STEEL BRIDGES

PRAGUE 2024

Remaining Fatigue Strength of an Orthotropic Steel Deck with Respect to a Repair Method by Cold Joining Techniques

F. Kalkowsky | M. Schröder | C. Blunk | R. Glienke | J. Alex | W. Flügge

Outline

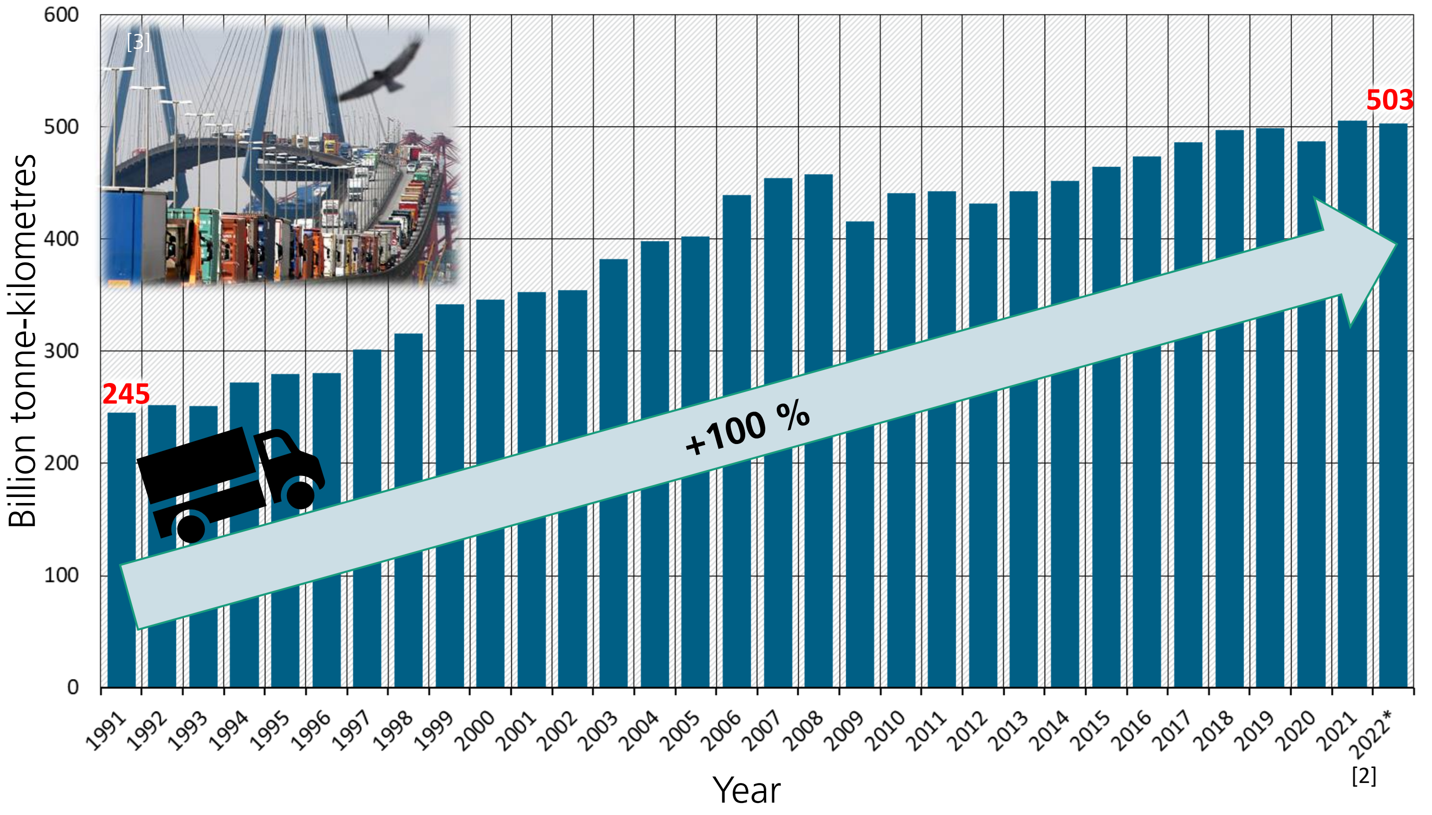
- Introduction
- Damages on Orthotropic Steel Deck Structure
- Experimental Investigations
- Execution Repair Method
- Summary

Introduction

1	2	3	4	5	6
Zeitraum	**bis 1950**	**1950 bis 1970**	**1970 bis 1990**	**1990 bis 2010**	**ab 2010**
N_{obs} je Jahr für Fahrstreifen 1	$0{,}25 \cdot 10^6$	$0{,}5 \cdot 10^6$	$1{,}0 \cdot 10^6$	$2{,}0 \cdot 10^6$	$2{,}5 \cdot 10^6$
	Verkehrszusammensetzung in %				
	45	30	20	20	10
	45	20	10	5	5
	-	-	20	50	60
	5	25	30	15	15
	5	25	20	10	10

[1]

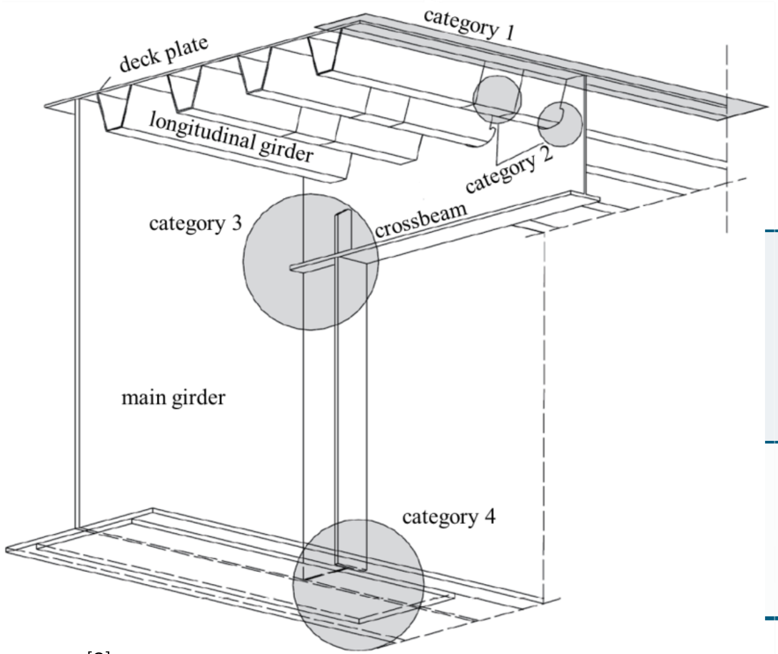
Freight transport performance in Germany



- Significant increase in size and weight of freight transport performance per vehicle
- Significant increase in freight transport performance
- ➢ Overuse of infrastructure that was not taken into account in the planning phase

Damages on Orthotropic Steel Deck Structure

Damage Categories



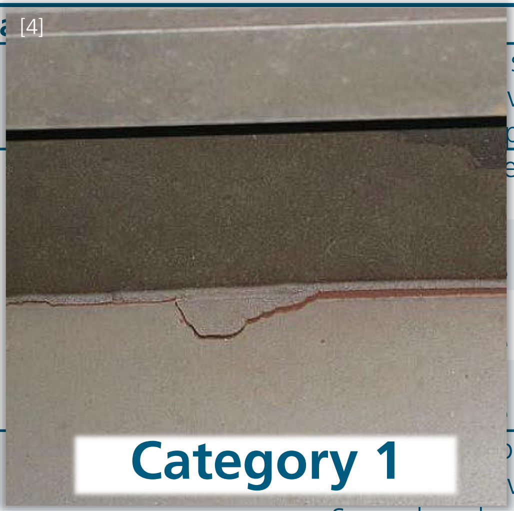
[8]

Da… …Tolerance

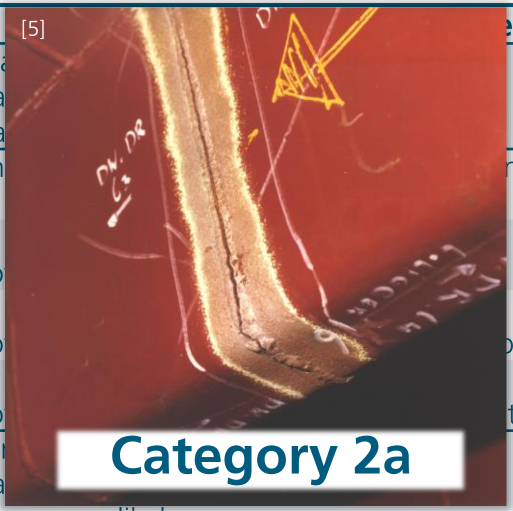
…nal girder or splice between continuous longitudinal

- Secondary damages very likely

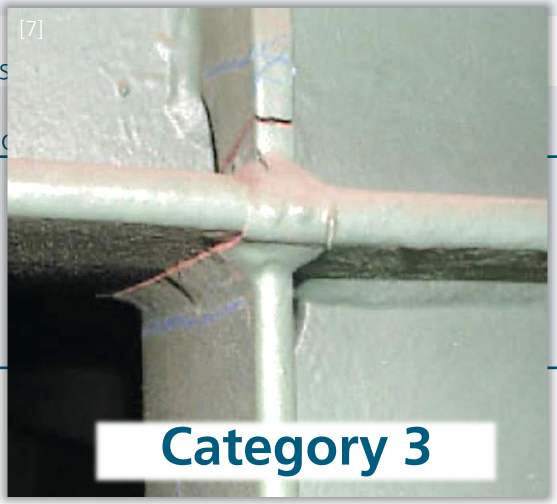
[4]

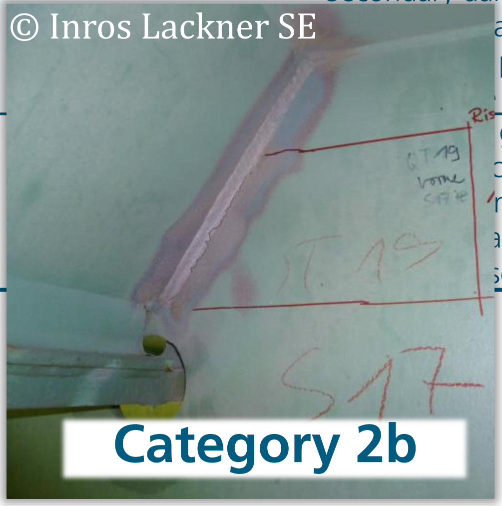


[5]



[7]

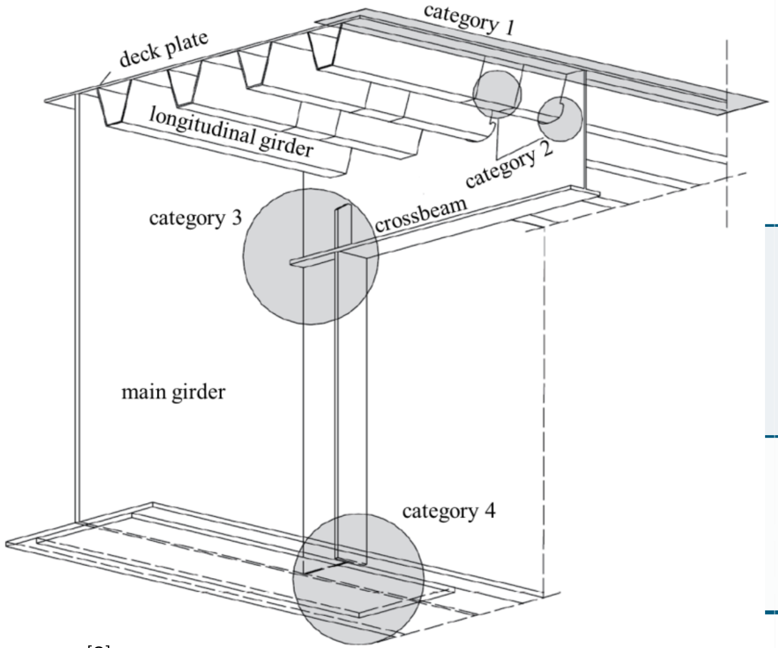




[6]

Damages on Orthotropic Steel Deck Structure

Damage Categories

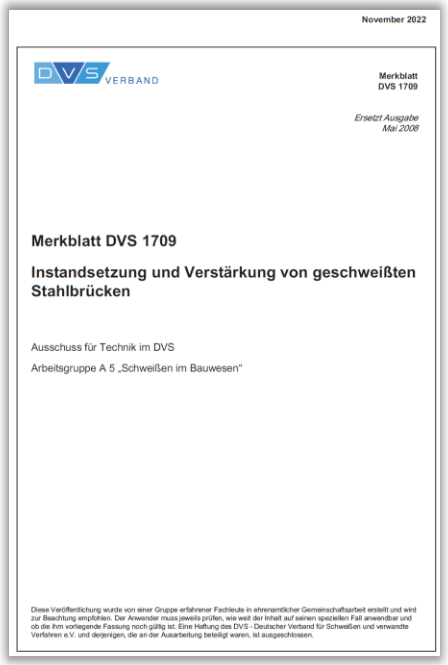


[8]

Damage category	Detail and Damage Tolerance
Category 1	Cover plate of deck slab • Redundancy available • Multiple load paths exist
Category 2	Connections between crossbeam and discontinuous longitudinal girder or splice between continuous longitudinal girder Category 2a • Fatigue failure of splice between longitudinal girder Category 2b • Fatigue failure of discontinuous longitudinal girder to crossbeam joint Category 2c • Fatigue failure of crossbeam at free edge of extended cut-out
Category 3	Components and connections in the crossbeam • Redundancy available to a limited extent • Secondary damages very likely • Component failure possible • Multiple load paths available to a limited extent • Local collapse of the structure
Category 4	Main structure and girder. • No redundancy available • Secondary damages likely • Single load paths • Global collapse of the structure

Damages on Orthotropic Steel Deck Structure

Repair Methods



November 2022

DVS VERBAND

Merkblatt DVS 1709

Ersetzt Ausgabe Mai 2008

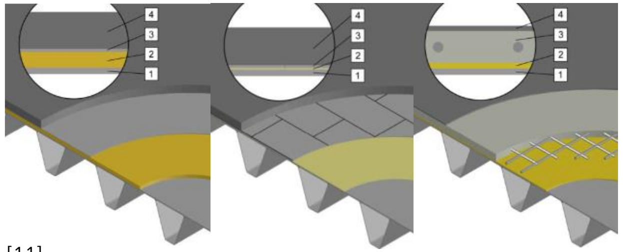
Merkblatt DVS 1709

Instandsetzung und Verstärkung von geschweißten Stahlbrücken

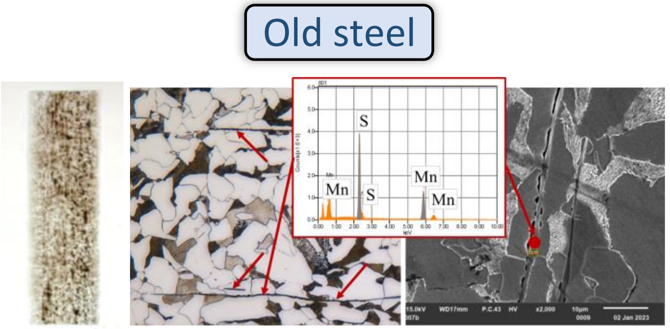
Ausschuss für Technik im DVS

Arbeitsgruppe A 5 „Schweißen im Bauwesen"

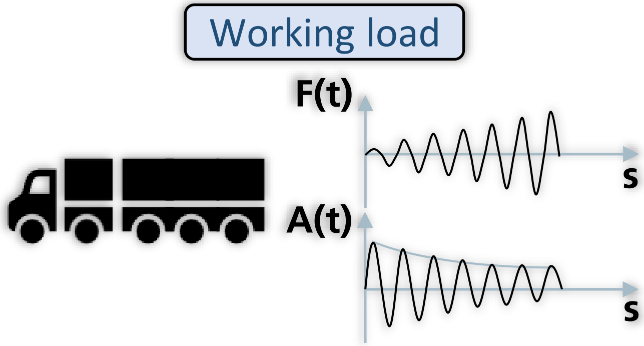
Diese Veröffentlichung wurde von einer Gruppe erfahrener Fachleute in ehrenamtlicher Gemeinschaftsarbeit erstellt und wird zur Beachtung empfohlen. Der Anwender muss jeweils prüfen, wie weit der Inhalt auf seinen speziellen Fall anwendbar und ob die ihm vorliegende Fassung noch gültig ist. Eine Haftung des DVS - Deutscher Verband für Schweißen und verwandte Verfahren e.V. und derjenigen, die an der Ausarbeitung beteiligt waren, ist ausgeschlossen.

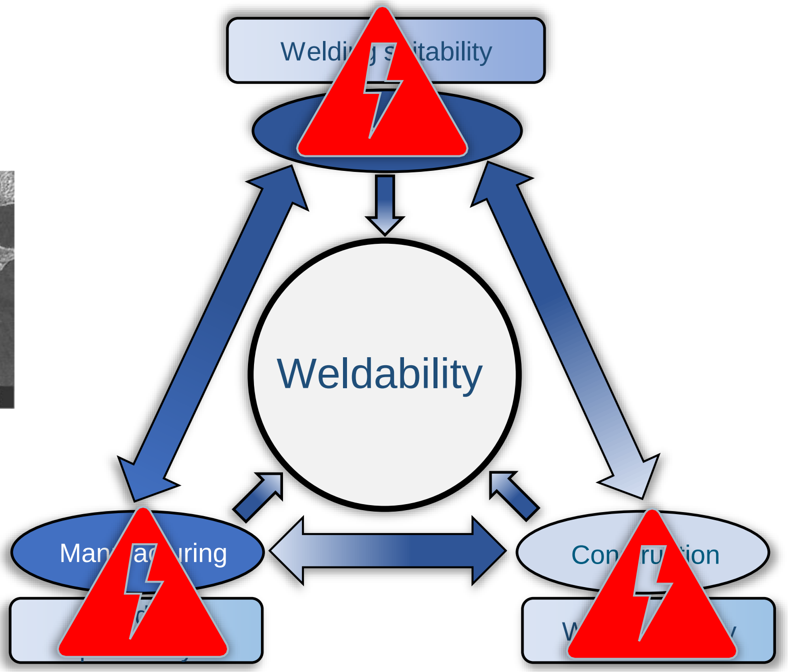


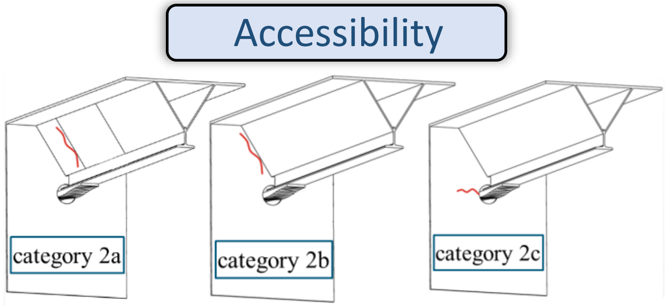
[11]



[10]





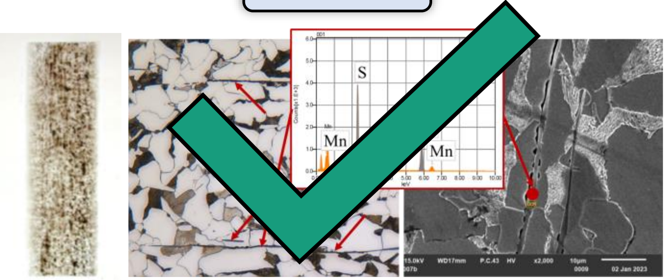


[9]

Damages on Orthotropic Steel Deck Structure

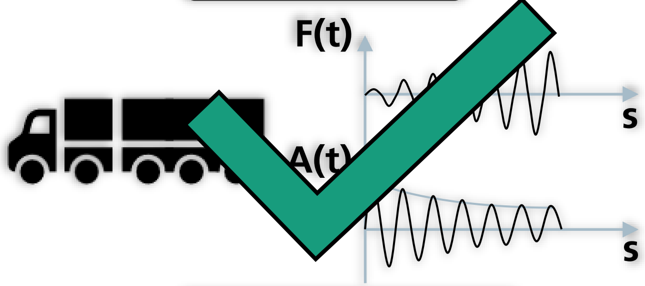
Repair Methods – Cold joining technology

Old steel

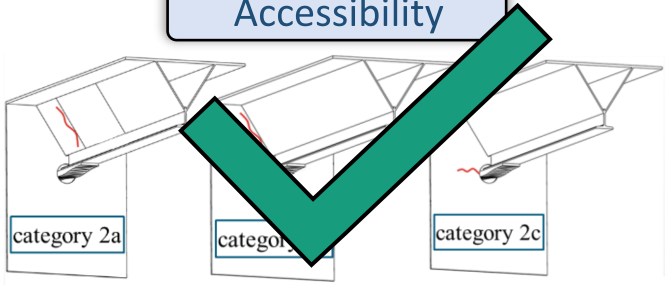


[10]

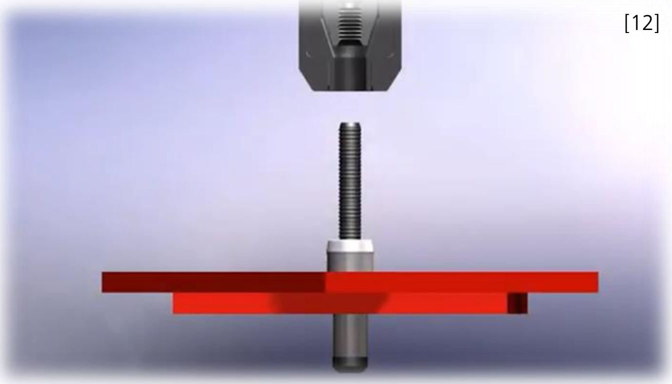
Working load



Accessibility



[9]



[12]

<u>Cold joining technology</u>

- No special preparation of the joint
- Easy installation of the blind fastener
- Only one-side accessibility is required
- ∅-range from 6.4 mm - 19.5 mm
- No thermal load shrinkage stress

<u>Application of blind fastener</u>

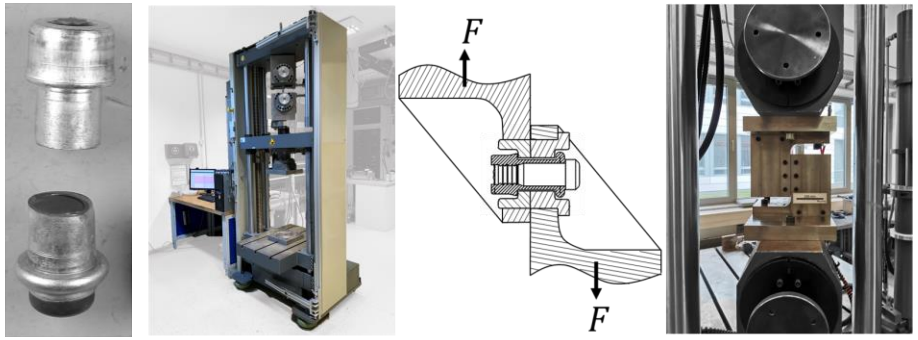
! Missing design rules acc. to Eurocode 3
! Application by individual case studies
! National Technical Approval | General Construction Technique Permit | European Technical Assessment
➢ Close gap of knowledge by systematic investigations

HOWMET AEROSPACE · INROS LACKNER · Fraunhofer IGP · Hochschule Wismar

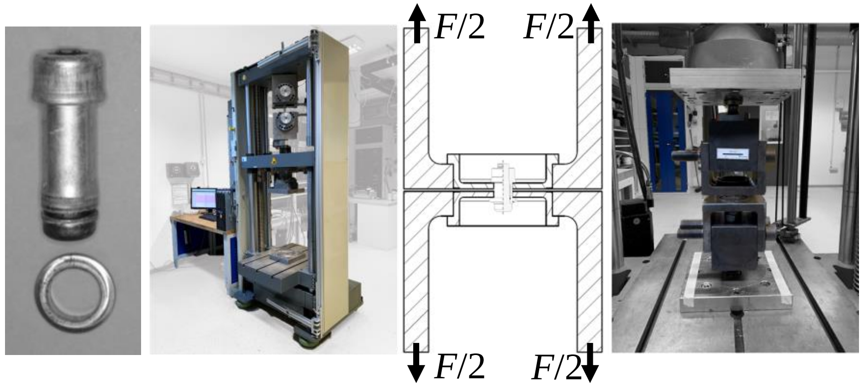
Experimental Investigations

Static tests on blind fasteners

Shear Test



Tension Test



Test procedure:

- DIN EN ISO 14589
- Hardened Inserts
- Test velocity 10 mm/min

Shear test parameter:

- Position shear plane
- Min. | max. clamping length
- Min. | max. hole diameter
- ➢ Characteristic shear resistance $F_{v,Rk}$

Tension test parameter:

- Min. | max. clamping length
- Max. hole diameter
- ➢ Characteristic tension resistance $F_{t,Rk}$

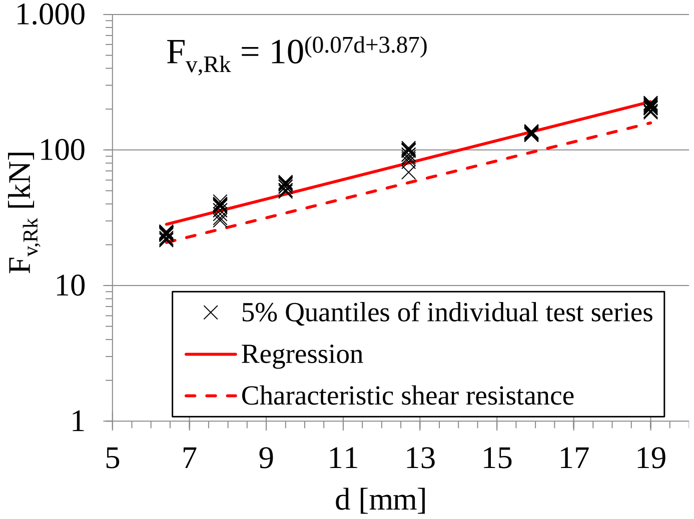
series	d [mm]	parameter I	parameter II		$d_{0,min}$	$d_{0,max}$
		l_K [mm]	$t_I < t_{II}$ [mm]	$t_I > t_{II}$ [mm]	[mm]	
01	6.4	4.0 – 18.2	2.0 + 5.1	5.1 + 2.0	7.1	7.4
02	7.8	4.8 – 27.0	2.5 + 8.6	8.6 + 2.5	8.9	9.3
03	9.5	8.0 – 30.1	3.0 + 24.0	24.0 + 3.0	10.5	11.0
04	12.7	9.6 – 41.2	4.0 + 34.2	34.2 + 4.0	13.9	14.7
05	15.9	12.8 – 21.6	5.0 + 20.6	20.6 + 5.0	17.5	18.4
06	19.1	12.8 – 31.6	6.0 + 19.6	19.6 + 6.0	21.1	22.1

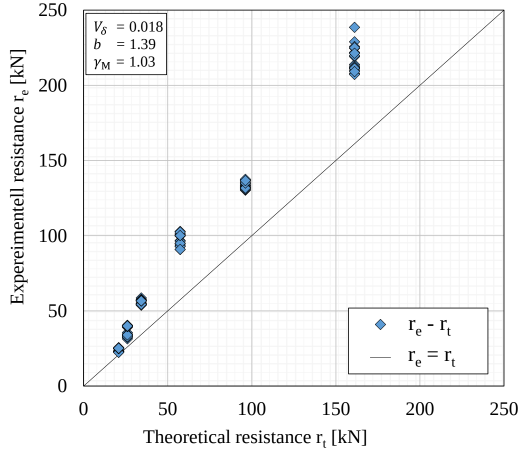
[1] **Configuration for tension tests**

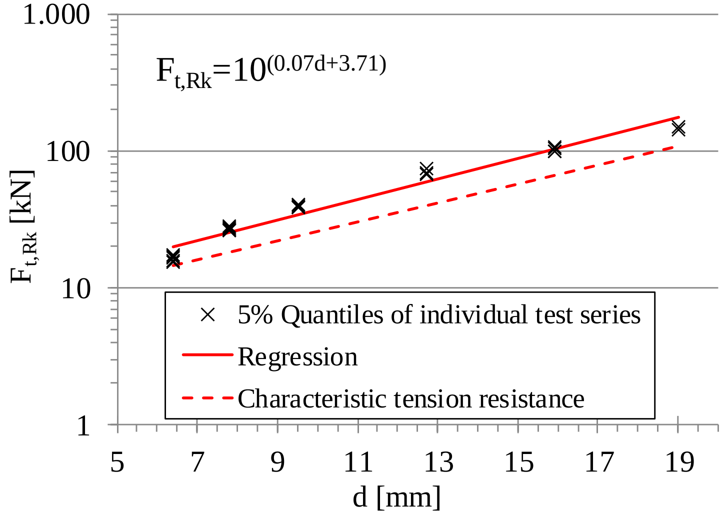
Experimental Investigations

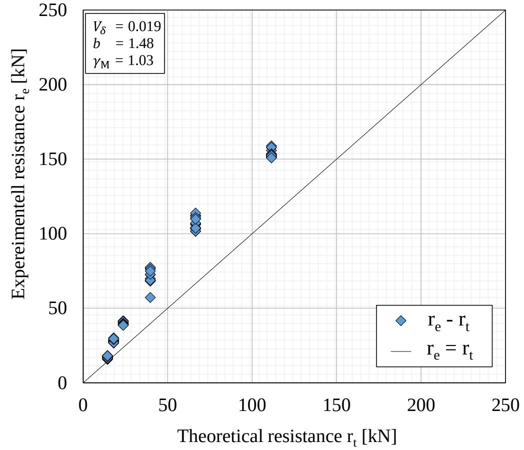
Static tests on blind fasteners

Shear Test | **Tension Test**



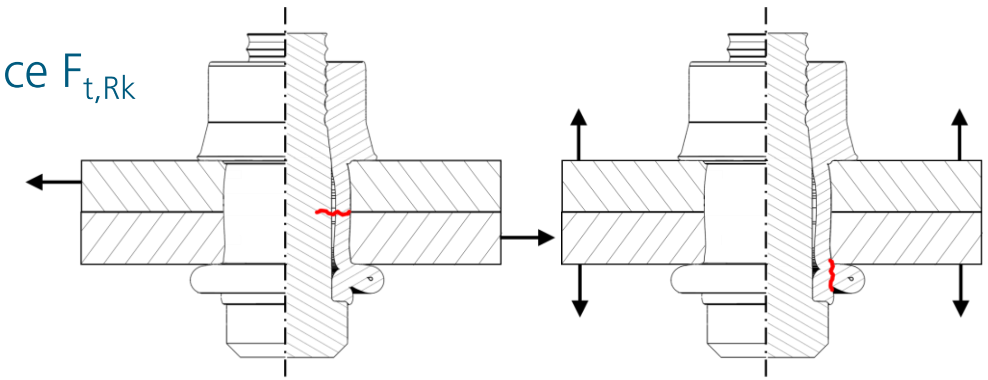




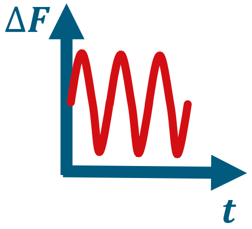


Results:

- Design equation for the characteristic shear $F_{v,Rk}$ and tension resistance $F_{t,Rk}$
- Statistical evaluation acc. to EN 1990 Annex D
  - Comparison of experimental and theoretical results
  - Partial factor γ_M below γ_{M2}= 1.25 (resistance of fasteners)



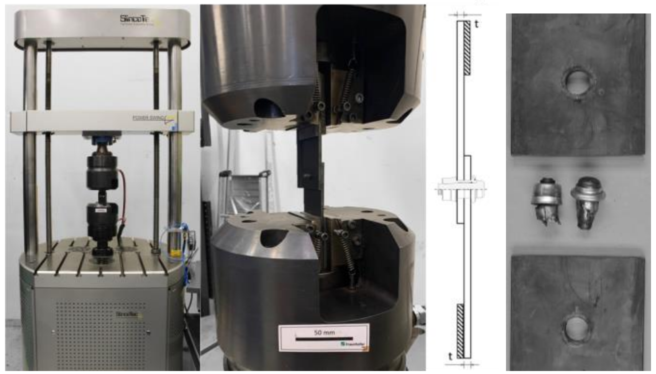
Experimental Investigations
Fatigue tests on blind fasteners



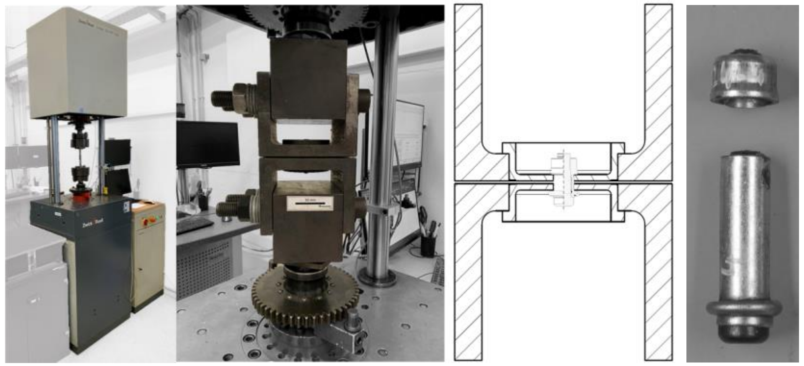
Test procedure:
- Load level method
- Load ratio $R = 0.1$
- Test frequency $f = 41 – 89$ Hz
- End of test – run-out ($N_D = 5 \cdot 10^6$) or fracture of specimen
- Evaluation acc. to Background Information of Fatigue Design Rules

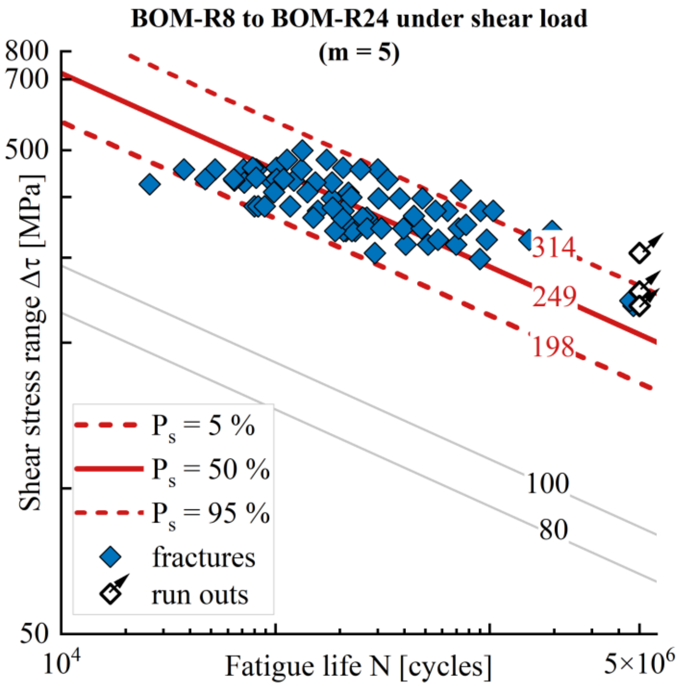
Results:
- Characteristic shear stress range $\Delta\tau_C = 198$ N/mm² (m=5)
- Characteristic direct stress range $\Delta\sigma_C = 77$ N/mm² (m=3)

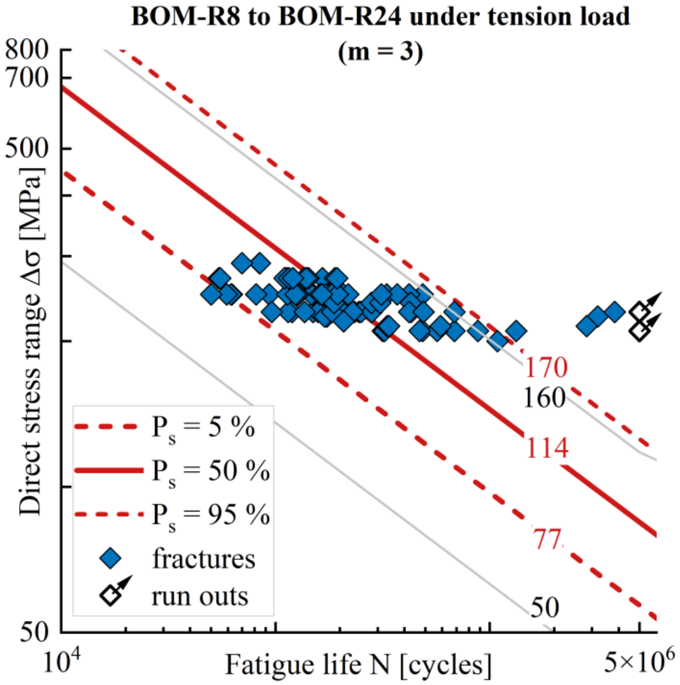
Shear Test



Tension Test





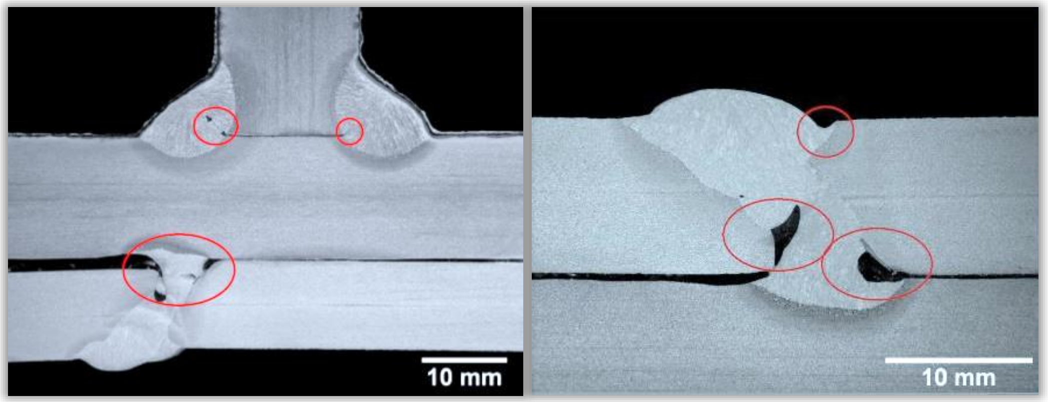


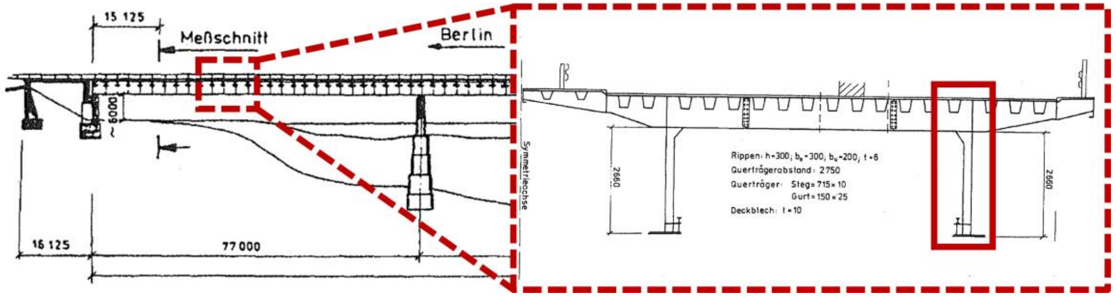
Experimental Investigations

Old steel from demolished bridge structure


[14]


[13]





Repair method by welding:

- **Repairing in main girder** area with additional plates
- Webs of the main girder subjected to **tensile stresses from welding**
- Old material failed by lamellar tearing → **Manganese sulphides** in the material was found as reason

➢ lack of stability of the old bridge and **problems with the repair method**

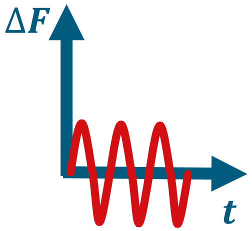
Demolished steel bridge:

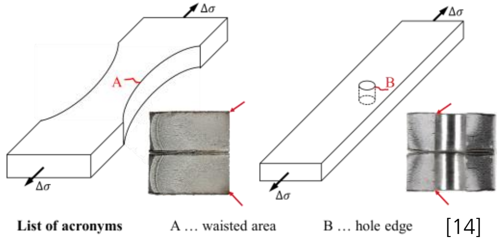
- Provision of **test material from middle section** for fatigue tests

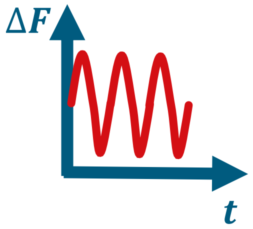

[10]

Experimental Investigations

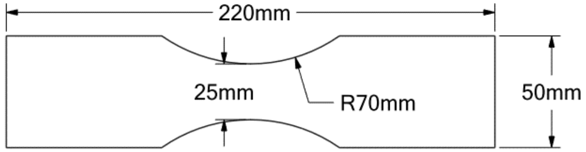
Fatigue tests on base material and perforated bar



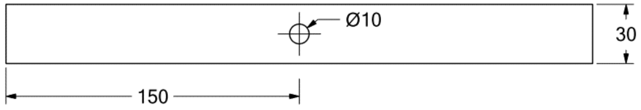


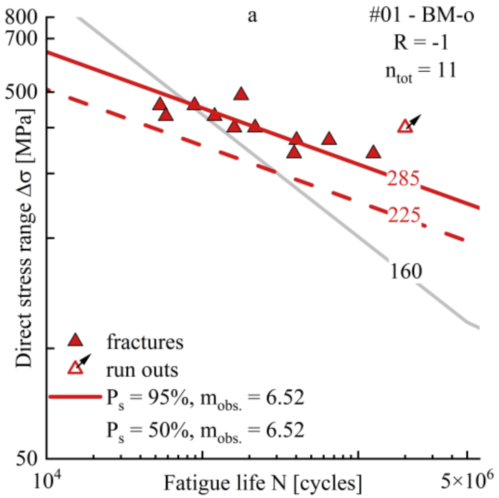


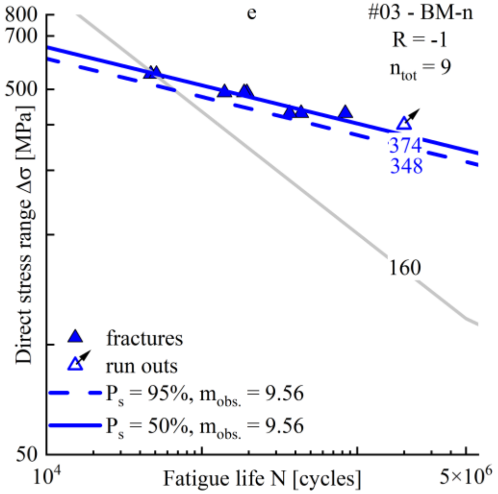
Base material(BM)

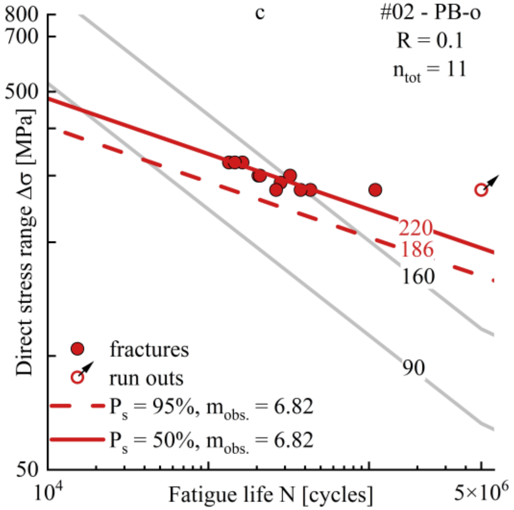


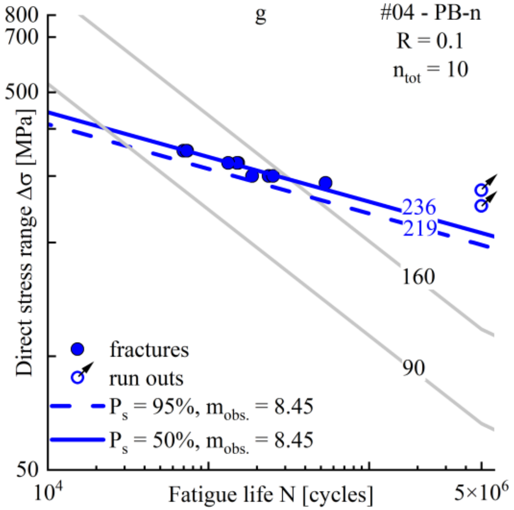
Perforated bar (PB)











Test procedure:

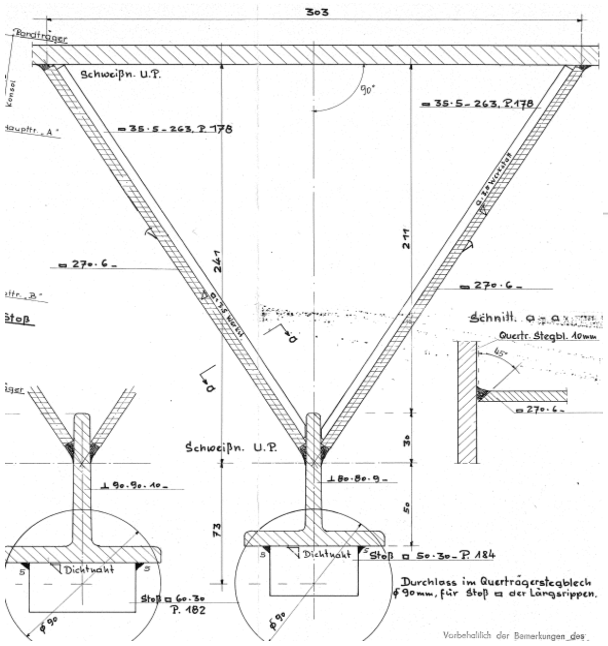
- Load level method
- Load ratio R = -1 (BM) | 0.1 (PB)
- Test frequency f = 8 – 20 Hz (BM) | 93 – 93 Hz (PB)
- End of test – run-out [$N_D = 2 \cdot 10^6$ (BM) | $N_D = 5 \cdot 10^6$ (PB)] or fracture of specimen
- Evaluation acc. to BACKGROUND INFORMATION OF FATIGUE DESIGN RULES

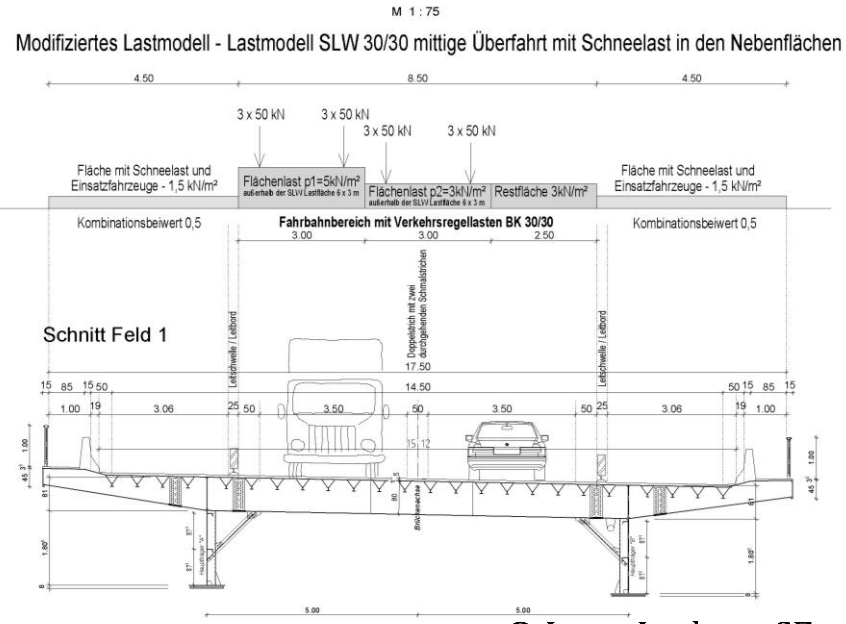
Results:

- Lower fatigue resistance of base material
- Comparable fatigue resistance of perforated bars
- ➢ Surface condition dominates the fatigue resistance of base material
- ➢ Notch effect dominates the fatigue resistance of perforated bars
- ➢ No pre-damage to the base material due to the service lifetime
- ➢ Repair solution with cold joining technology is like a new joint

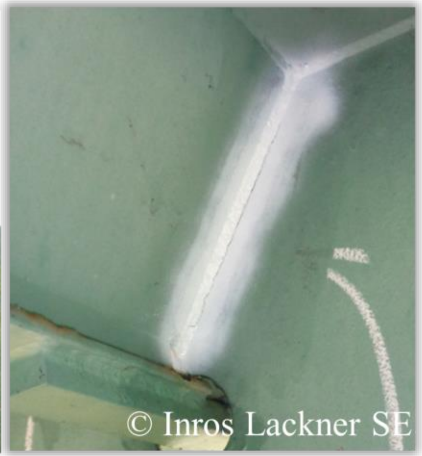
Execution Repair Method
Cold Joining Technology

Hasselholmer Talbrücke:
- Base material missing Z-grade – lamellar tearing
- Bad execution of welded joints
    - Bad weld preparation
    - Great weld seam volume
- Localisation of the damage in the structure not only in position of the main lanes





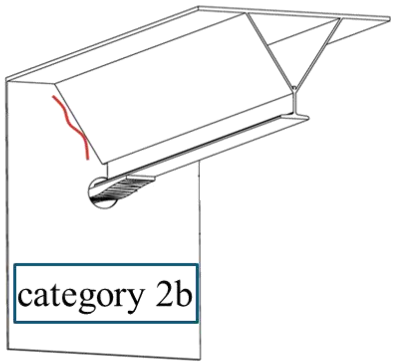
© Inros Lackner SE



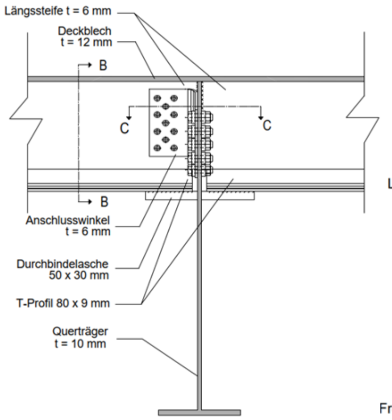
Execution Repair Method

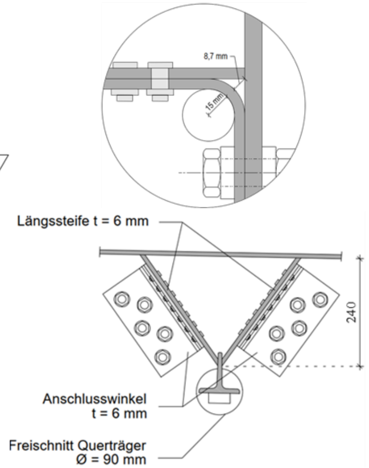
Cold Joining Technology

- Removal of coating and application of brittle lacquer
- Adapted bracket
- Hole manufacturing with magnetic drilling machine
- Provisional bolting of the bracket by 8 mm bolts with the crossbeam
- Alignment of the bracket for full contact between bracket and crossbeam as well as longitudinal stiffener
- Manufacturing of the holes in the longitudinal girder by reaming from 9.5 mm to 10.5 mm in the bracket and drilled through the girder
- Installation process of BOM-R12-8 from inside to outside - alternately
- Same procedure for connection between crossbeam and bracket with fit bolts according to EN 14399-8, strength grade 10.9, galvanised and bring to snug-tight condition
- Application of corrosion protection



[9]

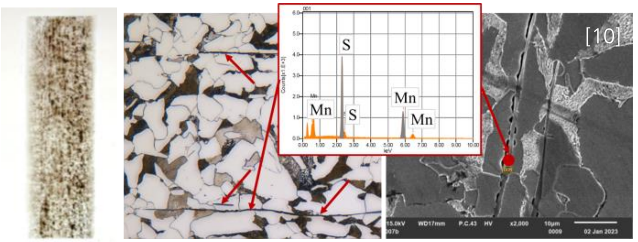




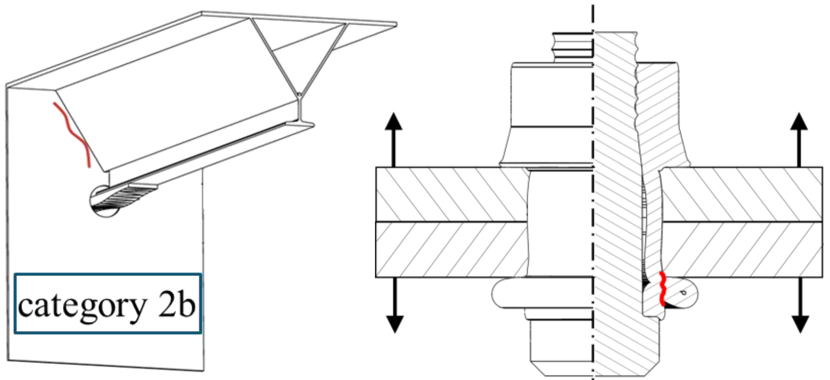
© Inros Lackner SE

Summary

Old steel



[10]



[9]

- Problem of repairing method by welding old steel - lamellar tearing
- Strengthening method by cold joining technology shows advantages for category 2 damages
- Special blind fasteners have high static load-bearing capacity and fatigue resistance
- Determined characteristic values for a Eurocode 3 compliant design
- Old steel showed comparable fatigue resistance - no damage from load history
- Application example of cold joining repair method shows no new damages since 2020
- Thesis:
  - Cold joining technology for category 2 damages preferred repair method
  - Wide use should also be recommended in other areas of application

Perforated bar

[9]

Many thanks for your attention!

Contact

M.Sc. Florian Kalkowsky
Mechanical Joining Technology
Phone +49 381 496 -141
Fax +49 381 496 -12
florian.kalkowsky@igp.fraunhofer.de

Fraunhofer IGP
Albert-Einstein-Str. 30
18059 Rostock
www.igp.fraunhofer.de

LinkedIn

X

Instagram

YouTube

Xing

References

[1] Richtlinie zur Nachrechnung von Straßenbrücken im Bestand (Große Entfernung) - Bundesministerium für Verkehr, Bau und Stadtentwicklung

[2] Federal Ministry for Digital and Transport

[3] Charisius: Köhlbrandbrücke Hamburg. url: https://fink.hamburg/wp/wp - content / uploads / 2019 / 05 / Br % C3 % BCckenbau - Finkenwerder .jpg

[4] Paschen et al. - Instandsetzungs- und Sicherungsmaßnahmen bei den Rheinbrücken Leverkusen und Duisburg- Neuenkamp – ein Zwischenbericht (Teil 1) (Stahlbau 86 2017, Heft 7)

[5] de Jong – Renovation techniques for fatigue cracked orthotropic steel bridge decks

[6] Bucak - Reparatur durch Stegaufpflasterung

[7] Ungermann et al. - Instandsetzung und Verstärkung von Stahlbrücken mit Kategorie-3-Schäden

[8] Merkblatt DVS 1709:2022-11 - Instandsetzung und Verstärkung von geschweißten Stahlbrücken

[9] Kuhlmann et al. - Instandsetzung und Verstärkung von Stahlbrücken mit Kategorie-2-Schäden

[10] Scharff et al. - Strategien zum Verlängern der Gesamtlebensdauer von orthotropen Fahrbahnplatten aus Sicht der Anwendungspraxis

[11] Friedrich et al. 2017: Stahlbrücken – Bestandsanalyse Erhaltung und Erweiterung

[12] https://www.youtube.com/watch?v=F7kF0EVc2WA

[13] https://www.deges.de/projekte/projekt/a-19-ersatzneubau-petersdorfer-bruecke-inklusiveas-waren/ Bildnachweis: Energieministerium Mecklenburg-Vorpommern

[14] - https://planen-bauen40.de/project/petersdorfer-bruecke/

[15] Schröder - Experimentelle und numerische Untersuchungen zur Ermittlung der Schwingfestigkeit an bauteilähnlichen Proben aus Altstahl mit Vorbelastung (Master-Thesis), Wismar: Hochschule Wismar, Fak. Für Ingenieurwissenschaften

