

# Richtlijnen niet-lineaire analyses voor balkconstructies

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## Richtlijnen voor niet-lineaire analyses

- Project TU Delft in opdracht van RWS
- Voorlopig alleen voor balkconstructies
- Auteurs:
  - Peter Feenstra
  - Max Hendriks
  - Beatrice Belletti
  - Cecilia Damoni
- Advies, review:
  - Jan Rots
  - Ane de Boer

## Doelen van de richtlijn

**Beperk** de **gebruikersfactor** en **modelfactor** in NL-FEM

**Beperk** het **werk van de FEM-gebruikers**:

bij het verantwoorden van NL-FEM keuzes.

**Beperk** het **werk van reviewers**:

door ook richtlijnen te geven over het **rapporteren** van NL-FEM-analyses

## Grootste uitdaging

Het maken van een **adequate keuze** uit een veelheid van **NL-FEM opties**:

- Element typen, • Materiaalmodellen, • Randvoorwaarden,
- Materiaalparameters, • Convergentienormen, • Scheurwijdtes,
- Belastingen, etc. etc.

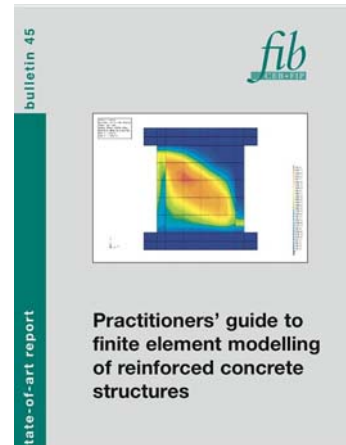
Aantonen dat dit leidt tot **veilige voorspellingen**,

waarbij **reserves** voldoende worden **uitgenut**.

## Bestaat dit al?

**fib** Practitioners' guide  
to finite element modelling  
of reinforced concrete  
structures (June 2008)

**aci** ...  
**jci** ...



## Aanpak (1 van 2)

Versie 0 gebaseerd op:

- Wetenschappelijk onderzoek,
- Algemene consensus onder experts,
- Ervaring
  
- Bruikbaarheid van de opties
- Beschikbaarheid van de opties

## Aanpak (2 van 2)

**Benchmarken** van de richtlijnen aan de hand van case studies:

- Balken
  - Gewapend,
  - Voorgespannen,
  - Nagespannen
- (Platen)



### Benchmarks (gewapend)

**RB1** → **Bending failure (F)**

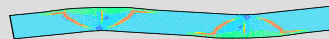


**Crack pattern at failure**



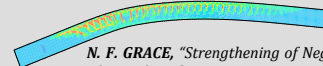
**F. J. VECCHIO, W. SHIM**, "Experimental and Analytical Reexamination of Classic Concrete Beam Tests", *Journal of Structural Engineering, ASCE*, 130 (3), 2004, pp. 460-469.

**RB2** → **Diagonal-tension failure (DT)**



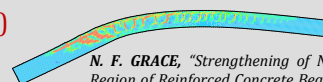
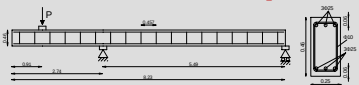
**M. P. COLLINS, D. KUCHMA**, "How Safe Are Our Large, Lightly Reinforced Concrete Beams, Slabs, and Footings?", *ACI Struct. Journal*, 96 (4), 1999, pp. 482-490.

**RB3** → **Bending failure (F)**



**N. F. GRACE**, "Strengthening of Negative Moment Region of Reinforced Concrete Beams Using Carbon Fiber-Reinforced Polymer Strips", *ACI Struct. Journal*, 98 (3), 2001, pp. 347-358.

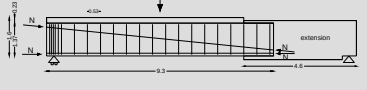
**RB3A** → **Shear-compression failure (SC)**



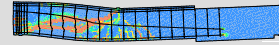
**N. F. GRACE**, "Strengthening of Negative Moment Region of Reinforced Concrete Beams Using Carbon Fiber-Reinforced Polymer Strips", *ACI Struct. Journal*, 98 (3), 2001, pp. 347-358.

## Benchmarks (Voorgespannen en Nagespannen)

**MNDOT** → Shear-compression failure (SC)

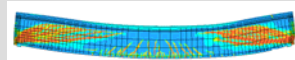
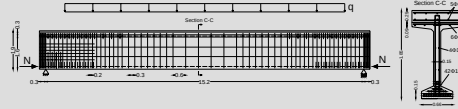


**Crack pattern at failure**



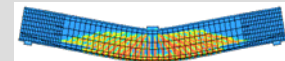
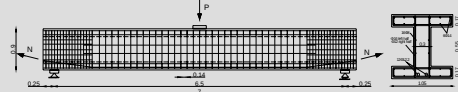
**B. RUNZELL, C. SHIELD, C. FRENCH**, "Shear capacity of prestressed beams", Minnesota Department of transportation Research Services Section, 2007.

**NSEL** → Shear-compression failure (SC)



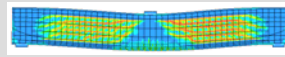
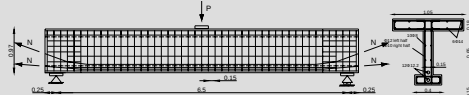
**S. SUN, D. KUCHMA**, "Shear behaviour and capacity of large-scale prestressed high-strength concrete bulb-tee girders", Department of Civil and Environment Engineering, University of Illinois at Urbana-Champaign, 2007.

**PB1** → Bending failure (F)



**E. F. LEONHARDT, R. KOCK, F. S. ROSTASY**, "Schubversuche an Spannbetontragern", Deutscher Ausschuss für Stahlbeton, 1973.

**PB4** → Shear-compression failure (SC)



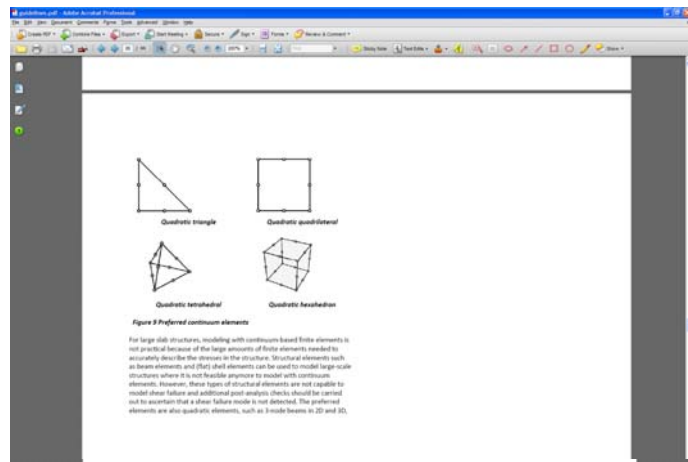
**E. F. LEONHARDT, R. KOCK, F. S. ROSTASY**, "Schubversuche an Spannbetontragern", Deutscher Ausschuss für Stahlbeton, 1973.

## Inhoud

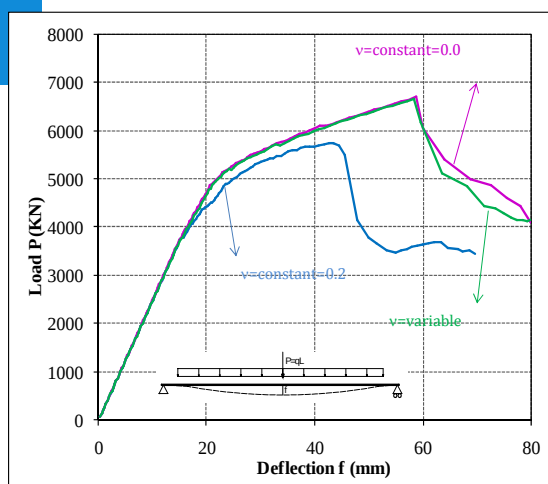
### Richtlijnen NL-FEM:

- Wat het is
- Doelen
- Aanpak
- "Sneak preview"
- Topics
  - Dwarscontractie
  - BGS: scheurwijdte
  - UGS: safety format
  - Druk:  $G_c$
  - Equivalente lengte:  $h_{eq}$

## Richtlijnen NL-FEM (versie 1)



## Dwarscontractie na scheuren



Case study NSEL

(shear compression failure)

## BGS: bepalen scheurwijdte

Scheurafstand op basis van Eurocode 2:

$s_{r,max}$  voor buigscheuren en

$s_{\theta,max}$  voor dwarskrachtscheuren

Gemiddelde rek  $\epsilon_s$  op basis van NL-FEM-resulaten langs wapening

“Hybride” bepaling van scheurwijdte:

$$w = s_{r,max} \times \epsilon_s$$

## UGS: safety format voor NL-FEM

3 Methodes:

GSF

PSF

ECOV

(fib Model code 2010, “first complete draft”)

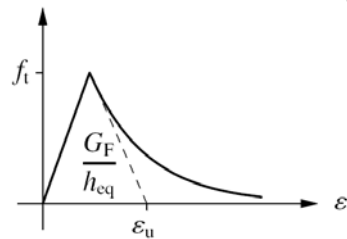
Bijvoorbeeld GSF:

$$f_{cm} = 0.85 f_{ck}$$

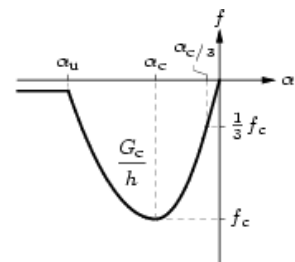
$$f_{ym} = 1.1 f_{yk}$$

$$P_d = P_u / 1.27$$

## Breukenergie onder druk: $G_c$



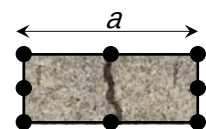
Trek:  $G_f$



Druk:  $G_c = 250 G_f$

(Nakamura, 2001)

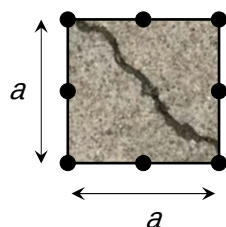
## Equivalente lengte: $h_{eq}$



$$h_{eq} = a$$



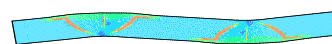
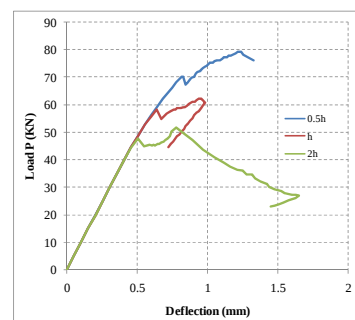
$$h_{eq} = b$$



$$h_{eq} = 1.5 \sqrt{2} a \approx 2 a$$

(Oliver, 1989)  
(Govindjee, 1995)  
(Cervenka, 2010)

### Case study: RB2



## Conclusie & vooruitzicht

