460 \text{ mm}$

The track modulus $U = b_* \cdot C = 0.46 \times 20$

$= 9.2 \text{ for poor track (MPa)}$

$= 46 \text{ for good track}$

The characteristic length for the system, from (4)

$$= \sqrt[4]{\frac{U}{4EI}}$$

$= 0.7719 \text{ for poor track}$

$= 1.15 \text{ for good track}$

Four sleeper spaces ($4 \times 650 \text{ mm}$) must fall within half wavelength of this system, i.e.

$$\frac{\pi}{\lambda} > 4 \times 650 = 2600 \text{ mm}$$

$\frac{\pi}{\lambda}$ for poor track $= 4070 > 2200$

$\frac{\pi}{\lambda}$ for good track $= 2270 > 2200$

12.6.1.1 Deflection

To calculate the deflection of the rail, from (5):

$$y = \frac{p \lambda}{2U} \cdot e^{-\lambda x} \cdot (\cos \lambda x + \sin \lambda x)$$

Where /......
Where $x$ is the horizontal distance from the wheel:

for poor track ($y$ in mm) for good track

$\begin{align*}
   x &= 0 & y &= 6,14 & y &= 1,83 \\
   x &= 1 & y &= 4,01 & y &= 0,76 \\
   x &= 2 & y &= 1,34 & y &= 0,01 \\
   x &= 3 & y &= 0,03 & y &= -0,07 \\
   x &= 4 & y &= -0,27 & y &= -0,02 \\
   x &= 5 & y &= -0,18 & y &= 0,002 \\
   x &= 10 & y &= 0,003 & y &= 0,000
\end{align*}$

12.6.1.2 Bending moment

To calculate the bending moment, from (7):

$$M = \left( \frac{P}{4\lambda} \right) \cdot e^{-\lambda x} \left( \cos \lambda x - \sin \lambda x \right)$$

Where $x$ is the horizontal distance from the wheel:

for poor track (M in kNm)

$\begin{align*}
   x &= 0 & M &= 47,66 & x &= 6 & M &= -0,22 \\
   x &= 1 & M &= 5,86 & x &= 7 & M &= 0,07 \\
   x &= 2 & M &= -5,69 & x &= 8 & M &= 0,11 \\
   x &= 3 & M &= -5,60 & x &= 9 & M &= 0,06 \\
   x &= 4 & M &= -3,07 & x &= 10 & M &= 0,03 \\
   x &= 5 & M &= -1,15
\end{align*}$

12.6.1.3 /......
12.6.1.3 Shear force

To calculate the shear forces, from (8):

\[ \tau = \left( -\frac{P}{2} \right) e^{-2x} \cos \lambda x \]

Where \( x \) is the horizontal distance from the wheel:

- for poor track
  - \( x = 0 \) \( \tau = 73.6 \text{ kN} \)
  - \( x = 1 \) \( \tau = 28.2 \)
  - \( x = 2 \) \( \tau = 5.8 \)
  - \( x = 3 \) \( \tau = 1.6 \)
  - \( x = 4 \) \( \tau = 2.5 \)
  - \( x = 5 \) \( \tau = 1.6 \)

GRAPH 12 Deflection diagram for one wheel on S60 rail.
GRAPH 13  Bending moment diagram for three wheels of an 11E locomotive on S60 rail.

GRAPH 14  Shear force diagram for three wheels of an 11E locomotive on heavy haul track.
12.6.1.4 Stresses in the rail

To calculate the stresses in the rail:

Case 1: Vertical bending, from (11), for the top of the rail crown:

\[ \sigma_s \sigma_3 = \frac{Q}{4 \lambda z_k} \cdot \eta + \frac{Q}{4 \lambda' z_k} \cdot \eta \]

The maximum stress occurs where \( x = 0 \), therefore \( \eta = 1 \)

The web modulus is calculated from (9)

\[ k_1 = t_1 E / 2.3 \cdot a_1 \log \left( \frac{a_2}{a_1} \right) \]

\[ = \frac{16.5 \times 10^6 \times 210 \times 10^3}{2.3 \times 47.5 \times 10^{-3} \times \log 144.5 / 47.5} \]

\[ = 65.64 \times 10^3 \text{ MPa} \]

\[ \lambda' = 4 \sqrt{\frac{k_1}{4 E I_k}} \]

\[ = 4 \sqrt{\frac{65.64 \times 10^3}{4 \times 210 \times 10^6 \times 1.19 \times 10^{-6}}} \]

\[ = 20.34 \]

For \( Q = 29.46 \) and \( = 0.7719 \) for poor track:

\[ \sigma_s \sigma_3 = \frac{29.46 \times 9.81 \times 10^3}{4 \times 0.77 \times 330.61 \times 10^{-6}} + \frac{29.46 \times 9.81 \times 10^3}{4 \times 20.34 \times 330.61 \times 10^{-6}} \]

\[ = 283.8 + 10.74 \]

\[ = 294.54 \text{ MPa} \]

For /.......
For the bottom of the rail flange, at \( x = 0 \) \( \eta = 1 \)
from (12):

\[
\sigma_k = \left( \frac{G}{4\pi I_t} \right) \eta
\]

\[
= \frac{29.64 \times 9.81 \times 10^3}{4 \times 0.77 \times 395.63 \times 10^{-6}}
\]

\[
= 236.57 \text{ MPa}
\]

Cases 2 and 4: Torsion

For design purposes the lateral force \( y \) is taken as

0.4 \times \text{the static load}

\( y = 15 \times 9.81 \times 0.4 = 58.86 \text{ kN} \)

Torsion \( Y_n \) above the rail crown, from (14):

\[
\sigma_n = \left( \frac{E I_n h_t}{Z_k} \right) \left( \frac{Y N y}{Z C_t} \right)
\]

\[
= \frac{210 \times 119 \times 100.55}{34} \times \frac{58.86 \times 0.106 \times 7.388}{2 \times 191.704}
\]

\[
= 739.04 \times 0.1202
\]

\[
= 88.83 \text{ MPa}
\]

\[
\sigma_n = \left( \frac{E I_n h_t}{Z_k} \right) \times \left( \frac{D e y}{2 C_t} \right) \quad \text{from (15)}
\]

\[
= \frac{210 \times 119 \times 100.55}{34} \times \frac{529.46 \times 9.81 \times 7.39 \times 22 \times 10^3}{2 \times 191.704}
\]

\[
= 739.04 \times 0.1225
\]

\[
= 90.56 \text{ MPa}
\]

Below / .......
Below the rail flange, from (16) and (17)

\[ \sigma_y = - \left( \frac{E \cdot I_z \cdot h_z}{Z_0} \right) \times \left( \frac{Y_n \cdot \varepsilon}{2 \cdot C_1} \right) \]

\[ \begin{align*} &\text{=} \quad - \frac{210 \times 3.19 \times 39.7 \times 58.86 \times 0.106 \times 7.388}{45.57} \times \frac{2}{191.704} \\ &\text{=} \quad - 58.36 \times 0.1202 \\ &\text{=} \quad - 70.16 \text{ MPa} \end{align*} \]

\[ \sigma_y = - \left( \frac{E \cdot I_z \cdot h_z}{Z_1} \right) \times \left( \frac{G \cdot e \cdot \varepsilon}{2 \cdot C_1} \right) \]

\[ \begin{align*} &\text{=} \quad - \frac{58.36 \times 29.46 \times 9.81 \times 22 \times 10 \times 7.388}{2 \times 191.704} \\ &\text{=} \quad - 58.36 \times 0.1225 \\ &\text{=} \quad - 71.51 \text{ MPa} \end{align*} \]

**Case 3:** Lateral force applied on the centre of gravity of the rail, from (18) and (19)

\[ \sigma_b = \frac{Y_n \cdot a}{6Z_b} \quad \sigma_q = \frac{Y_n \cdot a}{6Z_q} \]

\[ \begin{align*} &Z_b = I_{xx} / 0.5 b, \quad Z_q = I_{xx} / 0.5 b_q \\ &\text{=} \quad 5.504 / 0.5 \times 72 = 5.504 / 0.5 \times 150 \\ &\text{=} \quad 152.9 \times 10^{-6} = 73.39 \times 10^{-6} \end{align*} \]

\[ \begin{align*} \sigma_b &\text{=} \quad \frac{58.86 \times 0.65}{6 \times 152.9 \times 10^{-6}} \\ &\text{=} \quad 41.71 \text{ MPa} \end{align*} \]

\[ \begin{align*} \sigma_q &\text{=} \quad \frac{58.86 \times 0.65}{6 \times 73.39 \times 10^{-6}} \\ &\text{=} \quad 86.89 \text{ MPa} \end{align*} \]

Contact stresses on the rail surface:

From (20), the contact length

\[ 2a = 3.04 \times \sqrt{\frac{29.46 \times 9.81 \times 1220}{12 \times 210 \times 10^3}} \]

\[ = 25.43 \text{ mm} \]

From /......
From (21), the contact stress:

\[ \sigma = \frac{q \times 10^3}{2a \times 2b} \]

\[ = \frac{29.46 \times 9.81 \times 10^3}{12 \times 25.43} \]

\[ = 947.19 \text{ MPa} \]

\[ 947.19 / 600 = 1.578 < 2 \]

947.19 > 540 MPa, more than half the 1 080 MPa ultimate strength for chrome manganese rail steel. This explains the occurrence of head checks and other surface defects in the rail head.

12.7 Plane frame analysis

The results obtained in the calculated example above were compared to the results obtained from calculations in an industrial plane frame analysis computer programme. In the analysis programme a 57 kg rail was used and the model was set up with the rail being supported by vertical springs as supports every 650 mm, similar to sleeper supports. The springs were pinned to the rail and fixed at the bottom. The foundation modulus was used for the stiffness of the springs and a 13 ton wheel load (26 ton axle load) was used at 2.2 m centres, as in the calculated example, to load the structure. The programme calculated the deflection, shear forces and moments at every support point. To be comparable, the results should be within ten to fifteen per cent of the other method. This could not be /......
be obtained for either track in good or poor condition. In each case the results from the plane frame analysis programme were around 50 to 60% of those calculated by the accepted method. Track analysis can therefore be said to be a very special case and cannot be calculated by using standard plane frame analysis methods unless appropriate bridging methods and values can be found.

12.8 Finite element analysis on an insulated rail joint

It was decided to attempt to have a finite element analysis done on an insulated rail joint. As this is a very scientific method of structural analysis, it was reasoned that sound data could be obtained from this technique.

The rolling stock section of Spoornet was approached to do the analysis as they had the necessary advanced computer and software, as well as staff well versed in the use thereof. Assistance from the Civil Department was restricted to the more menial and time consuming tasks.

With the finite element method the piece under consideration is divided into a number of three dimensional bricks or elements, usually as small as possible. The corners of these elements are then defined in space and this data fed into the computer. Other data like the physical properties of the material under consideration, as well as loads and / ....
and other relevant information, are fed into the programme. Unfortunately the computer was replaced by a new one after the first run and the comparative data for various configurations, such as sleeper spacing and length of the fishplate, could not be extracted as planned. The calculation had to be abandoned as time did not allow for the whole mass of data to be fed into the new computer and the staff concerned were tied up with other work. A plot from the first trial run is reproduced here. The plot was done for the interface between the rail and the fishplate and shows the distribution of stresses in this plane. The joint was modelled as if the fishplate were glued to the rail, thus not being bolted to the rail.

A six hole S60 joint under heavy haul conditions was modelled. The plot shows that virtually all the stresses in the joint are concentrated on the fishing surfaces of the fishplate in the vicinity of the end post interface.

12.9 Conclusion

The above mentioned theory and the calculated example now quantify all the forces to be accounted for in order to design the fishplate and other components of the joint.

Fig. 40 /......
Fig. 40  Plot of stress distribution in the top and bottom fishing surfaces of a 6 hole 560 heavy haul insulated joint.
CHAPTER 13 SPECIAL CONDITIONS FOR THE PURCHASE OF INSULATED RAIL JOINTS

13.1 Scope and quantities

13.1.1 This specification covers insulated rail joints offered to Spoornet for use on 40, 48, 57, 560 and UIC 60 kg/m rail profiles.

13.1.2 Quantities

The quantities mentioned under each item in the schedule of quantities are the anticipated order quantities for the first year of the contract, but these figures are subject to change without notice. It is brought to the notice of tenderers that at this stage no indication can be given of future requirements for any item.

13.1.3 Minimum quantities

Tenderers must clearly state minimum quantities upon which tender prices are based, and state prices for larger quantities should these differ from minimum quantities.

Tenderers have to submit prices for the minimum number of units and in multiples of 100 units thereafter /...
thereafter, i.e. for 50, 100, 200 through to 1 000 units or more.

13.1.4 Splitting of tender items

Spoornet may purchase any one or part of one item or items on the schedule of quantities from any tenderer at its own discretion. Spoornet reserves the right not to purchase a particular item asked for on the schedule of quantities.

13.2 Materials and workmanship

13.2.1 Dimensional constraints

All components must conform to the dimensional requirements of the specified rail sections and the dimensions specified in diagram Z-2181.

The end posts must conform dimensionally to the rail profile except at the top of the bottom extremities of the rail flange where it may protrude above the rail. The thickness must be as specified in the schedule of requirements.

Studs or bolts must not to be more than 30 mm thick and 190 mm in overall length.

Fishplates should have hole spacings as specified
in diagram Z-2181. Holes are to be chamfered to a depth of 1 mm on both ends. The thickness of the plates are restricted by the length of the bolts or studs and the thickness of the nuts. The top outside faces of the fishplates must be cut away at an angle of 45° downwards from the horizontal at the extremity of the rail crown to accommodate worn wheel flanges. The bottom outside faces must be cut away to accommodate the rail fastenings as per drawing DOC 347 sheets 1 and 2.

13.2.2 Fishplates

13.2.2.1 Fishplates must be made of suitable quality new material and must be of the full fitting bar type of dimensions as specified on diagram Z 2181. When fixed in position, fishplates must be capable of supporting and transferring all loadings between rails without relative movement between rails and fishplates. A minimum sleeper spacing of 500mm must be designed for. Fist and Pandrol type sleepers F4, P2, PY and FY designs have to be catered for.

13.2.2.2 Steel fishplates must be fabricated from suitable high quality steel. Tenderers must clearly /......
clearly state what types of steel and heat treatment processes are used in the manufacture of the fishplates. The use of En8 or similar steel is recommended. The fishplate should have a minimum cross-sectional area over the holes of 2 000 mm². The positions of the holes in relation to one another and in relation to the fishing surfaces must be correct to within 0,5 mm. The thickness of the fishplates must be correct to 1 mm. The length of the fishplates must be correct to 4 mm.

13.2.2.3 When measured lengthwise with a straight-edge, the deviation from the straight on the top and bottom fishing surfaces of a 4 hole fishplate should not exceed 1,0 mm and of a 6 hole fishplate 1,5 mm. No hollow will be permitted in the top fishing surface. No hump will be permitted in the bottom fishing surface.

13.2.2.4 Manufacturing marks on fishplates

No manufacturing or scale marks deeper than 0,5 mm will be allowed on the fishplates. Not more than 5% of the surface area may be affected by manufacturing marks within 100 mm of the centre of /......
of the fishplate. On the rest of the fishplate not more than 10% of the surface area may be affected by manufacturing marks. Manufacturing marks may not have sharp edges of more than 45° angle. The fishplates must be free of marks or indentations that could act as stress risers and cause breakages of the plates under service conditions. The final decision regarding acceptance of the fishplates will rest with the Spoornet representative.

13.2.3 Bolts

Bolts or studs must be manufactured from high tensile steel with a minimum ultimate tensile strength of 720 MPa.

13.2.4 Electrical clearance

In the case of steel fishplates, the profiles of the fishplates are to be such that adequate electrical clearance exists between the fishplates and the sleeper fastening assembly. At any given point there should not be less than 1.8 mm of insulating material between the fishplate and the rail. On exposed surfaces at least 10 mm of insulation/...
insulation must separate one conductive surface from the next, excluding the end post.

13.2.5 Marking

Each completed fishplate must have a clear permanent marking on the front or end surface showing "Spoornet" and the nominal mass of the rail for which the fishplate is intended, e.g. 48 for 48 kg/m rail, as well as the manufacturer's name or mark. The top of the fishplate should also be clearly marked by an arrow or the word "top".

13.2.6 Engineering drawings

Upon request the manufacturer has to make drawings available to the Spoornet authorized representative showing the material description, dimensions, fabrication tolerances and assembly methods.

Drawings of Spoornet rail profiles and other drawings and diagrams mentioned in this document are available from the Track Design drawing office upon request from bona fide tenderers.

13.2.7 /......
13.2.7 Inspections

The authorized representative of Spoornet must have free entry to the factory and quality assurance facilities of the manufacturer and his sub-contractors to inspect the manufacturing process and testing of all insulated rail joint parts and components. The manufacturer must provide test certificates to satisfy Spoornet that the components are being furnished in accordance with this specification. Copies of documentation of all quality assurance tests are to be kept and made available at the request of the authorized representative of Spoornet.

13.3 Adhesive and insulating materials

13.3.1 General

All adhesive materials must be able to withstand the mechanical load and service conditions outlined in clause 13.5.1.

The insulating material, ferrules and end posts must have a minimum compressive strength of 300 MPa. The completed joint must have smooth extended surfaces which will not act as traps for water / ......
water, dust or any element that may reduce the life of the joint.

Adhesive materials for workshop assembled joints should be a two part epoxy resin with a minimum strength of 15 MPa when tested on a lap shear strength test.

13.3.2 End post insulator

The end post insulator should not protrude above the running surface of the rail. It must be manufactured from black glass filled nylon, using Nylon 6 or similar and filled with 30 - 33% glass. Each end post must have a clear permanent marking on the flat surface showing the nominal mass of the rail for which the end post is intended, e.g. 48 for 48 kg/m rail.

13.4 Electrical Resistance.

The completed joint and all its separate insulating components should register a resistance of a minimum of one hundred million Ω (100 Meg Ω) when measured with a 500 volt Megger.

13.5 Performance requirements and design criteria

13.5.1 /......
13.5.1 General

Joints must be suitable for use in tracks subjected to dynamic and impact forces imposed by locomotives and rolling stock having nominal axle loads and travelling at nominal speeds as listed in table 5. Joints must also be capable of withstanding repeated tensile and compressive forces as listed in table 5. It must be emphasized that higher forces could occur from time to time in track, but the magnitude and frequency of these cannot be quantified.

| TABLE 5 |
|---|---|---|---|---|
| RAIL SIZE | AXLE LOAD | SPEED | FORCE | FORCE |
| kg / m | tonnes | Km/h | tonnes | kN |
| 40 | 20 | 60 | 80 | 800 |
| 48 | 22 | 100 | 90 | 900 |
| 57 | 22 | 100 | 100 | 1000 |
| 60 | 28 | 100 | 120 | 1200 |
| UIC 60 | 28 | 110 | 120 | 1200 |

13.5.2 Laboratory tests

Two standard tests are performed on insulated rail joints:

Static /
Static tensile test: This test is done at the CSIR Mining Laboratory at Cottesloe, Johannesburg. The joint is subjected to a linearly increasing load in the horizontal plane by pulling the two rails apart. The values in Table 5 are applied as criteria.

Dynamic load test: This test is done at the Spoornet Track Testing Centre, George Goch, Johannesburg. The joint is subjected to dynamic loading to simulate track conditions, in both the horizontal and vertical planes. The test specification is available upon request.

13.5.3 Moisture absorption

Moisture absorption must be less than 1% by increase in weight with a sample immersed in water at 20°C for 48 hours, with the joint retaining its insulating properties.

13.5.4. Warranty

Should any joint or part thereof fail within twelve calendar months of delivery due to the tenderer's design, workmanship or faulty material, the tenderer will be liable for the replacement of the /......
the joint at his own expense and at the original point of delivery.

13.5.5 Previous tests

No item that had not previously been tested successfully on Spoornet track by the Rail Technology Section will be considered for purchase under this enquiry.

13.5.6 Samples

If deemed necessary any tenderer may be required to submit a sample of any item offered under this tender for evaluation and testing at the Track Testing Centre at George Goch to facilitate adjudication of this tender.
ANNEXURE: PROCEDURE FOR WORKSHOP ASSEMBLY OF INSULATED RAIL JOINTS

The following is a copy of the workshop procedure currently used in Spoornet workshops, represented here in basically the same format and wording as the original.

1. PREPARATION OF JOINTS

1.1 SAWING

1.1.1 A six metre length of rail is required for the assembly of one insulated rail joint. (6 000 mm ± 100 mm)

1.1.2 Cut the rail into two three metre lengths with a suitable cutting machine. The cut must be perpendicular to the rail in both the vertical and the horizontal planes with a tolerance not exceeding 1 mm. Where requested rails shall be cut at an angle of ± 70° across the crown section, see Annexure A.

1.1.3 The rail ends must be thoroughly deburred by grinding or using a deburring tool.

1.1.4 The two ends must have a perfect fit when rejoined. (NEVER USE ODD PAIRS OF RAILS)

1.1.5 /......
1.1.5 Straightness shall be in accordance with specification S116 (1984) paragraph 5.3.4 and Annexure D thereof, see Annexure D.

1.2 DRILLING

1.2.1 The position of the rail holes must be accurately drilled as per drawing or instructions, using a drilling jig or machine setting. See Annexure C.

1.2.2 All holes must be drilled clean and free of any burr marks, and must be perpendicular to the rail web in both the horizontal and vertical planes.

1.2.3 All burrs to be removed by grinding or deburring tool, to form a 45° chamfer for a depth of 1 mm. Tolerance allowed for each hole is ± 0,2 mm – 0,15 mm.

Tolerance for pitch is ± 0,5 mm, measured from the end of the rail.

1.3 CLEANING OF RAILS

1.3.1 The finishing recesses of the rail ends over the whole length of the insulated fishplate must be cleaned of all grease, dirt, scale, loose rust and must be free of moisture.

1.3.2 /......
1.3.2 All forms of oxidation and scale must be removed from the rail by means of shot-blasting.

1.3.3 The shot-blasting should be applied to a length of approximately 300 mm from each rail end where the fishplate will be assembled. Ensure that the rail end is also shot-blasted.

1.3.4 Roll marks in the joint area must be removed by grinding. The grinding should be at right angles to the rail and in the length only.

1.3.5 The rails should now be protected against weather by storing under roof. The rails should not be stored for a period longer than 24 hours as oxidation will take place.

2. ASSEMBLY OF JOINTS

2.1 This procedure must be done under roof in a dry place on an insulated jig table or workbench.

2.2 Alignment should be checked with a 1,0 m straight-edge for straightness on both the top and side of the crown over the joint.

2.3 Ensure that there are no iron filings or magnetic particles in the recesses, on the fishplates or the rail ends.

2.4 /......
2.4 Ensure that the rail gap is to the required specification and insert the end post.

2.5 APPLICATION OF EPOXY

2.5.1 All joints must be epoxied, unless otherwise specified.

2.5.2 The epoxy to be used is "Epoxy Resin Compound for use in Insulated Rail Joints" according to specification S172 (1986), Item No 53/715281, supplied in 1.2 kg kits.

2.5.3 The epoxy hardens within 30 to 40 minutes. Care should be taken to use it within ± 20 minutes. The final curing time is 24 hours and joints should be handled the minimum within this time. The epoxy can be heated to 30°C in winter to facilitate better workability.

2.5.4 The two parts of the epoxy resin must be thoroughly mixed until of uniform colour before application. It must be applied thinly and evenly on both sides of the end post, as well as on the fishing surfaces and in the holes of the fishplate.

2.5.5 The remaining epoxy resin should be applied on the inside (back) of the fishplates, in the middle section /.../
2.5.6 After the joint has been tightened the remaining epoxy resin must be cleared off with a spatula and applied to the toe of the rail for about 50 mm over the end post as protection.

2.6 When fishplates are fitted into the fishing recesses of the rails, it must be done in such a way that the top side is uppermost.

2.7 Care must be taken not to contaminate the cleaned rail surfaces.

2.8 Check whether the holes are in alignment. If the holes do not line up, the rails must be discarded.

2.8.1 Care must be taken not to damage fishplate insulation by forcing bolts/studs into holes.

2.9 Care must be taken when inserting the studs/bolts into the holes of the joints that the threads are not damaged.

2.10 Fastening of the nuts either side of the stud must be done with an approved torque wrench to a final torque as per specification for the joint.

3. /....
3. PROCEDURE FOR TORQUEING OF JOINT

3.1 The torque on each nut shall be brought on in steps of one quarter on all nuts, followed by half the torque, three quarter torque and then full torque in the following sequence:

3.1.1 Number the bolts in numerical order from one end of the joint to the other end.

3.1.2 6 Hole joint: For a six hole joint, fasten number three stud first, with a quarter of the final torque on both sides, followed by number four stud and thereafter number two stud, followed by number five stud, then number six stud and finally number one stud on both sides.

3.1.3 4 Hole joint: The same sequence will be followed for the four hole joint so that the torque is brought on step by step from the centre of the joint to both ends.

3.1.4 Care should be taken not to over-torque the bolts with an impact wrench. The final torque should be applied with a torque wrench.

3.2 For half torque, three quarter torque and full torque, follow the same procedure making sure that both /......
both nuts of the same stud are torqued each time to the correct torque.

3.3 For specified torques of the various types of joints, see Annexure B.

4. CLEANING JOINTS

4.1 Ensure that all drill cuttings, iron filings, oil and grease are removed from rail joints.

4.2 Care must be taken that none of the above is embedded between the fishplates and rails, and also at the bottom of the rail flange.

5. INSULATION CHECK

5.1 Ensure that the rails are insulated from any supporting structures by means of rubber pads.

5.2 Use a 500 volt megger resistance testing apparatus (1 000 meg. ohm scale) and measure the resistance between the two rails.

5.3 The resistance must read not less than 100 meg. Ω.

5.4 All grease and oil must be removed from the bottom of the rail flange for a distance of ± 25 mm on either side of the joint using white spirits.

5.5 /......
5.5 Before dispatching, the whole joint area must be painted with Polyvinyl Chloride, Copolymer, Highbuild Midgrey paint to CSS 183/18.10/G25 which is stocked as modulus item 9/024752.

5.6 All completed joints must be checked and passed by quality control, before dispatching.

5.7 If the completed joints are not stored under cover, the joints should be covered by e.g. a tarpaulin.

5.8 FOR KLÖCKNER JOINTS:

At 2.2.2 add: The temperature on the web of the rail around the holes should not be higher than 150°C.

ANNEXURE A / .......
ANNEXURE A

**PLAN VIEW**

Rail running surface

70°

ANNEXURE B

<table>
<thead>
<tr>
<th>Type of joint</th>
<th>Torque</th>
</tr>
</thead>
<tbody>
<tr>
<td>Klöckner</td>
<td>980 Nm</td>
</tr>
<tr>
<td>Benkler</td>
<td>1050 Nm</td>
</tr>
<tr>
<td>BTR Phenolic</td>
<td>450 Nm</td>
</tr>
<tr>
<td>Röchling</td>
<td>700 Nm</td>
</tr>
</tbody>
</table>

ANNEXURE C
ANNEXURE C

INSULATED RAIL JOINT ENDS FOR WORKSHOP ASSEMBLY

DIAGRAM Z-2195

<table>
<thead>
<tr>
<th>DIMENSION</th>
<th>48 kg</th>
<th>57 kg</th>
<th>S-60 SAR</th>
<th>UIC 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>A ±0,5mm</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>165</td>
</tr>
<tr>
<td>B ±0,5mm</td>
<td>67</td>
<td>67</td>
<td>68</td>
<td>46</td>
</tr>
<tr>
<td>C ±0,5mm</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>D ±0,5mm</td>
<td>66</td>
<td>70</td>
<td>78</td>
<td>76,25</td>
</tr>
<tr>
<td>E ±0,5mm</td>
<td>140</td>
<td>140</td>
<td>140</td>
<td>165</td>
</tr>
<tr>
<td>F +0,2-0,15mm</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>

OVERALL LENGTH OF PREFABRICATED JOINT = 6,0m (±100mm)
ANNEXURE D

STRAIGHTNESS OF RAIL

FIG. 1 DEVIATION AT END

FIG. 2 WAVINESS, HORIZONTAL

FIG. 3 WAVINESS, VERTICAL

FIG. 4 LIFT AT END
NOTATION

W = compressive force in the rail (wedging)
F = reaction force in the bolt (wedging)
T = force exerted by bolts (wedging)
μ = coefficient of friction (wedging)
θ = angle of cut in the rail
Ω = ohm (measurement of electrical resistance)
Y max = maximum rail temperature
X max = maximum air temperature
α = heat expansion coefficient of steel
ΔT = change in temperature in °C
E = modulus of elasticity of rail steel (210 x 10⁶)
I = moment of inertia
P = compressive force (temperature induced) static load
z = tensile force (temperature induced)
A = cross-sectional area of rail
q = track constant
s = speed adjustment
v = operating speed for the track section
t' = required statistical accuracy
φ = dynamic factor
C = foundation modulus (MPa/m)
U = track modulus (MPa)
bₜ = transposed sleeper width

λ /......
\( \lambda \) = characteristic length of the system
\( \sigma \) = stress
\( \sigma_b \) = bending stress
\( Y \) = lateral force
\( Z \) = section modulus
\( M \) = bending moment (kNm)
\( \eta \) = influence factor of other wheels
\( \gamma \) = deflection of the rail
\( \nabla \) = gradient of the deflected structure
\( \tau \) = shear force
\( k \) = web modulus
\( t \) = thickness of rail web
\( a \) = distance
\( T \) = torsion moment
\( c \) = torsion constant
\( J \) = polar moment of inertia
\( G \) = shear modulus
\( \nu \) = Poisson's ratio for steel = 0.3
\( \phi \) = torque per unit length
\( e \) = eccentricity
\( r \) = constant
\( R \) = wheel radius
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