Parametric Study of Web Shear Cracking

Based on the Master’s Project “Improved Design Method for Web Shear Tension Failure in Hollow Core Units” in the International Master’s Programme Structural Engineering

Lars Rettne
Web Shear Tension Failure in Hollow Core Units
Problem Description

”In the present standard the guidance on how to calculate shear tension capacity is not detailed enough and a more precise method is needed”
Aim of the Project

• Create finite element (FE) models of single hollow core units
• Perform calculations using Yang’s method of single hollow core units
• Compare the shear capacity and location of the critical point between the two methods
Critical Point

= The point where web shear cracking starts
Collaboration

• This project was initiated by Strängbetong, which is the largest hollow core unit producer in Sweden
Hollow Core Floors

Hollow core floors consist of hollow core units.
Web Shear Tension Failure in Hollow Core Units

Uncracked cross-section

\[ \sigma_1 < f_{ctm} \]

\[ \sigma_1 \] = Principal stress

\[ f_{ctm} \] = Mean tensile strength of concrete
Web Shear Tension Failure in Hollow Core Units

Web shear cracking

\[ \sigma_1 = f_{ctm} \]

Immediately failure (brittle)
Shear Capacity with Respect to Web Shear Tension Failure

- Failure when the concrete tensile strength is reached, \( \sigma_1 = f_{ctm} \)
- The principal stresses are dependent of the shear and normal stresses, \( \sigma_1 = \sigma_1(\sigma_x, \tau) \)
Shear Stress Calculations in Prestressed Members

Traditional (present)

Yang’s (new)
Shear Stress Calculations in Prestressed Members

Traditional (present)

\[ \tau(x_{cp}, z_{cp}) = \frac{S(z_{cp})V(x_{cp})}{I_1 b_w(z_{cp})} \]

Yang’s (new)

\[ \tau(x_{cp}, z_{cp}) = \frac{S(z_{cp})V(x_{cp})}{I_1 b_w(z_{cp})} + f\left(\frac{dP_{0i}}{dx}\right) \]

The shape is taken into account
Shear Capacity Calculations in Prestressed Members

Traditional (present)

Assumed location of critical point

Yang’s (new)

Assumed location of critical point somewhere along line
Reference Case – Principal Sketch

Self weight and imposed load

Prestresssing strand

Cross-section
Parametric Study

• Prestressing strand arrangement
• Prestressing strand amount
• Prestress
• Concrete strength class
• Concrete strength at strand release
• Prestress transfer function
• Type of cross-section
FE Model

Concrete part: Solid finite elements

Stiff steel support plate: Solid finite elements

Steel strands: Truss finite elements
FE Model - Boundary Conditions

- Roller support
- Solid concrete part
- Stiff support plate
- Line where the boundary conditions were applied
FE Model - Boundary Conditions: Symmetry Planes

Boundary conditions along transversal symmetry plane

Boundary conditions along longitudinal symmetry plane
FE Model - Loads

Self weight & Imposed load (pressure)

Initial stress from prestressing (initial condition)

Note that this is the stress distribution in the prestressing strands before “release”, i.e. before interacting with the concrete in the model.
FE Model - Mesh

Critical region
dense mesh (25 mm)

Non-critical region
coarse mesh (200 mm)
Results – FE Method
Principal Stresses in the Reference case

Critical point
Results – FE Method
Stress Field in the Reference Case

Short term response
(28 days age)

Long term response
(57 years age)
Results – FE Method
Stress Field in the Reference Case

Short term response
(28 days age)

Long term response
(57 years age)
Results – Yang’s Method
Principal Stresses in the Reference Case

Critical point

Relative Principal Stresses at Cracking

Height of Cross-Section [mm]
Shear Capacity

Support Reaction at Web Shear Cracking
FE Analyses

Support Reaction at Web Shear Cracking
Lin Yang, 35° Critical Path from Mid Support

Concrete Structures

Kristian Edekling & Lars Rettne
Shear Capacity
Comparison between FEM and Yang’s Method

Relative Support Reactions at Web Shear Cracking
$R_{\text{Lin Yang 35°}}/R_{\text{FE Analyses}}$

Yang’s method unconservative
Yang’s method conservative

$t=28$ days
$t=57$ years

Concrete Structures
Kristian Edekling & Lars Rettne
Location of Critical Point

Comparison Between FE Analyses / Yang

Concrete Structures

Kristian Edekling & Lars Rettne
Location of Critical Point
FE Analyses

Horizontal and Vertical Location of Critical Point Independently of Web, \( t = 28 \) days, FE Analyses

- Ref
- PSAr
- PSAm8
- PSAm12
- PS
- CC
- CSAR
- PTF
- STIFF
- TOCS
- TOCS-PSAr

Horizontal Distance from Middle Support [m]
Vertical Distance from Bottom Edge [m]
Location of Critical Point
Yang’s Method

Horizontal and Vertical Location of Critical Point
Independently of Web, $t=28$ days, Yang's Method

Horizontal Distance from Middle Support [m]
Vertical Distance from Bottom Edge [m]
Location of Critical Point: Reference Case

Comparison Between FE Analyses / Yang's Method

Horizontal Distance from Middle Support [m]

Vertical Distance from Bottom Edge [m]
Location of Critical Point: Prestressing Strand Amount, PSAm8

Comparison between FE Analyses / Yang's Method

- PSAm8 28 days, FEM
- PSAm8 57 years, FEM
- PSAm8 28 days, Yang
- PSAm8 57 years, Yang
- REF 28 days, FEM
- REF 57 years, FEM
Angle $\beta$ for Different Cases

![Graph showing the angle $\beta$ for different cases with FE analyses.](image-url)
Angle $\beta$ for Different Cases
Comparison between FEM and Yang’s Method

Angle $\beta^{**}$ for Different Cases
FE Analyses

Recommended $\beta$ from Yang (1994)

- $t=28$ days
- $t=57$ years

Concrete Structures
Kristian Edekling & Lars Rettne
Angle $\beta$ for Different Cases

Recommendations of New Angle

Angle $\beta^{**}$ for Different Cases

FE Analyses

Suggested $\beta$ for short term response and short transfer length

Suggested $\beta$ for long term response and long transfer length

REF  STIFF  PSAr  PSAm8  PSAm12  PS  CC  CSAR  PTF  TOCS  TOCS-PSAr

$\beta$

$\bullet$ $t=28$ days  $\square$ $t=57$ years
Relative Shear Capacity
New Recommended Angle is Used

Relative Support Reactions at Web Shear Cracking
$R_{Yang}$ New Suggestions / $R_{FE}$ Analyses

$t=28$ days
$t=57$ years

Concrete Structures

Kristian Edekling & Lars Rettne
Conclusions
General from FE Analyses

• For long term response and long transfer length, the critical point was found along a path with a smaller inclination than 35° proposed by Yang (1994).

• For long term response and long transfer length, the capacity of web shear tension failure was reduced.
Conclusions
Specific from FE Analyses

• Decreased reinforcement amount had a great influence on the position of the critical point; the horizontal distance from the support to the critical point was increased. The capacity in web shear tension failure is reduced.

• Increased prestress from 1000 MPa to 1200 MPa did not affect the location of the critical point, but reduced the shear capacity.
Conclusions

General from Comparison FEM – Yang’s Method

• The agreement between Yang’s method and FEM regarding the location of the critical point was, with some exceptions, good for short term response and short transfer length and less good for long term response and long transfer length.

• The agreement between Yang’s method and FEM regarding the web shear tension capacity was, with some exceptions, good for short term response and short transfer length and less good for long term response and long transfer length.
Recommendation

- Use $\beta=35^\circ$ for short term response and short transfer length with Yang’s method.
- Use $\beta=25^\circ$ for long term response and long transfer length with Yang’s method.
Thanks for your attention!