Surface fatigue initiated transverse defects and broken rails – an International Review
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Edited by

ANDERS EKBERG
ELENA KABO

Department of Applied Mechanics / CHARMEC
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2014
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Department of Applied Mechanics / CHARMEC
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone +46 (0)31 772 1000
Abstract
The current report briefly compares some operational experience of cracked and broken rails from China, Russia, South Africa, Sweden, UK and USA. Four key questions are addressed:

1. Is the critical crack length, i.e. the length of a surface initiated crack that causes a rail break (reasonably) constant in an international perspective?
2. Is it (reasonably) constant over a line?
3. Can the depth when a rolling contact fatigue crack deviates to a transverse propagation be estimated?
4. Is it (reasonably) constant in an international perspective?

The answers can briefly be summarized as

1. No. Deviations in crack sizes from roughly 10% up to roughly 80% of the railhead area at fracture have been found.
2. Not generally, but for some lines this seems to be the case if fractures at the same season are considered (i.e. climate effects are excluded).
3. There are indications that this depth is in the order of 5 mm with a fair amount of scatter. However it is very difficult to identify from a photo whether an area of the fracture surface actually corresponds to inclined fatigue crack propagation.
4. With a reservation in the considerable scatter, there seems to be some consistency also in an international perspective.

Details on how these conclusions were reached are given in the report.
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Introduction
The current report summarizes the results of a project initiated by the International Collaborative Research Initiative (ICRI) on rolling contact fatigue and wear of rail/wheel systems. The aim of the project was to establish whether the critical crack length corresponding to a transversal rail break was reasonably constant in an international perspective. In addition it was also investigated whether the crack length corresponding to a deviation from inclined to transversal growth was constant.

The investigation is based on failure data from around the world as detailed below.

China – general overview
Data courtesy Xin Zhao, Southwest Jiaotong University, Chengdu

The fracture surfaces found in different books etc revealed fatigue crack sizes at fracture of roughly 10% to 80% of the rail head (rail breaks measured on screen featured 10%, 25%, 40%, 70%, 80%).

For cases where any statement is made, RCF cracks are said to propagate to a depth of roughly 6–8 mm before deviating to transverse cracking.

China – case study
Data and picture courtesy Zhou Qingyue CARS

Rail grade ........................................980MPa
Rail section .....................................China 60kg/m, as-rolled rail
Service environment ..................Passenger and freight, 21t–23t axle load,
  a) 64–67Mt-km/km/year
  b) 70Mt-km/km/year
  c) 79 Mt·km/km/year
Track curvature ..........................a) R = 600m
  b) R = 1000 m
  c) R = 800 m
At a stress concentrator ...............No
Depth at downward deviation.......a) max 8–15mm
  b) –
  c) –
Type of ties and fasteners .............Type III Fasteners
Geographical location .......................Severe curves of mountainous railway
Figure 1  Rail damage corresponding to the cases reported above a) shelling caused by incorrect super-elevation causing cant excess; b) shelling caused by excessive lubrication in order to reduce the lateral wear c) head checks and shelling caused by the use of as-rolled rail, which is not a suitable choice for the current conditions.

Comments
The cracks presented have not formed complete rail breaks. It is therefore difficult to assess the critical crack size. However judging from Figure 1b, the critical crack size should be larger than some 10% of the railhead area.
Russia – general overview

Data and picture courtesy Sergey Zakharov (VNIIZHT)

No detailed failure analyses are available from Russia. However the data in Table 1, compiled by Sergey Zakharov, outlines the number of transverse fatigue cracks and resulting rail breaks.

Table 1  Distribution (in %) of rails removed from track on the Russian Railways [1]

<table>
<thead>
<tr>
<th>Defect type</th>
<th>Relative number of rail defects (%) by years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1980</td>
</tr>
<tr>
<td>Transverse fatigue cracks in rail head</td>
<td>21.7</td>
</tr>
<tr>
<td>Broken rails (transverse)</td>
<td>0.2</td>
</tr>
</tbody>
</table>

An example of a transverse crack is given in Figure 2. Other examples (photos) of transverse cracks in broken rails were given in [2].

![Figure 2](image)

Figure 2  Example of transverse fatigue crack of the railhead. Rail removed from single track [1].

Transverse fatigue crack sizes on the Russian railways are presented in Table 2.

Table 2  Distribution of transverse fatigue crack sizes in 59 studied broken rails [1]

<table>
<thead>
<tr>
<th>Crack size, mm</th>
<th>Number of rails</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>15</td>
<td>23</td>
</tr>
<tr>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td>35</td>
<td>11</td>
</tr>
<tr>
<td>47</td>
<td>2</td>
</tr>
</tbody>
</table>

The influence of climatic conditions on rail breaks for the Russian Railways is presented in Figure 3 (from [1]). It is seen that rail breaks are up to 8 times more likely during winter than during summer.
Figure 3  Example of transverse fatigue crack of the railhead. Rail removed from single track [1].

References
South Africa – case study
Data and picture courtesy Robert Fröhling, Transnet

Rail grade ........................................ a) Thyssen Head Hardened (7 years in service)
                                           b) CrMn (In service since 1986)
Rail section ........................................ UIC60
Service environment .............................. Freight at 26 ton axle load
Track Curvature ................................. a) 604 m
                                           b) 804 m
At a stress concentrator ........................ Longitudinal sub-surface defect 3 mm below the gauge corner
Depth at downward deviation .............. a) roughly 6 mm*
                                           b) roughly 7 mm*
Crack size at fracture ....................... a) 80% Detail Fracture
                                           c) 60% Detail Fracture
Geographical location ........................... a) Between Lejanedrif and Engogweni on the Coal Export Line
                                           b) Between Mkondo and Confidence on the Coal Export Line
Time of year ...................................... April 2004

* In the figures the upper "deteriorated" region is taken as initiation before deviating into a transversal direction. Note that this region need not correspond to inclined propagation. The data summary states that the deviation depth is not clear.

Comments
The two fracture surfaces (both resulting in rail breaks) are fairly similar in appearance. At final fracture the crack basically extends close to, or into the web. It can be noted that for both cases the propagation in the rail head was slightly inclined (not shown in the pictures below).
Figure 4  

a) Rail fracture between Lejane Drif and Engogweni,  
b) Rail fracture between Mkondo and Confidence.
Sweden – case study
Data and pictures from the report “Head checks (UIC 2223) och rälsbrott, undersökning av räler från Malmbanan, bdl 111, 2006” by Tamara Gronowicz, Banverket, 2007 (Id F07-2726/BA40).

The report covers laboratory investigations of six operational rails, five of which resulted in rail breaks

Rail grade ...........................................a) R350HT
b) 1100
c) not known
d) not known
e) 1100
f) not known

Rail section .......................................a) BV50 (50 kg/m rail)
b) BV50
c) BV50
d) BV50
e) BV50
f) BV50

Service environment .......................a) Heavy haul
b) Heavy haul
c) Heavy haul
d) Heavy haul
e) Heavy haul
f) Heavy haul

Track curvature ...............................a) not known
b) not known
c) not known
d) not known
e) not known
f) not known

At a stress concentrator .....................a) No
b) No, close to one sleeper.
c) No, in mid span
d) Partly: mid span 0.45 m from a thermite weld
e) No, close to one sleeper
f) No, mid span

Depth at downward deviation......a) No rail break. The cracks had not deviated downwards at a depth of 2mm.
b) Probably ~2 mm
c) Subsurface initiation ~3mm below rail surface*
d) Subsurface initiation 3 mm below rail surface*
e) Subsurface initiation 6 mm below rail surface*
Crack size at fracture

<table>
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<th>Option</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>a)</td>
<td>No final fracture</td>
</tr>
<tr>
<td>b)</td>
<td>&gt;50 % Detail Fracture</td>
</tr>
<tr>
<td>c)</td>
<td>&gt;80 % Detail Fracture</td>
</tr>
<tr>
<td>d)</td>
<td>~70 % Detail Fracture</td>
</tr>
<tr>
<td>e)</td>
<td>&gt;80 % Detail Fracture</td>
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<tr>
<td>f)</td>
<td>~40 % Detail Fracture</td>
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Type of ties and fasteners

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<th>Description</th>
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</thead>
<tbody>
<tr>
<td>a)</td>
<td>hard timber sleepers and hey-back</td>
</tr>
<tr>
<td>b)</td>
<td>hard timber sleepers and hey-back</td>
</tr>
<tr>
<td>c)</td>
<td>hard timber sleepers and hey-back</td>
</tr>
<tr>
<td>d)</td>
<td>hard timber sleepers and hey-back</td>
</tr>
<tr>
<td>e)</td>
<td>hard timber sleepers and hey-back</td>
</tr>
<tr>
<td>f)</td>
<td>hard timber sleepers and hey-back</td>
</tr>
</tbody>
</table>

Geographical location

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td>North of Torneträsk (km ~1465)</td>
</tr>
<tr>
<td>b)</td>
<td>Krokvik–Rautas (km 1431+200)</td>
</tr>
<tr>
<td>c)</td>
<td>Rensjön–Bergfors (km ~1450+500)</td>
</tr>
<tr>
<td>d)</td>
<td>Stenbacken–Kaisepakte (km 1475+682)</td>
</tr>
<tr>
<td>e)</td>
<td>Stenbacken-Kaisepakte (km 1476+630)</td>
</tr>
<tr>
<td>f)</td>
<td>not known</td>
</tr>
</tbody>
</table>

Time of year

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
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<tr>
<td>b)</td>
<td>winter</td>
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<tr>
<td>c)</td>
<td>winter</td>
</tr>
<tr>
<td>d)</td>
<td>winter</td>
</tr>
<tr>
<td>e)</td>
<td>winter</td>
</tr>
<tr>
<td>f)</td>
<td>winter</td>
</tr>
</tbody>
</table>

* The cracks are indicated as subsurface initiated in the report. Note that it may however be that the cracks initiated at the surface and the “initiation” depth really indicates depth at downward deviation. This is very hard to verify/falsify from the report.

Figure 5: Annual variations in the number of rail breaks on part of the Swedish Iron Ore line. Picture courtesy Kalle Karttunen.
Figure 6  Investigations of the headchecks from the rail sample taken out north of Torneträsk. a) Headchecks at the top of the rail b) Transversal section c) longitudinal section.
Djupet på head checks i här rälen mättes upp till 0,5-1,5 mm. Mätningen gjordes med virvelström bildats efter att rälen brustit och sprickan låg i närheten av ena slipern. En stor tvärgående utmattningsspricka fanns i rälshuvudet, (UIC 211).

Rälsbrott på km 1476+630, höger räl. På bräckorna syns områden med "svetsloppor" som ett BV50- rälshuvud med höjdslitage på 6 mm. Sprickan hade startat ca 6 mm under farkanten. Arean på utmattningssprickan var ca 2300 mm² från ett område ca 3 mm från farkanten. Arean på utmattningssprickan var ca 1100 mm² från ett område ca 2 mm från farkanten. Sprickan täckte ca 70 % av tvärsnittet på rälshuvudet, (UIC 211).

En stor tvärgående utmattningsspricka i rälshuvudet, (UIC 211).

**Comments**

With the exception of rail f, the crack size at fracture is fairly constant between the rails. Note that the traffic on the line is almost uniform (heavy haul) and that all failures occurred during winter.

The influence of winter conditions in Sweden can be estimated from Figure 5. Note that the distribution over the year is very similar to that in Russia.
UK – case study

Data and picture courtesy Claire Davis, University of Birmingham (sample provided by Tata steel)

Laboratory evaluated cracks
Rail grade ............................................. 220
Service environment ....................... Passenger
Depth at downward deviation ...... a) 7.5 mm (broken open crack)
                                 b) 5 mm (section with multiple cracks)
Geographical location ............... UK

Fracture

Figure 8 a) Crack broken open and measured with laser scanning
          b) Sectioning of a rail surface containing multiple cracks.
USA, Norfolk Southern Railway – case study
Data and picture courtesy Brad Kerchof, Norfolk Southern Railway

Data related to five fractures (four of which reported here). The fractures are reverse TDs – cracks originated in plastic flow at bottom of gage face.

- Rail grade: 2003 RMSM, Head Hardened
- Rail section: 141RE
- Service environment: Freight
- Track curvature: 12 degrees, high side
- At a stress concentrator: No
- Type of ties and fasteners: 8 x 18” tie plates with Pandrol e clips
- Geographical location: Kimball WV
- Time of year (if service break): December 26, 2013

Fractures

Figure 9: Overview of fractured rail

Figure 10: Fractures at sections 1HiA (a) and 1HiB (b)
The fractures have initiated as fatigue cracks related to plastic flow at the bottom of the gauge corner. At final fracture the fatigue crack size corresponded from roughly 17% for HiA, HiB and HiC to around 5% for HiD.

The fracture was in mid December, which means temperature effects would influence the rail. Note that this is a multiple fracture. Thus, the HiD fracture may have been affected by significantly increased load magnitudes owing to the other fractures.
USA, BNSF railways – case study
Data and picture courtesy David C. Sheperd, BNSF Railway

Rail .................................................................
  a) 112lb or 115lb rail
  b) RE116
  c) 112 RE OH BSC LACK
  d) RE115. 115 RE CC BETH LACKAWANNA 1975
  e) 136-10 CC CF&I 1994
  f) RE115LB. 11525 RE CC

Service environment ......................................
  a) Freight, speed 40 mph,
  b) Freight, speed 49 mph
  c) Freight, speed 70 mph
  d) Freight, speed 70 mph
  e) Freight, speed 60 mph
  f) Freight, speed 60 mph

Track curvature ..............................................
  a) 0°
  b) 2°
  c) 0°
  d) 0°
  e) 1°
  f) 0°

Crack size at fracture .................................
  a) 25% Detail Fracture
  b) 45% Detail Fracture
  c) 10% Detail Fracture
  d) (estimated 75%) Detail Fracture
  e) 25% Detail Fracture
  f) 50% Detail Fracture

Type of ties and fasteners ..............................
  a) Timber tie 2008
  b) Timber tie 2002
  c) Timber tie 2011
  d) Timber 2008
  e) Timber ties 2007
  f) Timber ties 2000

Geographical location .................................
  a) West Quincy, MO BNSF Hannibal Sub LS14 MP137
  b) Lester, IA BNSF Marshall Sub LS 197 MP152.3
  c) Lohman, MT BNSF Milk River Sub LS 35 MP418.7
  d) Hannibal, MO BNSF Hannibal Sub LS 14 MP136
  e) Vaughn, NM BNSF Clovis Sub LS7100 MP788.5
  f) Hastings, NE BNSF Hastings Sub LS 2 MP156.5
Time of year (if service break) ..... a) February 10, 2012  
                          b) November 04, 2013(?)  
                          c) September 21, 2012  
                          d) February 05, 2013  
                          e) March 24, 2013  
                          f) June 06, 2013

Comments
There is a rather large deviation in critical crack sizes for these rails even though the initiation site seem very similar.
Fractures

Figure 12  Overview of fractured rails
USA, BNSF railways – case study, part II
Data and picture courtesy David C. Sheperd, BNSF Railway

Rail ..........................................................a) 1946 Illinois 132# RE
 b) 136# CC CF&I 1994
c) 115# RE Tennessee 1980
d) 132# RE CC CF&I 1953
e) 132# RE Illinois 1979
f) 136# RE CC CF&I 1973
g) 115# RE CC CF&I 1949

Service environment ..........................a) Freight, 16.5 annual MGT
 b) Freight, 186 annual MGT
c) Freight Siding, ~13 MGT Annually
d) Freight, 44 annual MGT
e) Freight
f) Freight 15.5 annual MGT
g) Freight and passenger siding estimate
 13 MGT Annually

Track curvature ..............................................a) 2’ 0”
 b) 2’ 0”
c) 0°
d) 0°
e) 0°
f) 4’ 0”
g) 0°

Crack size at fracture ..........................a) (estimated 10% Detailed fracture)
b) (estimated 25% Detailed fracture)
c) (estimated 40% Detailed fracture)
d) (estimated 40% Detailed fracture)
e) (estimated 15% Detailed fracture)
f) (estimated 15% Detailed fracture)
g) (estimated 15% Detailed fracture)

Type of ties and fasteners ...............a) Wood ties, cut spikes
 b) Wood ties, cut spikes
c) Wood ties, cut spikes
d) Wood ties, cut spikes
e) Wood ties, cut spikes
f) Wood ties, cut spikes
g) Wood ties, cut spikes

Geographical location ..........................a) El Paso Sub New Mexico, USA
 b) Clovis Sub, New Mexico USA
c) Barstow Sub, Illinois USA
d) Boise City Sub, Texas USA
e) Canyon Sub, Wyoming USA
f) El Paso Sub, New Mexico USA
g) Ft Worth sub, Texas USA
Time of year (if service break) 

a) October 2013 

b) March 2013 

c) October 2013 

d) November 2012 

e) September 2012 

f) November 2012 

g) December 2012 

Fractures
Comments
Note that the critical crack size is very roughly approximated from the photos. Although there is considerable scatter, there is consistency in critical crack sizes and initiation sites.
Concluding remarks

There is a wide variation in critical crack sizes corresponding to transversal rail breaks. Possible reasons for this fact include:

- Variations in stress free temperatures
- Influence of cold climate (cf the influence of winter conditions in Russia and Sweden)
- Increased loading from other rail defects (or due to adjacent fracture)
- Support conditions
- Load magnitudes causing the final fracture
- Rail quality
- ...

Note that e.g. the investigated rails from the Swedish Iron Ore line have a fairly consistent critical crack size. This implies that it should be possible to obtain a state where the critical crack size is fairly constant. This might require fairly uniform traffic and track conditions, which is the case on the Swedish Iron Ore line.

Wear state seems to have limited influence on the critical crack size (as percentage of head area).

There is an indication that (on average) the critical crack size may be somewhat smaller in curves.

Depth of transversal deviation tends to be around 5 mm. However this depth is generally difficult to identify and subjected to a major scatter.

The information in this report provides a perspective to the results that have been obtained in work carried out on rail breaks e.g. in the European projects INNOTRACK (http://www.innotrack.eu/) and D-RAIL (http://d-rail-project.eu/). In these projects (long) crack growth has been predicted and influences of various parameters established. Further alarm limits for wheel impact loads have been established in the UIC-led HRMS project. These limits were established based on a prediction of which combinations of rail crack size, wheel impact load, vehicle and track conditions that will result in a rail fracture.

In addition to broaden the knowledge gained from these projects, it is also believed that the current report can help networks assess whether they have a good control on stress free temperatures (resulting in a fairly stable critical crack size) and to improve ultrasonic testing (knowing the depth for transversal propagation provides a basis for establishing the latest stage when cracks should be detected).

Naturally a lot of unknowns remain before the risk of rail breaks is fully managed. One important aspect in this strive is to recognize that passengers travelling by rail are typically 50–100 times safer than those travelling by car. Thus imposing very costly measures with limited effects that drives travel to road is a sub-optimization. The same holds for freight where the benefits of preventing rail breaks and thereby delays and in rare cases (see ERA reporting on freight derailments) human losses should be contrasted to the risk of transferring operations to less safe and environmentally friendly means of transportation.
## Annex I – summary of core data

Compiled by Eric Magel, NRC–CNRC

<table>
<thead>
<tr>
<th></th>
<th>rail (H/L)</th>
<th>initiation depth</th>
<th>defect size</th>
<th>rail grade</th>
<th>years in service</th>
<th>rail section</th>
<th>track curvature</th>
<th>axle loads</th>
<th>annual tonnage</th>
<th>speed</th>
<th>date of break</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert Frohling</td>
<td>Transnet</td>
<td>South Africa</td>
<td>6 mm</td>
<td>ThysseHH</td>
<td>7</td>
<td>UIC60</td>
<td>604</td>
<td>26</td>
<td>passenger service</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
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<td>7 mm</td>
<td>CrMn</td>
<td>27</td>
<td></td>
<td>804</td>
<td>26</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Claire Davis</td>
<td>Birmingham</td>
<td>UK</td>
<td>7.5 mm</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Sergey Zakharov</td>
<td>Russia</td>
<td></td>
<td>L?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>some statistics showing broken rails 8x more frequent in winter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brad Kerchof</td>
<td>NS</td>
<td>USA</td>
<td>H</td>
<td></td>
<td>5-17%</td>
<td>RMSM 2003</td>
<td>141RE</td>
<td>240 (120)</td>
<td>“reverse TD’s”</td>
<td></td>
<td></td>
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<td>Dave Sheperd</td>
<td>BNSF</td>
<td>USA</td>
<td>H</td>
<td>25%</td>
<td>112JB or 115b rail</td>
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<td>40 mph</td>
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<td></td>
<td></td>
<td></td>
<td>H</td>
<td>45%</td>
<td></td>
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<td>timber ties</td>
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<td>H</td>
<td>10%</td>
<td>OH BSC LACK</td>
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<td>timber ties</td>
<td>Sep-12</td>
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<td>H</td>
<td>75%</td>
<td>CC BETH LACK 1975</td>
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<td>70 mph</td>
<td>timber ties</td>
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<td>H</td>
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<td>H</td>
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<td>timber ties</td>
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<td>USA</td>
<td>H</td>
<td>10%</td>
<td>Illinois 1946</td>
<td>132RE</td>
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