

第 6 回 定 期 研 究 会

平成 23 年度 SGST 第 6 回定期研究会 議事録

日時：平成 24 年 1 月 27 日(金) 16:00 ~ 17:30

場所：愛知工業大学 本山キャンパス

出席者：近藤，渡辺，小塩（名城大），青木（愛工大），廣畠（名大），奥村，永田（名工大），
木下（岐阜大），山田（中日本ハイエイ），加藤（海洋架橋），川瀬（日中C），高橋（アスコ），
佐藤（片平エンジン），佐藤（中日本建設C），園部（JTS），安藤（ - ），
尾関，松村，藤井，佐藤（瀧上），窪田（日鉄トピー）

以上 21 名(敬称略)

1. 定期研究会 (16:00 ~ 17:30)

講演者：スイス工科大学ローザンヌ Lebet 教授

講演題目：「Recent research on composite bridges and recent examples of
composite bridges in Switzerland」

講演内容

最近の合成桁の設計法とスイスにおける複合構造橋の事例について紹介いただいた。また、Lebet先生の説明に平行して、木下先生から日本語で補足説明をいただいた。

スイスの斜張橋，アーチ橋，パイプ橋梁，箱桁橋，2主鉄骨等について、製作～架設～供用中の状況を写真で説明いただき、さらに設計法等も交えて説明いただいた。事例の中には意匠性を考慮して配置されている非構造部材もあるとのことで、他国においても技術者とデザイナーのせめぎ合いを垣間見ることが出来た。

以上 東海構造研究グループ (SGST) 事務局 //



Composite bridges in "Switzerland"



- ♦ Recent footbridges
- ♦ Recent composite bridges or under construction
 - Branson Bridge, Martigny, 2006
 - Léopold-Sédar-Senghor Bridge, Nantes (F), 2009
 - Taulhac Bridge, Puy-en-Velay (F), 2012
 - Langensand Bridge – Lucerne, 2010
 - Hans-Wilsdorf Bridge, Geneva, 2012
 - Pont de la Poya – Fribourg, 2013

Recent bridges, footbridges



1

3



Recent bridges, footbridges



Bridge over the Fiume Verzasca – Gordola, 2005, $L = 120\text{m}$ (60.0 + 60.0)



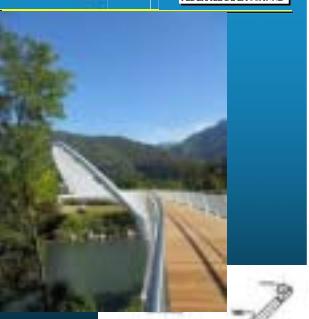
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Recent bridges, footbridges



5

6



Composite bridges in "Switzerland"



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Recent bridges, footbridges

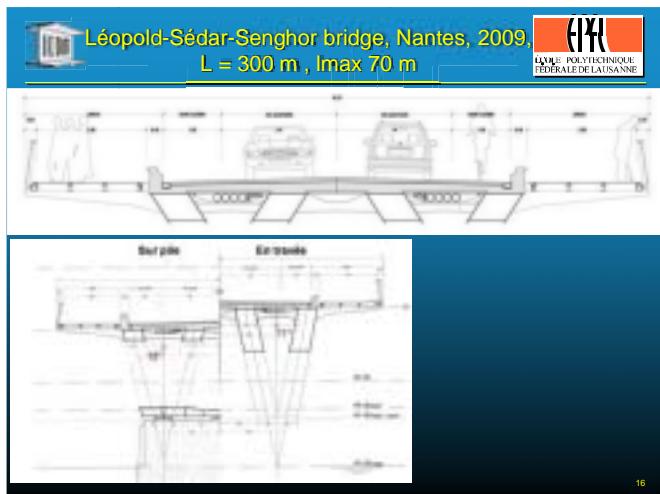
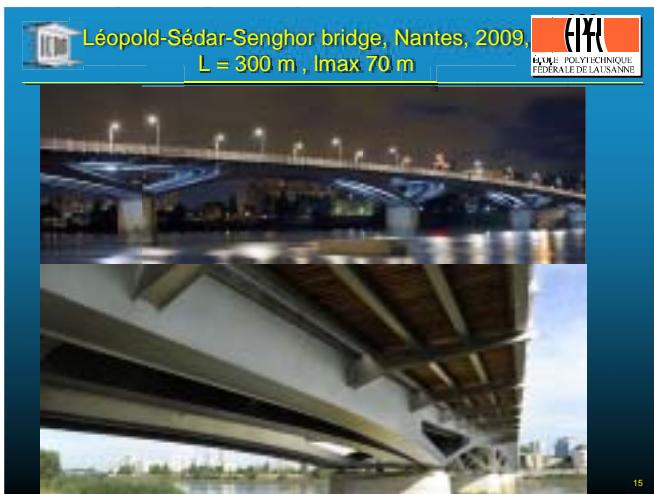
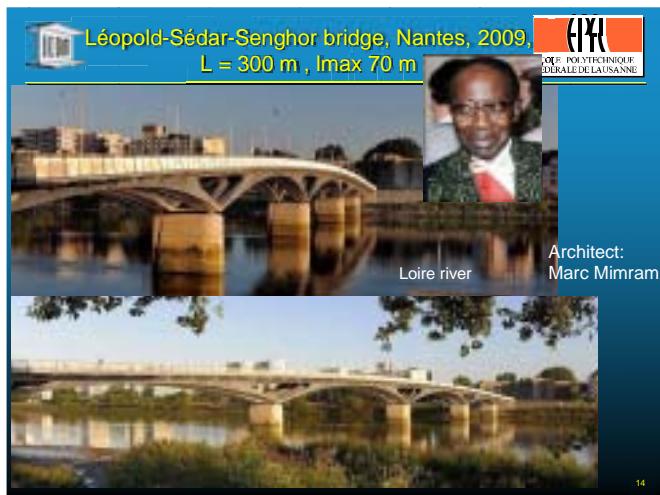
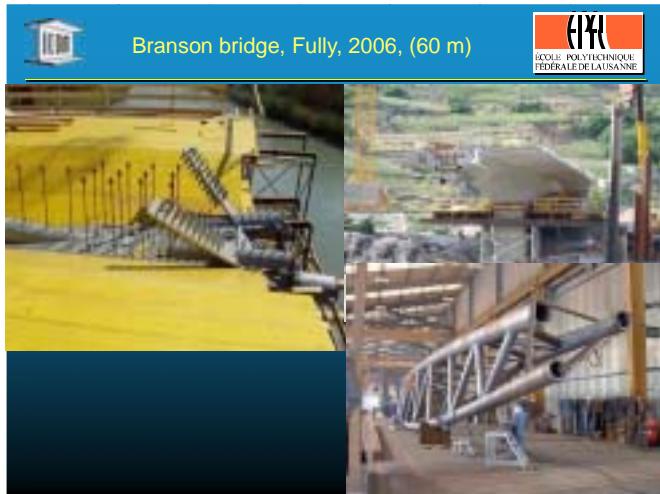
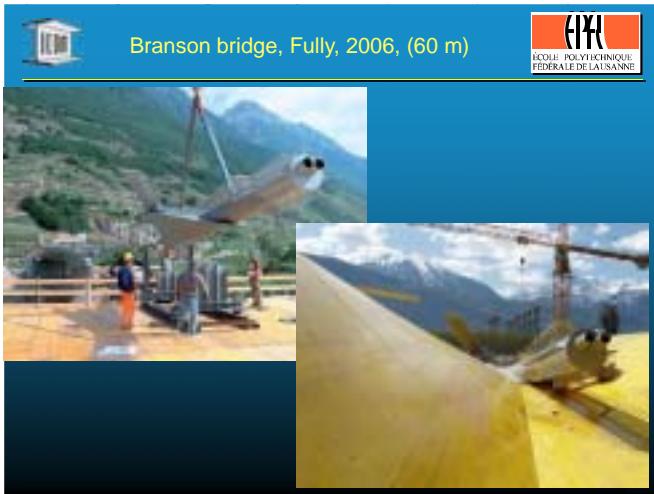
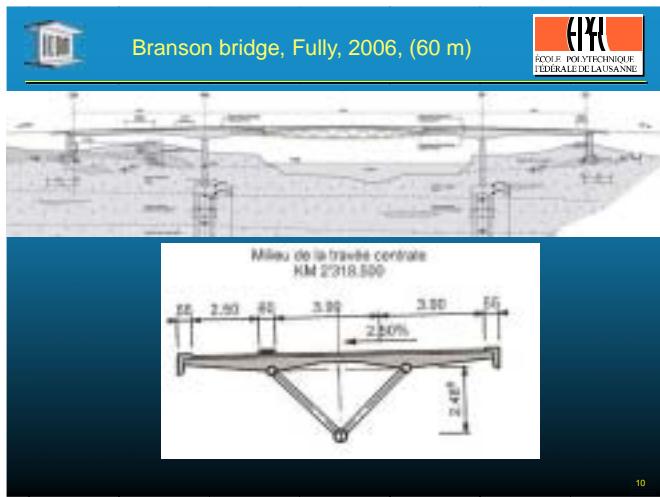
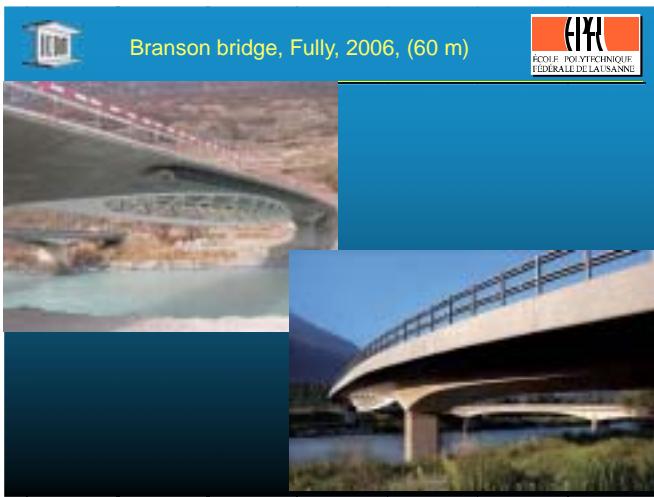


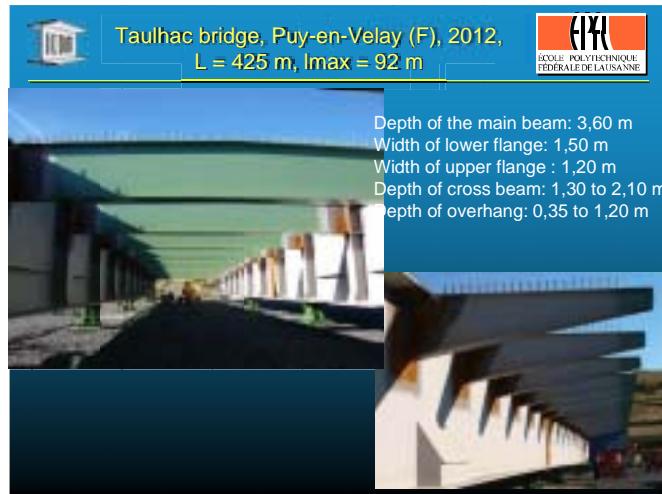
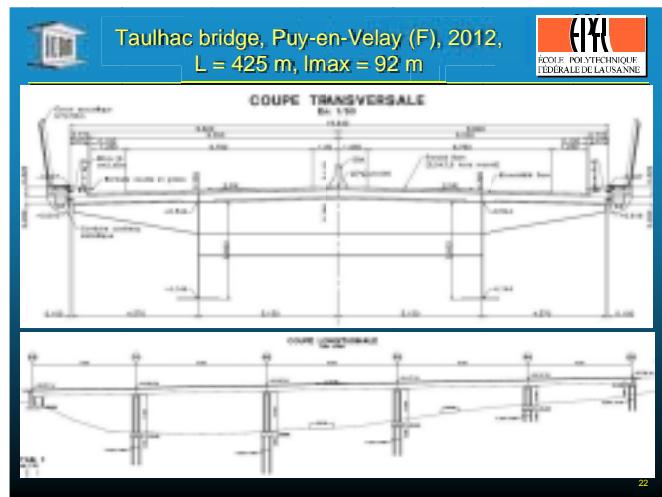
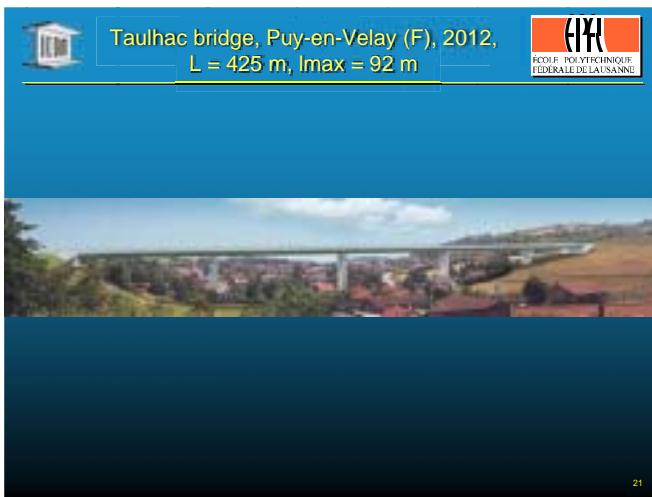
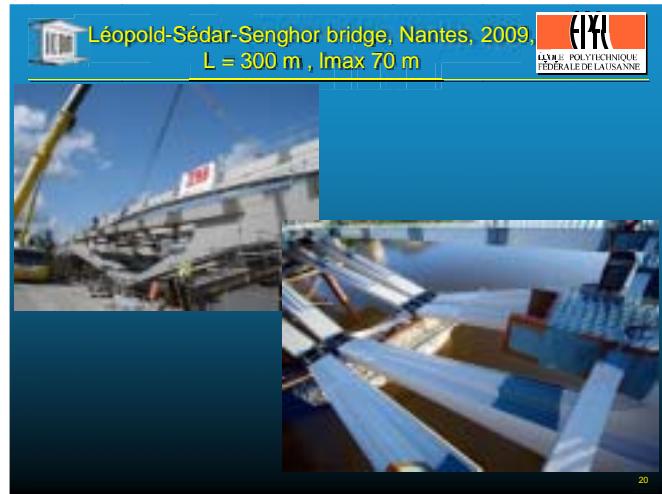
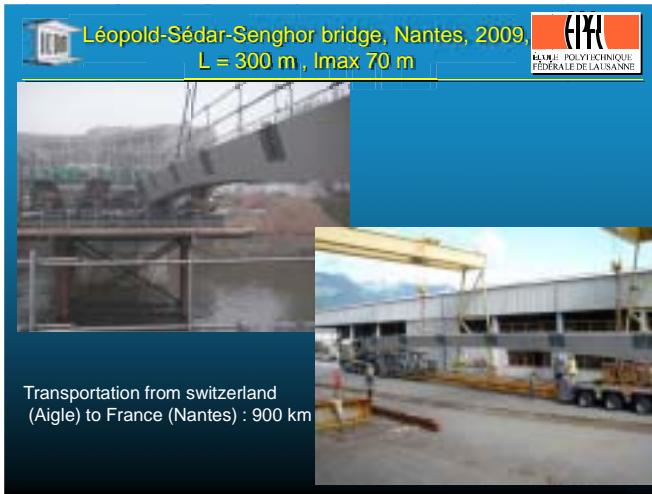
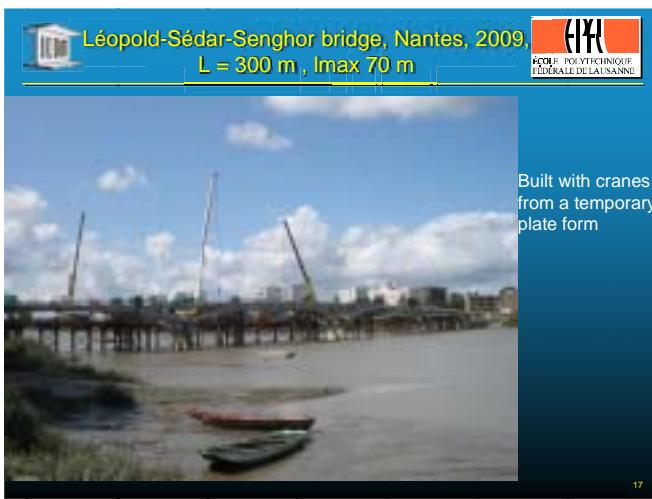
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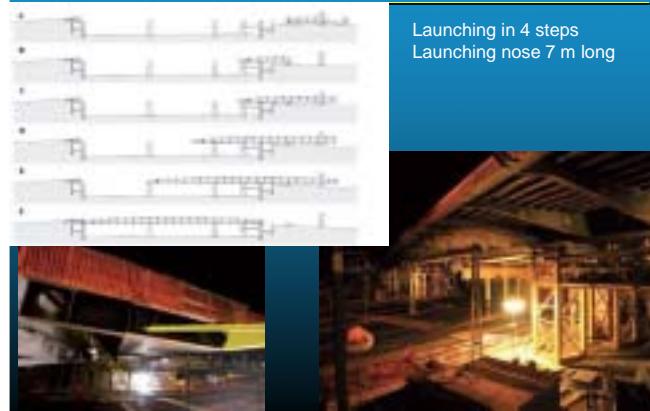
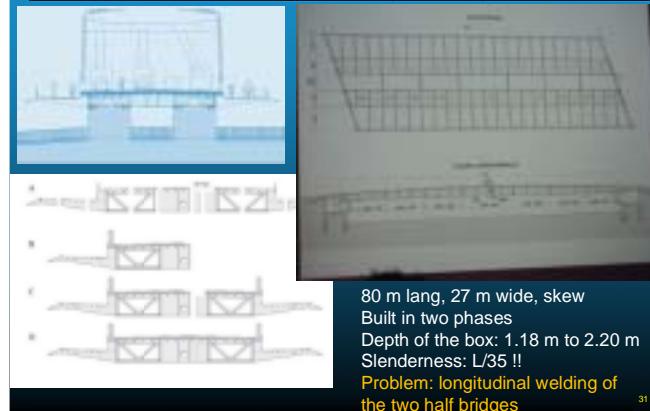
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Box section 4.5 m wide
Depth of the lower flange: 30 to 70 mm
Frame cross girders every 3.6 m

Concrete slab 24 cm depth

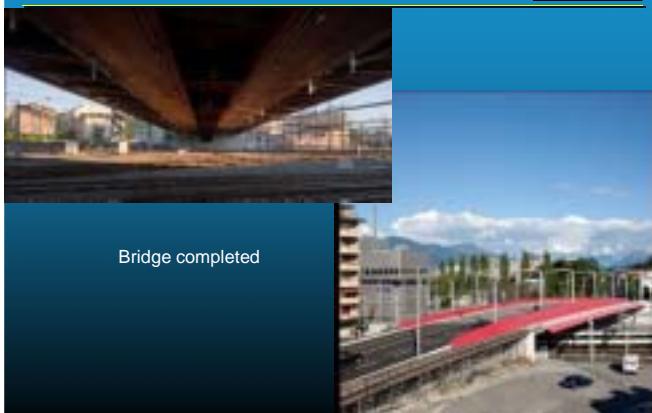
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First half bridge

Second half bridge finished

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Bridge completed

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100% paid by Rolex foundation

Architect picture



Truss-tube
composite bridge ??

Not a beam,
not a truss,
not an arch.

But the three resist

Old bridge

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Three bottom boxes
supporting a concrete slab

Two frames at the ends
of the bridge

Two upper chords

Two arches

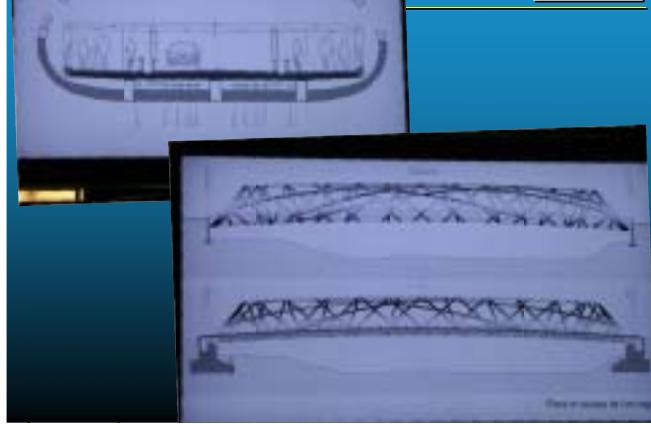
Elliptical diagonals

Curves to break
the symmetry



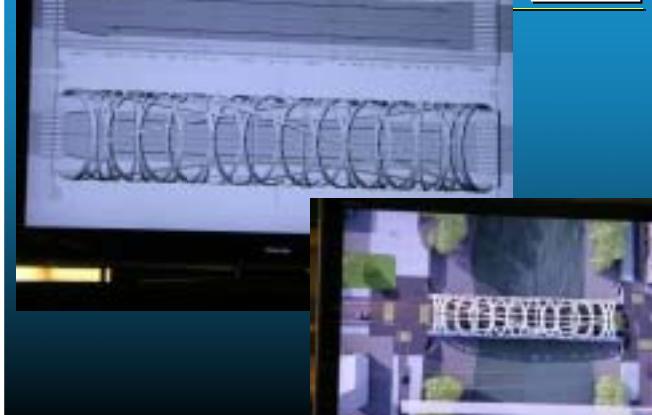
All square section tubes with thick walls -> joints welding on site!!!!

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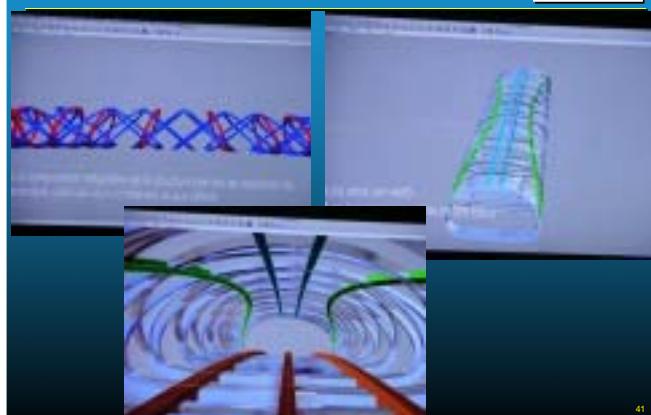


Création de la forme de l'arche

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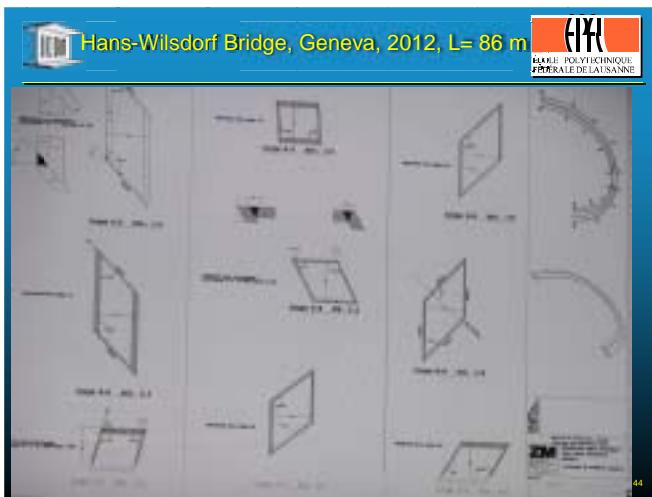
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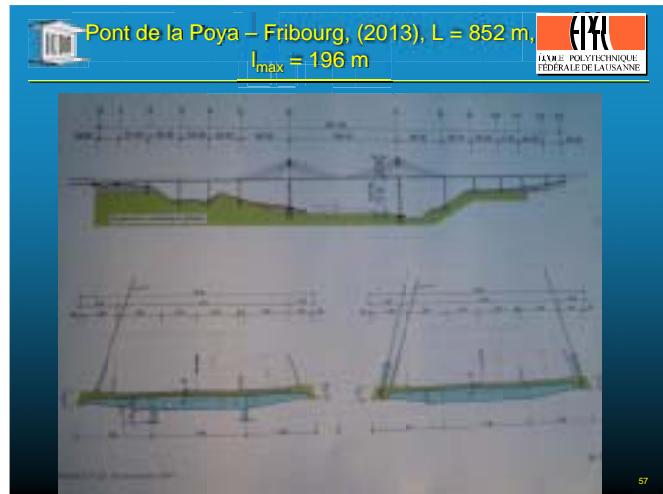


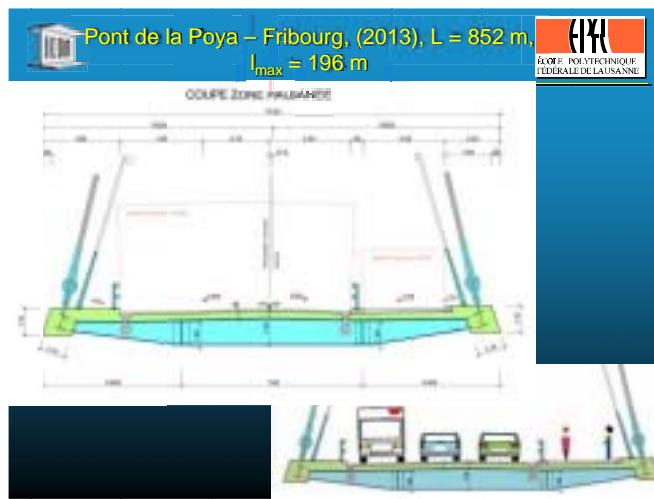
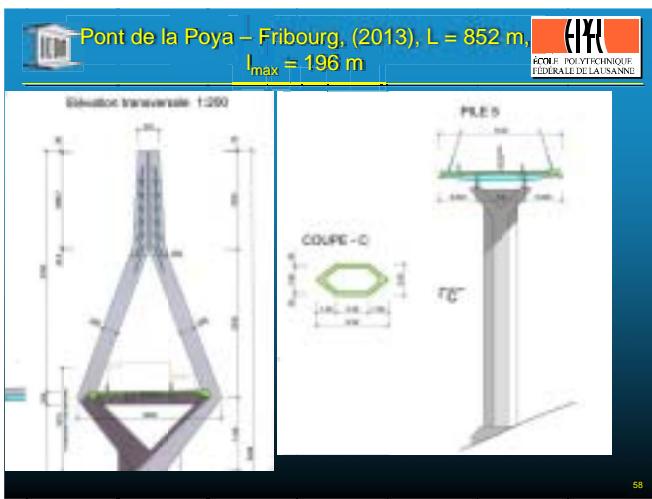
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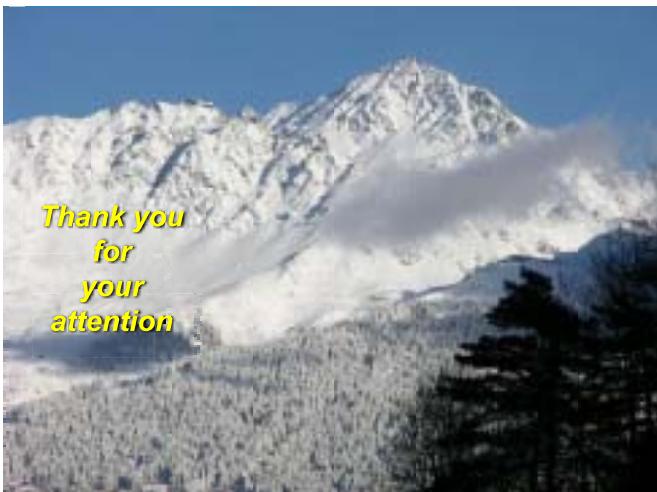


Souvenir from 2006



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Advances in composite bridge researches

research activities in bridge design at ICOM

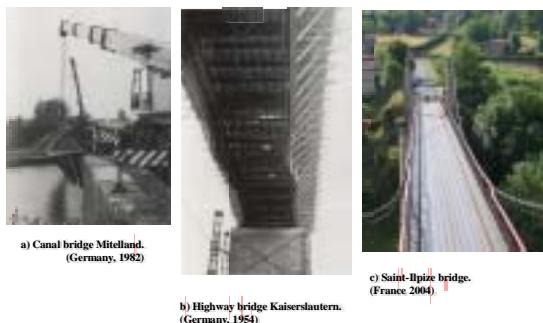
- LTB in bridge design (new research)
- New steel-concrete connection for composite bridges (ongoing)
- Innovative design method for steel-concrete composite plate girder bridges (just finished)
- Residual stress effects in tubular K-joints (ongoing)

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1



LTB in bridge design (new research)



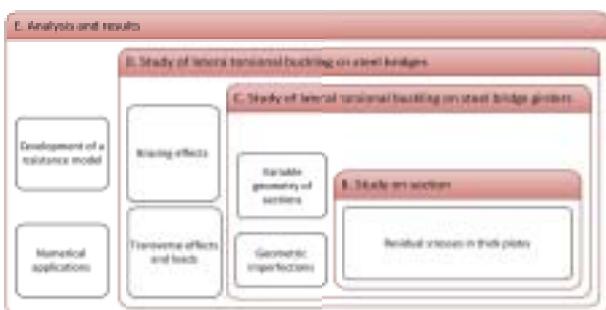
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3



LTB in bridge design (new research)

Methodology

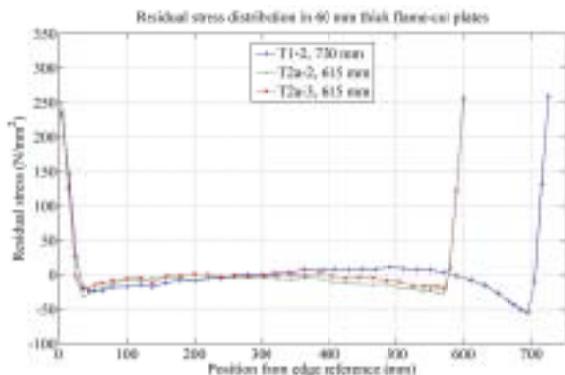


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LTB in bridge design (new research)



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7

- **Advances in composite bridge researches**
(research activities in bridge design at ICOM)

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- New steel-concrete connection for composite bridges (ongoing)
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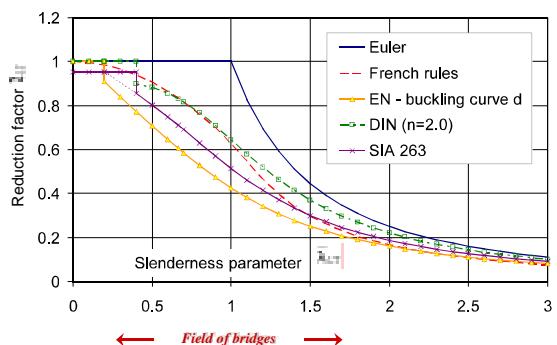
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LTB in bridge design (new research)

Different curves χ for LTB in bridges



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4

LTB in bridge design (new research)



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LTB in bridge design (new research)

- **Advances in composite bridge researches**
(research activities in bridge design at ICOM)

- LTB in bridge design (new research)
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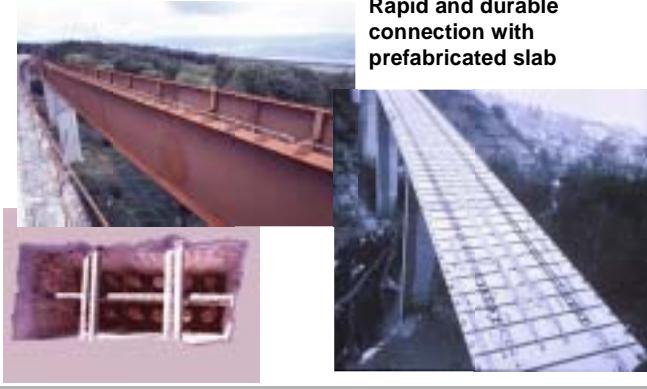
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Why search for new connections ?

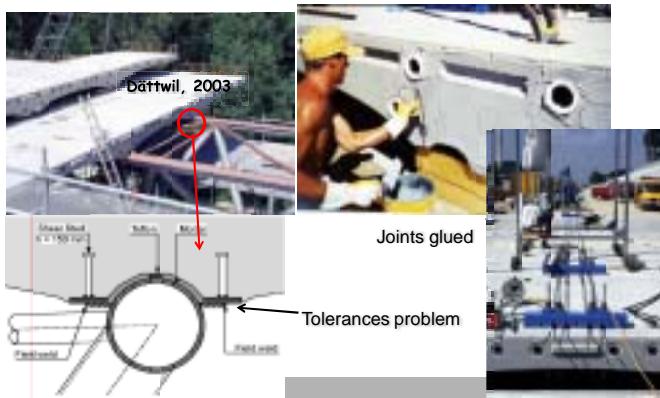
Rapid and durable connection with prefabricated slab



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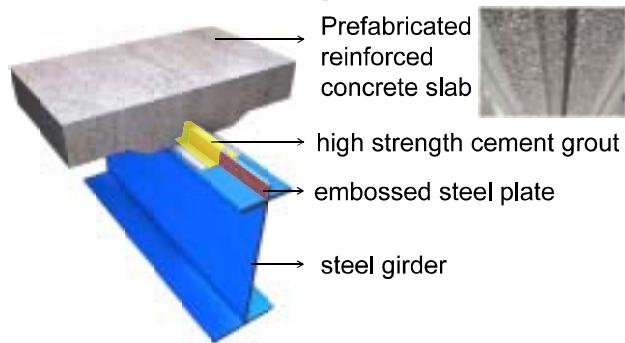
First solution: connection with field welding of two plates....tolerances problem, but for a bridge length of 215 m, only 8 month of construction...



Joints glued

10

Conception :



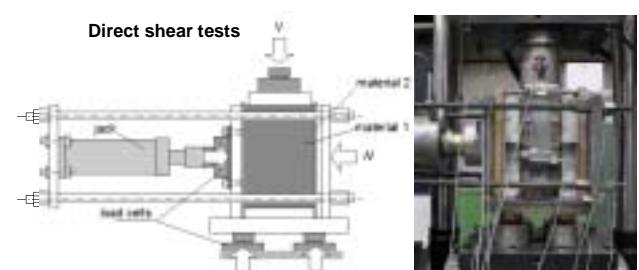
Connection resisting by adhesion, interlocking and friction

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Interfaces' behaviour

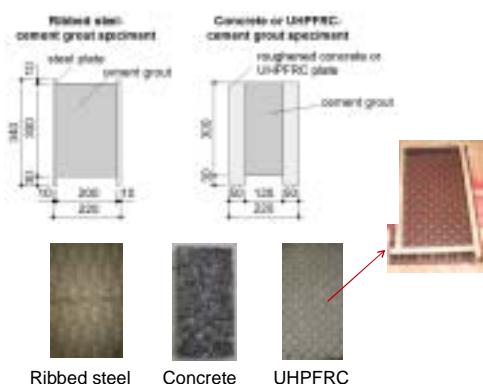
Direct shear tests



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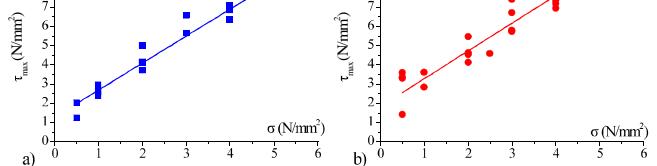
12

Interfaces' behaviour



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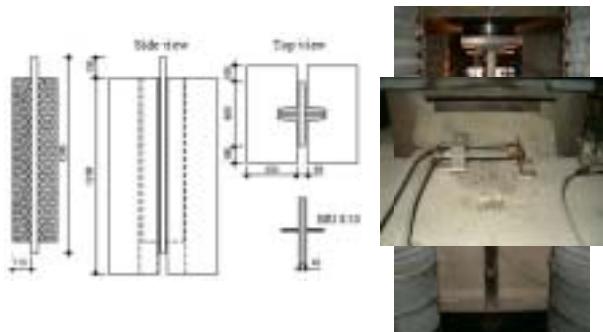


τ_{\max} versus normal stress σ - failure criteria
a) ribbed-steel cement grout interface,
b) roughened concrete cement grout interface

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push-out tests.

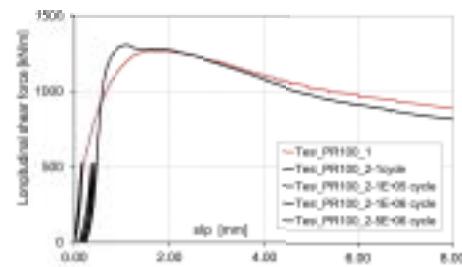


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Fatigue - Connection's behaviour

Longitudinal shear force versus slip, comparison between a fatigue and static test (push-out)



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Test of a composite beam



$P=275 (1\sin 3.14t)$ KN



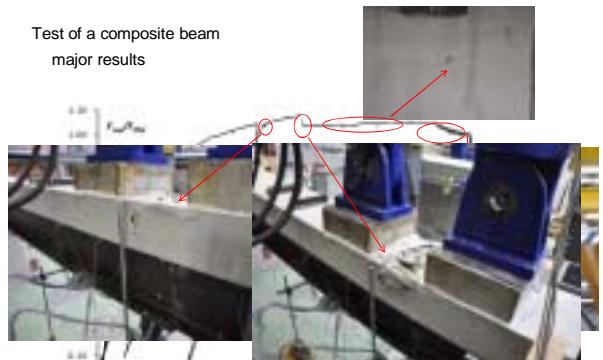
$P_{max} = 550$ KN
 $P_{min} = 140$ KN
 $V_{max} = 537$ KN/m
 $V_{min} = 137$ KN/m

2P/3 P/3

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Test of a composite beam major results



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50 m long injection test of the connection

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Conclusions

- Connection resisting by adhesion, interlocking and friction can support static and fatigue loadings with a good reliability
- Practical design rules were define
- This connection allows a rapid, safe and durable construction

• Advances in composite bridge researches (research activities in bridge design at ICOM)

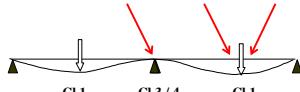
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Introduction, context

- Current analysis of steel-concrete composite bridges: EER and EE or EP



- Need to consider:
 - Loading history
 - Shrinkage and creep of concrete
- Long and tiresome calculations for an illusory precision

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• Introduction, context

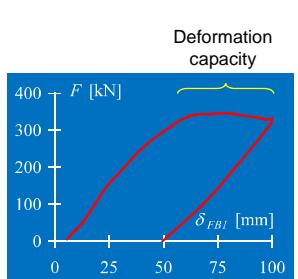
- Basis of the new design method
- Step by step procedure
- Conclusion, exemple

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Introduction, context

Under negative bending moment, slender composite beams show some deformation capacity



This deformation capacity is called
Available rotation capacity θ_{av}
of the composite beam in the support region

Basis of the new design method

- How to use the available rotation capacity over support?
 - To redistribute bending moments from supports to span
 - When span region in elasto-plastique domain, to redistribute bending moments from span to supports
 - Requires some rotation capacity from cross-sections over supports

Required rotation capacity θ_{req}

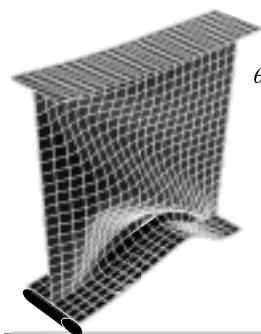
- Verification: $\theta_{req} \leq \theta_{av}$ over support

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Basis of the new design method

Available rotation capacity θ_{av}



θ_{av} is a function of:

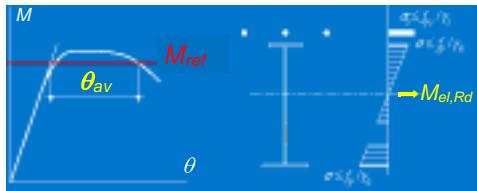
- Shear force if $V_{Ed} > 0.8 V_{Rd}$
- Slendernesses of the web and of the compressed flange
- Position of the neutral axis
- Steel grade

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Basis of the new design method

Available rotation capacity θ_{av}



$$M_{ref} = 0.9M_{el,Rd}$$

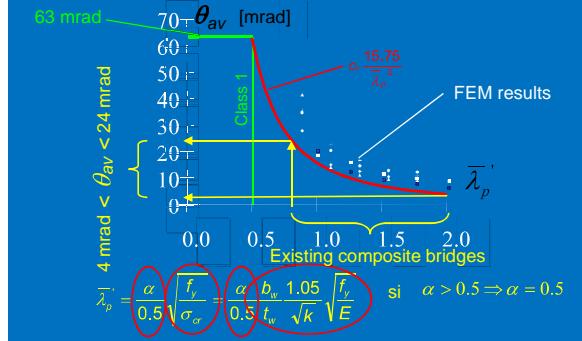
0.9 takes into account of the load history

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Basis of the new design method

Available rotation capacity θ_{av}



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Basis of the new design method

Required rotation capacity θ_{req}

$$\theta_{req} = \theta_{req,1} + \theta_{req,2}$$

$\theta_{req,1}$: redistribution of bending moments from intermediate supports to the span

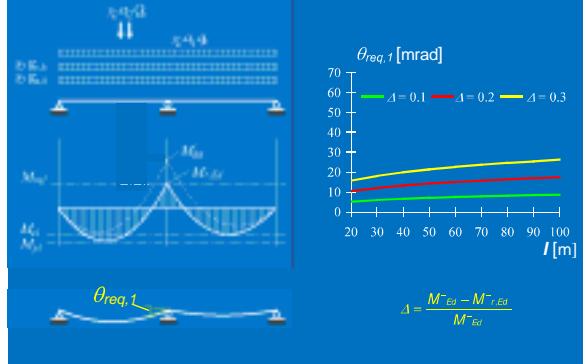
$\theta_{req,2}$: use of elasto-plastique domain in span

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Basis of the new design method

Required rotation capacity $\theta_{req,1}$

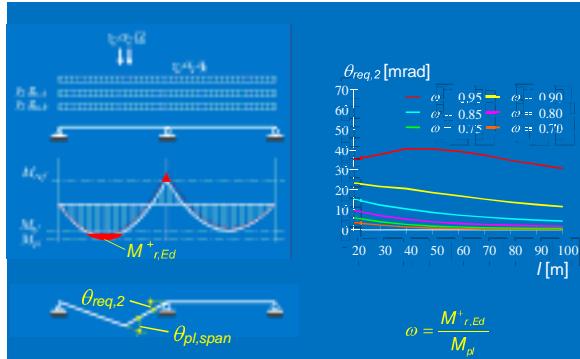


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Basis of the new design method

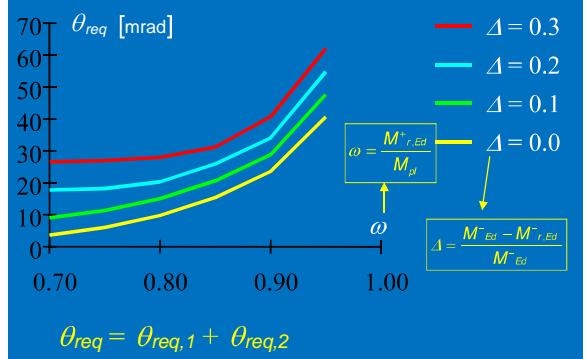
Required rotation capacity $\theta_{req,2}$



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Required rotation capacity θ_{req}



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Basis of the new design method



Existing bridges

Allow to find hidden bearing capacity
(evolution of the traffic loading)

Design method applicable with other assumptions

- Larger deflection
- Use of updated load models

Allow to take into account of longitudinal stiffeners on the web

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Step by step procedure to apply the new design method



1. PRELIMINARY DESIGN
2. PRELIMINARY CONDITIONS
3. RESISTANCE OF CROSS-SECTIONS
4. AVAILABLE ROTATION CAPACITY
5. BENDING MOMENTS
6. REQUIRED ROTATION CAPACITY
7. PLASTIC MOMENT UTILIZATION RATIO
8. VERIFICATIONS



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Step by step procedure



1. PRELIMINARY DESIGN
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Shear force:

$$V_{Ed} \leq 0.80 V_{Rd}$$

Distance between lateral supports of the compressed flange (lateral torsional buckling):

$$L_D \leq 0.225 \frac{\pi}{\sqrt{3}} b_c \sqrt{\frac{E}{f_y}}$$

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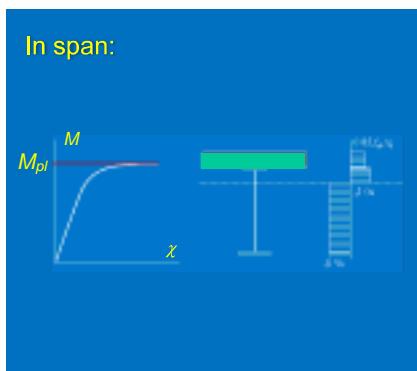
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Step by step procedure



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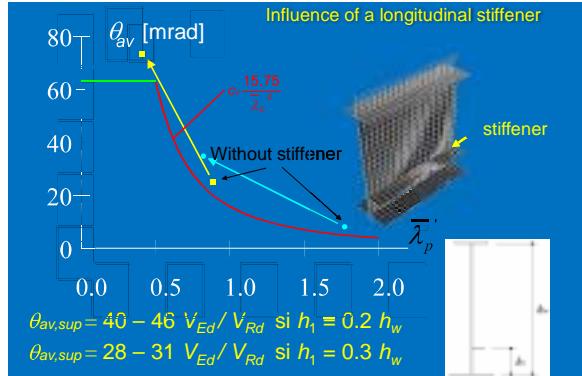
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Existing bridges



Influence of a longitudinal stiffener



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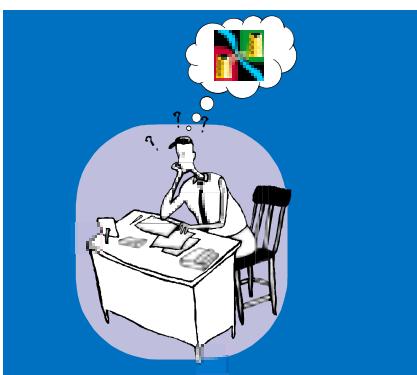
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Step by step procedure



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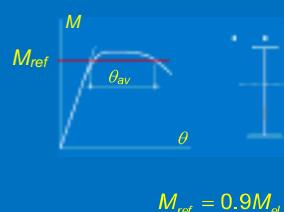


Step by step procedure



1. PRELIMINARY DESIGN
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Over support:



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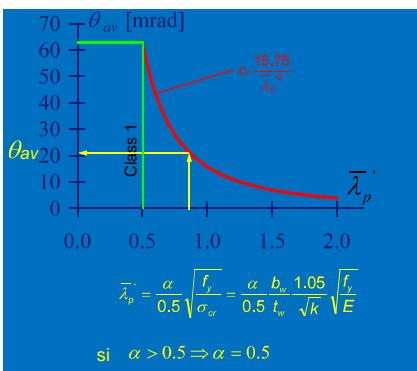
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Step by step procedure



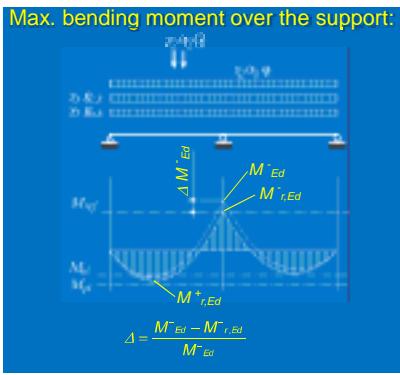
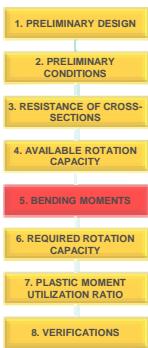
1. PRELIMINARY DESIGN
2. PRELIMINARY CONDITIONS
3. RESISTANCE OF CROSS-SECTIONS
4. AVAILABLE ROTATION CAPACITY
5. BENDING MOMENTS
6. REQUIRED ROTATION CAPACITY
7. PLASTIC MOMENT UTILIZATION RATIO
8. VERIFICATIONS



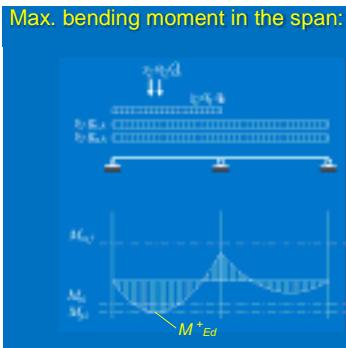
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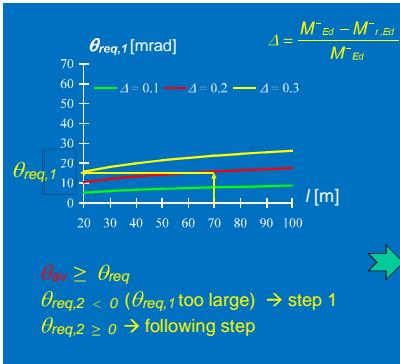
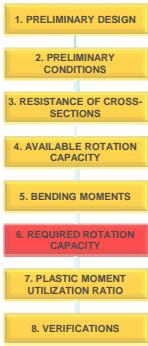
Step by step procedure



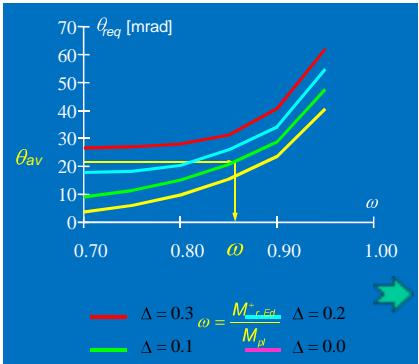
Step by step procedure



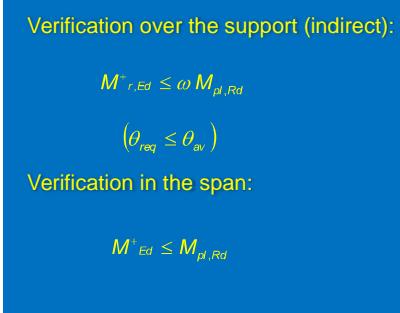
Step by step procedure



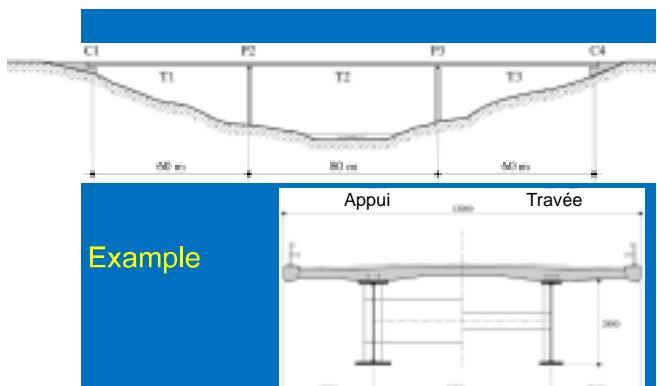
Step by step procedure



Step by step procedure



Conclusion



Conclusion

Analysis	Element	Cross-sections support	Cross-sections in span	Cross-sections area [%]	Benefit
EER, EE Support,span	Upper fl. web Lower fl.	1000x120 22x2560 1200x120	700x40 14x2700 800x60	Support : 100 Span : 100	-

The new design method makes it possible to carry out a calculation of structural safety nearer to the behaviour of the structure and more precise

The advantages which result from this are numerous and are related to the plastic design of the structures:

- The history of the loading and the visco-elastic behaviour of the concrete can be neglected at ULS
- Better optimization of the cross-sections of the beams
- Very interesting Method for the verification of the safety of existing bridges

- **Advances in composite bridge researches**
(research activities in bridge design at ICOM)

- LTB in bridge design (new research)
- New steel-concrete connection for composite bridges (ongoing)
- Innovative design method for steel-concrete composite plate girder bridges (just finished)
- **Residual stress effects in tubular K-joints (ongoing)**

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Residual stress measurements

Fatigue tests

Numerical modeling of welding

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RESIDUAL STRESS EFFECTS IN TUBULAR K-JOINTS FATIGUE CRACK GROWTH S355 AND S690

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Tubular bridges

- Challenging, modern and aesthetic bridges

Pont Branson, Suisse, 2006 Pont d'Antrenas, France, 1994 Viaduc de Lully, Suisse, 1997

Puente del Centuri, Espagne, 2000 Humboldthafenbrücke, Allemagne, 1999

- joints susceptible to fatigue loadings

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I. Residual stress measurement methods

- Neutron diffraction method (PSI, Switzerland / ILL, France)

3D in depth σ_{res}

- Hole-drilling method (home-designed for K-joints)

2D surface σ_{res}

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I. Neutron diffraction residual stress measurements (S355)

$\sigma_{\text{res, transv}} \approx f$ on the first millimeters in the weld toe vicinity

- Inter-braces restraining effect: $\sigma_{\text{res, transv}}$ remain high
- Geometry of K-joint creates high residual stresses transversely oriented and combining in fatigue with high applied stresses

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2. Fatigue tests

Principal characteristics

Specimens

CHS K-joints Steel S355/S690

Upper chord:
168.3 x 20 ou 30

Lower chord:
168.3 x 30 ou 20

Braces: 88.9 x 8

Length: 8.6 m

Height: 1.8 m

$f = 0.7 \text{ Hz}$

$Q_{\min} = 60 \text{ kN}$

$Q_{\max} = 610 \text{ kN}$

$R = 0.1$

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2. Fatigue tests: results

- Cracks in all joints: in tension or compression from hot spot Ic
- Details loaded in tension (hot spot I): crack propagation is driven by the applied stress range

Residual stresses do not affect the crack growth (tension)

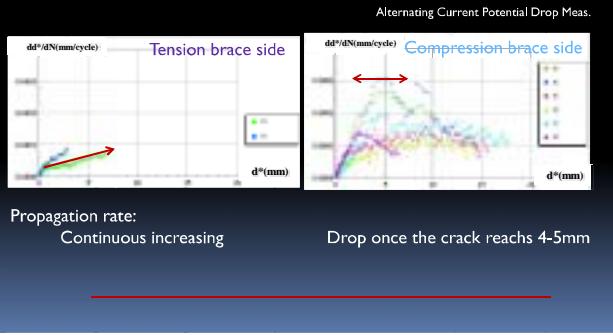
- Details loaded in compression (hot spot IIc): crack propagation is driven by tensile residual stresses ⇒ making the fatigue cycle partly or entirely effective to crack propagation

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2. Fatigue tests: results

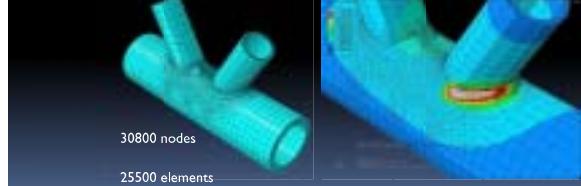
- Propagation rate decreases in joints loaded in compression after approx. 5mm depth : through thickness crack occurs first in joints loaded in tension



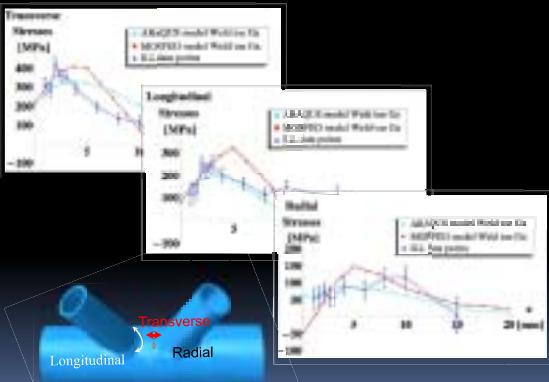
Propagation rate:
Continuous increasing
Drop once the crack reaches 4-5mm

3. Numerical model

- 3D FEM model
- Uncoupled thermo-mechanical analysis
- 3D torch trajectory moving from the crown heel to the crown toe
- Single pass
- Analysis programs: Abaqus, Morfeo



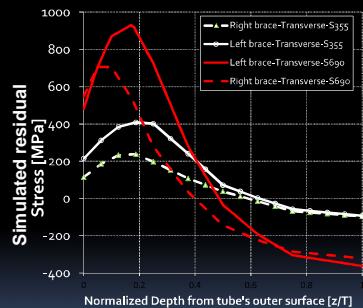
3. Residual stress profiles



Longitudinal Transverse Radial

Transverse
Longitudinal
Radial

3. S355 and S690



Transverse direction



$T=20\text{mm}$

Conclusion

Influence of residual stresses in case of stable crack propagation

- Welding induces high tensile residual stresses, critically oriented (transversally) in bridge K-joints
- Tensile residual stresses lead to similar fatigue crack growth in tubular joints loaded in tension and compression
- 3D thermo-mechanical FE model can predict the 3D residual stress field for steel grade S355 and S690

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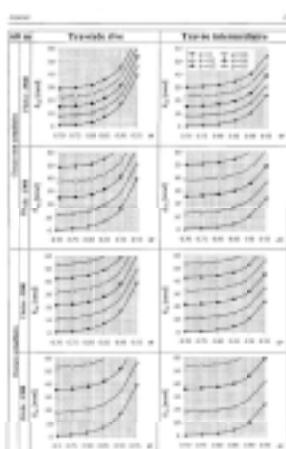
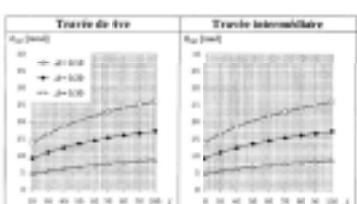


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Table 1: Capacité de rotation résiduelle $\Delta \theta_{res}$ et capacité de rotation initiale $\Delta \theta_{init}$ pour les matériaux REHUF									
$\Delta \theta_{init} (\text{rad}) = \text{Capacité de rotation initiale}$ ($\Delta \theta_{init}$) pour une épaisseur donnée (t)									
1[m]	20	40	60	80	100	120	140	160	180
$\Delta \theta_{init}$ (rad)	4.6	4.1	4.2	4.8	7.5	7.7	8.8	10.4	10.7
$\Delta \theta_{res}$ (rad)	9.2	11.9	12.4	13.6	18.8	19.6	20.2	21.7	21.8
$\Delta \theta_{res}/\Delta \theta_{init}$	1.9	2.3	2.4	2.6	2.4	2.4	2.2	2.0	2.0
$\Delta \theta_{res}$ (rad)	13.8	14.0	16.6	20.3	32.8	33	34.3	38.1	38.8



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