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Joint Committee
on Structural Safety

Lessons Learnt Assessing Structures in the Last 30 Years

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Workshop on Assessment of
Existing Structures
28th and 29th January 2021

École
polytechnique
fédérale
de Lausanne

EPFL

Muttoni et Fernández
INGÉNIEURS CONSEILS SA

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Approximations and uncertainties in design, verification and assessment

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- Calculations of internal forces and local resistances are based on models which are an approximation (simplification) of reality. Depending on the needs, different Levels of Approximation (LoA) can be suitable.
- Actions, geometrical values and strengths of materials are based on (i) previous measurements (defined in codes); (ii) new measurements or (iii) specifications (e.g. material grades, drawings…). They can have very different Levels of Knowledge (LoK).
- Different LoA and LoK have different levels of uncertainties. Increasing their accuracy requires variable amounts of work.

Approximations and uncertainties in design, verification and assessment

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- Variability of **actions** *) — LoK
- Approximations in modelling actions (e.g. spatial distr.) — LoA
- Approximations in the probability model — LoA

→ γ_f

- Approximations in **modelling the structure** — LoA
- Uncertainties related to the structure — LoK
- Approximations in modelling the behaviour — LoA
- Uncertainties related to structural behaviour — LoK
- Approximations in "**safety formats**" and "methods" — LoA

→ γ_{Sd}

γ_f, γ_{Sd} → γ_F

- Model uncertainties related to local resistance — LoA
- Geometrical variability influencing **local resistance** — LoK
- Variability of material strengths *) — LoK

→ γ_M

*) magnitude and spatial distribution for actions and concrete strength

Example: assessment of an existing soil-covered parking garage

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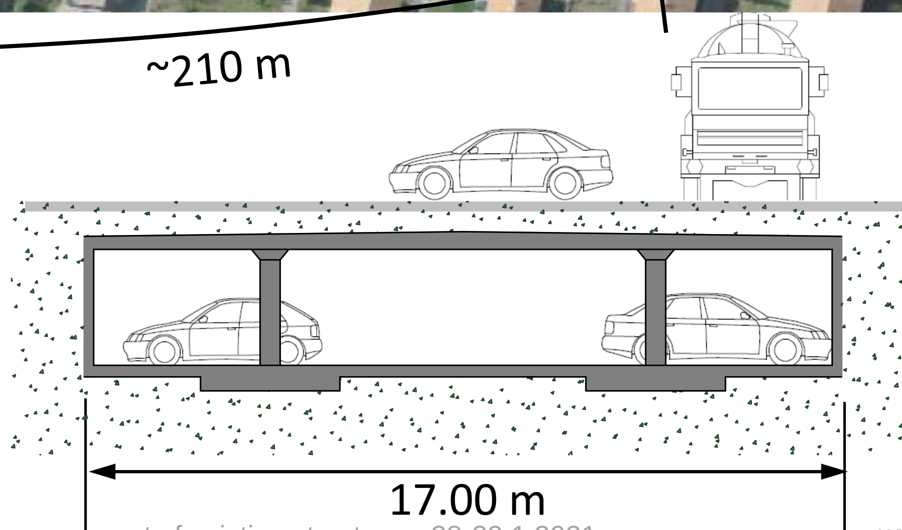
Parking cross section



Example: assessment of an existing soil-covered parking garage

- Structure erected in 2008
- Cast in-situ continuous flat slab (without joints) on precast columns with capitals
- No integrity reinforcement, but with shear reinforcement
- Neighbourhood **street without particular load limitation over the deck**

Example: assessment of an existing soil-covered parking garage

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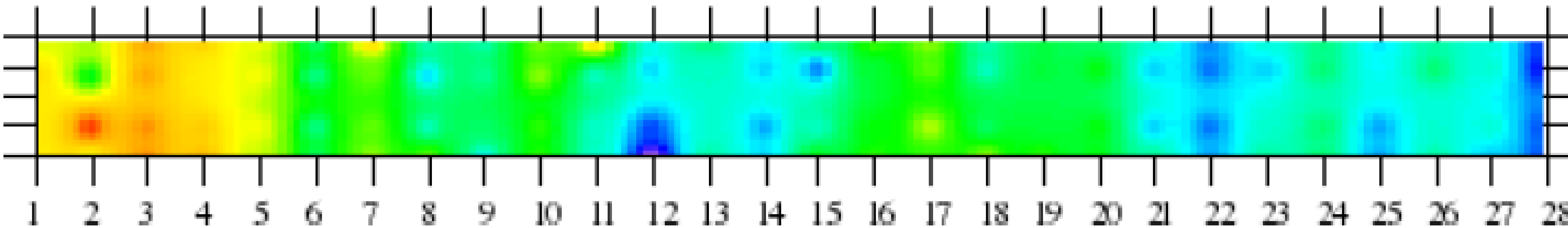
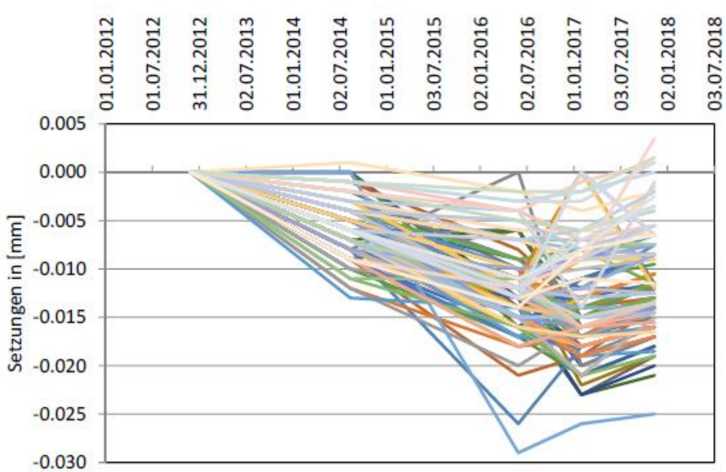
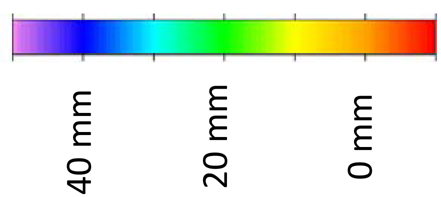
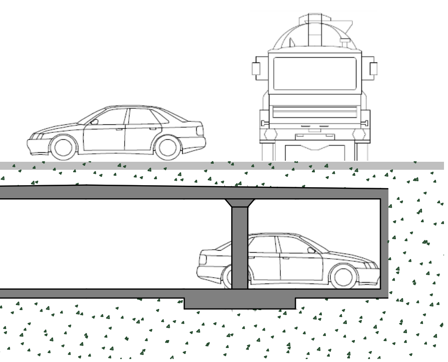
- Structure erected in 2008
- Cast in-situ continuous flat slab (without joints) on precast columns with capitals
- No integrity reinforcement, but with shear reinforcement
- Neighbourhood street without particular load limitation over the deck
- Quite significant **differential settlements** since construction, leading to **extensive cracking**









Example: assessment of an existing soil-covered parking garage

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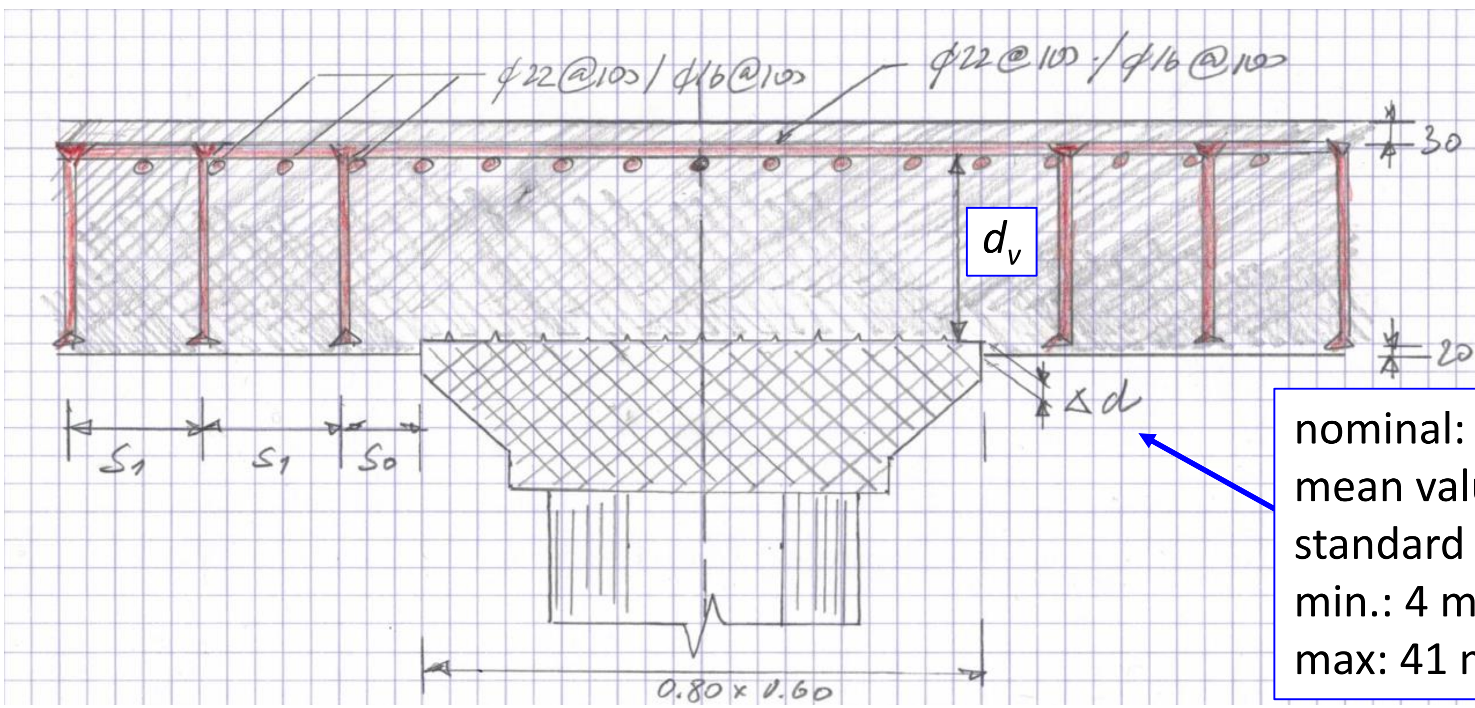
- Quite significant differential settlements since construction, leading to extensive cracking
- **Slightly inaccurate construction** (position of precast capital, representing the supporting area, with respect to slab soffit)



nominal: 20 mm
mean value: 21 mm
standard dev.: 9.6 mm
min.: 4 mm
max: 41 mm

Some similarities with similar collapsed structures

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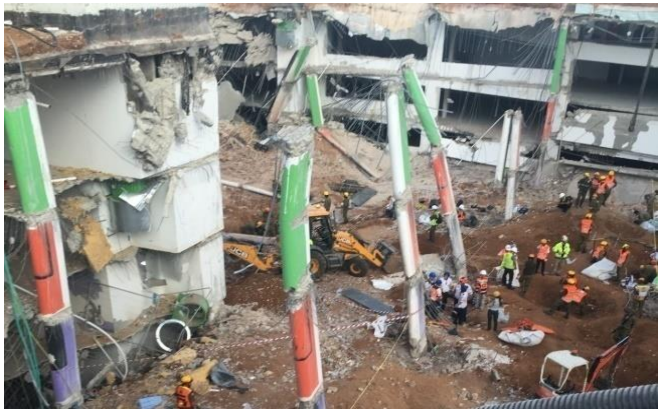
Bluche (VS), Switzerland, 1981

Vitoria, Brazil, 2016

Santander, Spain, 2020



Tel Aviv, Israel, 2016

In all these cases, total collapse initiated by punching of one column

Some similarities with similar collapsed structures

Collapse of parking garage at Gretzenbach, Switzerland (November 2004)

- 7 casualties (firemen trying to extinguish a car fire inside the garage lost their lives)
- Total collapse of a soil-covered flat slab due to initial punching of one column and progressive collapse
- Consequence of several causes

(study for the investigating judge by A. Muttoni, A. Fürst and F. Hunkeler)

Causes of the Gretzenbach collapse

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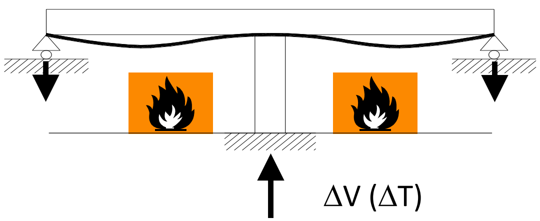
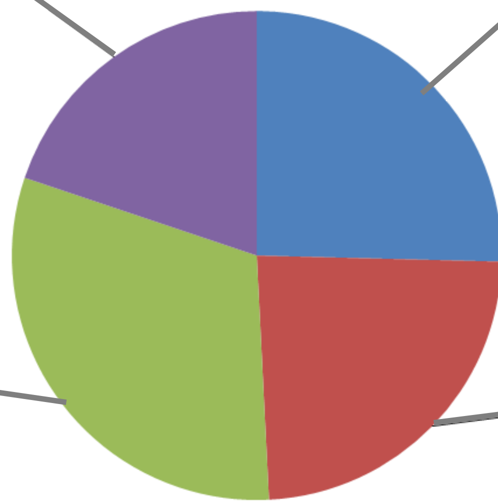
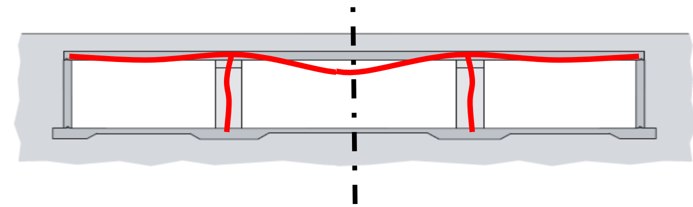
- Calculated punching shear resistance according to the most advanced model (MC2010 LoA IV), measured geometries and properties = 100%
- Estimated acting shear force just before collapse: 96%
- Calculated shear resistance of a correctly designed, executed and loaded structure: 232%

4) **Accidental action:** Car fire (imposed deformation) 1.11·1.08 / 0.96 -1.00 = 25%

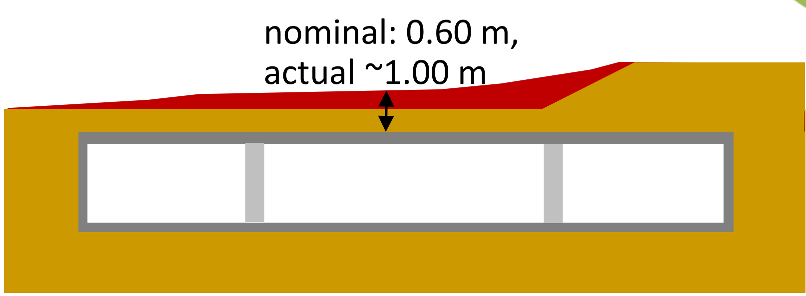




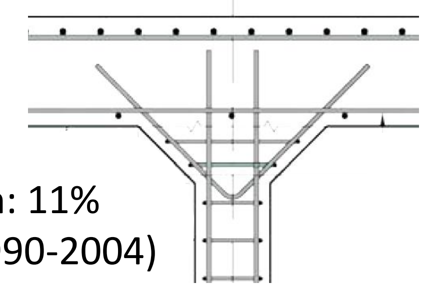
1) **Too large approximations in design** (e.g. influence of different spans to eccentric punching underestimated) 2.32 / 1.75 -1.00 = 33%



3) Error in **permanent load**: soil cover (0.60 assumed, actual thickness ~1.00 m) 1.11·1.35 / 1.08 -1.00 = 39%



2) **Too large execution errors** (capital too high with respect to slab soffit and hogging reinforcement too low, leading to a reduction of the shear resisting effective depth) 1.75 / 1.35 -1.00 = 30%



- Shear strength increase due to continued cement hydration: 11% between 2) and 3) (1989-1990); 11% between 3) and 4) (1990-2004)

Approximations and uncertainties in the 1st verification of the soil-covered garage to be assessed

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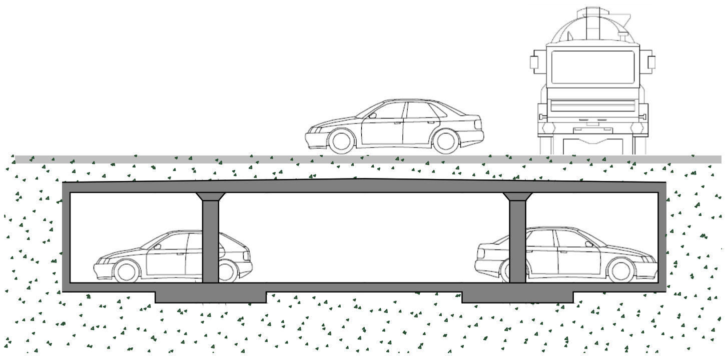

- **Weight of soil cover** and other permanent loads (LoK)
  1. *Same assumptions as for design (γ_G = 1.35)*
- **Traffic load** (LoK)
  1. *Same assumptions as for design (SIA 261)*
- **Differential settlements** (magnitude and evolution) (LoK)
  1. *as for design (neglected)*
- Structural behaviour (**influence of modelling on column forces**) (LoA)
  1. *same as for design (FEM, elastic, uncracked)*
- **Model uncertainties** in calculating the punching shear **resistance** (LoA)
  1. *same as for design (SIA 262 ~ MC2010 LoAII)*
- **Geometrical variability** influencing **local resistance** (variability of effective depth) (LoK)
  1. *nominal values*
- **Variability of concrete strengths** (LoK)
  1. *specified concrete grade*

Swiss codes for existing structures

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- EN 1990 — SIA 462:1994 — SIA 269:2011 ← Allows reducing γ_G to 1.20 in case the permanent actions are assessed
- EN 1991 — SIA 269/1:2011 ← Allows reducing the traffic loads
- EN 1992 — SIA 162/5:1997 — SIA 269/2:2011 ← Defines some rules how to use LoAIV for shear and punching (allows considering membrane effects and redistribution due to cracking/yielding)
- EN 1993 — SIA 269/3:2011
- EN 1994 — SIA 269/4:2011
- EN 1995 — SIA 269/5:2011
- EN 1996 — SIA 269/6.1:2011 / SIA 269/6.2:2014
- EN 1997 — SIA 269/7:2011
- EN 1998 — SIA 2018:2004 — SIA 269/8:2017

Sensitivity of the punching shear resistance

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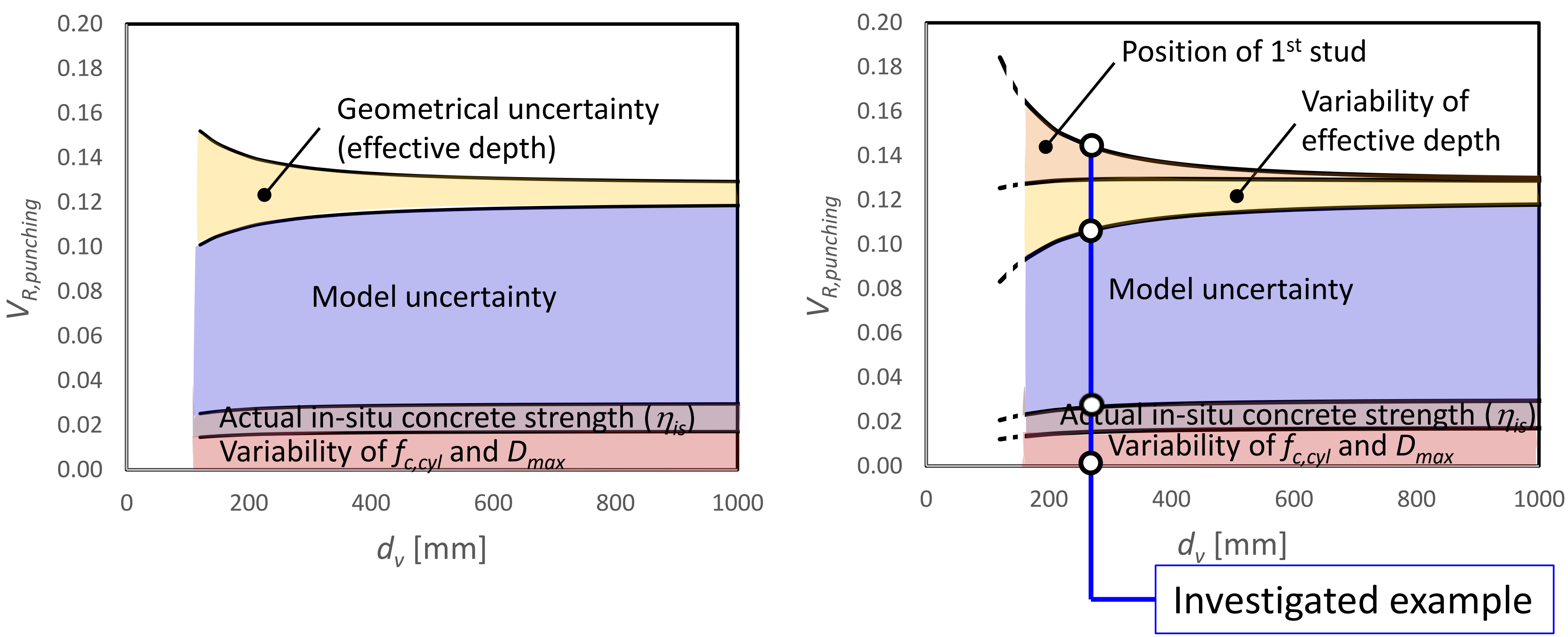
Contributions to total coefficient of variation of punching shear resistance (prEN 1992-1-1:2020) as a function of the effective depth

Slabs without shear reinforcement

slabs with shear reinforcement



Influence of Levels of Approximation and of differential settlements

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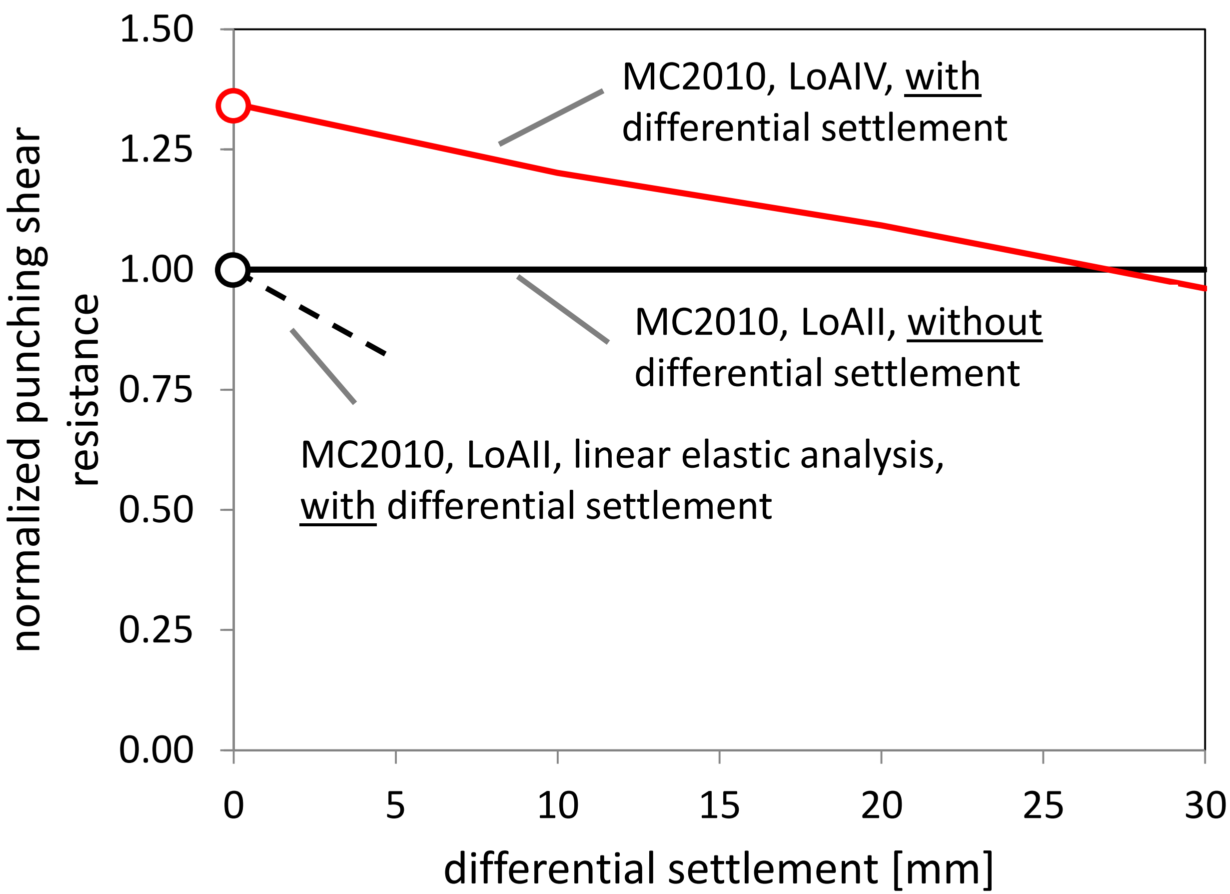

Assumption: all surrounding supports settle more than the investigated column

Increased levels of knowledge and of approximation in more refined verifications

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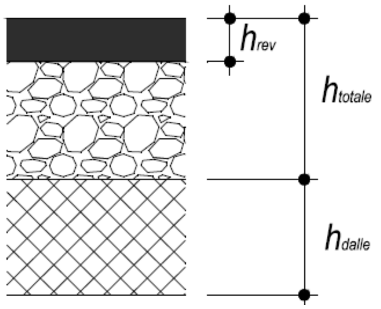

- **Weight of soil cover** and other permanent loads (LoK)
  1. Same assumptions as for design (γ_G = 1.35) -> 2. measured thicknesses, spatial variability considered explicitly (γ_G = 1.20)
- **Traffic load** (LoK)
  1. Same assumptions as for design (SIA 261) -> 2. adjusted values (SIA 269/1)
- **Differential settlements** (magnitude and evolution) (LoK)
  1. as for design (neglected) -> 3. based on measurements
- Structural behaviour (**influence of modelling on column forces**) (LoA)
  1. same as for design (FEM, elastic, uncracked) -> 3. nonlinear shell analysis
- **Model uncertainties** in calculating the punching shear **resistance** (LoA)
  1. same as for design (SIA 262 ~ MC2010 LoAII) -> 3. MC2010 LoAIV
- **Geometrical variability** influencing local resistance (variability of effective depth) (LoK)
  1. nominal values -> 5. measured values of capital position
- **Variability of concrete strengths** (LoK)
  1. specified concrete grade -> 2. measured concrete strength ("some" cores according to EN 13791)

Increased levels of knowledge and of approximation in more refined verifications

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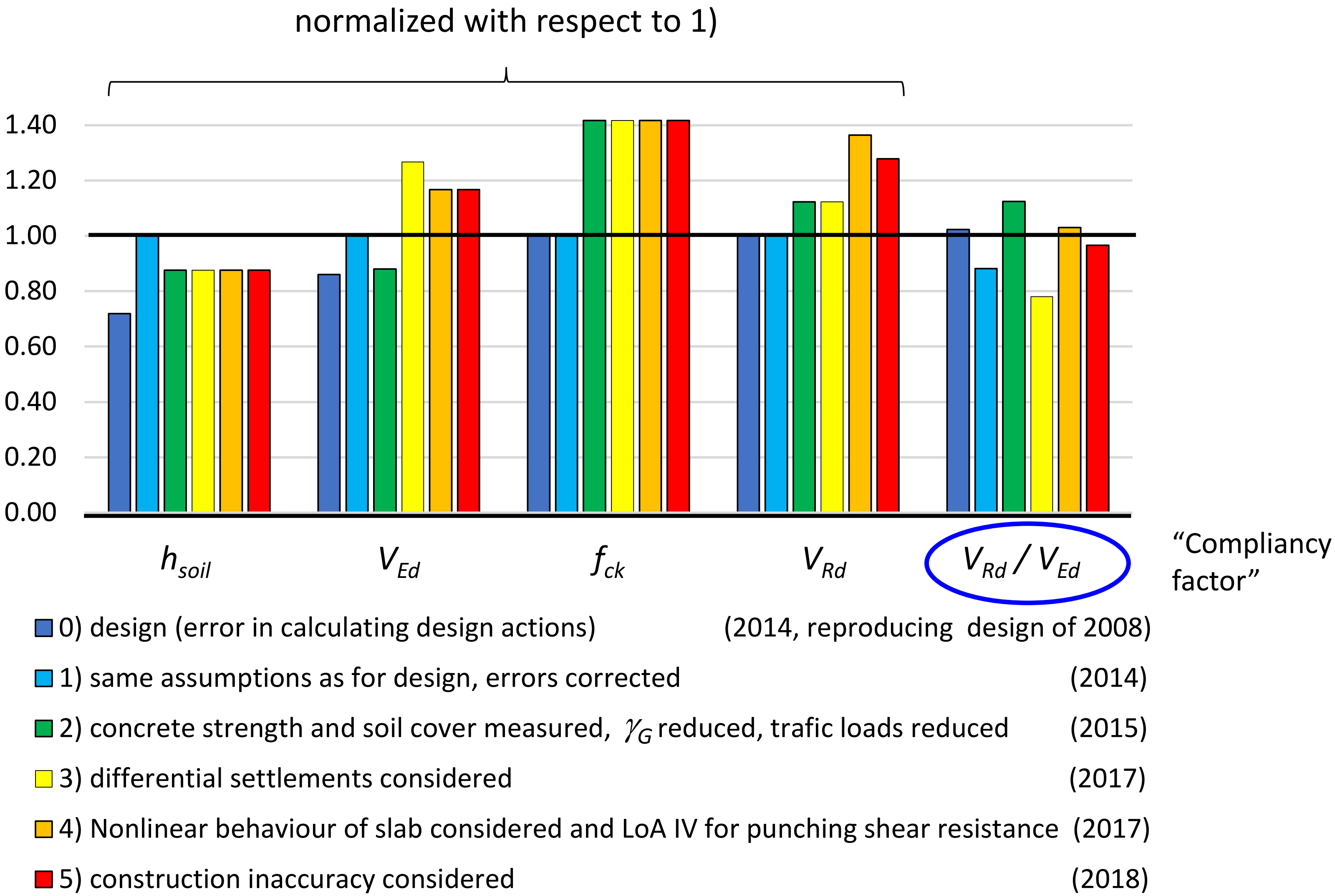

Interventions

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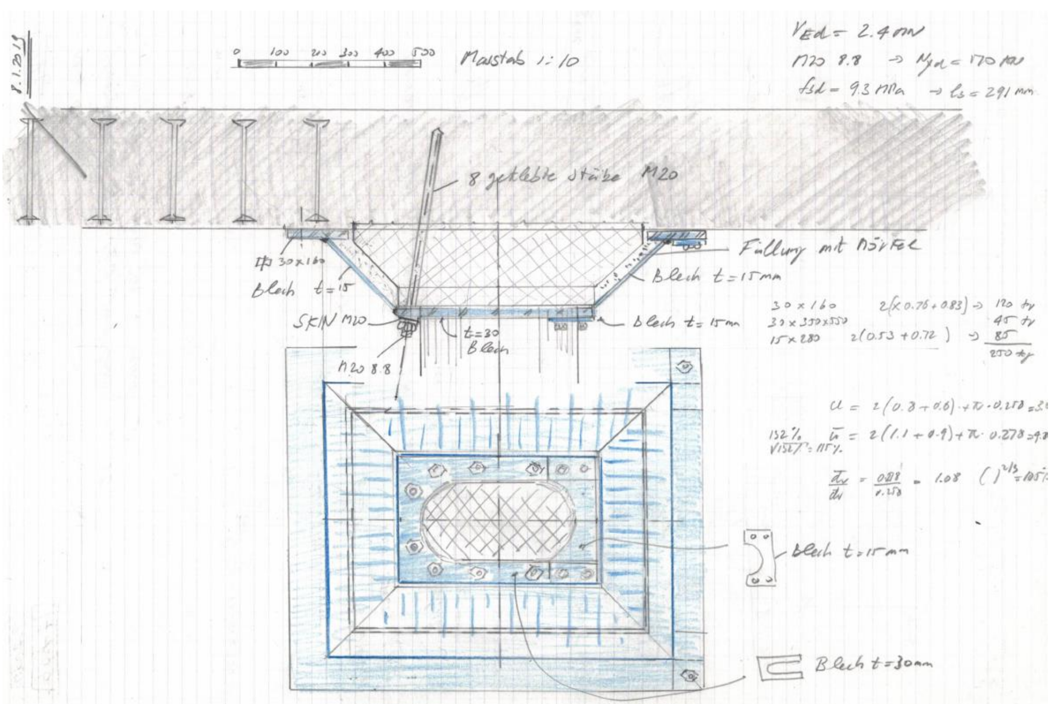
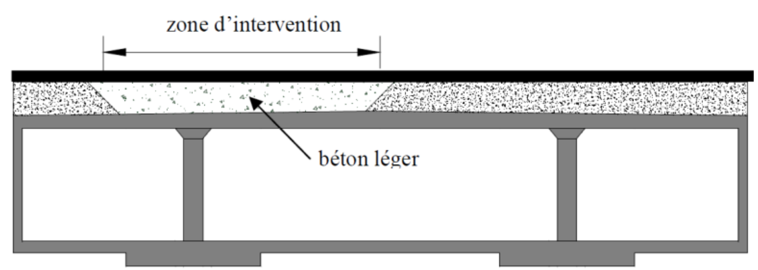
12 out of 50 columns have an insufficient compliance ratio (V_{Rd} / V_{Ed} < 1)
$\Rightarrow$ For those columns, an intervention is required

Investigated options:

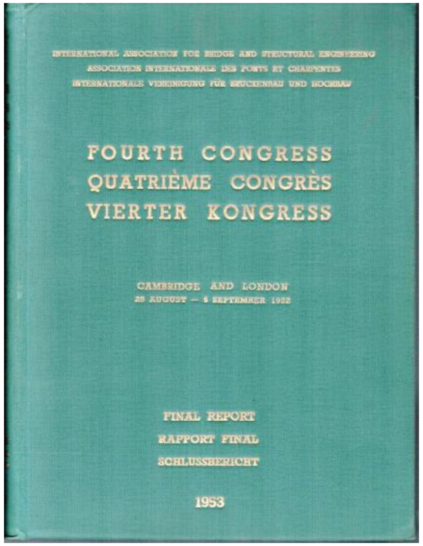


Increase of V_{Rd}
with steel collars around the capitals



Reduction of V_{Ed}
by partially replacing soil with very light concrete (220 kg/m^3)

Conclusions: “partial safety factors” or “probabilistic methods” ?



- The “partial safety factors” approach based on FORM can also be conducted with different LoAs, where at the highest levels (updated characteristic values and adjusted partial safety factors, considering refined β_{tgt} values, updated statistical values, refined α-values…), similar refinement levels as with (full) probabilistic methods can be achieved.

For common cases, I personally prefer it mainly for practical reasons, since it allows for:

- a smooth transition from well-known procedures, commonly used in practice for design, to increasingly more refined verifications, and
- a simple and understandable communication with all engineers involved in the verification and in the decisions.

“Considering the so-called «safety factors» or «partial safety factors,» the author points out that, for equal safety, they are neither constant for a given type of structure, nor transferable from one type to another, and finally that they differ greatly according to the definition adopted. The probability method, on the contrary, leads to the definition of the permissible moments by means of safety formulae as explicit functions of the various characteristics”

R. Lévi, 4th IABSE Congress, 1952

Research needs / possible developments of future codes on assessment from the perspective of practicing engineers

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- The **difference between "brittle" and "ductile" behaviour** (different levels of ratios between deformation capacity and deformation demand) is often not sufficiently accounted for in assessment. With this respect, some subthemes deserve to be studied and potentially implemented in codes:

  - influence (and uncertainties) of imposed deformations for brittle failure modes

  - β_{tgt} (should be) defined accounting for the presence or not of warning signs

  - model uncertainties related to the calculation of internal forces are significant for brittle failures, but play a minor role in case of sufficient deformation capacity (part of γ_{Sd} potentially to be moved to the partial safety factors for materials?)

- The role of **"human errors"** needs perhaps to be reconsidered: there is a smooth transition between (i) "significant human errors", (ii) "less significant human errors", (iii) "unacceptable approximations" and (iv) "acceptable approximations". Accidents are almost always a combination of them.

  Human errors and unacceptable approximations are possible not only in design, but **also in assessment**. How to reduce the probability that they occur?

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