## This Booklet

Nordco Rail Services and Inspection Technologies (NRS&IT), a global provider of rail flaw testing equipment and services, is pleased to offer this flaw identification handbook as a service to our current and future customers.

It is designed to help track safety and maintenance-of-way personnel understand what causes different rail flaw types, how flaw types appear, and how quickly flaws can develop. In addition, there is a full glossary of rail and NDT terms.

The Nordco Rail Services and Inspection Technologies staff worked with railroad personnel and agencies around the world to identify major rail flaw types. This booklet is a compilation of our research findings, developed over our 40 years of industry experience.

For your convenience, this handbook is arranged according to the location of each defect in the rail. The various types of defects are listed according to the classification system used by NRS&IT.

We welcome your suggestions and comments for future versions of this handbook. Please contact 414-766-2180 or marketing@nordco.com to share your rail flaw experiences.

## Our Company

Nordco is a major supplier to North American Class 1 railroads, regional and short-line railroads, public transit systems, railroad contractors, equipment leasing companies, and rail mills. Nordco also serves industries that rely heavily on rail transportation, including port authorities, agriculture, mining, chemicals, and energy.

Nordco Rail Services and Inspection Technologies is a leader in non-destructive testing solutions for railroads and other industries. Our rail flaw detection systems, include the compact and portable Flex system, rail flaw inspection vehicles, portable inspection systems, as well as rail-bound and wheel inspection systems.

Our patented ultrasonic wheel probe includes nine complementary high-frequency transducers - the most integrated transducers in one unit in the industry - that search for flaws in transverse, longitudinal, and oblique directions.

In addition, we provide a broad range of rail inspection-related services, including rail flaw inspection, U/T certification of replacement rail, crossover testing, data management, and NDT training/certification.

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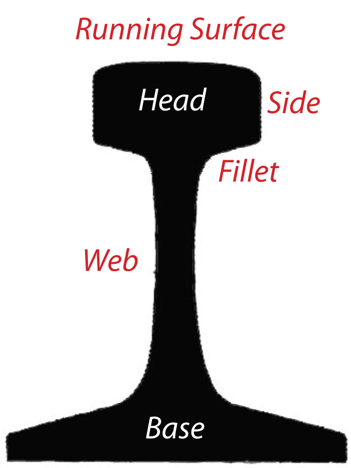
## Defect Type Overview

A critical defect is a rail defect that affects the safety of train operations. Non-critical defects are defects that do not affect the structural integrity of the rail or the safety of the trains operating over the defect. The following illustration shows the portions of the rail that can sustain defects.

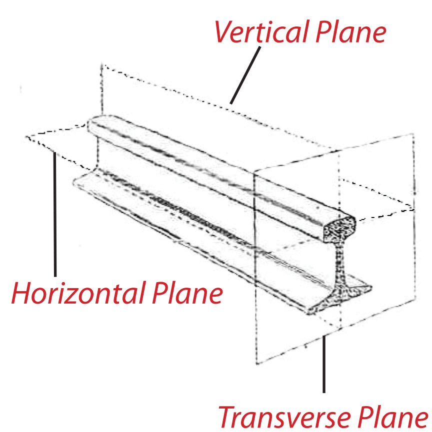



While improvements in rail milling processes have eliminated many transverse fissure defect types, there are still transverse defects that may be found, including detail fractures, engine burn fractures, and compound fractures. In addition, progressive transverse defects may develop underneath engine burns or resurfaced rail welds that were not properly cleaned or cooled during the rebuild process.

Longitudinal defects include vertical split heads, horizontal split heads, head and web separations, split webs, and piped webs. Rail that is disturbed after being in one position for many years is prone to longitudinal defects due to altered stresses and changed loading patterns. In some cases, contour grinding aggravates dormant rail conditions.

Rail welds - both factory and thermite process field welds - are also common. Frequently, rail weld defects occur due to inclusions or slag entrapments at the weld interface. In addition, longitudinal weld defects in the mid-web area may result from residual stresses.

The following illustration depicts the planes of stresses in rail.



## Defect Development

There are several factors that can influence the expected service life of rail. However, it is important to note that it is impossible to predict rail service life or defect development.

**Track maintenance programs** - these programs consist of any track maintenance procedure that allows track to maintain adequate support in order to reduce rail flexing, provide proper friction control, and provide rail profile maintenance.

**Wear** - lateral wear occurs primarily on the gauge face due to high-wheel flange force (rail is located on the high side of a curve). Vertical wear occurs on the running surface due to the wheel/rail interaction and rail grinding patterns.

**Plastic flow** - plastic flow, or mechanical deformation of the rail head, can occur on high or low rail and is associated with curves that carry high axle loads. Plastic flow results from wheel/rail contact stress that exceeds the material strength of the rail steel.

**Rail defects** - rail defects can develop in any rail type or rail welds as a result of the rail manufacturing process, cyclical loading, impact from rolling stock, rail wear, and plastic flow.

**Rail Loading at the Rail/Wheel Interface**

**Vertical loading** - load forces applied by the wheel tread under normal train operation. They are normally characterized as static load, dynamic load, and impact load. Static load is the gross weight of the railcar divided by the number of wheels; static loading can be influenced by track curve super elevation. Dynamic loading is the increase in static load that results from train speed. Impact loading is the additional increased loading over static and dynamic loads that occurs when a wheel travels over the head irregularly or the wheel contains a flat spot.

**Lateral loading** - load forces applied by the wheel flange to the high rail in curved track. In sharp curves, lateral loading is normally stable throughout the curve; however, in a shallow curve or tangent track, lateral loading may occur due to track hunting.

**Creep** - load forces that are generated at the rail/wheel interface by the rolling action of the wheel. Longitudinal creep results from traction applied by the wheel. Transverse creep results from lateral movement of the wheel during track hunting.

### Rail Stresses

**Bending stress** - bending of the rail that occurs from vertical or lateral wheel loading. Vertical wheel loading results from loading between tie supports and causes tensile longitudinal stresses in the base and head/web fillet areas. Lateral wheel loading applies tensile longitudinal stresses in the web area and head/web area of the rail field side.

**Thermal stress** - occurs in continuous welded rails due to thermal expansion and contractions (when actual rail temperature increases above or below the rail neutral temperature). When the temperature is above, compressive longitudinal stresses occur. When the rail temperature is below, tensile longitudinal stresses occur. These stresses can drastically influence rail flaw development.

**Residual stress** - a result of the manufacturing process, particularly from roller straightening and head hardening. It can also result from the rail welding since expansion and contraction occurs during the weld process. Residual stresses can be found in any location within the rail section.

### Development Identification

Defect development identification is determined by the type of defect, origin, and direction of development in relation to the planes of the rail section (transverse, vertical, and horizontal). Defects that develop in a transverse plane are normally internal in original and cannot be visibly identified until the defect cracks through the rail head.

Internal transverse defect size can only be positively identified by breaking the cross section of the rail; however, it can be estimated through ultrasonic inspection. After the rail is broken, a transverse defect is measured against the cross-sectional area of the rail head. For example, if half the rail head cross section shows defect growth, the defect is called a 50% fracture.

Nordco has identified three types of defect development in transverse defects:

**Normal growth** - takes place in very gradual stages over a considerable period of time. When the development is complete, the entire face of the transverse separation is smooth and well defined. There is no limitation on the number of growth rings, the distance between the rings, or the development time.

**Rapid growth** - shows defect growth in numerous small stages. When the development is complete, the small, polished, well-defined fracture is surrounded by a rough granular surface, showing several growth rings of gradually increasing size.

**Sudden growth** - shows defect growth in a few large stages. When the development is complete, the small, polished, well-defined fracture is surrounded by a rough granular surface, showing one or two growth rings. The distance between the rings increases in proportion with the rate of defect growth.

**Multiple Stage Ruptures**

Defects that develop in an angular or longitudinal direction also produce identifiable stages of development called multiple stage fractures (including bolt hole breaks, base breaks, and head and web separations). When a defect shows multiple development stages, each stage is considered a separate development stage. Normally, there is a pre-existing identifiable fatigue condition, followed by another growth stage. If a pre-existing fatigue condition does not exist, the failure is called a sudden rupture.

Impact batter from wheels

**Rail batter**

Batter is significant rail-end damage or a smooth polished fracture face. The two significant types of rail batter are impact batter and friction batter. Impact batter results from a rail break, exposing the fracture face to wheel impact from rolling stock. Friction batter results from sufficient rail section separation allowing the two fracture faces to make contact under load. Both types of batter can obliterate the matching fracture faces, preventing identification of underlying fatigue conditions.

## Transverse Defects

A transverse defect is a progressive fracture that develops transverse to the cross-sectional area of the head.

When the rail is broken for further examination, the transverse defect is more accurately identified. It should be noted that any defects showing a transverse component are reported as transverse defects by rail testing software. The most common transverse defects are:

- Transverse fissure
- Compound fissure
- Detail fracture
- Engine burn fracture
- Welded burn fracture

Sizing for transverse-oriented defects is reported by an approximated percentage of cross-sectional area of the rail head.

Development can be normal or in multiple stages prior to a failure. Transverse defects have no exterior indications until the defect reaches the rail surface (cracks out). It is then recognized by one or more of the following characteristics:

- A hairline crack at a right angle to the running surface, usually on the side of the head or at the fillet under the head. Less frequently, the crack appears on the running surface.
- Discoloration (red or purple oxidation) around the crack. This discoloration is caused by internal rusting and is called bleeding.
- A hairline crack at the upper gage corner of the rail head. On transposed rail, this crack may occur on the field corner. Gage cracks often appear, but should only cause concern when a single crack extends further down the side of the rail or further across the running head (when compared to other cracks).
- A horizontal hairline crack on the side of the head that turns upward/downward at one or both ends. This crack usually displays bleeding. In addition, a flat spot normally appears on the running surface.
- A hairline crack extending downward at a right angle to a horizontal crack created by shelling of the upper gage corner of the head. Shelling can be identified through the presence of slight discolorations on the gage side of the running surface. If this is transposed rail, the shelling appears on the field side.

## *Transverse Fissure*

**Definition** - A transverse fissure is a progressive crosswise fracture originating from a nucleus located inside the head, spreading outward as a smooth, bright or dark, round or oval surface substantially at a right angle to the length of the rail. Transverse fissures come from the manufacturing process and are found predominately in non control-cooled rail from the 1930s. However, it can develop in modern high-chrome rail from a hydrogen imperfection.

**Origin** - The origin is an imperfection in the steel, such as a shatter crack or a minute inclusion. Wheel impact or bending stresses frequently start the growth of a transverse separation around the originating imperfection.

**Growth** - Growth of these types of defects is normally slow until the defect reaches 20-25%. It is normal for rail with a transverse fissure to remain in service for some time without further development. After 25% is reached, the growth is rapid.

**Hazard** - The transverse fissure is dangerous because:

- It tends to occur in several places across the same rail.
- Failure almost always occurs before defect becomes visible.
- Service failure is usually a complete break of the rail across head, web, and base.

Transverse Fissure

**Identification** - The distinguishing features are the crystalline center or nucleus and the nearly smooth surface of development that surrounds it. A transverse fissure must show a nucleus that is more than 1/4 inch from any surface of the head. Separation is substantial and at a right angle to the running surface. The fissure completely surrounds the nucleus and shows growth originating from the nucleus.

**Appearance** - A transverse fissure cannot be positively identified until the rail is broken for further inspection.

**Detection** - Transverse fissures can be detected by seventy degree (70) transducer beams.

## *Compound Fissure*

**Definition** - A compound fissure is a progressive fracture originating in a horizontal split head, which then turns up or down in the head as a smooth, bright or dark surface, progressing until it is substantially at a right angle to the length of the rail.

Compound Fissure

**Origin** - The fissure usually starts as a horizontal separation from an internal longitudinal seam, segregation, or inclusion (from the manufacturing process). It develops longitudinally for some distance, then turns (upwards, downwards, or both) in relation to the transverse plane.

**Growth** - Growth is normally slow until the defect reaches 30-35%. If horizontal separation is severe enough to reach the surface and cause a flat spot on the running surface, growth is rapid.

**Hazard** - The compound fissure can result in an oblique-type failure and is dangerous because:

- It may occur in several places on the same rail if the seam or segregation exists throughout the rail length.
- Failure sometimes occurs before defect becomes visible.
- Service failure is usually a complete break of the rail across head, web, and base.

**Identification** - Both longitudinal and transverse separations are usually exposed. The longitudinal separation may be as short as 1/8 inch, appearing only as a displacement between two transverse planes; it is usually parallel to the running surface. The transverse separation often resembles a transverse fissure except that there is no nucleus.

**Appearance** - A compound fissure cannot be positively identified until the rail is broken for further inspection.

**Detection** - Compound fissures can be detected by seventy degree (70) transducer beams.

## *Detail Fracture from Shelling*

**Definition** - A detail fracture from shelling, whether visible or not, is a progressive fracture at or near the surface of the rail head. Do not confuse these fractures with transverse fissures, compound fissures, or other defects with internal origins.

**Origin** - The origin is usually a longitudinal seam or streak near the running surface on the gage side (field side if rail was turned). The separation progresses longitudinally (not as a true horizontal crack), at an angle related to the amount of rail wear on the gage corner. The crack then turns downward and inward to form a transverse separation.

**Growth** - Growth is normally slow until the defect reaches 15%. Growth between 20% and 60% is often rapid and sudden, occurring just prior to complete failure. It is not uncommon for more than one detail fracture to develop in an immediate area where shelling is present.

**Hazard** - The detail fracture is dangerous because:

- Growth may be rapid and sudden during the early growth stage.

Detail Fracture Originating from a Visible Shell

- Failure usually occurs before defect becomes visible.
- Service failure is usually a complete break of the rail across head, web, and base.

**Identification** - The longitudinal separation and the streak/seam where it originated is not often visible. The transverse component resembles a transverse fissure except that no nucleus is present and the transverse separation spreads from a longitudinal separation in the upper gage corner.

**Appearance** - A detail fracture cannot be positively identified until the rail is broken for further inspection.

**Detection** - Detail fractures can be detected by seventy degree (70) transducer beams.

## *Detail Fracture from Head Check*

**Definition** - A detail fracture from a head check is a progressive fracture that starts at the gage corner of the head and spreads transversely through the head.

**Origin** - The origin is a head check condition located in the upper gage corner of the rail, usually caused by concentrated loads, which then cold works the steel. This can also be referred to as a thermal crack.

**Growth** - Growth is normally slow until the defect reaches 5%. After 5%, growth is very rapid.

**Hazard** - The detail fracture from head check is dangerous because:

- It tends to occur in several places on the same rail.
- Many fail completely before 15% size is reached due to the stresses on the gage corner in sharp curves.
- Service failure is usually a complete break of the rail across head, web, and base.

**Identification** - A detail fracture shows a transverse separation which starts at the gage corner and spreads in crescent-shaped rings around the point of origin.

**Appearance** - A detail fracture from a head check cannot be positively identified until the rail is broken for further inspection.

**Detection** - Detail fractures from head checks can be detected by seventy degree (70) transducer beams.

Detail Fracture
from a Head Check

## *Reverse Detail Fracture*

**Definition** - The reverse detail fracture is a progressive fracture, starting at either bottom corner of the gage side of the rail head, spreading transversely through the head.

**Origin** - The origin is a stress riser associated with a notching condition on the cold rolled lip located on the bottom corner of the rail head. This defect is typically associated with severely worn rail and high axle loads.

**Growth** - Growth is normal until the defect reaches 10%. After 10%, growth is rapid or sudden prior to a complete failure of the rail section. It is not uncommon for a complete failure at a size much less than that of a typical detail fracture type defect.

**Hazard** - The reverse detail fracture is dangerous because:

- It can occur in several places in the same rail.
- It can fail completely before the 15% size is reached.
- Failure usually occurs at 80% of the time for a typical detail fracture.
- Service failure is usually a complete break of the rail across head, web, and base.

Reverse Detail Fracture

**Identification** - A reverse detail fracture shows a transverse separation which starts at the lower gage corner and spreads in crescent-shaped rings radiating from the point of origin.

**Appearance** - A reverse detail fracture cannot be positively identified until the rail is broken for further inspection.

**Detection** - Reverse detail fractures can be detected by seventy degree (70) transducer beams.

## *Engine Burn Fracture*

**Definition** - An engine burn fracture is a progressive fracture in the head, starting from a burn (where driving wheels slipped on top of the head). In developing downward, they frequently resemble compound or transverse fissures, but should not be confused with these defect types.

**Origin** - The defect originates when a slipping engine driver wheel heats a portion of the rail surface and then rapid cooling forms thermal cracks. Impact from wheels over the affected burned area starts a small horizontal separation of the burned metal from the parent rail metal, developing a flat spot. Transverse separation may start from a thermal crack in the burn region at any time.

**Growth** - Growth is normally slow until the 10-15% size . After that, growth is rapid. It is common to have more than one engine burn within a short proximity.

**Hazard** - An engine burn fracture is dangerous because:

- It may occur at several places in the same rail since all drivers are slipping together.
- Failure may occur before defect is visible.
- Service failure is usually a complete break of the rail across head, web, and base.

**Identification** - An engine burn fracture shows the surface burn. The transverse separation has no nucleus and may exist in any of the three planes. The horizontal separation starts at the running surface and slants downward.

**Appearance** - Transverse separation is not visible until the defect reaches the rail surface (cracks out). After the crack out, the fracture shows the following characteristics:

- A hairline crack on the side of the head, in the immediate vicinity of the burn and at right angles to the running surface.
- Transverse thermal cracks extending from the burn to the gage corner and down the gage side of the head.
- A cracked-out horizontal separation visible on the field side under the burned area.

**Detection** - Engine burn fractures can be detected by seventy degree (70) transducer beams.

## *Welded Burn Fracture*

**Definition** - A welded burn fracture is a progressive transverse separation in the head, which develops substantially at right angles to the running surface (starts at a burn area that was resurfaced by welding).

**Origin** - A welded burn fracture usually results from insufficient cleaning of an engine burn prior to resurfacing through welding, which fails to eliminate thermal cracks created by the original engine burn. Improper cooling of a resurfaced burn can also create new thermal cracks.

**Growth** - Growth is fairly slow until the defect reaches 15-20%. After that, growth is more rapid and is exacerbated by heavy traffic and loading or inadequate track maintenance.

**Hazard** - The welded burn fracture is dangerous because:

- Failure may occur at a relatively small size.
- Failure usually occurs before the defect becomes visible.
- Service failure is usually a complete break of the rail across head, web, and base.

**Identification** - A welded burn fracture often shows external evidence of the rail having been resurfaced by welding (uneven buildup, grinder marks, etc.). The transverse separation usually develops at the line of demarcation between the parent metal and the filler metal and usually appears to be a shallow horizontal separation.

**Appearance** - A welded burn fracture is not visible until the defect reaches the rail surface (cracks out). It is then identified by a hairline crack at right angles to the running surface. The crack may be visible on the field or gage side of the head or in the fillet area.

**Detection** - Welded burn fractures can be detected by seventy degree (70) transducer beams.

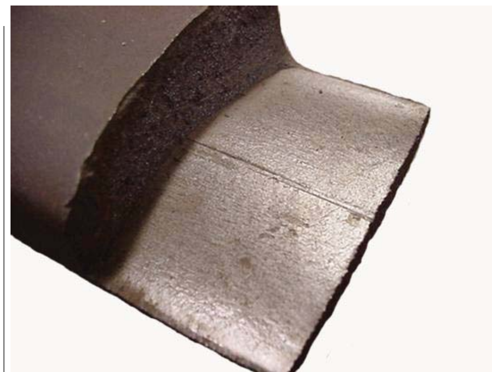
## Longitudinal Defects

A longitudinal defect is any progressive fracture which has a longitudinal separation only.

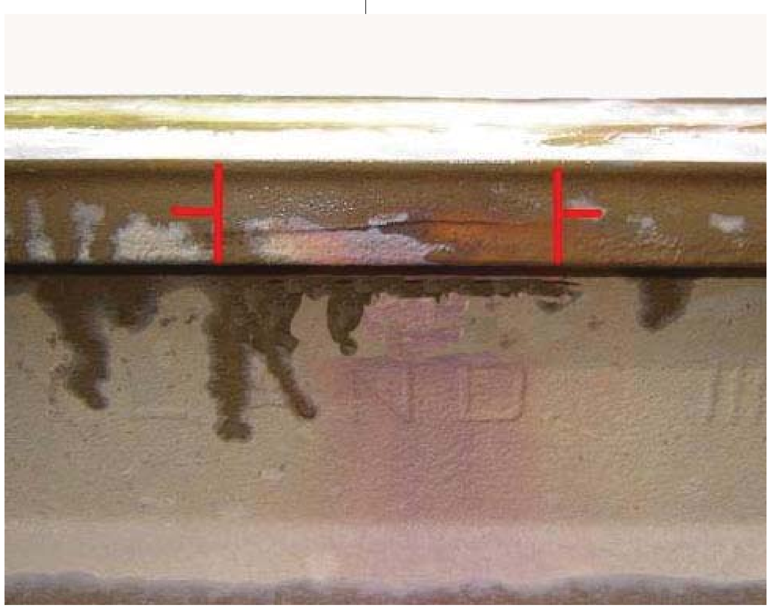
It should be noted that any defects showing a horizontal component are reported as longitudinal defects by rail testing software. The most common longitudinal defects are:

- Horizontal split head
- Vertical split head

Sizing for longitudinal-oriented defects is normally reported in inches.



Horizontal split head originating from an internal seam



Side view of horizontal split head

## *Horizontal Split Head*

**Definition** - A horizontal split head is a progressive longitudinal fracture originating inside the rail head, usually 1/4-inch or more below the running surface and progressing horizontally in all directions. It is normally accompanied by a flat spot on the running surface. The defect appears as a lengthwise crack when it reaches the side of the rail head.

**Origin** - The origin is an internal longitudinal seam, segregation, or inclusion from the manufacturing process. Separation progresses longitudinally and horizontally, parallel to the running surface. Wheel impact can initiate transverse separation; in these cases, the defect is then classified as a compound fissures. A horizontal separation may be present in several locations within the same rail section.

**Growth** - Growth is usually rapid for the length of the internal longitudinal separation, but may stop altogether. The horizontal crack may also curve downwards and start a transverse crack. Shock loads can start a transverse separation, changing the defect classification to a compound fissure.

**Hazard** - The horizontal split head is dangerous because:

- It tends to occur in several places across the same rail since the seam or segregation may exist throughout the rail length.
- It may develop into a compound fissure, in which case the service failure is a complete transverse break.

**Appearance** - A horizontal split head shows the following:

- Before crack out, it shows a flat dark spot on the running surface, accompanied by a slight widening or dropping of the head.
- After crack out, a hairline crack appears in either the field or gage side (or both) and at least 1/3 of the way below the top of the head.

**Detection** - Horizontal split heads can be detected by 0 (zero) and 45 degree transducer beams.

## *Vertical Split Head*

**Definition** - A vertical split head (VSH) is a progressive longitudinal fracture through or near the middle of the head, extending into or through it. A crack or rust streak may show under the head, close to the web, or pieces may be split off the side of the head.

**Origin** - The origin is an internal longitudinal seam, segregation, or inclusion from the manufacturing process. Separation progresses longitudinally and horizontally, parallel to side of the head, then gradually turns out to the gage or field side of the head. Sometimes, one end of a VSH turns to the gage side with the other end turning towards the field side.

**Growth** - Growth is usually rapid after the seam or separation opens up. It continues to grow rapidly until the split turns outward.

**Hazard** - The vertical split head is dangerous because:

- It is usually not visible on the surface until it has grown to a length of several feet.
- If the split is on the gage side of the rail and breaks off in service, car wheels will have a tendency to climb to the top of the rail or drop into gage, causing a derailment.

- Upon service failure, the rail may break into several pieces.
- A considerable portion of the rail head is weakened.

**Appearance** - A vertical split head shows the following:

- A dark streak on the running surface.
- Widening of the head for the length of the split. The side of the head where the split is offset could show signs of sagging or dropping.
- Dropping of the head causes a rust streak to appear on the fillet.
- In advanced stages, a bleeding crack is apparent at the fillet.

**Detection** - Vertical split heads can be detected by 0 (zero) and 45 degree transducer beams.

## *Shear Break*

**Definition** - A shear break is a longitudinal separation of the rail head resulting from the loss of significant rail head parent metal. This results in a weakened ability to support loading.

**Origin** - A shear break is usually not associated with inherent conditions in the material. Instead, a shear break normally occurs when the rail is loaded off the center axis, causing rail head collapse, and is often associated with gaging problems, lightweight rail, severely worn (vertical wear) rail, or off-center loads caused by worn rolling stock wheels.

**Growth** - Growth is usually sudden. A precursor to a shear would be creep or strain in the fillet radius similar to a crushed head.

**Hazard** - The shear break is dangerous because:

- It is usually not visible on the surface until it has grown to a length of several feet.
- A considerable portion of the rail head is weakened.
- If the split is on the gage side of the rail and breaks off in service, car wheels will have a tendency to climb to the top of the rail or drop into gage, causing a derailment.
- Upon service failure, the rail may break into several pieces.

**Appearance** - Visual characteristics are the same as a vertical split head (VSH) and the defect is classified as a VSH defect when discovered. A shear break shows the following:

- A dark streak on the running surface.
- Widening of the head for the length of the split. The side of the head where the split is offset could show signs of sagging or dropping.
- Dropping of the head causes a rust streak to appear on the fillet.
- In advanced stages, a bleeding crack is apparent at the fillet.

**Detection** - Shear breaks can be detected by 0 (zero) and 45 degree transducer beams.

## Web Defects

A web defect is any progressive fracture occurring in the web of the rail having, primarily, a longitudinal separation.

It should be noted that any defects in the web area will be reported as web defects by rail testing software. The most common web defects are:

- Head and web separation
- Split web
- Piped rail

Joint area web defects are progressive fractures in the web area of the rail at or near the rail end. These are generally associated with conditions resulting from bolted joints. The most common joint area web defects are:

- Bolt hole crack
- Head and web separation at rail end

Sizing for web defects is normally reported in inches.

Head and web separation showing progression into the web.

## *Head and Web Separation*

**Definition** - Head and web separation is a progressive fracture longitudinally separating the head and web of the rail at the fillet under the head. Separation is along a seam extending vertically into or through the head at or near the middle of the head. A crack or rust streak may show under the head close to the web or pieces may split off the side of the head.

**Origin** - Acid from some asphalt-based fillers used at highway crossings may start corrosion fatigue where the head joins the web. Gravel crossings, excessive speed on curves, or improper canting of the rail can cause eccentric loading of the rail head. Fatigue can appear as rust-colored rail strain in the head/web fillet area, slight horizontal cracking under the head, or a creeped and wrinkled fillet. This type of defect can also develop in the head fillet area at the joint rail end as a result of extreme stress conditions created by pumping or swinging joints.

**Growth** - Growth of these types of defects is usually rapid once the rail is turned, as this moves the loading point to the opposite side of the head.

**Hazard** - Head and web separation is dangerous because:

- The entire length of the rail is usually weakened.
- Upon service failure, the rail may break into several pieces.

**Appearance** - Head and web separation usually occurs at highway crossings where visual inspection is impossible. When inspection can be made, the separation shows the following:

- In early stages, wrinkled lines appear along the fillet.
- As the condition develops, a small crack appears along the fillet on either side, indicating growth through the web. It progresses longitudinally with slight, irregular turns upward and downward.
- In advanced stages, bleeding cracks extend downward from the longitudinal separation through the web and may extend through the base.

**Detection** - Head and web separation defects can be detected by 0 (zero) and 45 degree transducer beams.

## *Split Web*

**Definition** - A split web is a progressive, lengthwise crack along the side of the web, extending into or through it.

**Origin** - The origin is a seam in the web or damage to the web or at locations where heat numbers are stamped into the web. Split webs can also develop as the result of high residual stresses from the roller straightening process, rail welding, and joint application.

**Growth** - Growth of these types of defects is usually rapid after the crack extends through the web and is accelerated by uneven or heavy axle loads.

**Hazard** - The split web is dangerous because:

- The rail is weakened for the distance of the separation.
- Upon service failure, the rail may break into several pieces.

**Appearance** - A split web shows rust-colored bleeding cracks along the crack development in the web, which may be horizontal, vertical or a combination of both. A crack or rust streak may show under the head close to the web or pieces may split off the side of the head.

**Detection** - Split web defects can be detected by 0 (zero) and 45 degree transducer beams.

Web failure resulting from high residual stress.

## *Piped Rail*

**Definition** - Piped rail is a progressive longitudinal fracture, (vertical split) in the web of the rail, with a vertical separation or seam that opens into a cavity in advanced stages of development. Most defects in new rail are detected prior to shipment and welding. A and B rail sections are more prone to pipe and segregation. The defect length can vary from inches to more than a full rail section.

**Origin** - The origin is a wide longitudinal seam or internal oxidized cavity inside the web that comes from the manufacturing process (when the original bloom or ingot was cast). Do not confuse it with non-metallic segregations where surfaces are not oxidized. Once development starts, the seam develops vertically toward the head and base. This type of defect is seldom found in modern rail at an advanced stage.

**Growth** - The original seam does not generally grow either vertically or horizontally. However, heavy axle loads may eventually cause it to spread or open up in a cross-wise direction, causing a bulge in the web that resembles a pipe. Internal seams, which might cause little or no trouble under normal traffic conditions, could open when subjected to pressure butt welding.

**Hazard** - Piped rail is dangerous because:

- Rail is weakened for the distance of the pipe.
- The head is not properly supported by the web where the pipe exists.
- Upon service failure, the rail may break into several pieces.

**Appearance** -Piped rail shows the following:

- Bulging of the web on either or both sides.
- A slight sinking of the rail head in the area above the pipe.

**Detection** - Piped rail can be detected by 0 (zero) and 45 degree transducer beams.

## *Bolt Hole Crack*

**Definition** - A bolt hole defect is a progressive fracture that originates at a bolt hole, originating inside the rail web (usually 1/4 inch or more below the running surface) and generally accompanied by a flat spot on the running surface. Fully developed bolt hole cracks may continue horizontally along the head/web or base/web fillet, or progress into and through the head or base to separate a piece of rail end from the rail. Multiple cracks occurring in one rail are considered to be a single defect.

**Origin** - A bolt hole crack is normally the result of unusual stresses along the edge of the hole from the bolt itself. These stresses may be caused by pumping or swinging joints, improper drilling, excessively worn joint bars, or abnormal rail end impacts from rolling stock. Origin points may be a stress contact between the rail and the bolt or at a burr on the edge of the hole left by the drilling operation.

**Growth** - Growth is erratic compared to transverse defects. These defects frequently rupture from a very small defect when the rail end is subjected to stresses of an unusual nature.

**Hazard** - A bolt hole crack is dangerous because:

- The rail is weakened for the distance of the separation.
- Upon service failure, the rail may break into several pieces, thereby becoming a serious derailment hazard.

**Appearance** - Bolt hole cracks are not visible until a bolt or angle bar is removed, unless the defect has progressed above the bar (through the head) or below the bar (through the base). After removal of the joint bar, the defect may be recognized by a hairline crack extending from the bolt hole for the length of the defect.

**Detection** - Bolt hole defects can be detected by 0 (zero) and 45 degree transducer beams.

## *Web & Head Separation (Rail End)*

**Definition** - A head and web separation at the rail end is a progressive fracture, longitudinally separating the head from the web of the rail at the fillet area.

**Origin** - The defect originates in the fillet area at the end of the rail and is is believed to be caused by eccentric loading of the rail head and the resulting fatigue breakdown at the weakest point on the rail end.

**Growth** - Growth usually occurs in gradual stages but can develop quite rapidly under extreme stress conditions created by pumping or swinging joints. The length to which these separations extend before spreading upward into the head is unpredictable, but they will usually turn upward between 3 and 10 inches from the rail head. Rail end head and web separations sometimes progress downward through the web and base area, but initial failure usually results in the displacement of a piece of the rail head from 3 to 10 inches in length.

**Hazard** - A web and head separation at the rail end is dangerous because:

- Rail is greatly weakened for a distance in excess of the progressive separation.
- In the event of a service failure under traffic, the rail is likely to break into several pieces.

**Appearance** - Head and web separations appear as a hairline crack along the fillet area, viewable once the angle bars are removed. With the joint bars in place, visual detection is not possible until the defects reach an extremely advanced stage of development.

**Detection** - Web and head separations can be detected by 0 (zero) and 45 degree transducer beams.

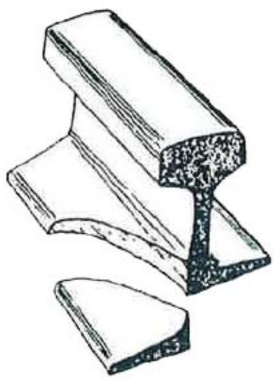
## Base Defects

A base defect is any break originating in the base of the rail.

It should be noted that any defects in the base area cannot be currently detected by rail testing software. The most common base defects are:

- Broken base
- Base fractures

Sizing for base defects is normally reported in inches.



### *Broken Base*

**Definition** - A broken base is a progressive fracture in the base of the rail, with a vertical separation or split. A broken base is normally confined within the flange area of the rail base and is usually an oval-shaped break called a half-moon break.

**Origin** - Separation may be caused by improper bearing on ties or tie plates, or may originate in a seam, segregation, or inclusion.

**Growth** - Growth usually depends on the location of the break and the loading of the rail.

**Appearance** - Broken base defects appear as one the following:

- A crack starting near the junction of the base and web, extending outward to the edge of the base.
- A longitudinal crack extending along the junction of the web and base.
- A half-moon break in the base of the rail.

**Hazard** - A broken base is dangerous because:

- The remainder of the rail cross section becomes weakened.
- Upon service failure, the rail may break into several pieces.

## *Base Fracture*

**Definition** - A base fracture is a progressive fracture in the base of the rail which develops substantially in a transverse plane. As a rule, these defects originate on the outer edge of the base.

**Origin** - These fractures are usually caused by a nick or blow on the edge of the base which results in an identifiable indentation. This type of damage can be caused by improper rail handling.

**Growth** - Growth is relatively slow until the defect progresses from the edge of the base into the rail (1/2 inch). At this point, a complete and sudden transverse rupture of the rail usually occurs. Base fractures seldom extend progressively farther than 1/2 inch into the rail before causing a complete break.

**Hazard** - A base fracture is dangerous because:

- Service failure is usually a complete break of the rail across head, web, and base.
- Failure frequently occurs before the defect can be discovered visually.

**Appearance** - Base fractures are visible as hairline cracks for the extent of the progressive development into the rail. However, these defects are seldom found visually since a complete rupture usually occurs from a relatively small defect.

Base fracture showing nick with transverse development

## Surface Defects

Rolling contact fatigue (RCF) conditions develop in rails at the wheel/rail interface. A surface defect is any imperfection, damage, or deformation at or near the exterior surface of a rail. Any type of surface condition can be a significant obstacle in the detection of the underlying rail defect.

It should be noted that any surface defects are NOT reported by rail testing software. However, internal defects resulting from surface defects are reported based on the type of internal defect.

The most common surface defects are:

- Nicked rail
- Shelling
- Flaking
- Slivers
- Flowed rail
- Burned rail
- Mill defects
- Corrosion
- Corrugation
- Damaged rail

Sizing for surface defects is normally reported in inches.

### *Nicked Rail*

**Definition** - Nicked rail is rail that is nicked on the head, web, or base.

**Origin** - Nicked rail is caused by a flat or broken wheel, a spike mall, or dragging equipment.

**Growth** - Growth of these types of defects usually depends on the location of the nick on the rail and the loading of the rail.

**Appearance** - Nicked rail can be recognized by the presence of nicks, cuts, or scars on any part of the rail surface.

**Hazard** - Nicked rail is dangerous if the nicks are deep or sharp enough to cause the development of another type of defect.

## *Shelling*

**Definition** - Shelling is a progressive horizontal separation which may crack out at any level on the gage side, usually at the upper gage corner. Shelling extends longitudinally - not as a true horizontal or vertical crack - but as an angle related to the amount of rail wear. Shelling may turn down to form a transverse separation and, once detected, is classified as a detail fracture. Uncapped or gutted shells result in the dislodgement of parent metal from the rail section.

**Origin** - The exact origin of shelling has not been definitely determined by the industry. It is prevalent at curves and is accelerated if streaks or small seams are present that provide stress concentration points.

**Growth** - Growth of these types of defects depends on loading. The separation progresses in the path of least resistance. Shelling may turn downward to form a transverse separation; if this happens, the defect is then classified as a detail fracture from shelling.

**Hazard** - Shelling is dangerous because:

- It occurs most frequently in curve territory.
- Transverse separation may develop at any shelling stage or at any point along the shell.

**Appearance** - Shelling shows the following:

- Dark spots irregularly spaced on the gage side of the running surface.
- Longitudinal separation at one or several levels in the upper gage corner, with discoloration from bleeding.
- If rail was turned, shelling spots appear on the field side, with an irregular overhanging lip of metal. The appearance is then similar to flowed rail.

**Detection** - Shelling defects can be detected by visual inspection.

## *Flaking*

**Definition** - Flaking is a progressive horizontal separation of the running surface of the rail near the gage corner, with scaling or chipping of small slivers. Flaking should not be confused with shelling, as flaking takes place only on the running surface near the gage corner and is not as deep as shelling.

**Origin** - Flaking originates at the surface of the rail. It is prevalent on the high side of curves, switch points, and locations where concentrated loading on the tread and gage corner cold works the steel.

**Growth** - Growth of these types of defects depends on loading. The separation progresses about 1/32 inch below the running surface towards the gage side of the head, usually coming to the surface close to the point where the tread contour turns downward at the gage side..

**Hazard** - Flaking is not a serious defect. It may develop into shelling or indicate a possibility of shelling on the same rail.

**Appearance** - Flaking shows the following:

- Horizontal separation with scaling or chipping of small segments of parent metal.
- Very shallow depressions with irregular edges, occurring on the running surface near the upper gage corner. Generally will not occur more than 1/3 inch from the gage corner of the rail.
- Horizontal hairline cracks along the running surface near the upper gage corner of the rail head, resembling small slivers.

**Detection** - Flaking defects can be detected by visual inspection.

## *Slivers*

**Definition** - A sliver is a separation of a thin, tapered mass of metal from the surface of the head, web, or base.

**Origin** - A sliver originates in the rolling process in the rail-production mill, when a small pre-oxidized section of the rail laps over, instead of flowing and welding under the pressure of the rollers.

**Growth** - Slivers are more apt to separate, rather than grow. However, they may chip off, cause batter, or provide a point of origin for a separation.

**Hazard** - Slivers are not serious defects.

**Appearance** - Slivers show the following:

- Thin slivers on surface of head and parallel to the rail length.
- Darkened slivers (advanced stages) look like a vertical split head, but without spreading of the head.
- Slivers on the side of the head. These are shorter and thicker (but less than 1/4 inch thick)than slivers on the running surface. They form part of the rail contour, lying flat on the surface, but may be cracked loose from the rail metal on three sides. If a sliver is dislodged, only an indentation remains.

**Detection** - Sliver defects can be detected by visual inspection.

## *Flowed Rail*

**Definition** - Flowed rail is a rolling out of the tread metal beyond the field corner, with no breakdown of the underside of the head.

**Origin** - Flow is due to distortion of the rail metal under repeated loads. This gradual change of the head contour does not damage the metallic structure of the metal.

**Growth** - Flowed rail is a change in shape, rather than a growth. It occurs, predominately in curved track, under repeated service. The extent is usually proportionate to the length of service for the rail. Rail in tangent track may also become flowed, although at a slower rate than in curved track.

**Hazard** - Flowed rail is not a serious defect.

**Appearance** - Flowed rail shows the following:

- Surface metal on the head flowed towards the field side, giving a creased appearance on the running surface.
- A smooth protruding lip, which may extend the length of the rail.
- In advanced stages, the flow becomes blade-like, jagged, or non-uniform. It may hang down/separate from the head.

**Detection** - Flowed rail can be detected by visual inspection.

## *Burned Rail*

**Definition** - Burned rail is rail that has been scarred on the running surface by the friction of slipping locomotive wheels.

**Origin** - Burned rail is caused by intense friction heating from slipping wheels, which overheats and displaces tread metal on the running surface.

**Growth** - A burn does not actually grow. However, the damaged area may gradually chip out and roughen under repeated traffic. Once the surface has a significant amount of displacement of the rail head surface material, the detection of the underlying rail flaw is obstructed.

**Hazard** - Burned rail is potentially dangerous because transverse separation may develop from thermal cracks at the burn.

**Appearance** - Burned rail shows the following:

- A rough spot - round or oval - with slivers (from metal flow where metal has flattened or separated just below the surface) on the tread of the running surface, where metal was displaced and solidified.
- Thermal tracks originating at the rough spot.

**Detection** - Burned rail can be detected by visual inspection.

Thermal cracks on burned stock rail

## *Mill Defects*

**Definition** - Mill defects are deformations, cavities, seams, or foreign material found in the head, web, or base of a rail.

**Origin** - Mill defects occur when the ingot is poured and slag, gas, or foreign material get included. Metal splashes on the side of an ingot may cool and oxidize before fusing with the liquid metal.

**Growth** - Although mill defects do not grow, they may provide the point of origin for a transverse or longitudinal separation. Further development depends on the type of mill defect, location in the rail, and loading of the rail.

**Hazard** - Mill defects are serious defects if they are deep or large enough to cause the development of a defect.

**Appearance** - Mill defects shows the following:

- A deformation of the rail head causing passing car wheels to batter the rail severely.
- Broken out inclusions leaving large or dangerous cavities in the side or running surface of the rail head.
- Inclusion of foreign material in the rail metal.

**Detection** - Mill defects can be detected by visual inspection.

## *Flattened Rail*

**Definition** - Flattened rail is a short length of rail (not at a joint) that has flattened out across the width of the rail head to a depth of 3/8 inch or more below the rest of the rail.  Flattened rail occurrences have no repetitive regularity, so do not include corrugations.

**Origin** - Flattened rail has no apparent localized cause such as a weld or engine burn.

**Growth** - Individual lengths are relatively short, as compared to a condition such as head flow on the low rail of curves.

**Appearance** - Flattened rail shows the following:

- A flattening and widening of the head for several inches, with the entire head sagging.
- Small cracks in the depression on the running surface.

**Detection** - Flattened rail can be detected by visual inspection.

## *Crushed Head*

**Definition** - Crushed head is the flattening of several inches of the railhead, usually accompanied by a crushing down of the metal but with no signs of cracking of the fillet. The flattened rail and crushed heads should not be confused with battered rail ends.

**Origin** - Crushed head usually originates from a softer spot in the steel of the head, which gives way under heavy wheel loads, or from an advanced rail surface collapse condition.

**Growth** - Crushed head growth is caused by the continued passage of heavy loads. Higher speeds and increasing depth of the flat spot accelerate growth.

**Hazard** - Crushed head is not a serious defect, but it is generally removed from high-speed track because it causes rough riding and points of concentrated loading may develop defects.

**Appearance** - Crushed head shows the following:

- A flattening and widening of the head for several inches, with the entire head sagging.
- Small cracks in the depression on the running surface.
- In advanced stages, a bleeding crack may be present at the fillet under the head.

**Detection** - Crushed head can be detected by visual inspection.

## *Corrosion*

Corrosion on rail, fastening systems, and plates

**Definition** - Corrosion is the decaying or corroding of the metal on the web or base of the rail which results in irregular pits or cavities.

**Origin** - Corrosion normally occurs in wet or damp areas, such as tunnels or buried grade crossings. Essentially, corrosion is the rusting away of the metal. Salt brine from refrigerator cars also causes corrosion when a concentration of such traffic occurs.

**Growth** - Corrosion is usually a slow process which occurs over an extended period of time. However, this process can be greatly accelerated by electrolytic action on roads where electricity is the primary means of motive power.

**Hazard** - Corrosion is potentially dangerous because complete failure through the head, web, and base usually occurs when the cross-sectional area of the rail is sufficiently weakened by the corrosive action. Severe impact from flat wheels often causes ruptures if the rail was previously weakened through corrosion.

**Appearance** - Corrosion is identified as pits or cavities on the upper base or web of the rail. The severest corrosion usually occurs underneath the base; therefore, it is normally not visible when the rail is in place in the track.

**Detection** - Corrosion can often be detected by visual inspection.

## *Corrugation*

**Definition** - Corrugation, sometimes called washboard rail, is a repeated wavelike pattern on the running surface of the rail.

**Origin** - Corrugation is generally attributed to a repetitious wheel sliding action of some nature, whether through braking or lateral motion across the rail surface.

**Growth** - Corrugation is usually created over an extended period of time.

**Hazard** - Corrugation is not considered to be a serious defect, but the rail is usually removed from high-speed track because of rough riding conditions.

**Appearance** - Corrugations appear as small, hard, bright, short-pitch ridges along the running surface of the rail varying anywhere from 2 to 18 inches apart and usually less than 1/16 inch deep. Although the individual waves are usually only a short distance apart, the corrugations may extend over a considerable distance.

**Detection** - Corrugation can be detected by visual inspection.

## *Damaged Rail*

**Definition** - Damaged rail means any rail broken or injured by derailments, broken, flat, or unbalanced wheels, slipping or similar causes.

**Hazard** - Damaged rail is dangerous since the rail is physically broken, which can lead to derailments.

**Detection** - Damaged rail can be detected by visual inspection.

## *Head Checks*

**Definition** - Head checks are the slight separations of metal on the gauge side of the rail head, normally found on the high side of curves.

**Origin** - Head checks are common in switch areas, due to the lateral force induced on the rail head from wheel displacement through turnouts.

**Growth** - Head checks can turn down and develop into a transverse separation.

**Detection** - Head checks can be detected by visual inspection.

Gauge side head checking and flaking

## *Spalling*

Flattened rail head showing displacement of parent metal (spalling)

**Definition** - Spalling is generally referred to as the displacement of parent metal from the rail head.

**Origin** - Spalling originates from high-contact stresses associated with cyclical loading.

**Growth** - In the first stages, spalling may be referred to as a slight flaking. Further deterioration increases the amount of metal displacement.

**Detection** - Spalling can be detected by visual inspection.

## Defective Welds

Defective welds are field or plant welds containing any discontinuities or pockets exceeding 5% of the rail head (cross-sectional) area individually or 10% of the aggregate (in or near the transverse plane) due to incomplete penetration of the weld metal between the rail ends, lack of fusion between weld and rail end metal, entrapment of slag or sand, underbead or other shrinkage cracking, or fatigue cracking.

Weld defects may originate in the rail head, web, or base, and in some cases, cracks may progress from the defect into either or both adjoining rails.

The most common miscellaneous defects are:

- Defective plant weld
- Defective field weld
- Detail fracture from welded bond connection

Sizing for defective welds is normally reported in percentage of cross section.

Thermite weld with slag entrapment

Thermite weld showing severe porosity

## *Defective Plant Weld*

**Definition** - A defective plant weld is a progressive transverse defect in the rail head within the area where two rails are joined by a pressure welding process, a slug inclusion or oxide entrapment within the weld area, or a longitudinal fracture in the web area which originated at a weld. The defect results from the shearing processes used to remove excessive weld material.

**Origin** - Defective plant welds are caused by slag inclusions, oxide entrapments, improper fusion during the welding process, or thermal cracks resulting from rapid or otherwise improper cooling.

**Growth** - Growth of a progressive head defect is normally slow until it reaches 15-20% of the cross-sectional area of the head. After 20%, growth is more rapid. Ruptures of improperly fused welds or other gross weld imperfections usually occur in handling or when initially exposed to traffic. Growth of longitudinal cracks through the weld in the mid-web area usually progress several inches in one stage from fatigue areas less than one inch in length and less than 1/2 the width of the rail web.

**Hazard** - A defective weld is dangerous because:

- Failure frequently occurs before the defect becomes visible.
- A service break is a complete break through the head, web, and base. A longitudinal break across the web will sometimes cause a separation of a portion of the rail head.

**Identification** - The fracture face usually shows a progressive transverse defect similar to a transverse fissure in the head. The core or focal point of the defect reveal the cause of the defect. Inclusions or oxide entrapments are sometimes found in the fillet or flange areas.

**Appearance** - No outward sign is visible until the internal head defect reaches the rail surface. A defective weld may then be recognized by a vertical, bleeding hairline crack where the separation has reached the surface. A longitudinal web defect, similar in appearance to a split web defect, is usually visible as a bleeding hairline crack running lengthwise through the weld.

**Detection** - Defective plant welds can be detected by 70 and 45 degree transducer beams.

## *Defective Field Weld*

**Definition** - A defective field weld may be either a progressive fatigue failure or an internal weld discontinuity which occurs as a result of improper weld materials or procedures. The fatigue failure will progress in a manner similar to a transverse fissure, usually in the rail head. Slag entrapments, inclusions, or porosity can be found in any part of the weld area. Split webs through the weld area from slag, piping, or stress risers in the weld upset area may also occur.

**Origin** - Defective field welds are caused by slag entrapments, inclusions, porosity, or stress risers in the weld upset area.

**Growth** - Growth of field web defects is usually relatively slow until the defective area is approximately 20% of the cross-sectional area of the rail head. Progression above 20% will likely be more rapid and the weld is also subject to sudden failure from impact or shock load, especially if the discontinuity is located in the web or base section of the weld.

**Hazard** - A defective weld is dangerous because:

- Failure from slag entrapments or other internal defects usually occurs before the defect is visible.
- Longitudinal web cracks which extend outside the weld area frequently cause a complete displacement of a portion of the rail head.

**Identification** - The fracture face may show typical transverse defect progression rings around an internal discontinuity or the fracture may occur from the internal weld discontinuity prior to the development of fatigue rings. Progression of longitudinal cracks in the mid-web area is usually extremely rapid. A focal point for longitudinal web cracks at a weld can usually be identified within the weld area.

**Appearance** - Much like plant weld defects, no outward sign of a head defect is apparent until the internal defect reaches the rail surface. It is then visible as a vertical, bleeding hairline crack. Split webs in the mid-web area, when present, are usually visible as bleeding hairline cracks running lengthwise through the weld. However, in some instances, the hairline crack is too tight to be readily apparent.

**Detection** - Defective field welds can be detected by 70 and 45 degree transducer beams.

## *Detail Fracture (Welded Bond)*

**Definition** - A detail fracture from a welded bond connection is a progressive transverse defect which develops and expands from the point on the rail had where a head bond is attached by welding.

**Origin** - It is questionable whether the primary cause of detail fractures from welded bonds is due to thermal cracks created by rapid or irregular cooling at or near the point where the bond is attached or whether the focal point of the defect is a metallurgic reaction and the resulting penetration of the native metal through the martensite layer sometimes developed between the bond and the rail head. The inspector should be aware that rail defects can also develop from bond applications in the rail web.

**Growth** - Growth is usually very rapid after the defect attains size equal to 10-15% of the cross-sectional area of the rail head.

**Hazard** - A detail fracture from a welded bond connection is dangerous because:

- Service failure results in a complete break through the head web and base.
- Growth is exceptionally rapid once the defect develops.
- Failure usually occurs before there is any external evidence that a defect is present.

**Identification** - The face of the rail shows a polished transverse defect with typical growth rings, which have the appearance of gradually enlarging semi-circles with the center at a welded bond.

**Appearance** - No sign of transverse defect is visible until the separation reaches the rail surface (cracks out). The defect is then identified by a hairline crack at right angles to the running surface near the point where a welded bond connection is or has been attached to the rail head.

**Detection** - Detail fractures (welded bond) can be detected by 70 and 45 degree transducer beams.

## Definitions of Rail Terms

**Base**: the part of the rail lying below the web area, also referred to as the foot or flange.

**Bleeding**: reddish-brown streak indicating internal rusting.

**Bonds**: short wires used to bridge gaps in electrical circuits, usually at track circuit joints or between rails.

**Break**: a complete separation of one or more pieces of rail.

**Broken rail**: a term commonly used to describe any rail that has been completely broken through the entire rail section.

**Cant**: the angle of an individual rail relative to vertical. Rail is canted by the inclination of the tie plate in order to match the conical wheel profile. Cant is usually expressed as a rate of inclination, such as 1 in 40.

**Cold work:** plastic deformation of the rail material at low temperatures. Also known as cold rolled.

**Continuous welded rail (CWR)**: rail sections that are welded end-to-end into rail strings that result in a rail without rail joints, also referred to as welded rail or ribbon rail.

**Corrugation**: a series of wave-like variations of the rail head running surface, identified by an uneven head wear pattern.

**Crack**: a separation of metal extending partially, but not completely, through the rail section.

**Creep**: the longitudinal movement of rail produced by the passage of trains over it.

**Defect**: a term generally used to refer to an identifiable imperfection internal to the rail section or rail section geometrical surface.

**Detected defect**: a defective rail detected by a rail flaw detection (RFD) vehicle or visual means by the operator of a RFD vehicle.

**Fatigue**: irreversible damage to a material caused by cyclic loading, normally leading to the formation of a crack.

**Field side**: the side of the rail head away from the wheel flange.

**Flaking**: usually refers to small pieces of parent rail material becoming detached from the rail running surface - a type of minute spalling sometimes associated with a faulty manufacturing process.

**Flaw**: a general term often associated with cracks originating from rail defects.

**Fracture**: usually the complete separation of one or more portions of the rail.

**Gage corner**: the smaller upper rail head radius region that makes contact with the flange of the wheel.

**Gage side**: the side of the rail head closest to the wheel flange.

**Gage line**: the location on the gage side of the rail head 5/8 inch below the rail tread that is used to establish track gauge.

**Hairline crack**: a fine and usually shallow crack.

**Head checks**: transverse surface cracks on the gage corner of rails, resulting from cold working of the rail surface. Often these are controlled by preventive rail grinding.

**Head-hardened rail**: a rail that has only the rail head hardened to provide a harder steel for locations where excessive loading forces may increase head wear, such as the high side of a curve.

**Heat**: one batch of metal from a steelmaking furnace at the steel mill. All rails rolled from ingots or cast blocks from one heat.

**Heat treatment**: the process of altering the properties of the rail material by a specific heating and cooling process. Heat-treated rail is good in locations that require a rail section of higher strength and durability.

**High carbon rail**: a rail with extra carbon added during the manufacturing process to increase hardness.

**Inclusion**: an impurity, normally an oxide or a sulfide. The inclusion can be generated by the steelmaking process or by in-track thermite welding processes.

**Lip**: a length of material, usually towards the lower edge of the rail head, which as undergone severe plastic deformation to form a folded layer.

**Nucleus**: a term often used by metallurgists to refer to the origin or starting point of a defect.

**Origin**: the cause of a defect, the initial location of a defect, the point of initiation of a crack.

**Outside joint area**: the part of the rail that is not located within the prescribed confines of the "rail end."

**Percent size**: percentage of rail head cross-sectional area that is weakened by the defect (transverse defects only).

**Piped rail**: term assigned to defects that originate from ingot casting procedures.

**Pressure butt welding**: a welding technique used to connect parts which are nearly parallel and don't overlap.

**Progressive fracture**: term usually used to describe the gradual propagation of a crack over a period of time.

**Rail defect**: may be a defect detected visually, ultrasonically, by other NDT methods, or may be exposed by an in-service rail failure that may render the rail unfit for normal operations.

**Rail end**: the part of the jointed rail covered by the angle bar or a similar linear length in welded rail.

**Rail flaw**: imperfections on the surface or interior of the rail section.

**Rail failure**: rail that is broken while in service. An internal defect may be present. However, a rail failure can result from conditions other than an internal defect, e.g. load impact or stress failure.

**Rail lip**: a length of rail steel material that has undergone severe plastic deformation to form a folded layer overhanging at the lower corner of the rail head. This condition is typically found on the high side of curves.

**Rail neutral axis**: the point in the rail web where internal pressure is compressive (pushing) above and tensile (pulling) below during vertical loading of the rail section.

**Rail neutral temperature**: the rail temperature at which there are no axial thermal forces in the rail section.

**Rail surface irregularities**: rail surface irregularity is deformation or damage to the running surface of a rail which can include flaking, spalling, shelling, corrugation, localized rail head surface collapse, and crushed head and crack-out under the rail head.

**Rail wear**: a reduction of the rail head as a result of abrasive action between the steel wheel on the steel rail.

**Relayed rail**: worn, but still usable, rail taken from track and reused in another location (often referred to as secondhand or used rail).

**Rolling contact fatigue**: a form of rail fatigue originating primarily from cyclic loading in the wheel/rail interface zone.

**Running surface**: a longitudinal band on the rail head where the wheels make contact with the rail - also referred to as the "bright band" or "rail tread".

**Rupture**: a synonym for fracture or break.

**Seam**: an internal rail longitudinal pocket that is inherent from the manufacturing process.

**Section modulus**: the bending strength of a particular rail section.

**Segregation**: a result of an improper steel manufacturing process that can be identified by a separated or partially separated steel microstructure, mostly associated with the rail web.

**Service failure**: An undetected rail that breaks in service.

**Shatter crack**: discontinuous, internal cracks formed in steel due to stresses produced by localized transformation and decreased solubility of hydrogen during cooling after hot working.

**Shelling**: A term associated with cracks originating from sub-surface defects or at the rail running surface that can result in considerable dislodgment of the rail parent metal.

**Slag**: fused glassy material that is produced when a metal is separated from its ore during smelting.

**Spalling**: a term used to refer to the dislodged parent material area of the rail head that results from rolling contact fatigue.

**Streak**: dark line seen on the running surface of the rail head.

**Stress relief**: normally referred to as post-weld heat treatment.

**Tangent track**: straight track.

**Thermal cracking**: a rail defect identified as fine cracks across the rail head, caused by excessive heat generated at the wheel/rail interface.

**Transposed rail**: rail that is removed from one side of the track to the other side, without turning the rail, so gauge and field sides are interchanged. Also known as turned rail.

**Tread**: path of wheel contact with running surface of the rail.

**Work-hardened rail**: rail that has a hardness greater than when manufactured, as a result of the cold working of the steel by cyclical traffic loading.

**A-scan display**: a data presentation method where signal amplitude is plotted along the y-axis versus time on the x-axis. The horizontal distance between any two signals represents the material distance between the two conditions causing the signals. In a linear system, the vertical excursion is proportional to the amplitude of the signal.

**Acoustic impedance (Z):** the resistance of a material to the passage of sound waves. The value is the product of the material density and sound velocity. The acoustic impedance of a material determines how much sound is transmitted and reflected when the wave encounters a boundary with another material. The larger the difference in acoustic impedance between two materials, the larger the amount of reflected energy is.

**Amplitude**: 1) the maximum absolute value obtained by the disturbance of a wave or any quantity that varies periodically. 2) the vertical height of a received signal on an A scan.

**Angle beam testing**: ultrasound testing technique that uses an incidence wave angle other than 90 degrees to the test surface. The refracted angle of the sound energy is calculated using Snell's law.

**Angle beam transducers**: a device used to generate sound energy, send the energy into a material at an angle other than 90 degrees to the surface, and receive reflected energy and convert it to electrical pulses.

**Angle of incidence**: the angle between the direction of propagation of an electromagnetic or acoustic wave incident on a test object and the local normal to that test object.

**Angle of reflection**: the angle between the direction of propagation of an electromagnetic or acoustic wave reflected by a test object and the local normal to that test object.

**Angle of refraction**: the angle between the direction of propagation of an electromagnetic or acoustic wave refracted by an optically homogeneous test object and the local normal to that test object.

**Array transducer**: a transducer made up of several individual piezoelectric elements connected so that the signals they transmit or receive may be treated separately or combined as desired.

**Attenuator**: a device for causing or measuring attenuation, usually calibrated in decibels.

**B-scan**: a data presentation method applied to pulse echo techniques. It produces a two-dimensional view of a cross-sectional plane through the test object. The horizontal sweep is proportional to the distance along the test object and the vertical sweep is proportional to depth, showing the front and back surfaces and discontinuities between the two.

**Back (backwall) reflection**: the signal received from the far boundary or back surface of a test object.

**Beam spread**: the divergence of the sound beam as it travels through a medium - specifically, the solid angle that contains the main lobe of the beam in the far field.

**Compressional wave**: a wave in which the particle motion in the material is parallel to the wave propagation direction, also called a longitudinal wave.

**Contact method**: the testing method in which the transducer face makes direct contact with the test object through a thin film of couplant.

**Contact transducers**: an ultrasonic transducer that is designed to be used in direct contact with the surface of the test article.

**Couplant**: a substance, usually liquid, used between the transducer and the test surface to permit or improve transmission of ultrasonic energy into the test object.

**Cross talk**: the unwanted signal leakage (acoustical or electrical) across an intended barrier, such as leakage between the transmitting and receiving elements of a dual transducer (also called cross noise and cross coupling).

**Cycle (Hertz)**: comprises a complete set of recurrent values of a periodic quantity.

**Decibel**: a logarithmic unit for expressing power relationships.

**Defect**: a discontinuity or other imperfection causing a reduction in the quality of a material or component.

**Density**: the mass of a substance per unit volume.

**Discontinuity**: a break in the continuity of a medium or material.

**Echo**: a signal indicating reflected acoustic energy.

**Elasticity**: a term that describes how quickly molecules return to their original positions.

**Far field**: the area beyond the near field where the ultrasonic beam is more uniform.

**False indication**: a test indication that could be interpreted as originating from a discontinuity but which actually originates where no discontinuity exists.

**Flat bottom hole**: a type of reflector commonly used in reference standards. The end (bottom) surface of the hole is the reflector.

**Frequency**: the number of waves that pass a given point in a specified unit of time.

**Gain control**: a control which varies the amplification of the ultrasonic system (also considered the sensitivity control).

**Gate**: an electronic device for monitoring signals in a selected segment of the trace on an A-scan display. The interval along the baseline that is being monitored.

**Hertz**: one cycle per second.

**Inherent defects**: discontinuities that are normal in the material at the time it originally solidifies from the molten state.

**Longitudinal waves**: commonly used term for compressional wave.

**Loss of back reflection**: absence or significant reduction of an indication from the back surface of the test object.

**Near field**: wave interference that leads to extensive fluctuations in the sound intensity near the source.

**Noise**: any undesired signal that obscures the signal of interest. It might be electrical noise or a signal from specimen dimensional or property variations.

**Nondestructive testing (NDT)**: testing to detect defects in materials using techniques that do not damage or destroy the items being tested.

**Orientation**: the angular relationship of a surface, plane, discontinuity or axis to a reference plane or surface.

**Phase array**: a mosaic of transducer elements in which the timing of the elements' excitation can be individually controlled to produce certain desired effects, such as steering the beam axis or focusing the beam.

**Piezoelectric effect**: the ability of certain materials to convert electrical energy into mechanical energy and vice versa.

**Piezoelectric element**: a material that vibrates when an electric current passes through it.

**Propagation**: advancement of a wave through a medium.

**Pulse**: a transient signal or ultrasonic signal.

**Pulse echo method**: an ultrasonic test method in which discontinuities are detected by return echoes from the transmitted pulses.

**Pulse-echo test**: a test that can determine the location of a discontinuity by measuring the time required for a short ultrasonic pulse to travel through the material.

**Pulse method**: equipment that generates a series of pulses that are separated from each other by a constant period of time, i.e. energy is not sent out continuously.

**Pulse rate**: number of pulses that are transmitted in a unit of time (also called pulse repetition rate).

**Pulser-Receiver**: used with a transducer and oscilloscope for flaw detection and thickness gauging.

**Range**: the maximum ultrasonic path length that is displayed.

**Refracted beam**: a beam that occurs in the second medium when an ultrasonic beam is incident at an acute angle on the interface between two media having different sound velocities.

**Resolution**: ability to clearly distinguish signals obtained from two reflective surfaces with a minimum difference in depth. Near surface resolution is the ability to clearly distinguish a signal from a reflector under the near surface without interference from the initial pulse signal. Far surface resolution is the ability to clearly distinguish signals from the back surface when the sound beam is normal to that back surface.

**Scanning**: movement of the transducer over the surface of the test object in a controlled manner so as to achieve complete coverage. May either be contact or immersion method.

**Search unit**: an assembly comprising a piezoelectric element, backing material (damping), wear plate or wedge (optional) and leads enclosed in a housing (also called transducer or probe).

**Sensitivity**: a measure of the ability to detect small signals. Limited by the signal-to-noise ratio.

**Shear waves**: waves that move perpendicular to the direction the wave propagates.

**Shear wave transducer**: an angle beam transducer designed to cause converted shear waves to propagate at a nominal angle in a specified test medium.

**Shoe**: a device used to adapt a straight beam transducer for use in a specific type of testing, including angle beam or surface wave tests and tests on curved surfaces. See also "Wedge".

**Sound**: mechanical vibrations transmitted by an elastic medium.

**Test frequency**: the frequency or vibration of the ultrasonic transducer employed for ultrasonic testing.

**Test surface**: the surface of the test object at which the ultrasonic energy enters or leaves.

**Time of flight**: the time for an acoustic wave to travel between two points; for example, the time required for a pulse to travel from the transmitter to the receiver via diffraction at a discontinuity edge or along the surface of the test object.

**Transducer**: an electro-acoustic or magneto-acoustic device containing an element for converting electrical energy into acoustical energy and vice versa. See "search unit".

**Ultrasonic**: a term referring to acoustic vibration frequencies greater than about 20,000 hertz.

**Ultrasonic testing**: the transmission of high-frequency sound waves into a material to detect imperfections or to locate changes in material properties.

**Ultrasonic vibrations**: vibrational waves of a frequency above the hearing range of the normal human ear are referred to as ultrasonic, and the term includes all waves of a frequency of more than approximately 20,000 cycles per second. Also known as ultrasonic waves.

**Ultrasonic waves**: sound waves too high in frequency for humans to hear.

**Ultrasonically sound material**: a material having no discontinuities that cause discernible ultrasonic indications at the required test sensitivity level.

**Velocity**: distance traveled per unit of time.

**Vibration**: a rapid back-and-forth motion of a particle or solid.

**Wavelength**: the distance needed in the propagation direction for a wave to go through a complete cycle.

**Wedge**: a device used to direct ultrasonic energy into a test object at an acute angle. See also "shoe".

## Rail Defect Abbreviations

**BBJ**: Broken base joint area

**BBO**: Broken base outside joint area

**BHB**: Bolt hole break

**BHJ**: Bolt hole break joint area

**BHO**: Bolt hole break outside joint area

**BRJ**: Broken rail joint area

**BRO**: Broken rail outside joint area

**CF**: Compound fissure

**CH**: Crushed head

**DF**: Detail fracture

**DHS**: Deep horizontal separation

**DWE:** Defective weld - electric

**DWG**: Defective weld - gas pressure

**DWP**: Defective weld plant

**DWF**: Defective weld field

**EB**: Engine burn

**EBF**: Engine burn fracture

**HSJ**: Horizontal split head joint area

**HWJ**: Head and web separation joint area

**HWO**: Head and web separation outside joint area

**NT**: No test

**PRJ**: Piped rail joint area

**REWF**: Rail end weld fracture

**PRO**: Piped rail outside joint area

**REX**: Rail exception

**SD**: Shell defect

**SSC**: Shelled, spalled, corrugated

**SSH**: Shell defect

**SWJ**: Split web joint area

**SWO**: Split web outside joint area

**TDC**: Compound fissure

**TDD**: Detail fracture

**TDE**: Transverse defect electrode burn

**TDT**: Transverse fissure

**TDW**: Transverse defect welded burn

**TF**: Transverse fissure

**TWB**: Thermite weld boutet

**TWBW**: Thermite weld boutet wide gap

**TWO**: Thermite weld orgotherm

**TWOW**: Thermite weld orgotherm wide gap

**VSJ**: Vertical split head joint area

**VSH**: Vertical split head outside joint area

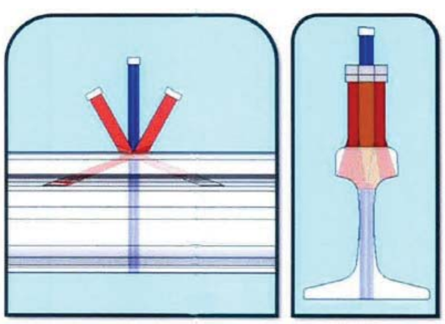
**WEBF**: Welded engine burn fracture

## Beam Angles & Flaw Detection

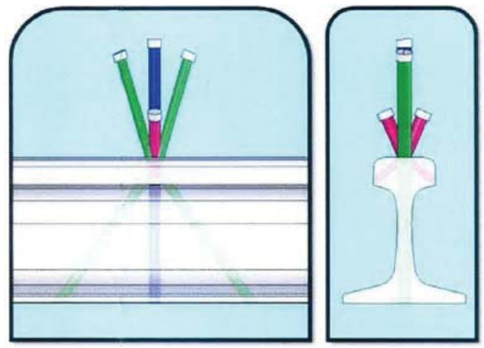
Ultrasonic rail flaw detection systems use transducers set at different beam angles within a wheel probe to capture defects in specific sections of the rail. The following sections show what types of defects are found with different beam angles.

**70 degree beams** - this beam angle captures the following types of defects:

- Progressive transverse cracks in the rail head
- Transverse cracks in the rail heads (welds)
- Transverse fissures in the rail head
- Compound fissure
- Detail fracture
- Engine burn fracture
- Welded burn fracture



70 degree beam angles



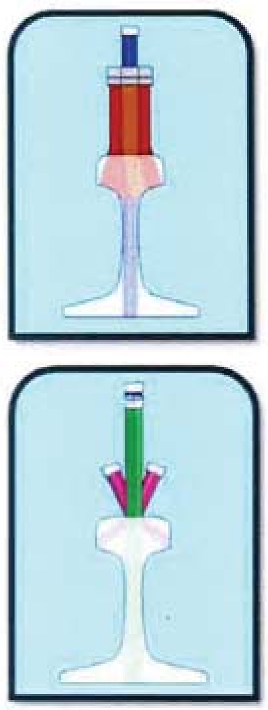
Zero and 45 degree beam angles

**0 (zero) degree & 45 degree beams** - this combination of beam angles captures the following types of defects:

- Horizontal cracks in the rail head
- Horizontal cracks in the rail head-web separation
- Vertical breaks in the rail section
- Cracked bolt holes
- Vertical and horizontal split head defects on the centerline (zero degree)
- Vertical split head defects off the center line (45 degree)
- Split web
- Shear breaks
- Piped rail

**70 degree & 45 degree beams** - this combination of beam angles captures the following types of defects:

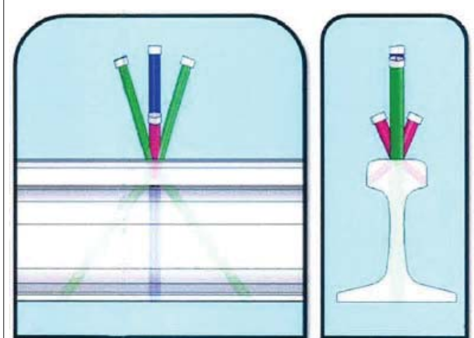
- Transverse cracks in the section (welds)



70 degree (top) and 45 degree (bottom)beam angles

**0 (zero) degree beams** - this beam angle captures the following types of defects:

- Horizontal cracks in the web-foot separation
- Horizontal cracks in the web (welds)



**70 degree & 0 (zero) degree beams** - this combination of beam angles captures the following types of defects:

- Horizontal cracks in the rail head