

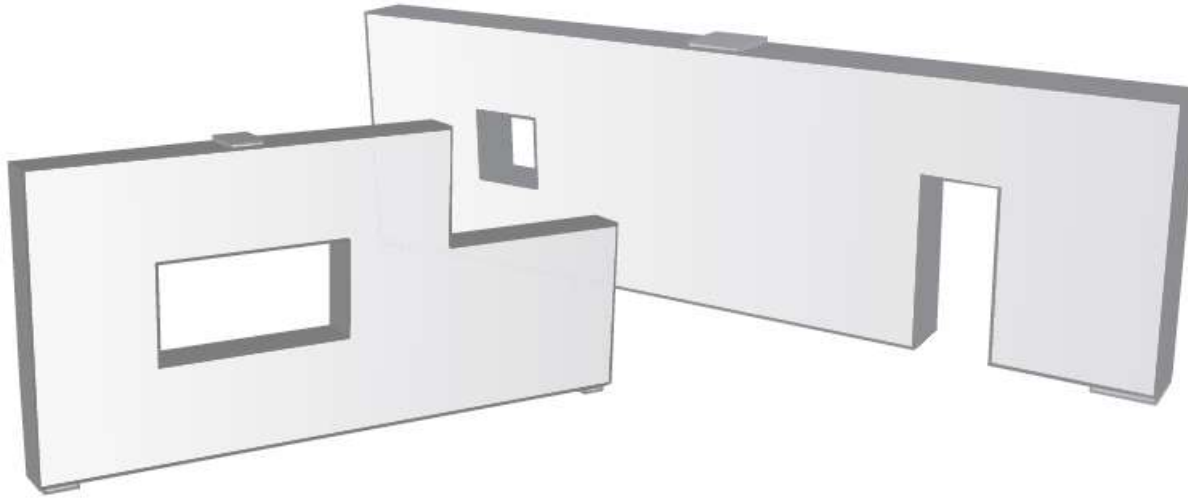
# *Análise e Dimensionamento de Regiões Especiais em Concreto Estrutural*

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Instituto de Engenharia de São Paulo  
São Paulo, 27 de Setembro de 2012

# Introdução

Créditos da Ilustração: Eng. Filipe Manuel Correia de Menezes Leal



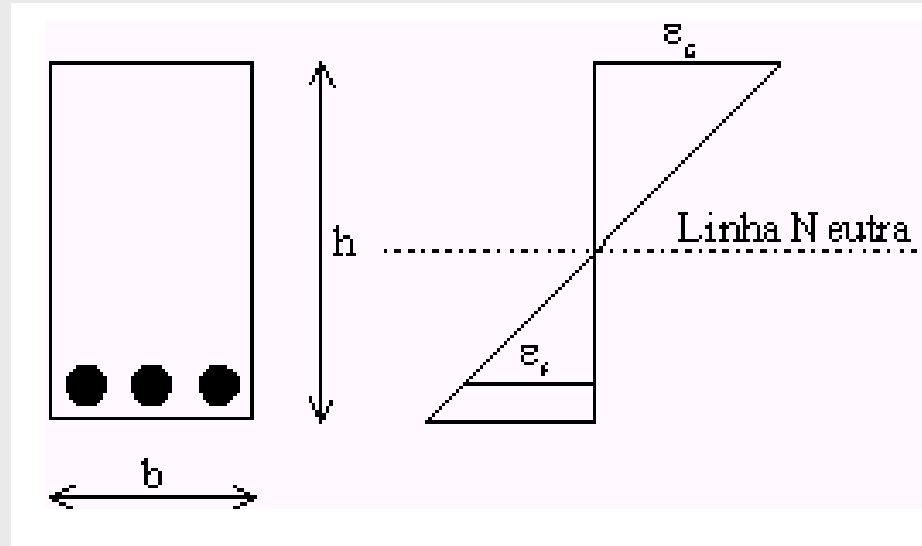
Soluções Empíricas  
Método dos Elementos Finitos  
Método dos Campos de Tensão  
Método das Bielas

Método Biela e Painel (Stringer and Panel)



# Regiões B e Regiões D

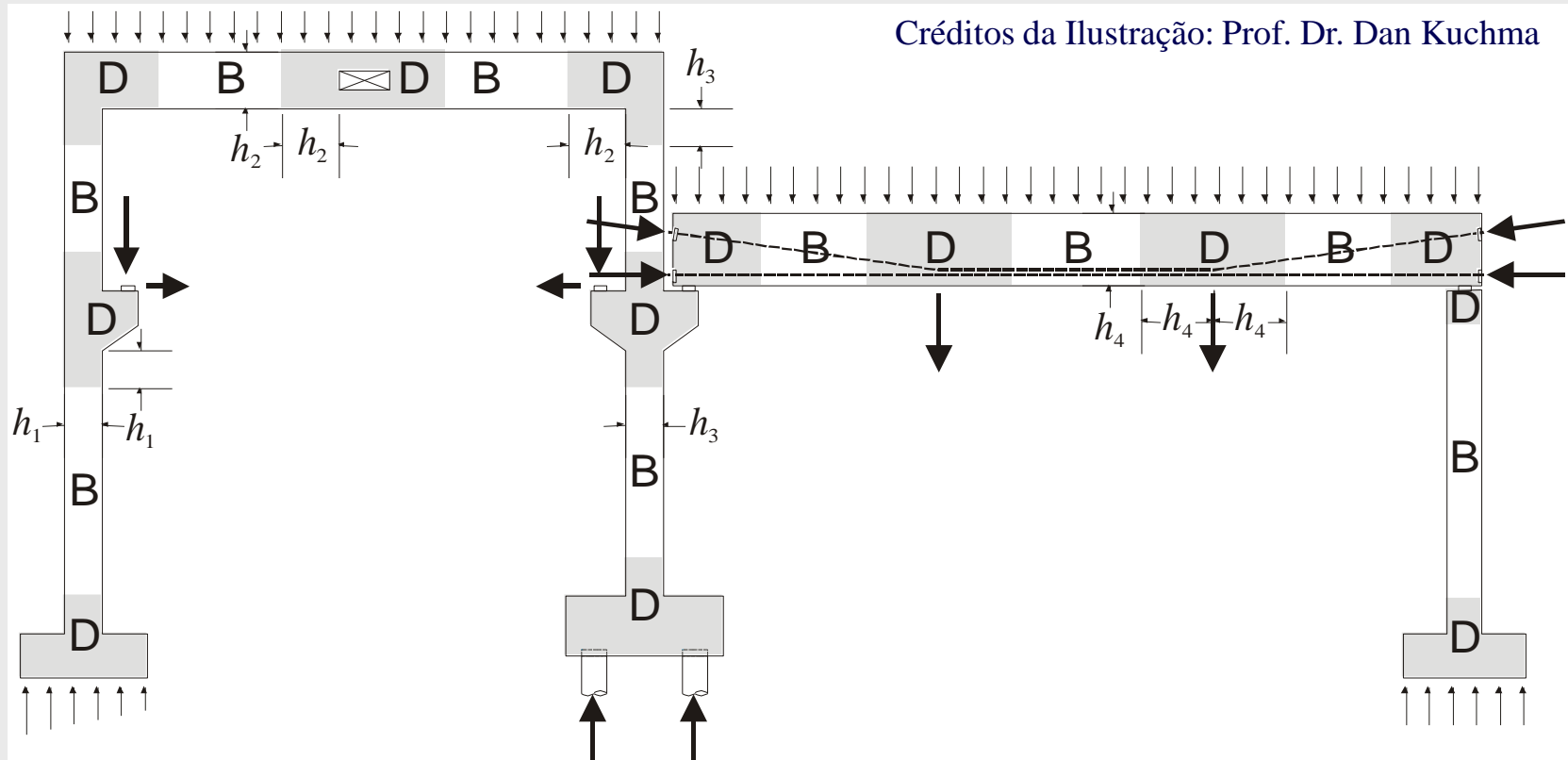
- A maioria dos elementos estruturais podem ser dimensionados utilizando a “Hipótese de Bernoulli” (“Regiões B”);

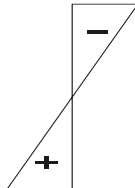


- No entanto, tal hipótese não tem validade para algumas regiões, denominadas de “Regiões D”;

# Regiões B e Regiões D

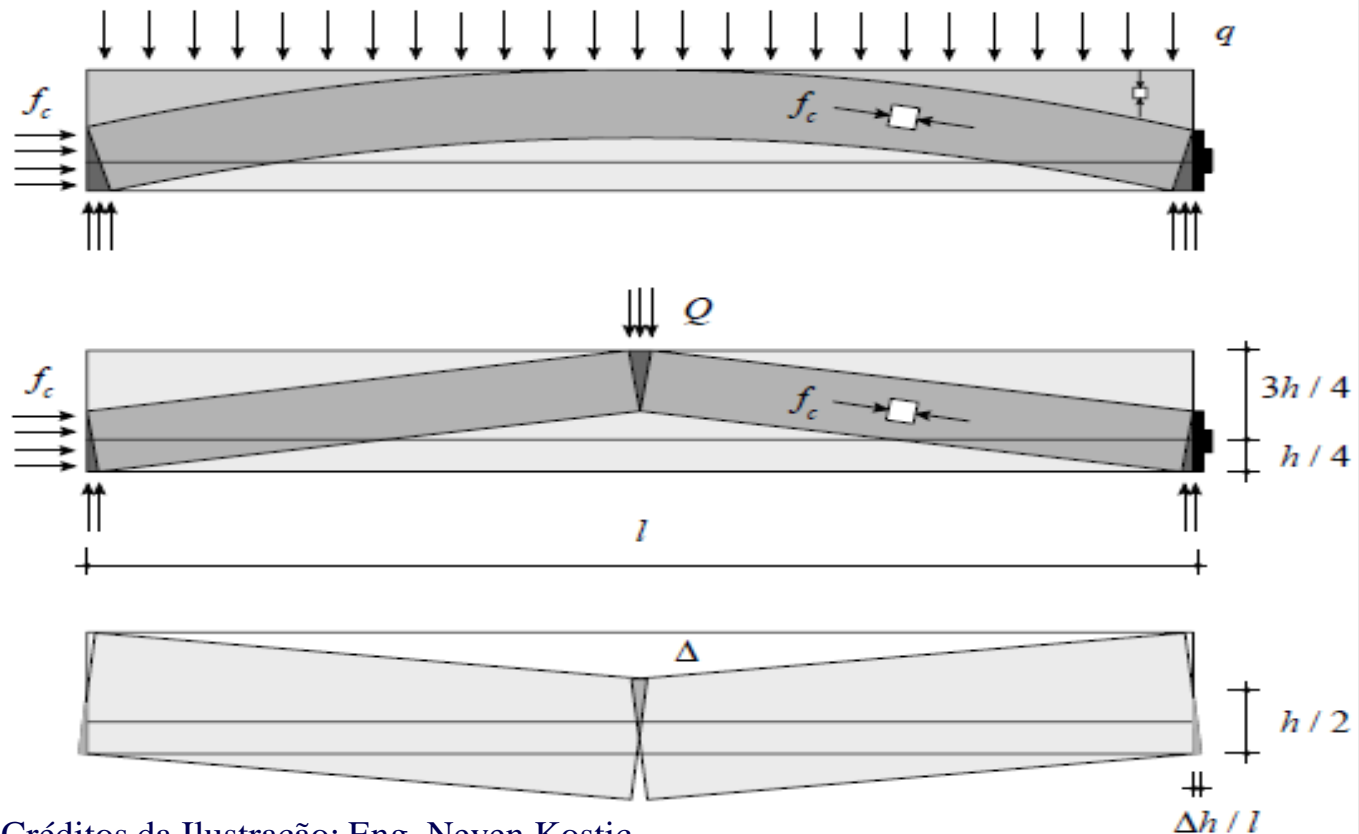
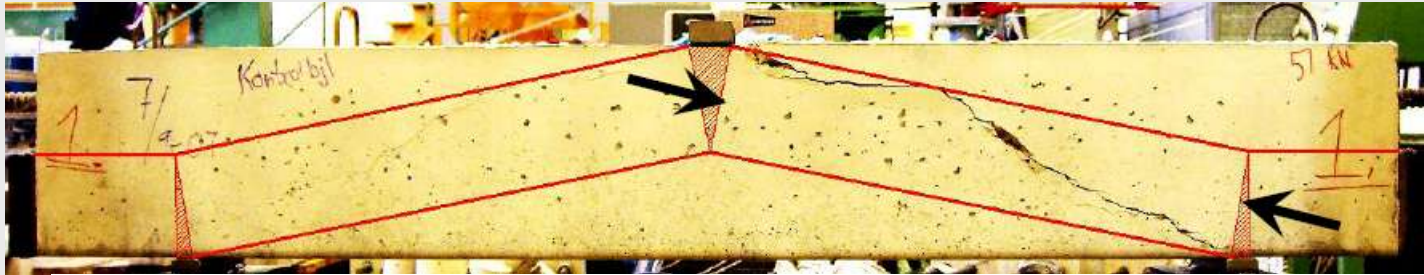
Créditos da Ilustração: Prof. Dr. Dan Kuchma



Region	Strain Condition	Design Procedure
<b>B</b> (Beam or Bernoulli)		Sectional
<b>D</b> (Discontinuity or Disturbed)	Complex	Empirical, FEM, STM

# ***Método dos Campos de Tensão***

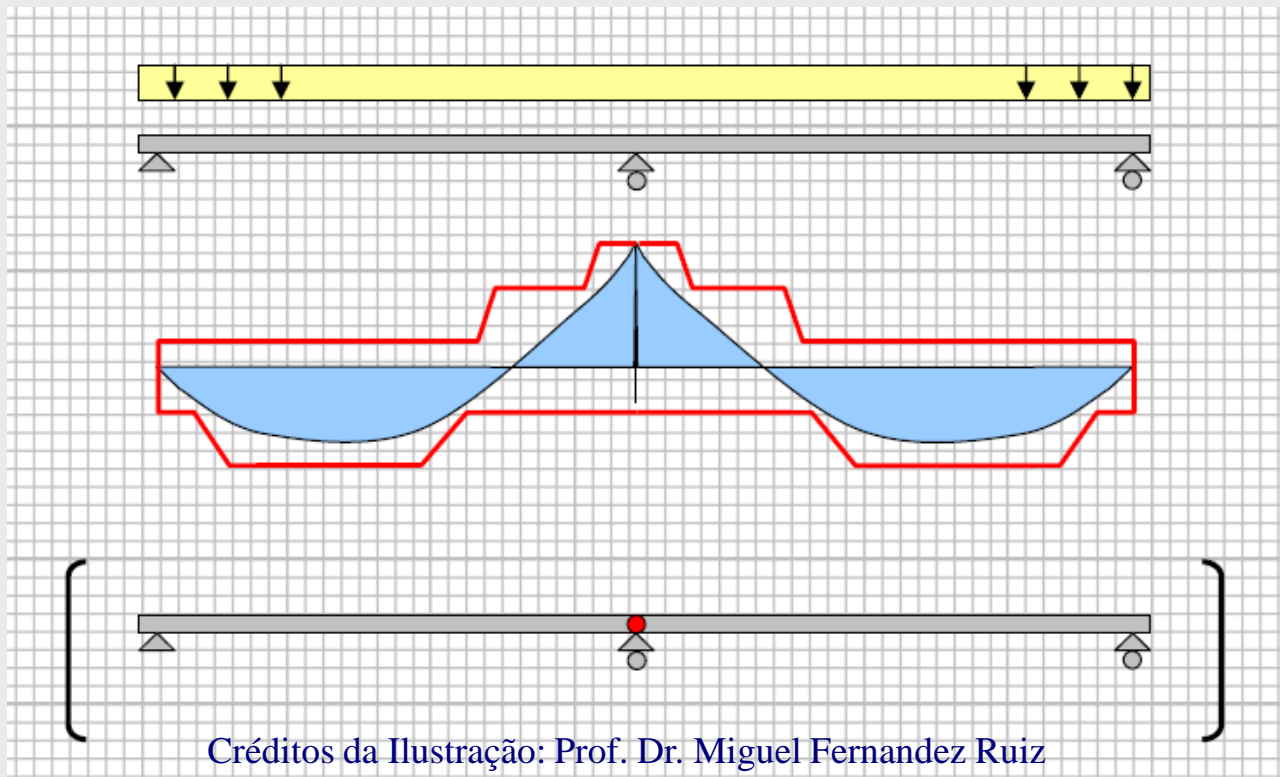
# Viga Clássica de Drucker (1961)



Créditos da Ilustração: Eng. Neven Kostic

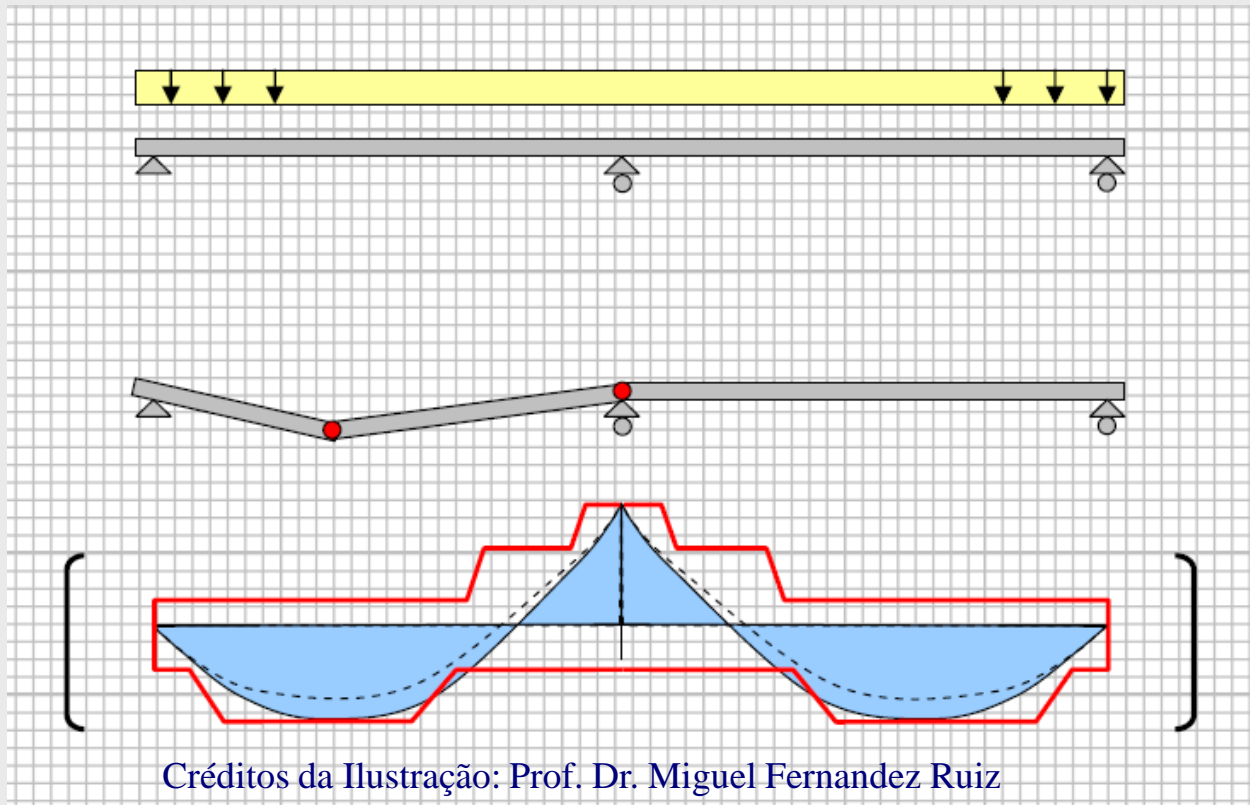
# Teoremas da Teoria da Plasticidade

- **Teorema Estático (Limite Inferior):** Um conjunto de cargas  $Q_s$ , em equilíbrio com um campo de tensões, e que satisfaça a condição estática de plasticidade, é um limite inferior para a carga de ruptura  $Q_r$ .



# Teoremas da Teoria da Plasticidade

- **Teorema Cinemático (Limite Superior):** Um conjunto de cargas  $Q_c$ , correspondente a um mecanismo lícito satisfazendo a condição cinemática de plasticidade, é um limite superior para a carga de ruptura  $Q_r$ .

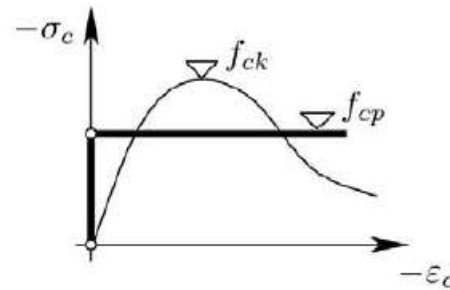
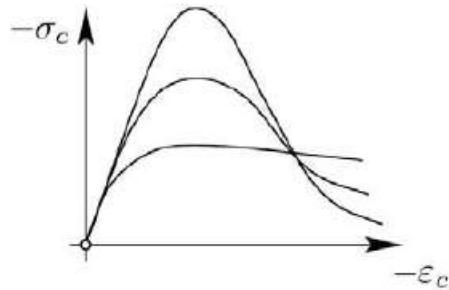




# Comportamento Rígido-Plástico

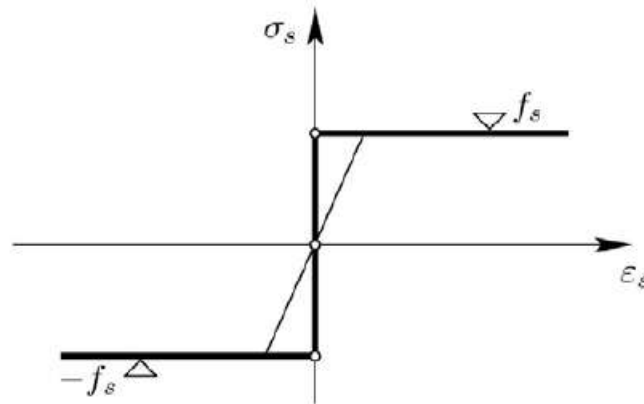
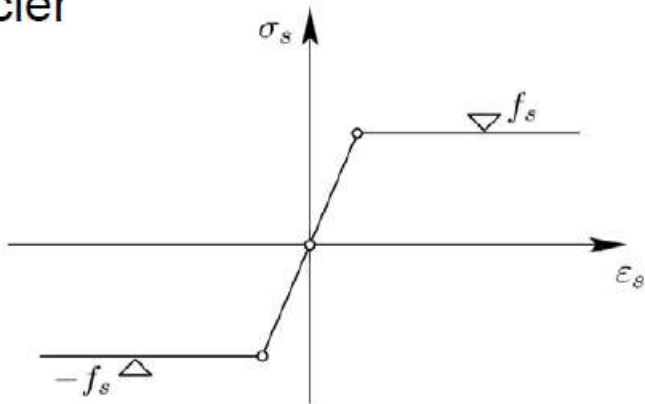
Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

## Béton

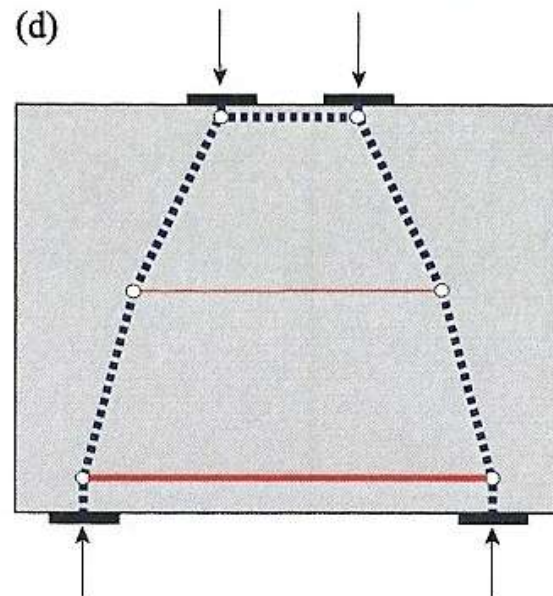
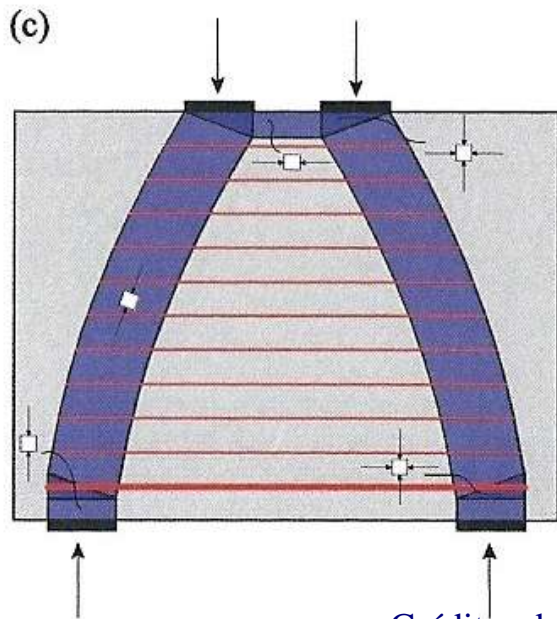
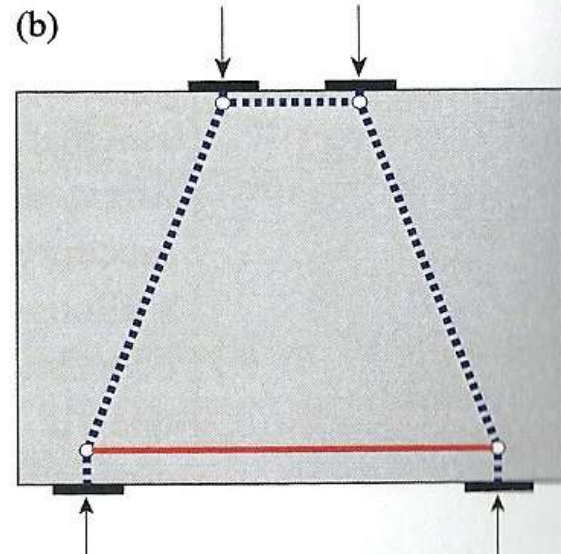
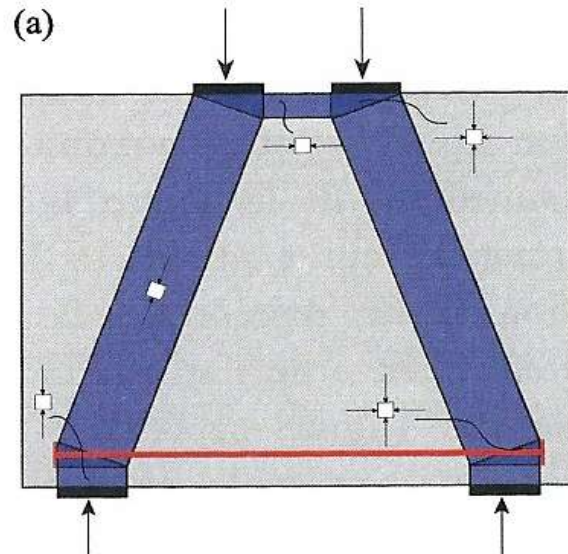


$$f_{cp} = \eta_{fc} \cdot f_{ck}$$
$$\eta_{fc} = \left( \frac{30}{f_{ck}} \right)^{\frac{1}{3}} \leq 1.0$$

## Acier



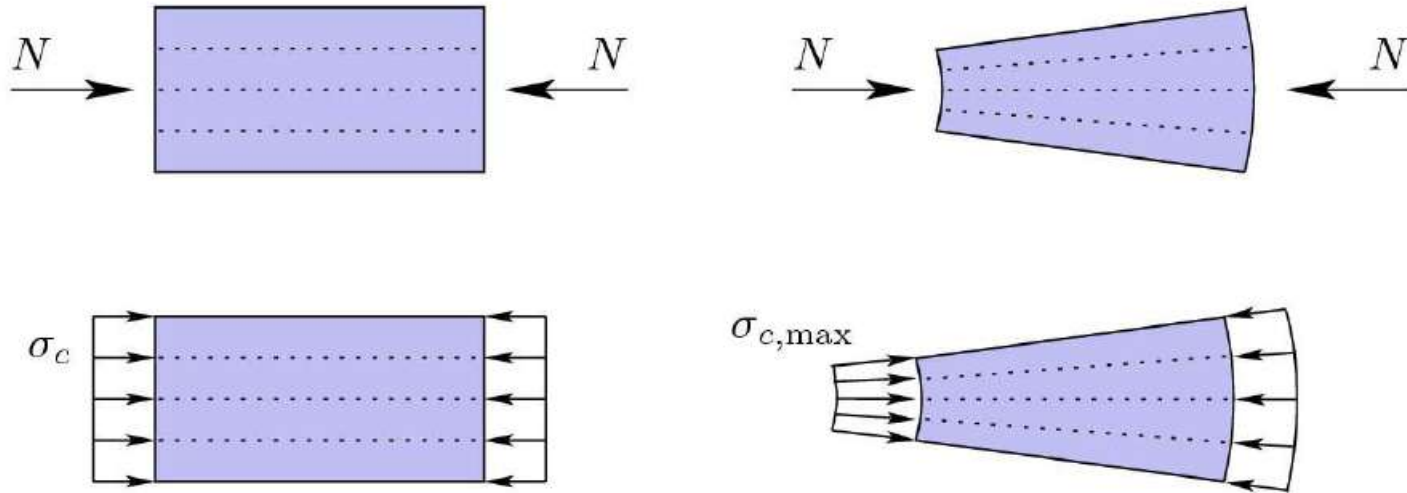
# Comportamento Rígido-Plástico



Créditos da Ilustração: Aurelio Muttoni, Miguel Fernandez Ruiz, Neven Kostic

# Tipos de Escoras

Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz



$$|\sigma_{c,max,d}| \leq f_{ce,d}$$

$$f_{ce,d} = \frac{f_{ce}}{\gamma_c} = \frac{f_{cp}}{\gamma_c} \cdot k_c$$

$$k_c = \frac{1}{0,8 + 170 \cdot \epsilon_1} \leq 1,0$$

$$f_{cp} = \eta_{fc} \cdot f_{ck}$$

$$\eta_{fc} = \left( \frac{30}{f_{ck}} \right)^{\frac{1}{3}} \leq 1,0$$

# Abrandamento à Compressão

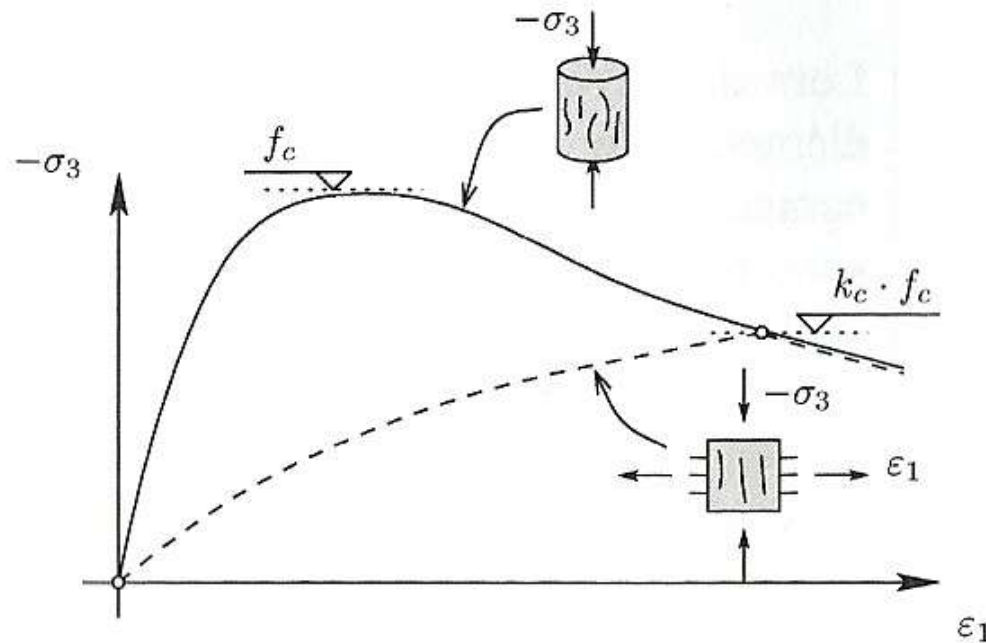
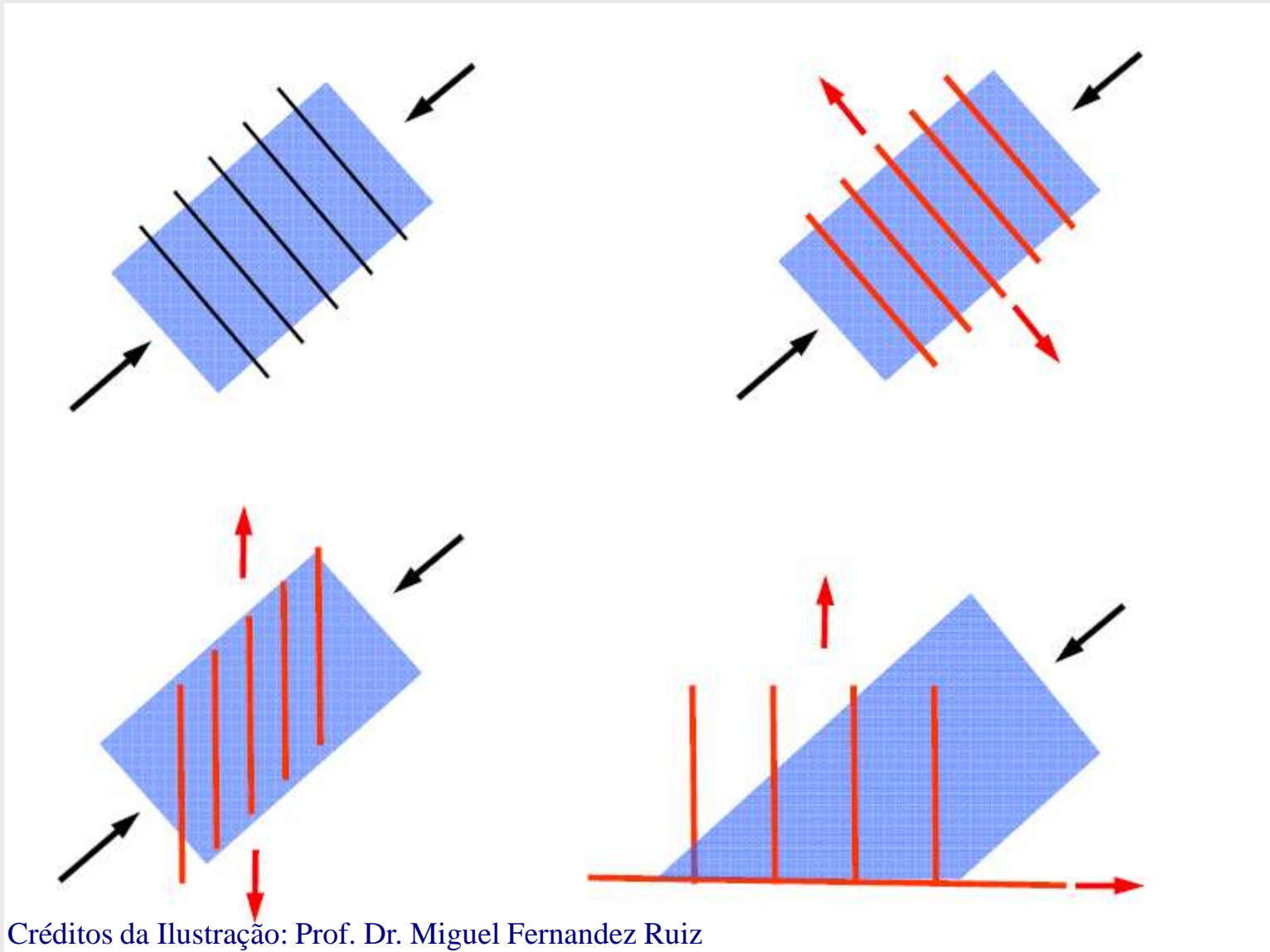
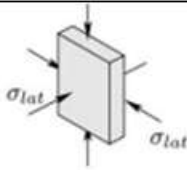

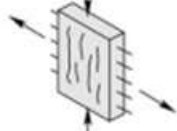
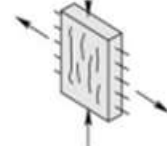
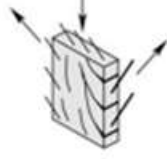
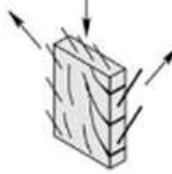


Figure 2.5 : Influence des déformations transversales dans la résistance à la compression du béton

# Tipos de Escoras



# Resistência Simplificada das Escoras

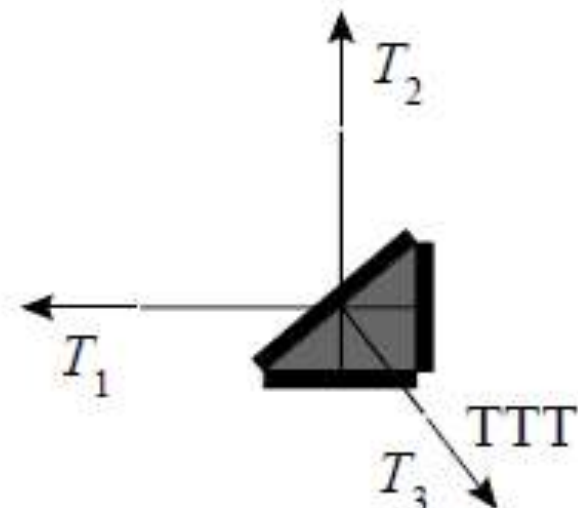
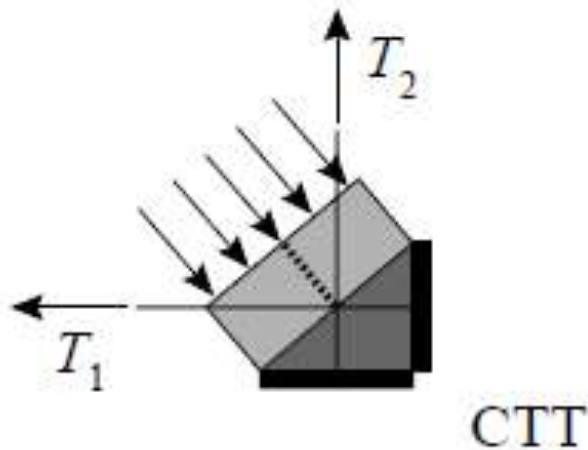
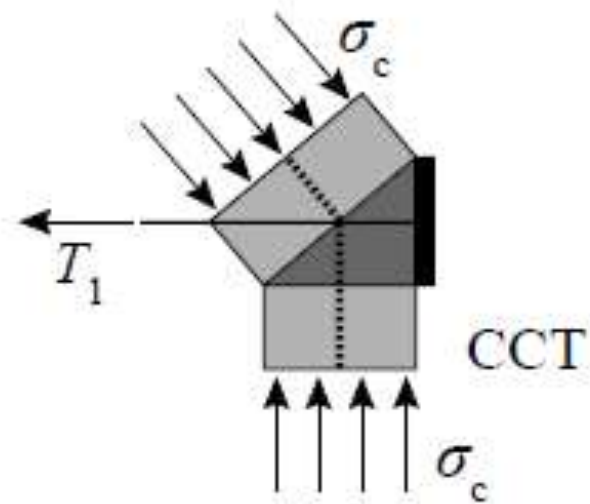
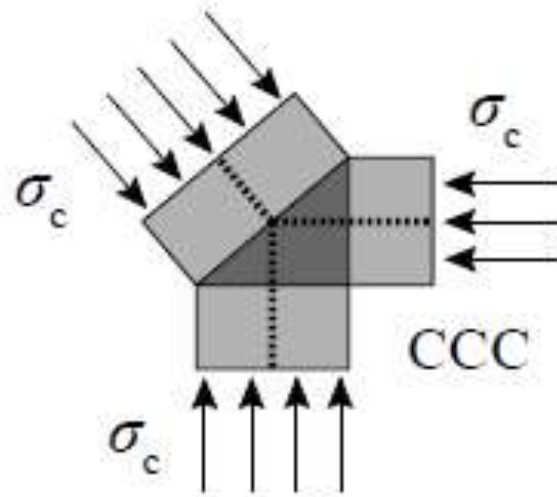
Tipo de Solicitação		Tensão efetiva ( $f_{ce}$ )	Aplicações
Concreto confinado ativamente ou passivamente e sem fissuração		$f_{cp} + 4 \cdot  \sigma_{lateral} $	<ul style="list-style-type: none"> <li>Compressão triaxial</li> <li>Confinamento lateral</li> <li>Introdução de cargas concentradas</li> </ul>
Concreto sem fissuração sujeito à compressão uniaxial		$f_{cp}$	<ul style="list-style-type: none"> <li>Compressão simples com armadura de controle de fissuração</li> <li>Pilares, muros e vigas em flexão</li> </ul>
Concreto fissurado com deformação lateral imposta		$0,8 \cdot f_{cp}$	<ul style="list-style-type: none"> <li>Muros</li> <li>Lajes</li> <li>Vigas com deformação lateral</li> </ul>
Concreto fissurado com deformação diagonal imposta		$0,6 \cdot f_{cp}$	<ul style="list-style-type: none"> <li>Muros</li> <li>Lajes com torção</li> <li>Vigas com cortante ou torção</li> </ul>
Concreto fissurado com armadura plastificada nas duas direções		$0,4 \cdot f_{cp}$	<ul style="list-style-type: none"> <li>Vigas ou muros com armadura longitudinal e transversal plastificadas</li> </ul>
Concreto sem controle de abertura de fissuras		Teoria da Plasticidade não é aplicável	<ul style="list-style-type: none"> <li>Elementos com armadura mínima insuficiente</li> <li>Punção</li> </ul>

$$f_{cp} = \eta_{fc} f_{ck}$$

$$\eta_{fc} = \left( \frac{30}{f_{ck}} \right)^{1/3} \leq 1,0$$

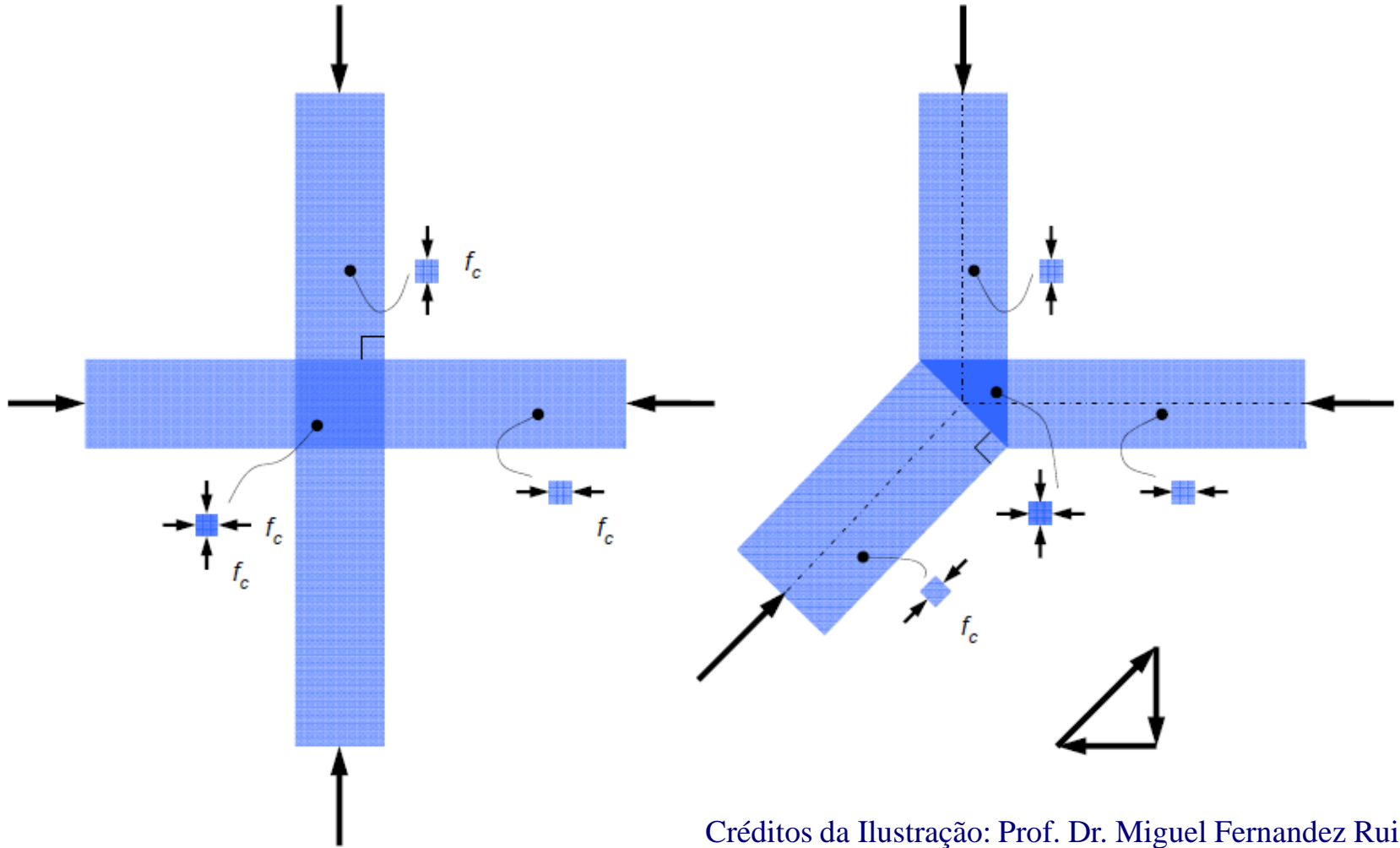


# Regiões Nodais



Créditos da Ilustração: Eng. Neven Kostic

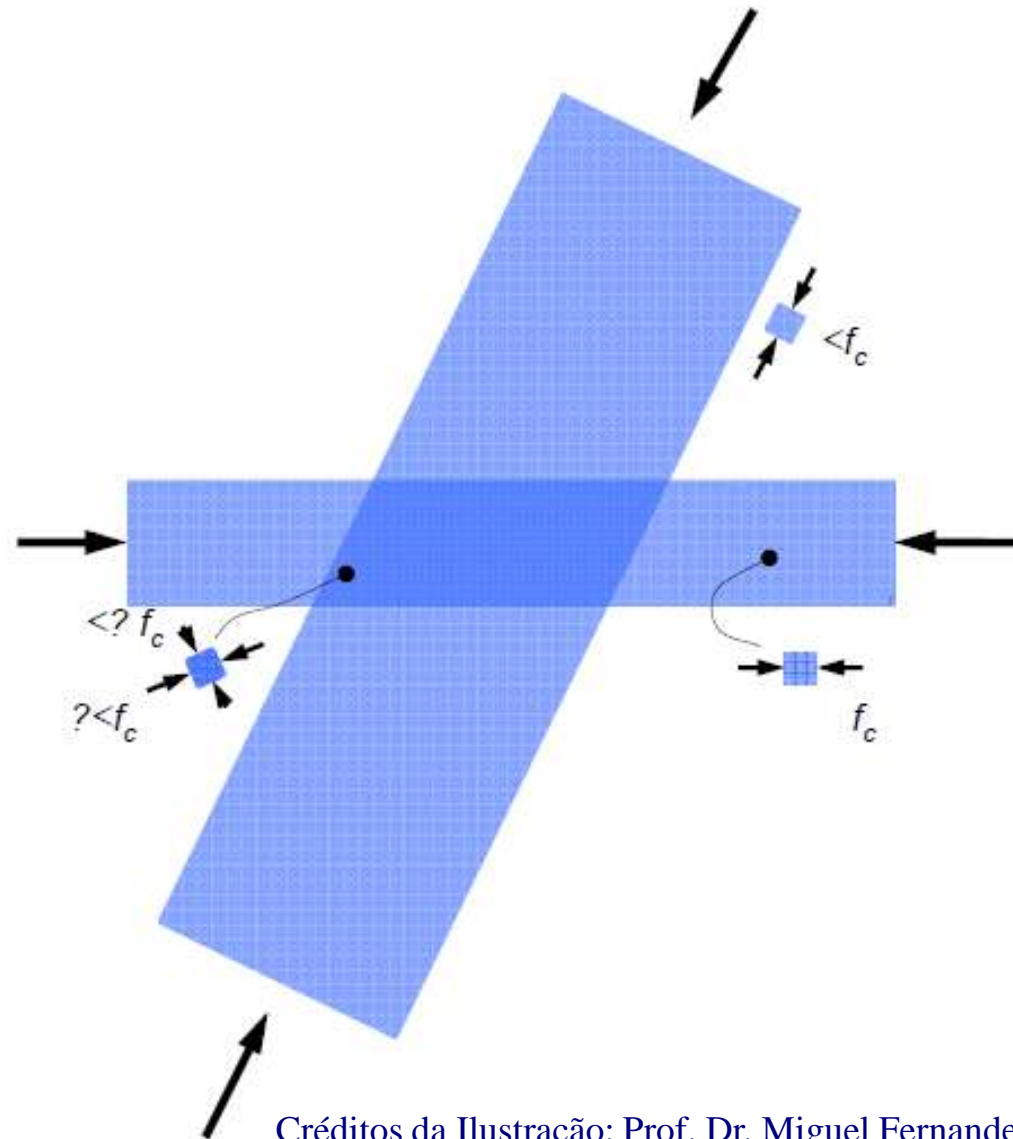
# Regiões Nodais CCC



Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

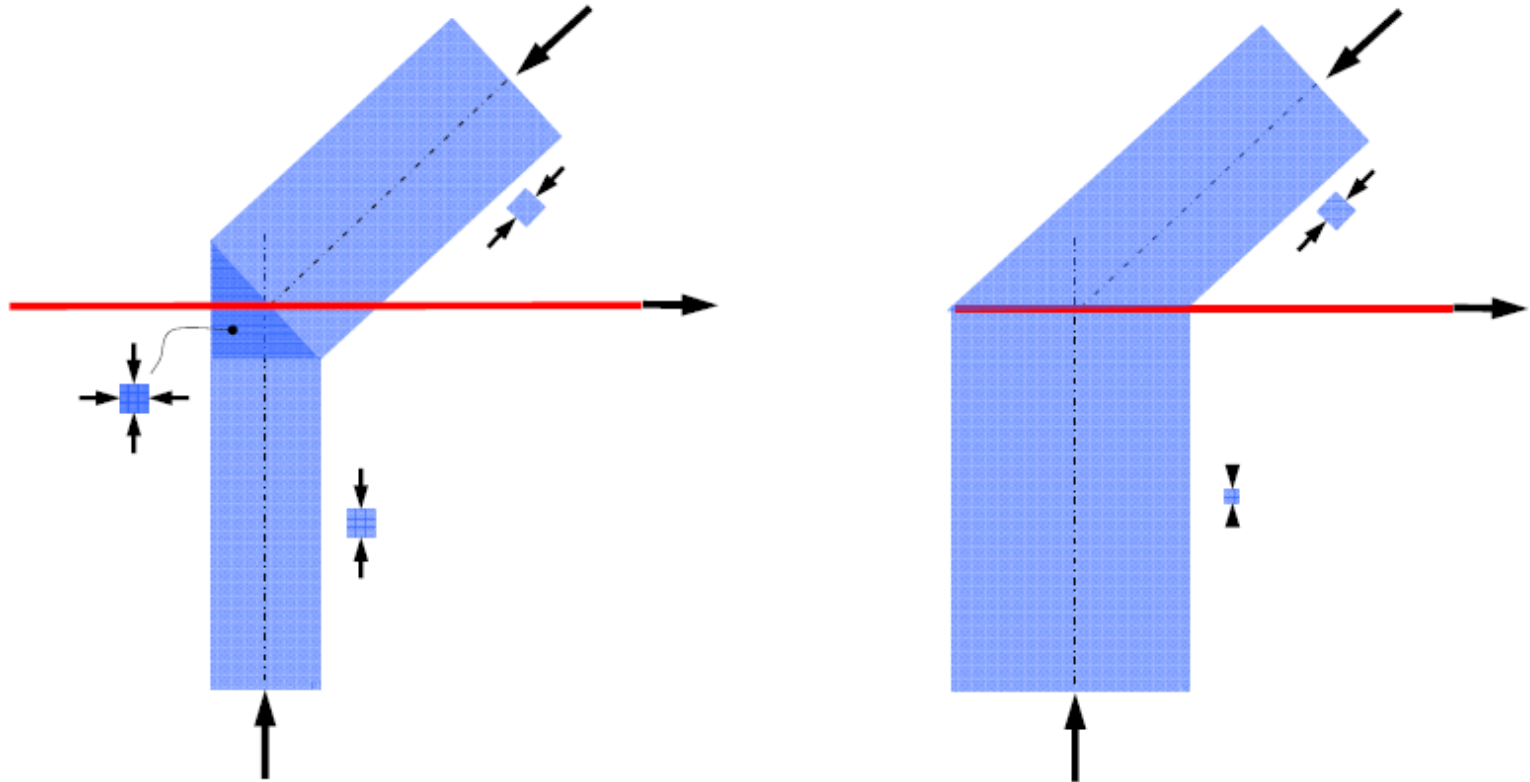


# Regiões Nodais CCC



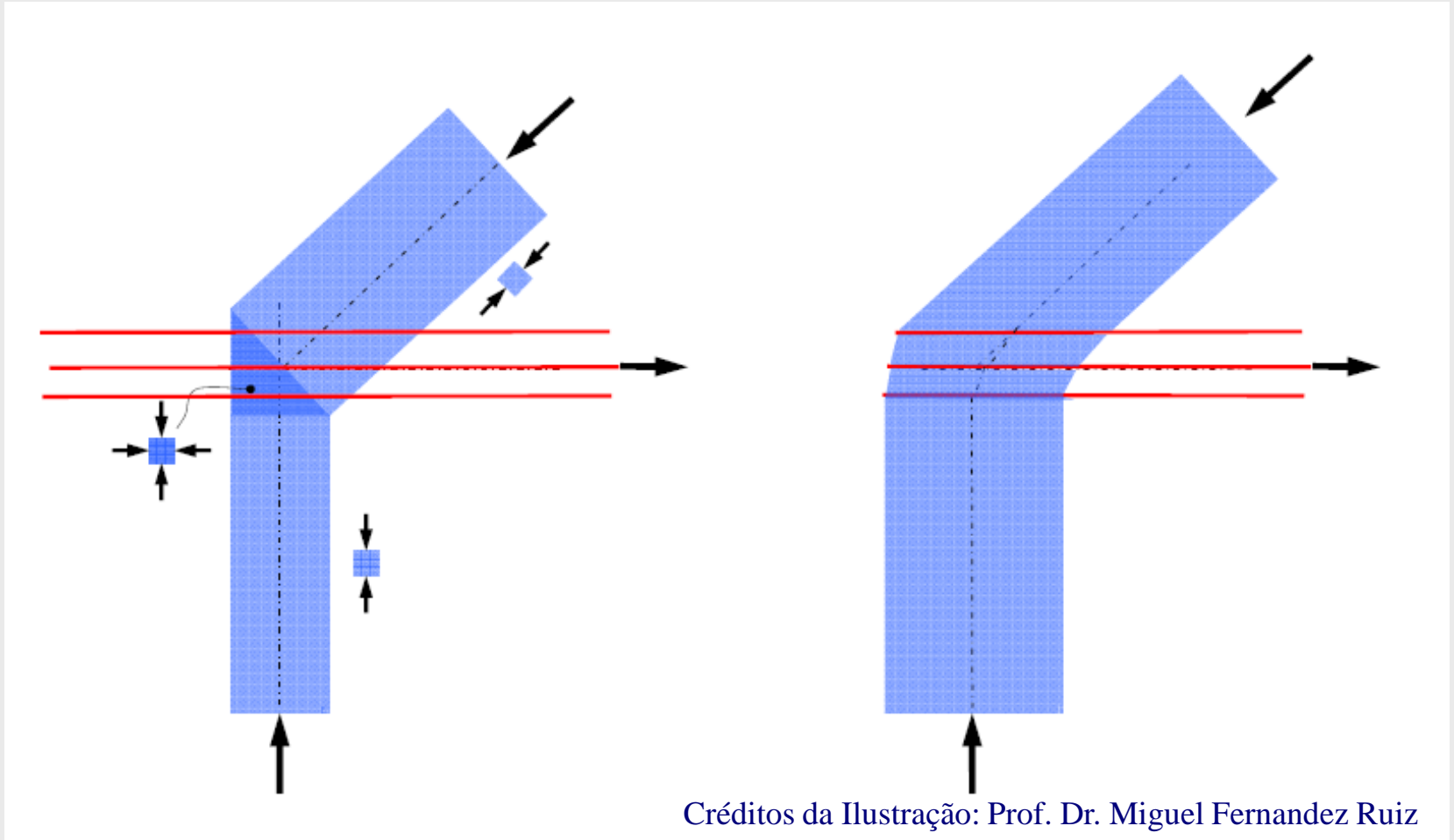
Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

# Regiões Nodais CCT

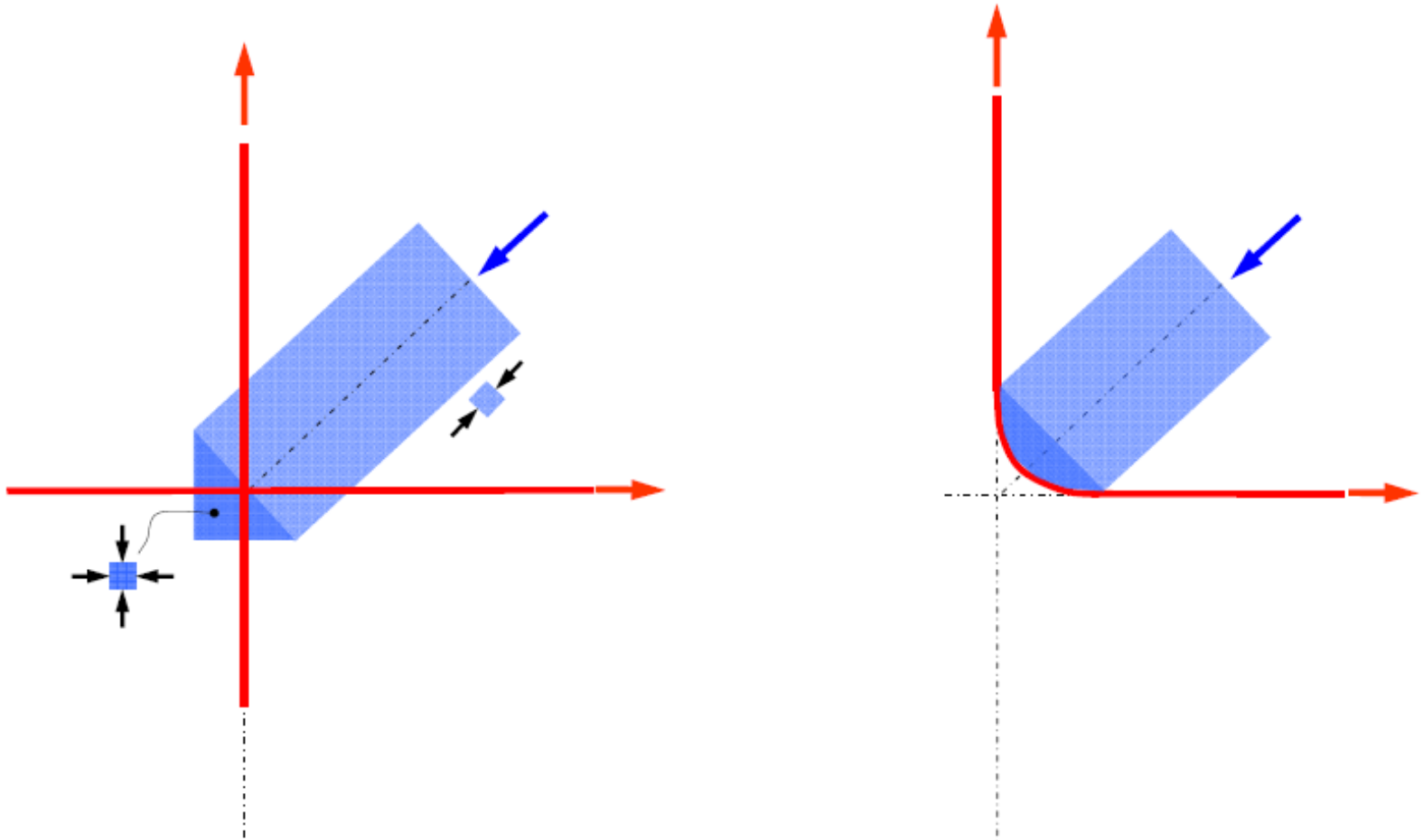


Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

# Regiões Nodais CCT

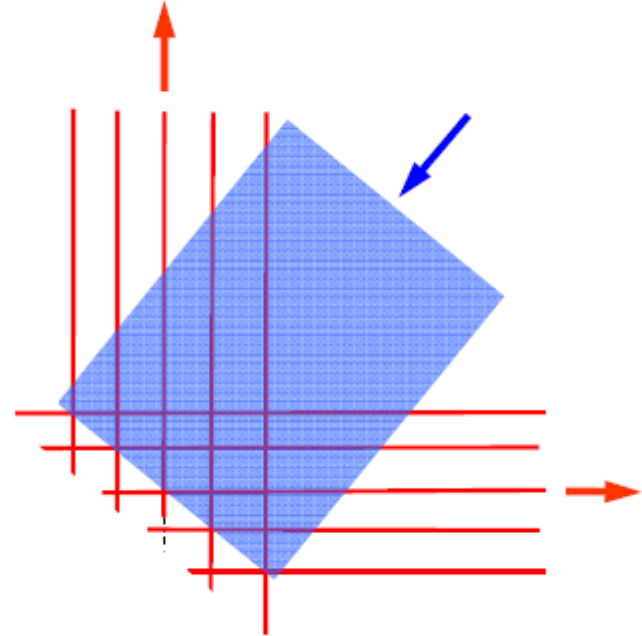
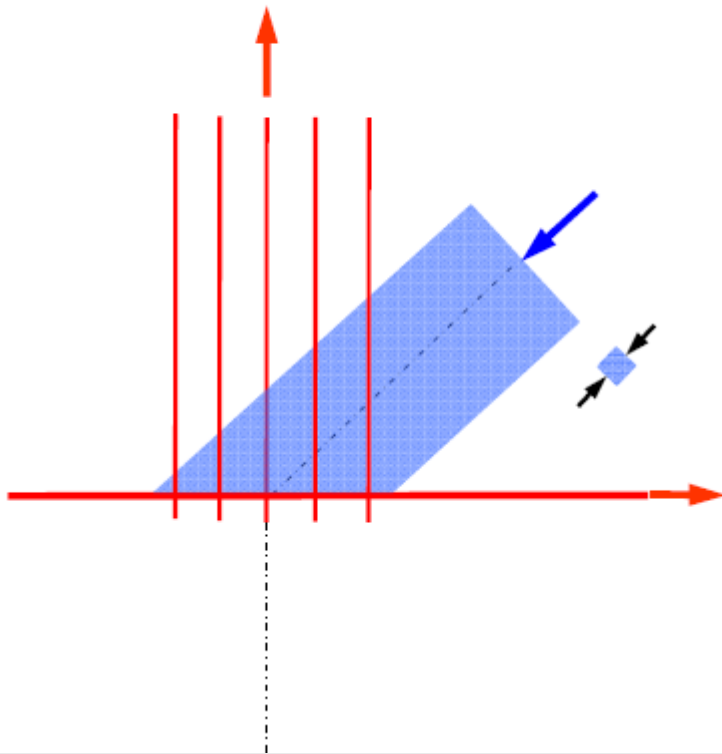


# Regiões Nodais CTT



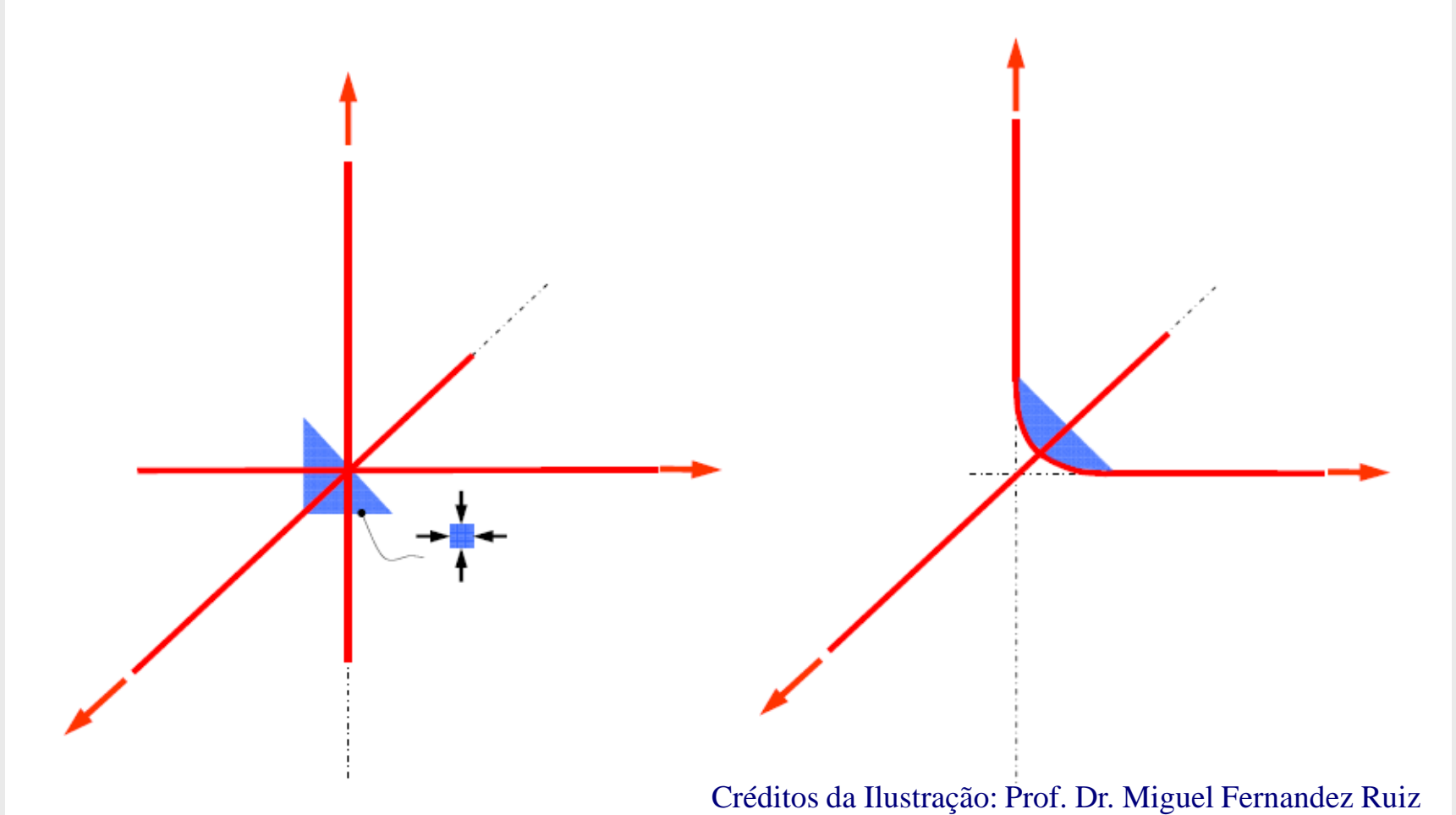
Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

# Regiões Nodais CTT



Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

# Regiões Nodais TTT



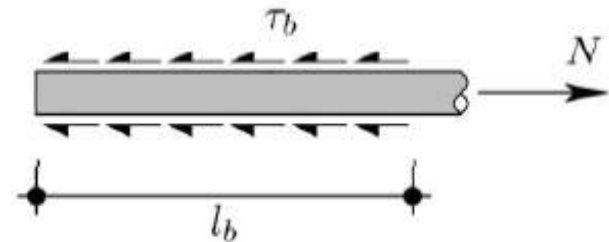
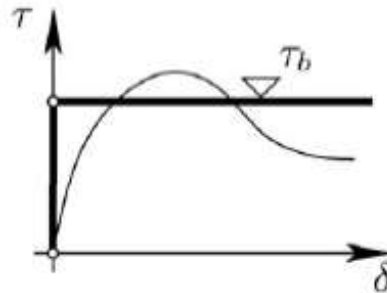
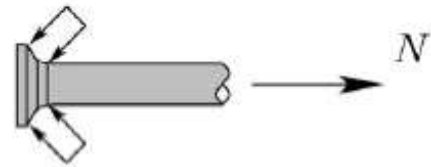
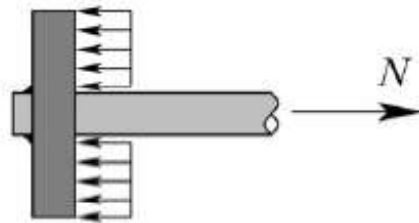
Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

# Resistência dos Tirantes

Résistance

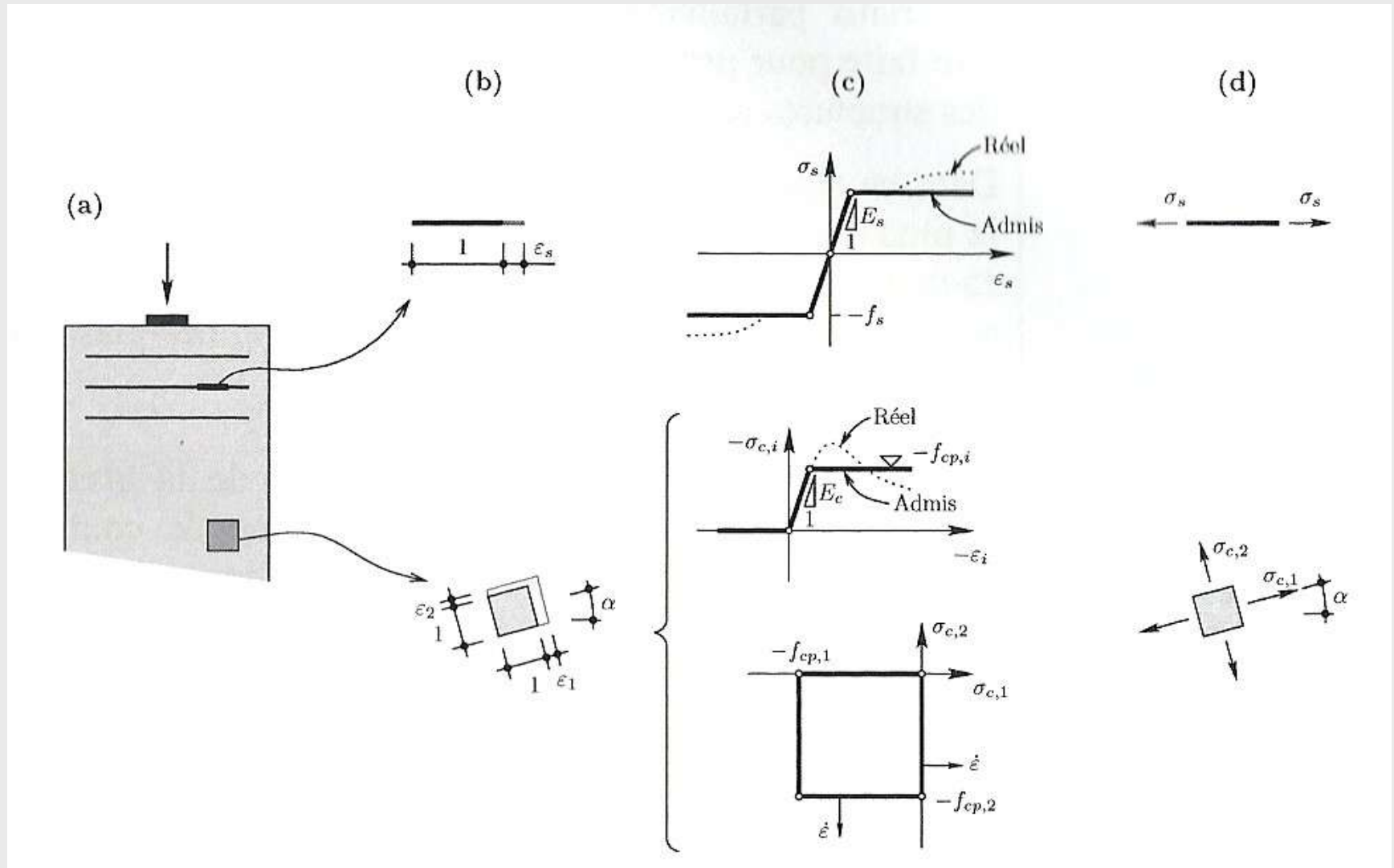
$$\sigma_{s,d} \leq f_{sd} = \frac{f_{sk}}{\gamma_s}$$

Ancrage



Créditos da Ilustração: Prof. Dr. Miguel Fernandez Ruiz

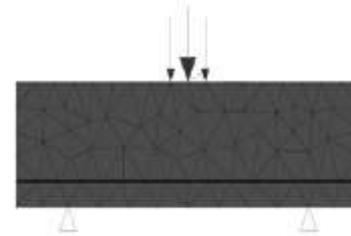
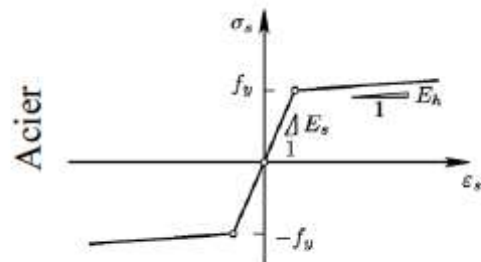
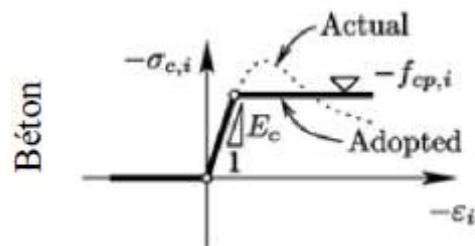
# Comportamento Elástico-Plástico



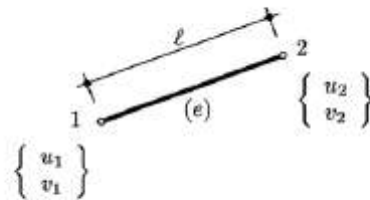
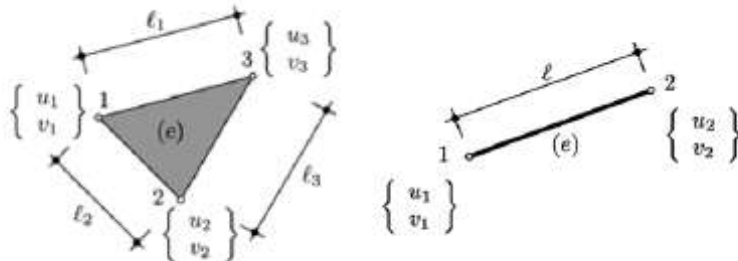


# Applet iCONC

## Modélisation de l'élément avec champs de contraintes continus élastiques-plastiques



- Traction
- Compression
- Affaiblissement du béton

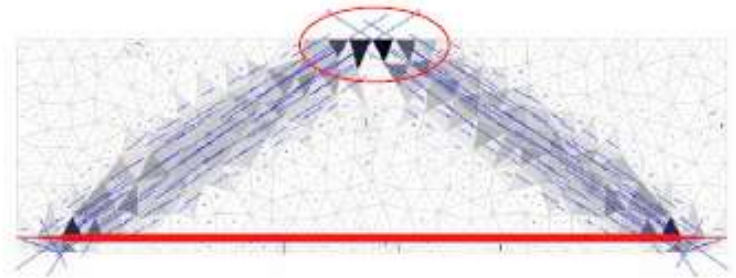
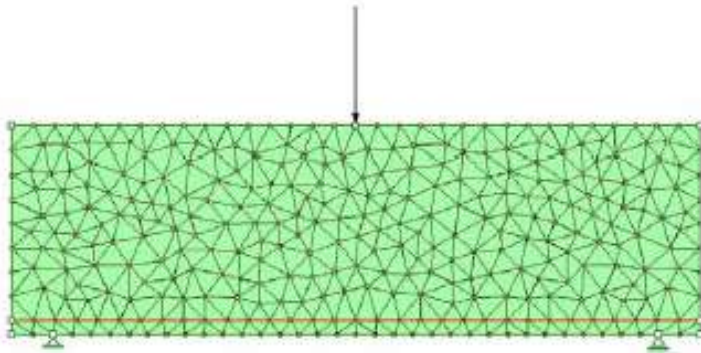


## Caractéristiques principales de l'applet

- Modélisation 2D
- Comportement élastique-plastique des matériaux
- Résistance à la traction du béton négligée
- Résistance du béton  $f(\text{déformation transversale})$
- Engrainement des granulats négligé
- Ancrage parfait des armatures

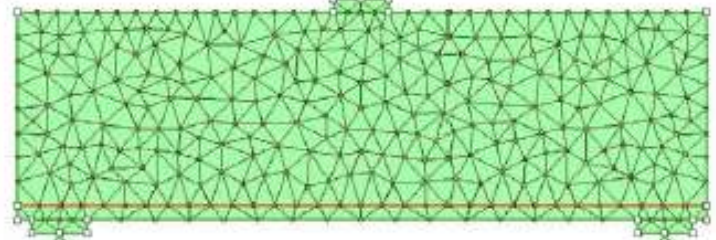
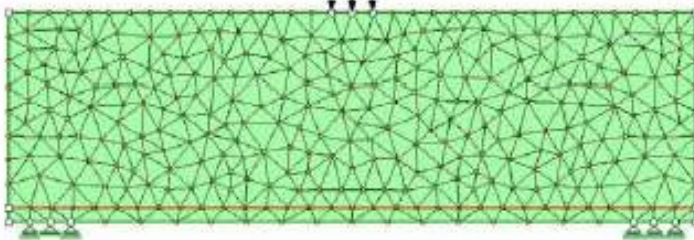
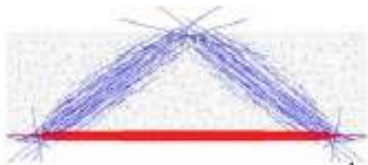
# Applet iCONC

Rupture liée à l'introduction de la force  
*problème dans la modélisation!*



Pour résoudre ce problème?

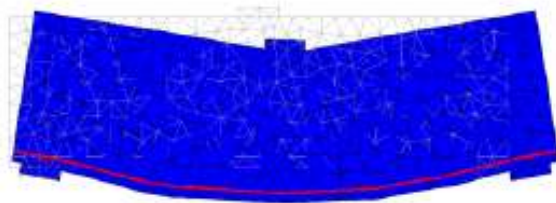
*Introduction de plaque (en acier  
avec comportement élastique) et/ou  
répartition des forces sur plus  
d'éléments*



# Applet iCONC

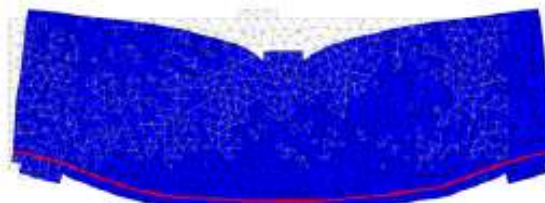
Écoulement des armatures

*flexion dans le cas de  
la figure ci-dessous*

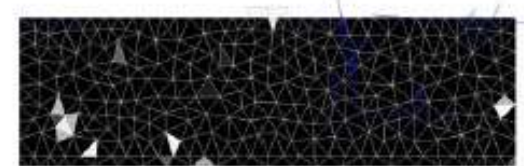


Rupture du béton

*effort tranchant dans le cas de  
la figure ci-dessous*



Divergence du calcul!





# Applet iCONC

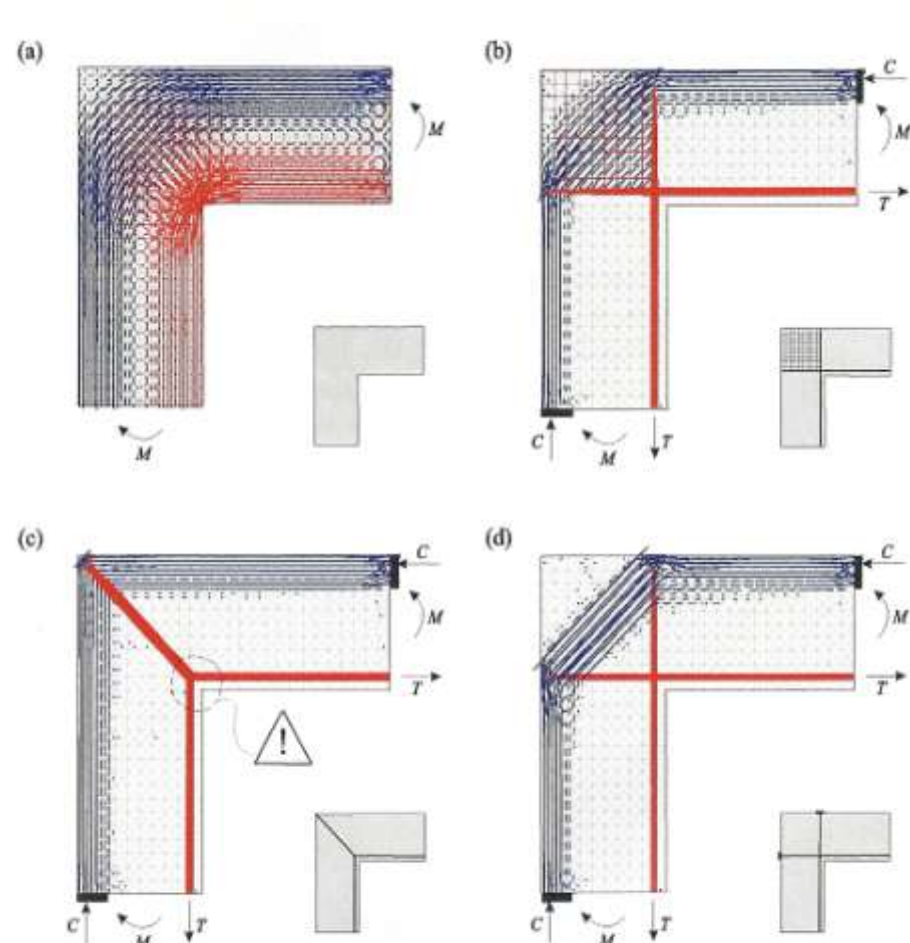


Figure 4.7: Angle de cadre avec traction à l'intérieur : (a) champ de contraintes élastique-linéaire ; (b) champ de contraintes élastique-fissuré ; et (c,d) variantes d'armature

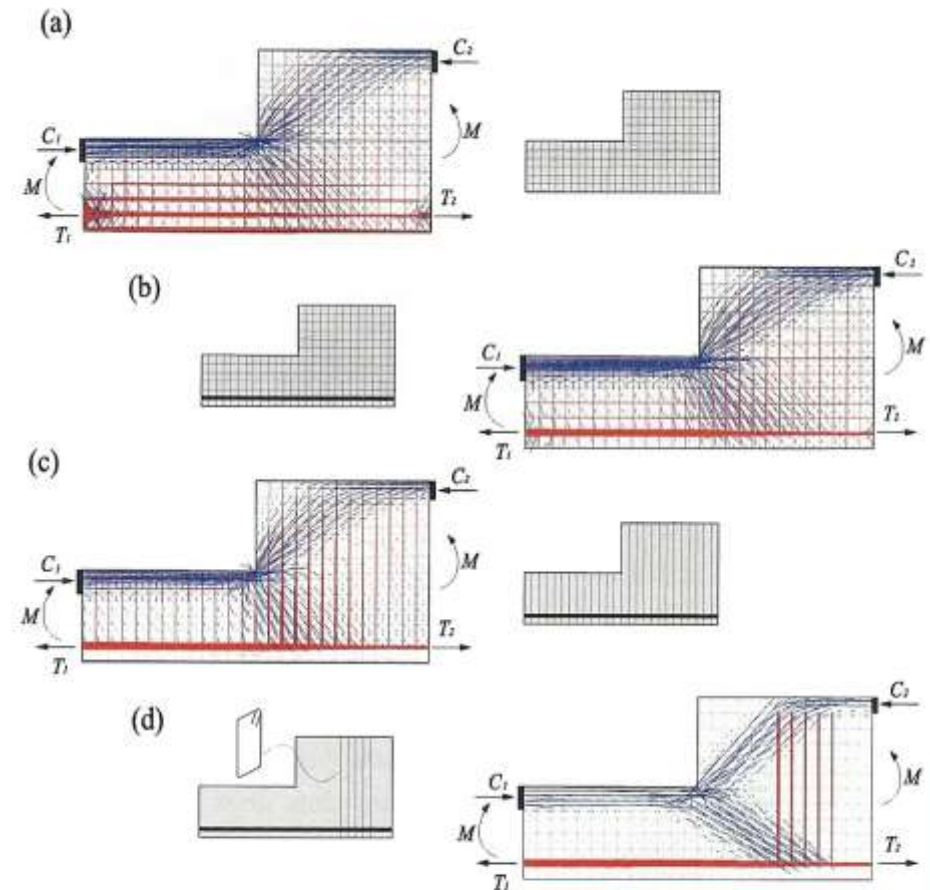


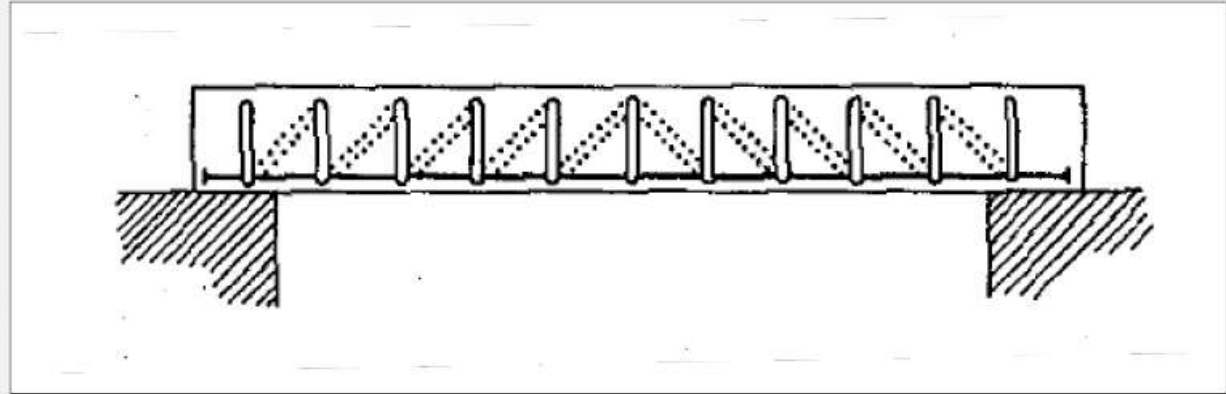
Figure 4.3: Élément avec discontinuité géométrique dans la zone comprimée : (a) champ de contraintes élastique-fissuré avec armature minimale distribuée ; (b-c) détermination de l'armature nécessaire ; et (d) disposition finale des armatures

# ***Método das Bielas***

# Introdução



Wilhelm Ritter – *Der Bauweise Hennebique* (1899)



## PRIMER MODELO DE BIELAS Y TIRANTES –

Característica principal del método: Es un método de análisis basado exclusivamente en el equilibrio. Su aplicación no requiere el planteamiento de ecuaciones de compatibilidad y, en cuanto a los materiales, sólo es necesario conocer la tensión de agotamiento pero no la ecuación constitutiva completa.



Emil Mörsch

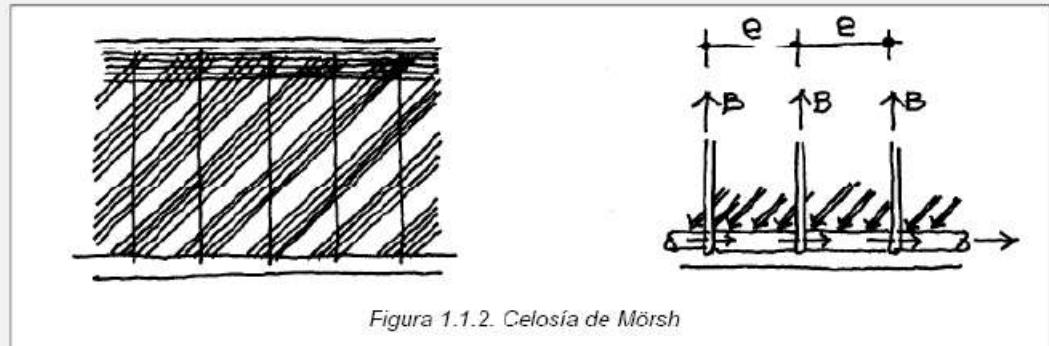


Figura 1.1.2. Celosía de Mörsch

## CONCEPTO DE CAMPO DE COMPRESIONES

Exemplos Práticos:

ACI SP-208

ACI Second SP

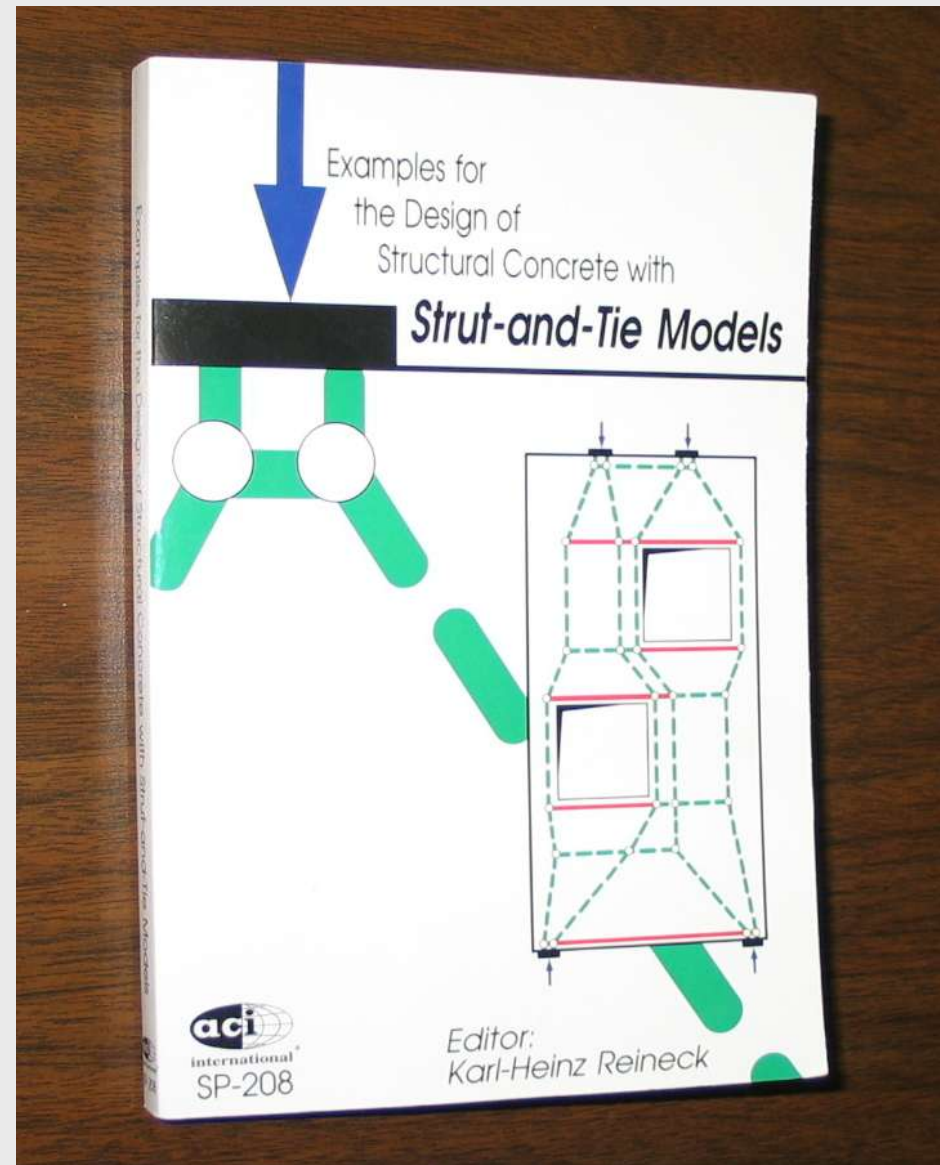
fib Examples

Livros

Journal Papers

fib Bulletin 3

FIP Practical Design  
of Structural Concrete



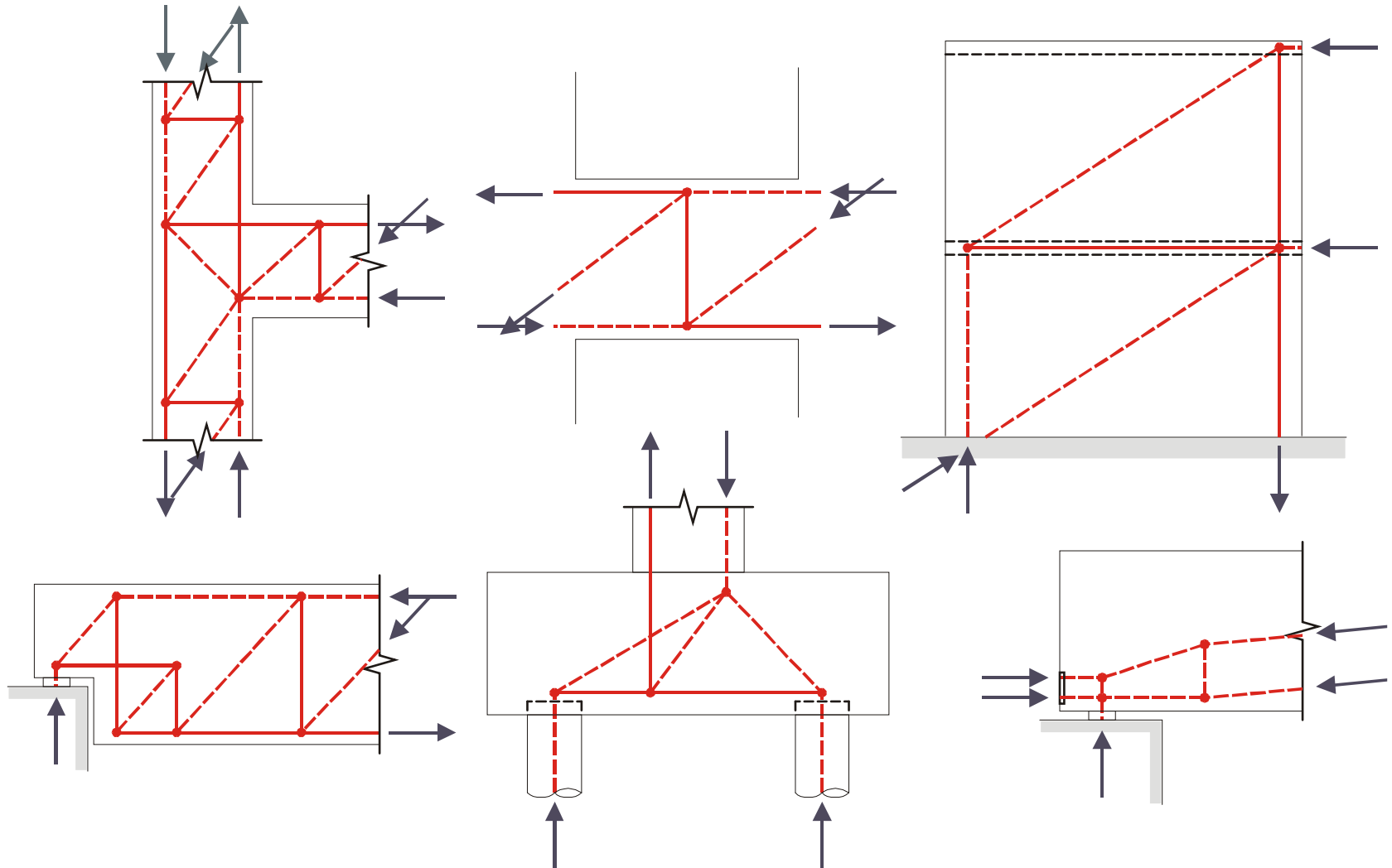
# Prática Profissional

Vigas Sujeitas à Torção e Força Cortante;  
Armadura de Costura e de Suspensão;  
Cargas Próximas de Apoios e Nós de Pórtico;  
Dimensionamento de Consolos e Dentes;  
Dimensionamento de Vigas-Parede;  
Dimensionamento de Blocos e Sapatas;  
Regiões de Aplicação de Protensão;  
Cálice de Fundação;  
Conexão de Lajes Cogumelo;  
Estruturas com Geometria Qualquer.



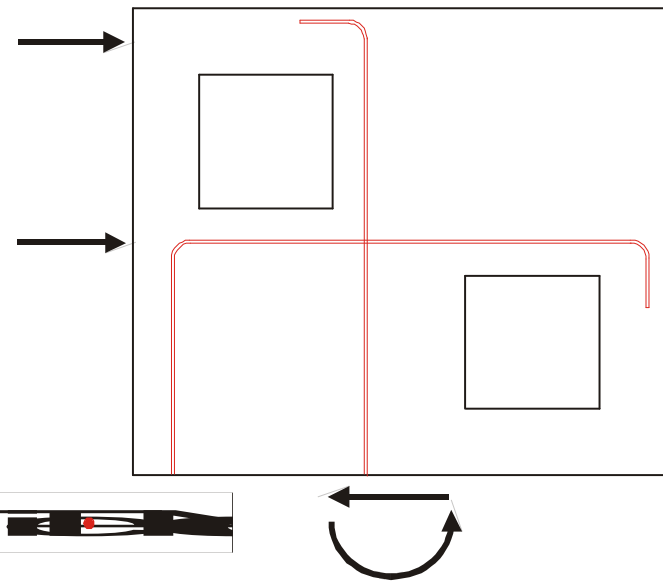
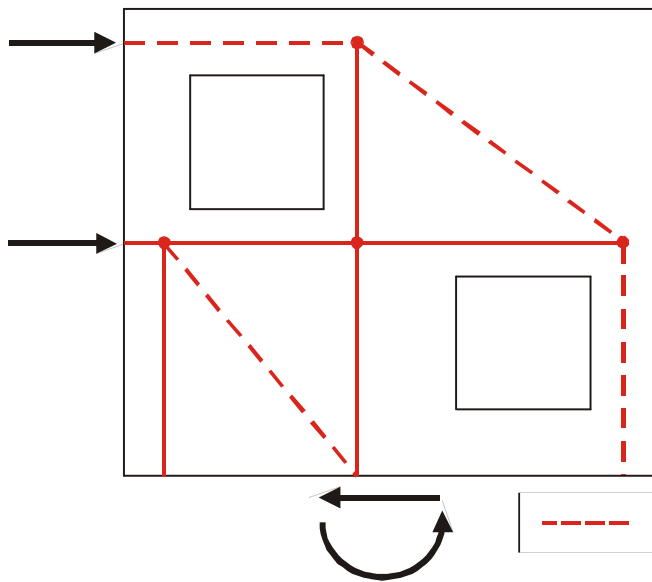
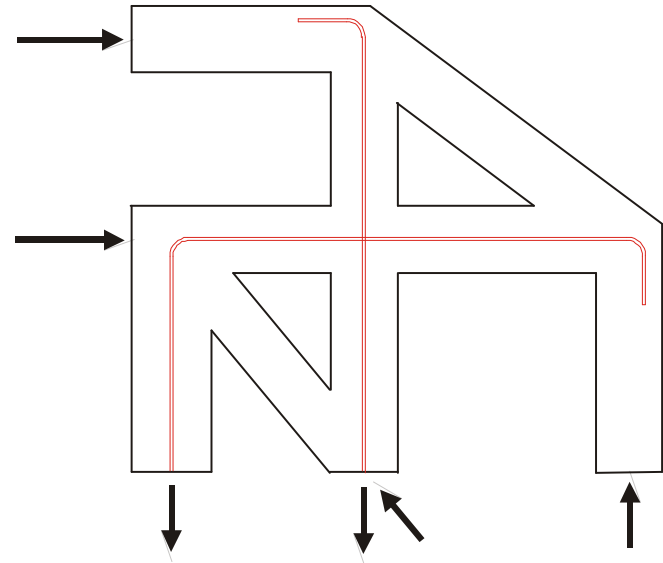
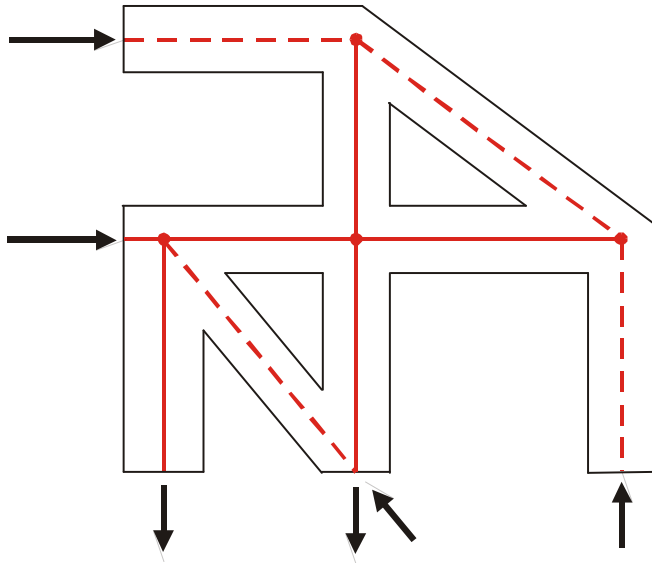
# Exemplos

Créditos da Ilustração: Prof. Dr. Daniel Kuchma

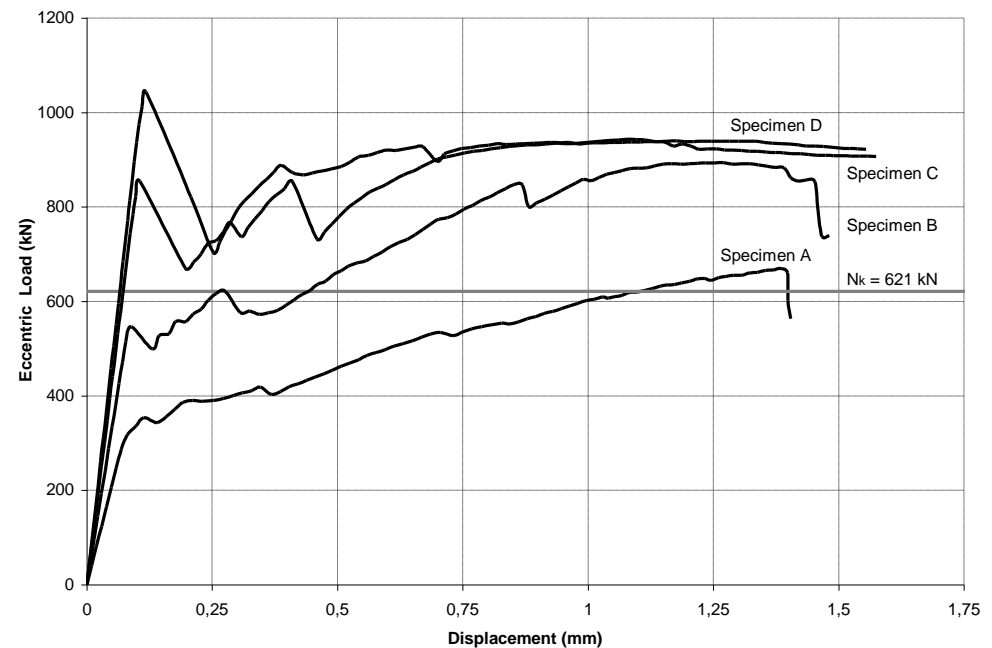
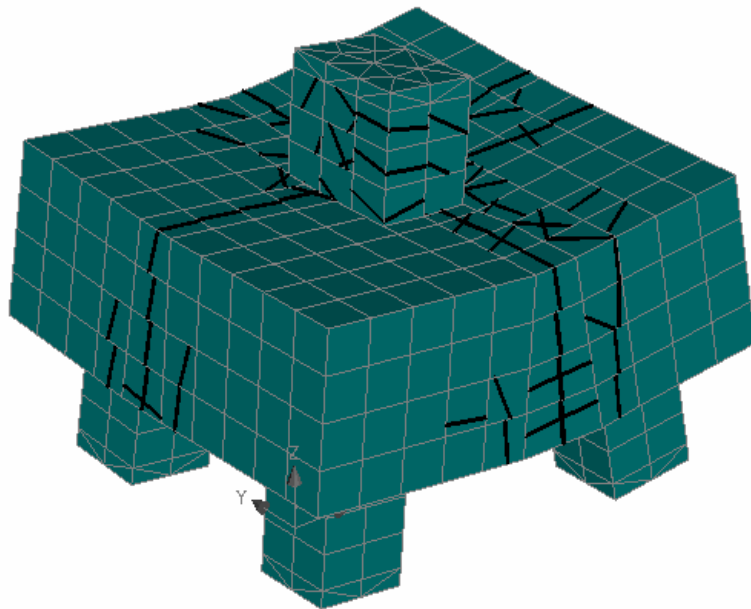
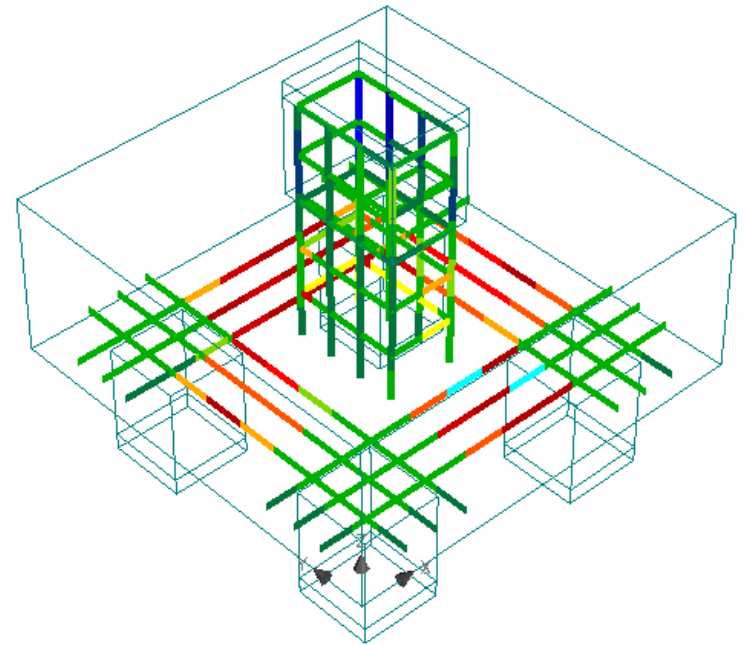
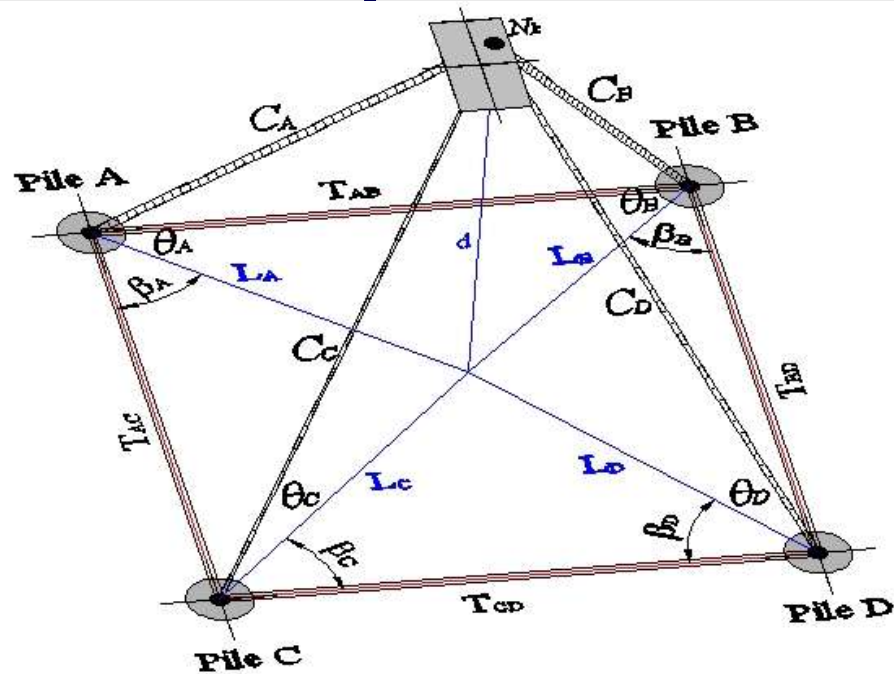


# Exemples

Créditos da Ilustração: Prof. Dr. Daniel Alexander Kuchma



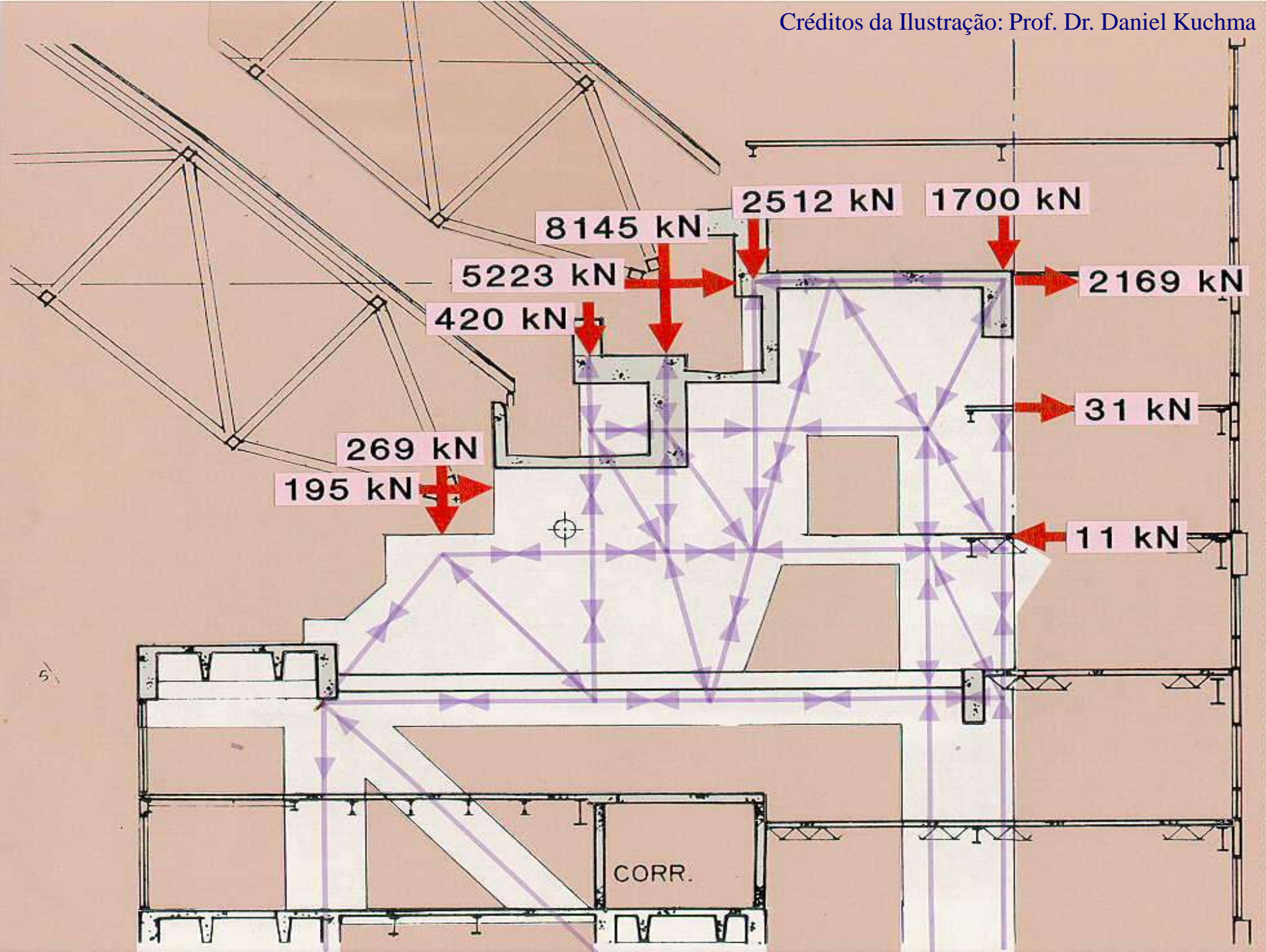
# Exemplo de Modelo de Escoras e Tirantes



# Toronto Sky Dome

PENTHOUSE LEVEL  
 ELEV. 28.850  
 -  
 -#8  
 ELEV. 25.250  
 -  
 -#10  
 ELEV. 23.250  
 -  
 -#9  
 ELEV. 19.250  
 -  
 -#8  
 ELEV. 16.250  
 -  
 -#7  
 ELEV. 13.250  
 -  
 -#6  
 ELEV. 10.250  
 -  
 -#5  
 ELEV. 07.250  
 -  
 -#4  
 ELEV. 04.250  
 -  
 -#3  
 ELEV. 00.850  
 -  
 -#2  
 ELEV. 37.850  
 -  
 -#1  
 ELEV. 34.850  
 -

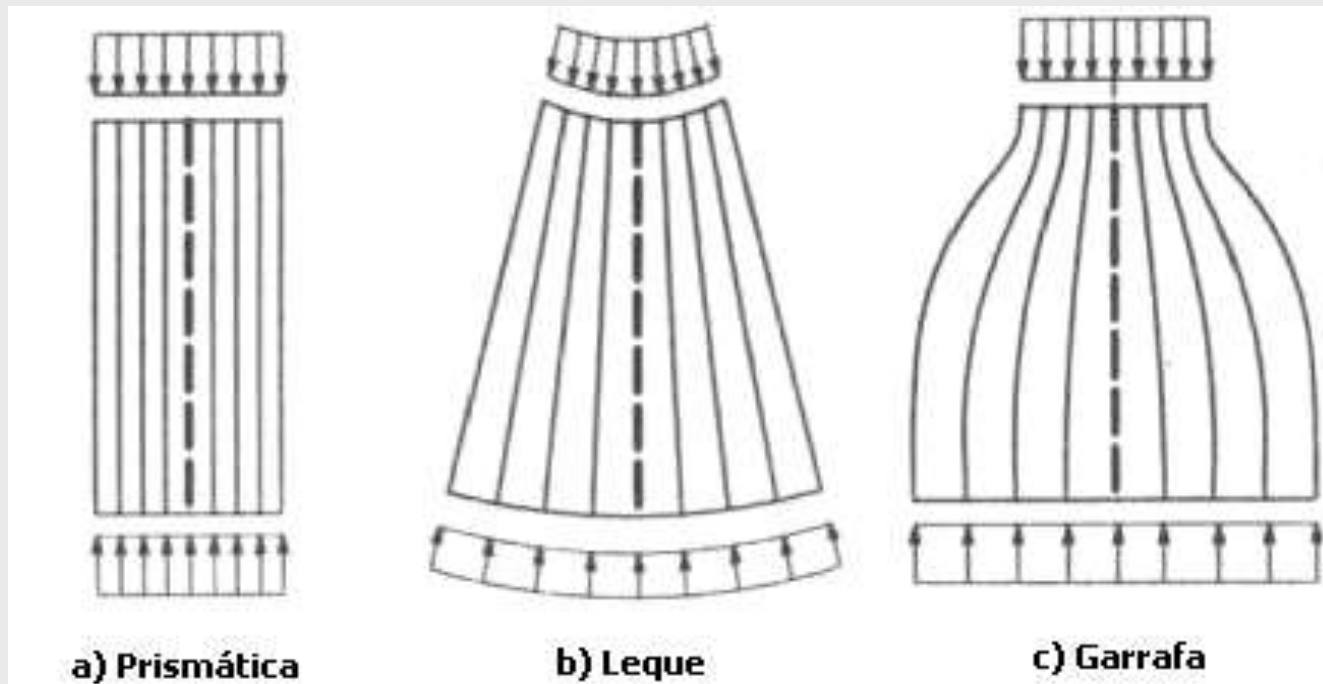




# Resistência das Escoras

✓ Deve ser mantido um nível de tensão adequado para as escoras, de maneira a evitar fissuração ou ruína:

$$f_e = v.f_c$$



# ACI Code Provisions for Design using the STM

## ■ Struts -- Compression Members

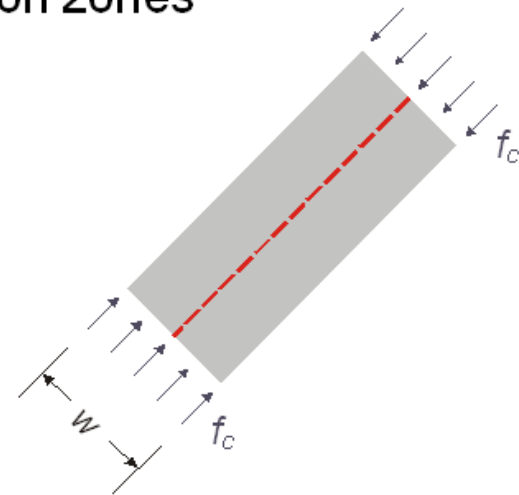
■ Design Strength of Struts =  $\phi F_{ns}$  where  $F_{ns} = f_{cs} \times A_{cs}$

$$f_{cs} = 0.85 \cdot \beta_s \cdot f'_c$$

- ❑  $\beta_s = 1.00$  for prismatic struts in uncracked compression zones
- ❑  $\beta_s = 0.75$  when struts may be bottle shaped and crack control reinforcement\* is included
- ❑  $\beta_s = 0.60$  when struts may be bottle shaped and crack control reinforcement\* is not included
- ❑  $\beta_s = 0.40$  for struts in tension members
- ❑  $\beta_s = 0.60$  for other cases

\*crack control reinforcement requirement is  $\sum \rho_{vi} \sin \gamma_i \geq 0.003$

■  $\phi = 0.75$  for all elements of truss



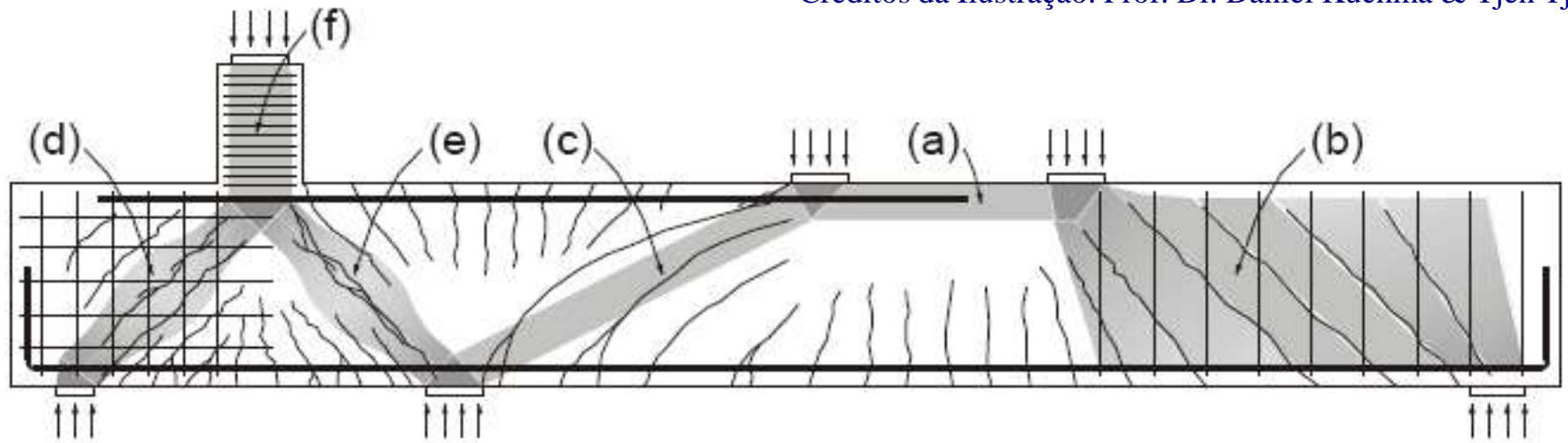
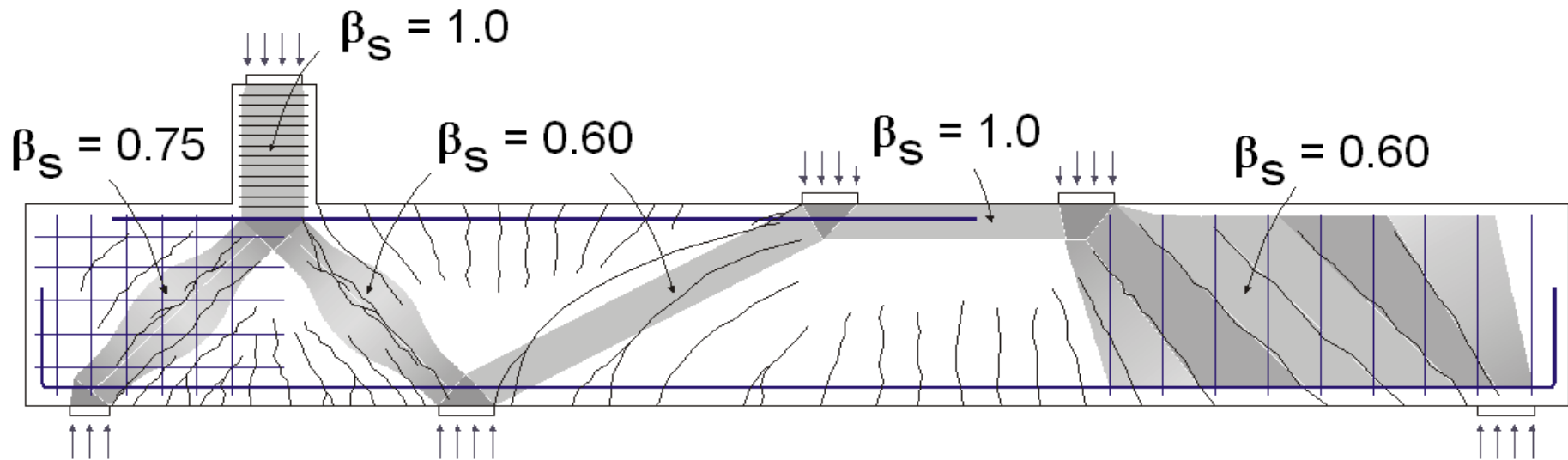


Fig. 11—Types of struts in discontinuity region: (a) prismatic in uncracked field; (b) prismatic in cracked field where struts are parallel to cracks; (c) prismatic in cracked field where struts are not parallel to cracks; (d) bottle-shaped with crack control reinforcement; (e) bottle-shaped without crack control reinforcement.



ACI: Compressive Stress Limit  $f_{cs} = 0.85\beta_s f'_c$



# Resistência das Escoras: SOUZA (2004)

✓ Proposta elaborada a partir do enquadramento das expressões julgadas mais relevantes, obtidas na literatura:

$$f_e = 0,63.f_{ck}$$

escoras prismáticas

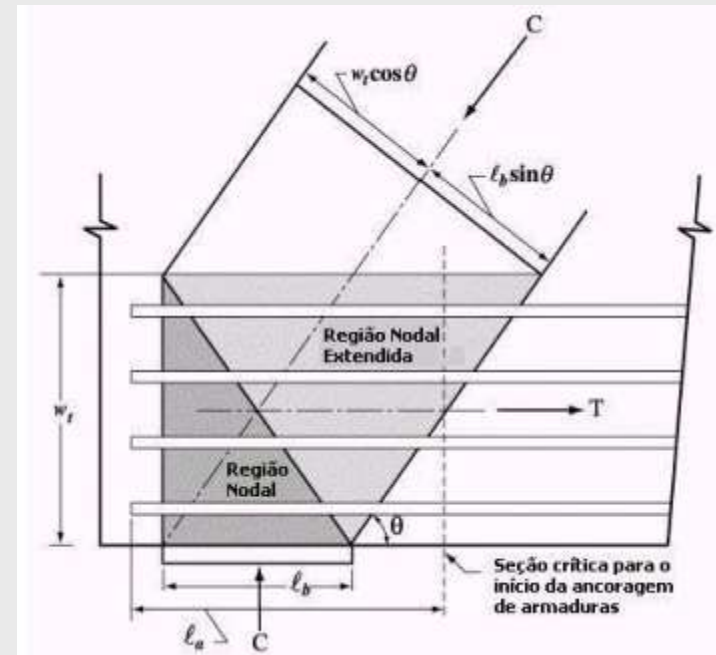
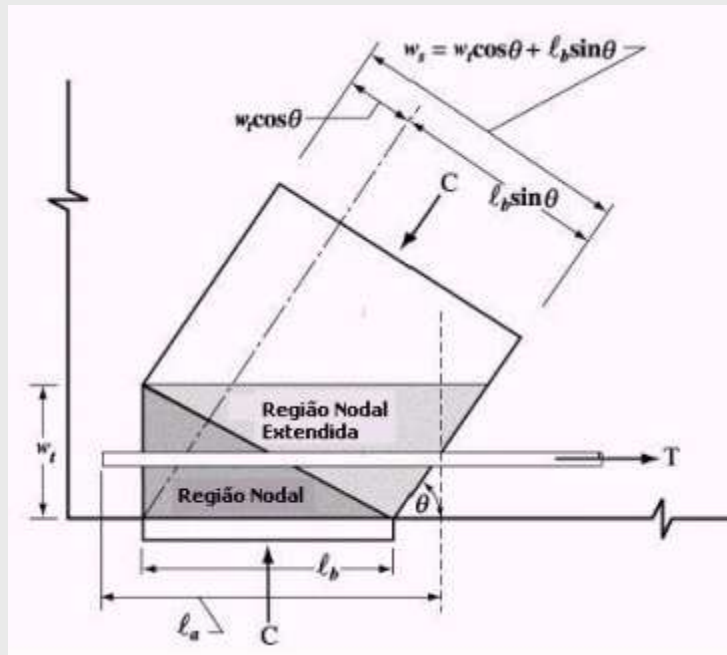
$$f_e = 0,48.f_{ck}$$

escoras do tipo garrafa atravessadas por tirantes

# Resistência dos Tirantes

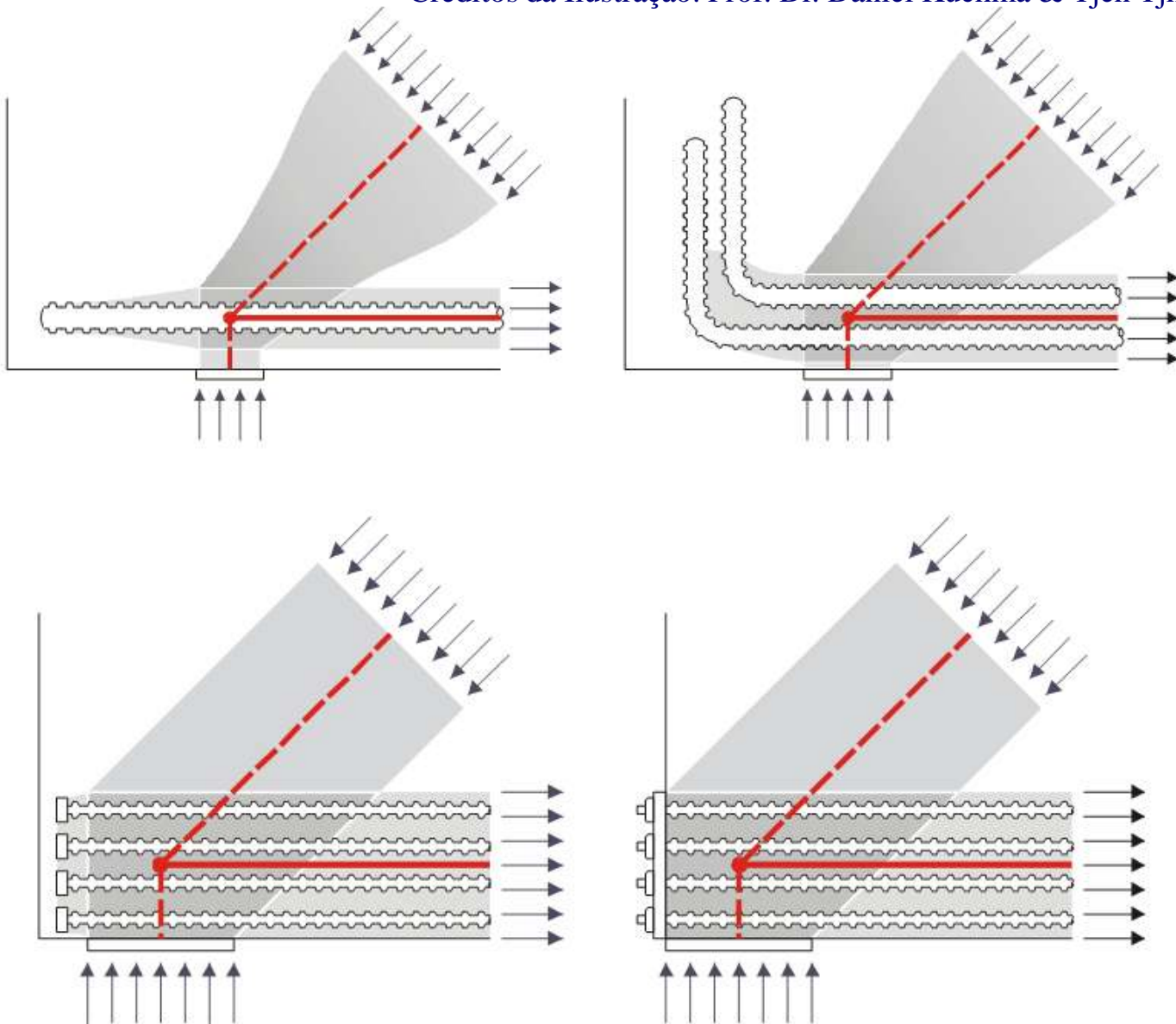
$$A_s = \frac{\gamma_f \cdot R_{st}}{f_{yd}} \rightarrow \text{Para o dimensionamento de tirantes de aço;}$$

$$A_c = \frac{\gamma_f \cdot R_{st}}{f_{td}} \rightarrow \text{Para o dimensionamento de tirantes de concreto.}$$



# Ancoragem dos Tirantes

Créditos da Ilustração: Prof. Dr. Daniel Kuchma & Tjen Tjin



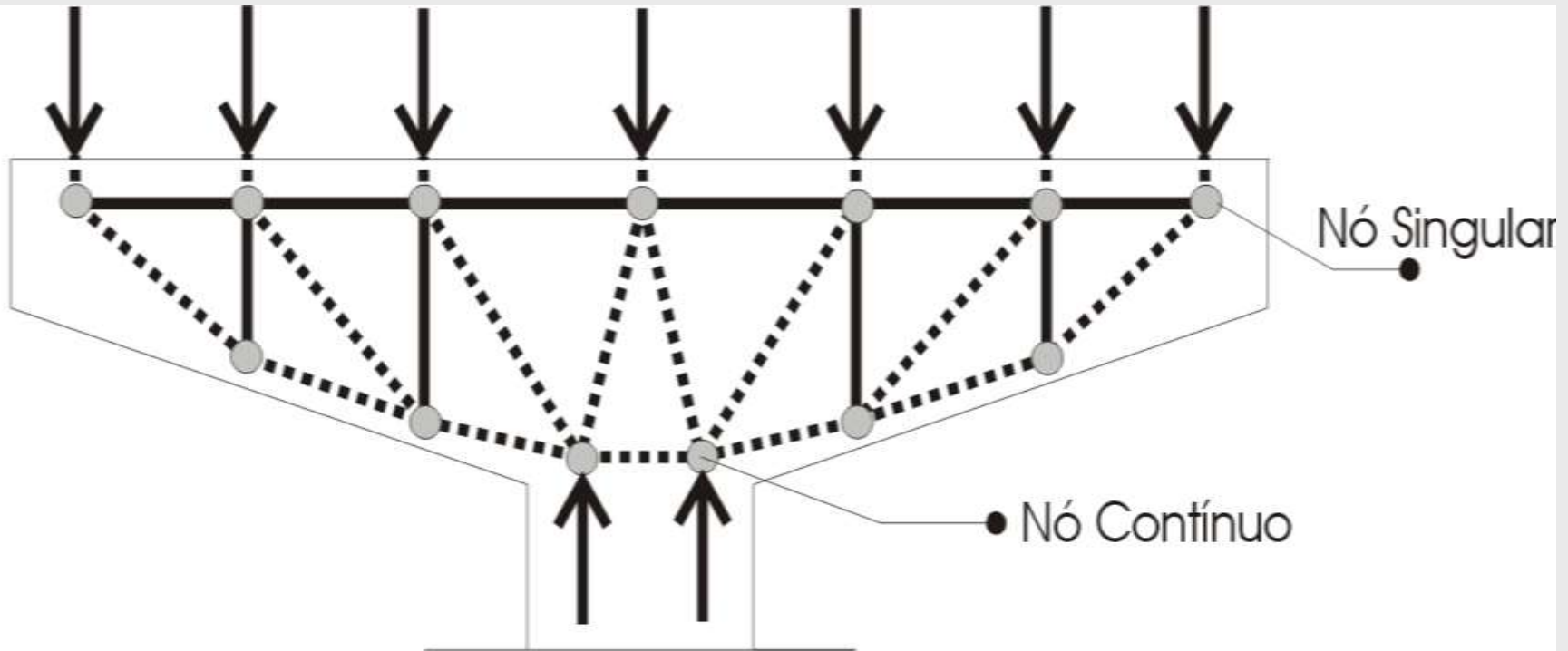
# Ancoragem dos Tirantes



**Ancoragem Mecânica de Tirantes em Vigas de Transição – Wanderlan Paes – Salvador (BA)**



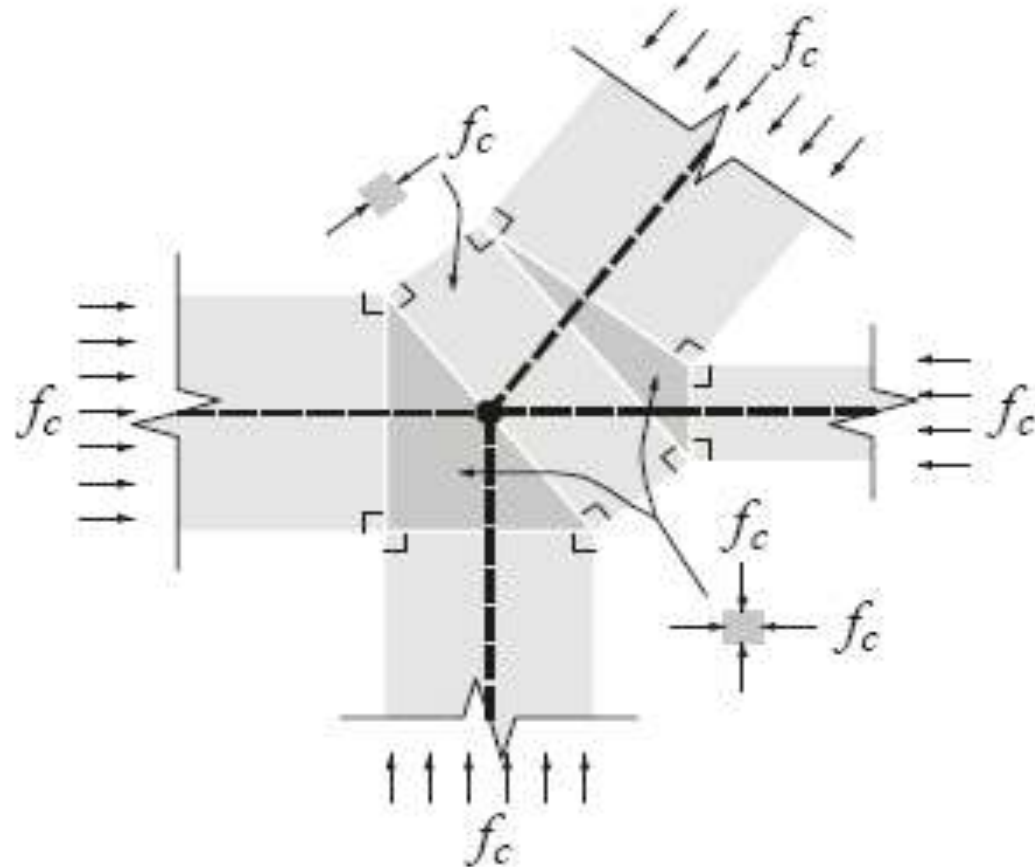
# Tipos de Regiões Nodais



Ainda de acordo com Schäfer; Schlaich (1988, 1991), uma vez que os nós singulares são oriundos de “garrafas” de tensão, pode-se assumir que uma “Região D” estará inteiramente segura se a pressão abaixo da placa de apoio mais carregada ou da placa de ancoragem for menor do que  $0,6 f_{cd}$  e se todas forças de tração significantes são resistidas por armaduras em condições adequadas de ancoragem.

# Tensões nas Regiões Nodais

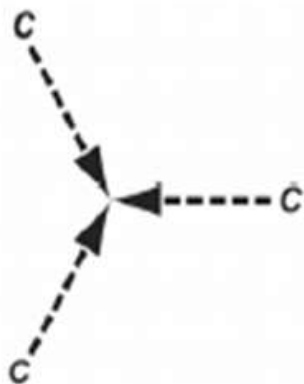
Créditos da Ilustração: Prof. Dr. Daniel Kuchma & Tjen Tjhin



*Fig. 9—Arrangement of CCC node of Fig. 8(a) that comprises two hydrostatic nodes of triangular shape and short prismatic strut.*

# ACI Code Provisions for Design using the STM

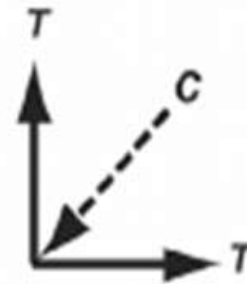
- Nodal Zones (Joints)
- Design Strength of Each Nodal Zone Face =  $\phi F_{nn}$  where  $F_{nn} = f_{cn} \times$  Area on Face of Nodal Zone perpendicular to the line of action of the associated strut or tie force. Again  $f_{cn} = 0.85 \cdot \beta_n \cdot f'_c$ 
  - $\beta_n = 1.00$  in nodes bounded by struts and bearing areas
  - $\beta_n = 0.80$  in nodes anchoring a tie in one direction only
  - $\beta_n = 0.60$  in nodes anchoring a tie in more than one direction



(a) C-C-C Node



(b) C-C-T Node



(c) C-T-T Node



(d) T-T-T Node



# Resistência das Regiões Nodais: SOUZA (2004)

$$f_e = 0,58.f_{ck}$$

Nós circundados por escoras ou placas de apoio (CCC)

$$f_e = 0,46.f_{ck}$$

Nós ancorando um único tirante (CCT)

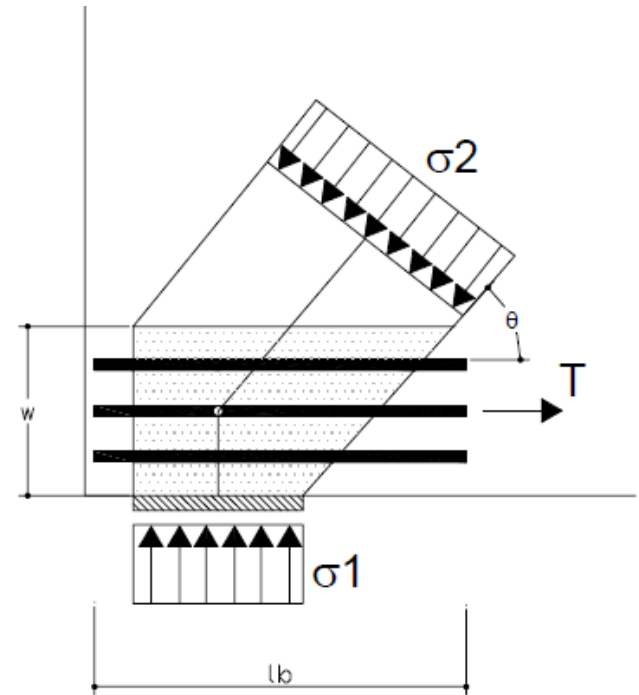
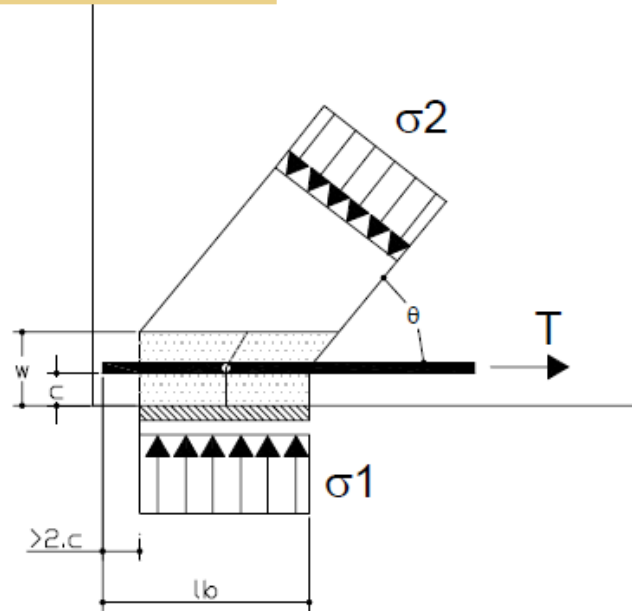
$$f_e = 0,40.f_{ck}$$

Nós ancorando vários tirantes (CTT)

# Nó N6 de Schlaich et al (1987) (Recomendações para Várias Situações)

$$\sigma_1, \sigma_2 \leq 0,8.f_{cd}$$

C2  
C1  
Nó N6

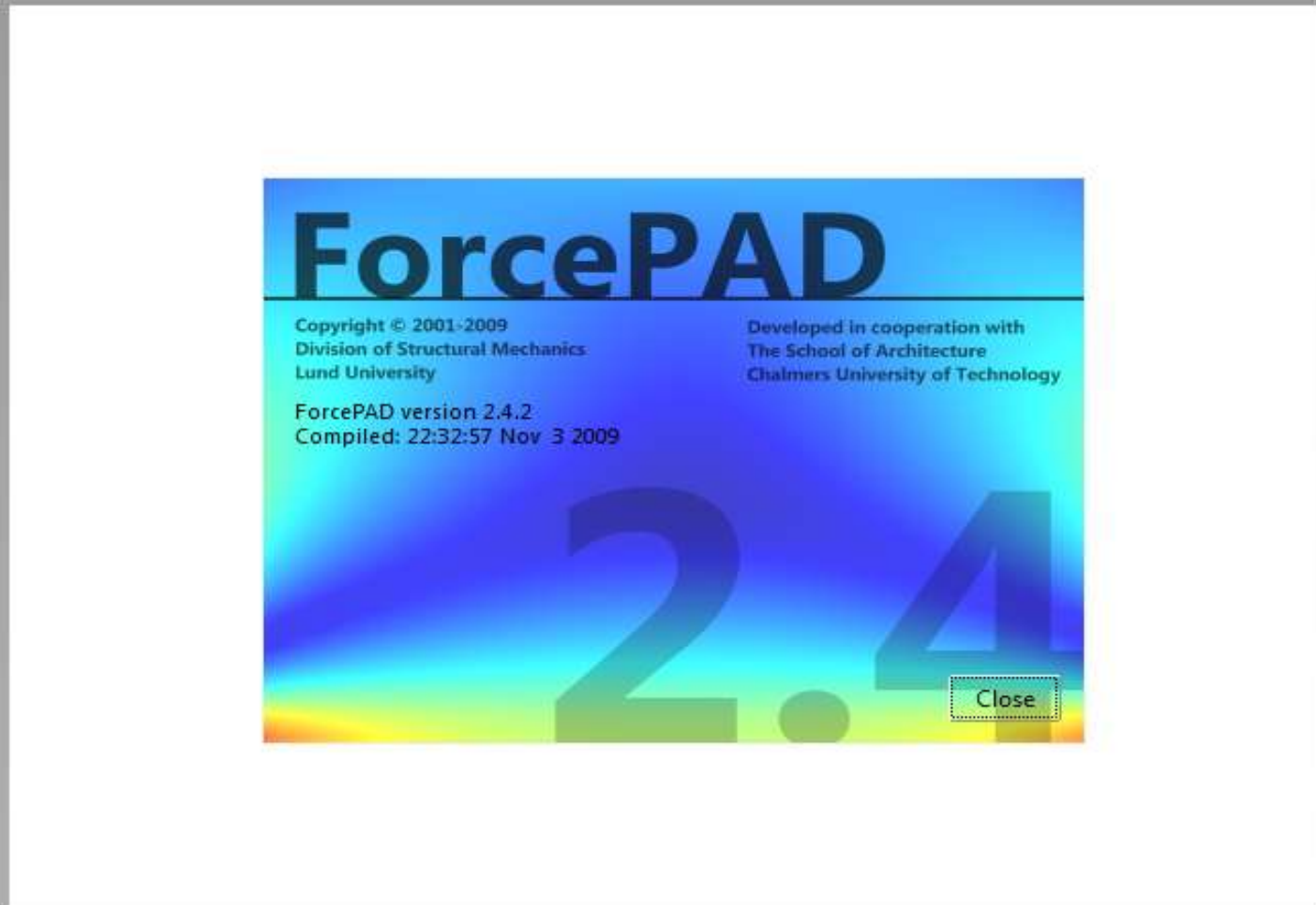


Nó CCT, típico de regiões de apoio. Em vigas-parede  
 $w \approx 0,15.h \leq 0,2.h \leq 0,2.l$

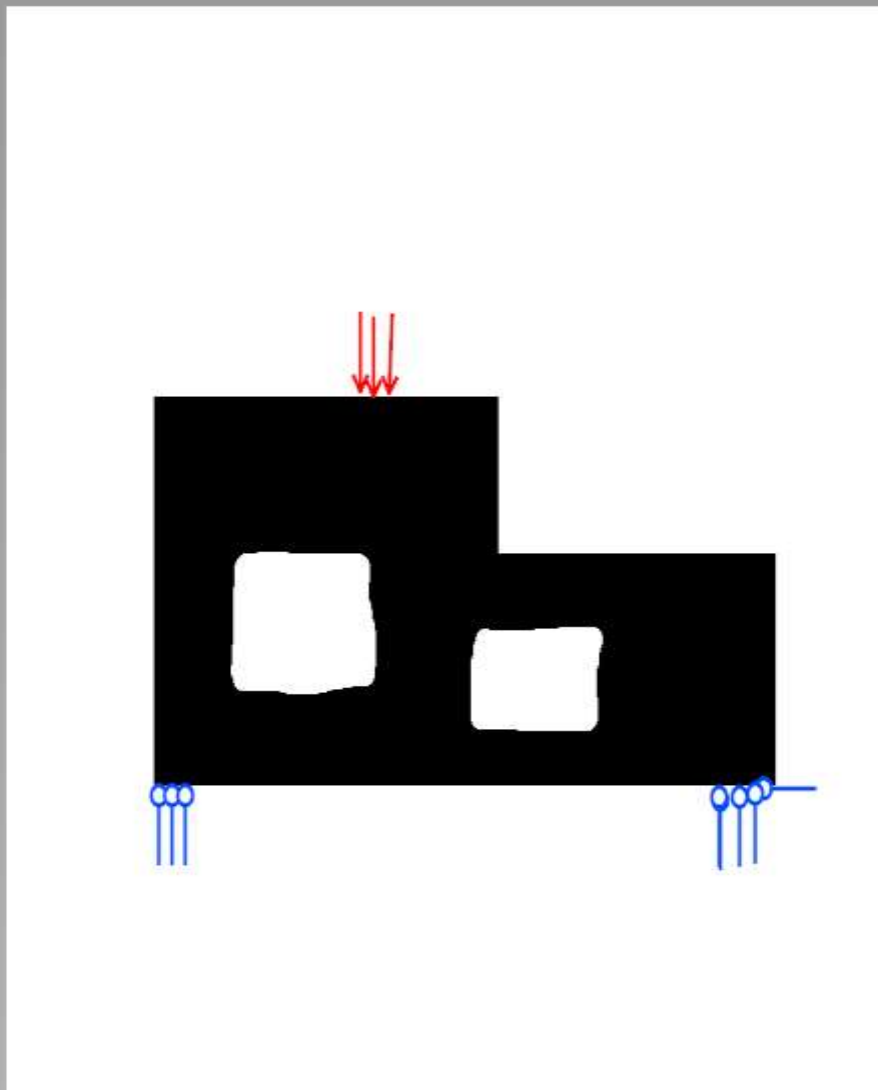
# Seleção de Modelos Adequados

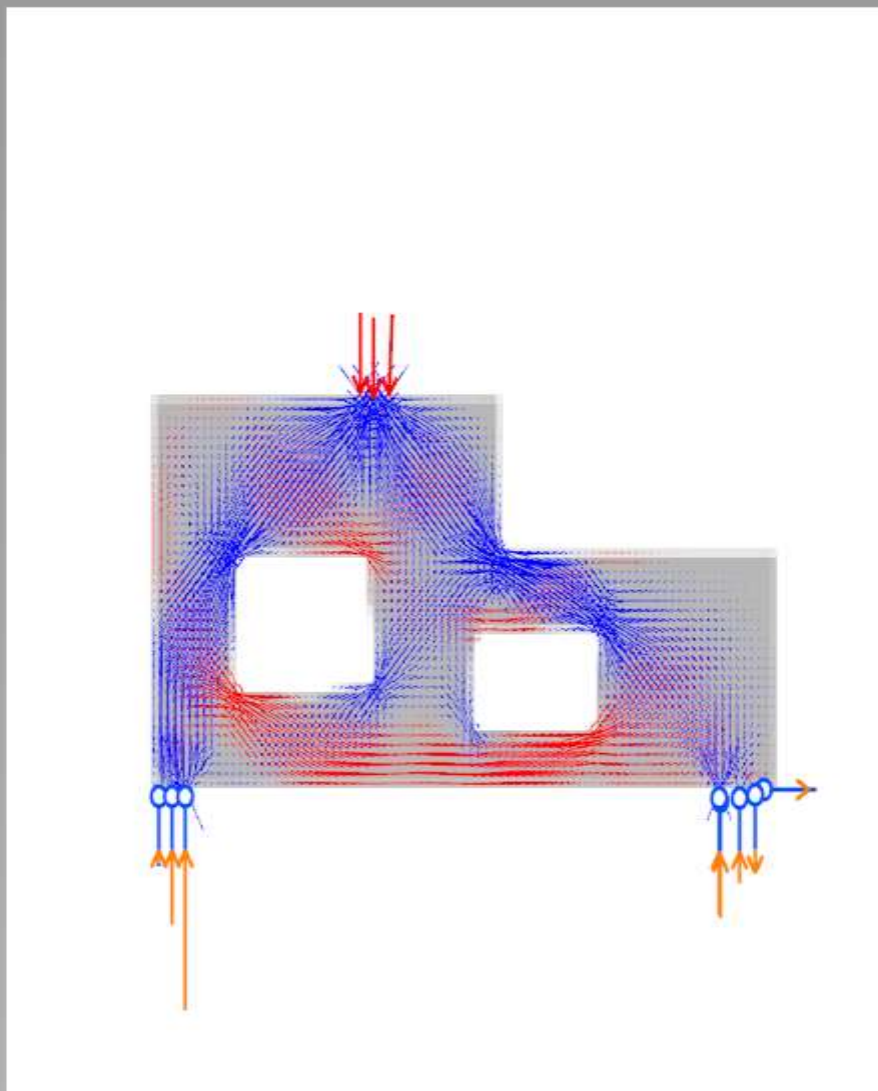
✓ Difícil conceber o melhor modelo de treliça que represente com eficiência os mecanismos de resistência de uma determinada estrutura:

Modelos padronizados;  
Caminho das cargas (“Load Path Approach”);  
Análises elásticas utilizando o MEF;  
Análises não-lineares (fissuração);  
Ensaaios experimentais;  
Processos de otimização.



<http://forcepad.sourceforge.net/download>

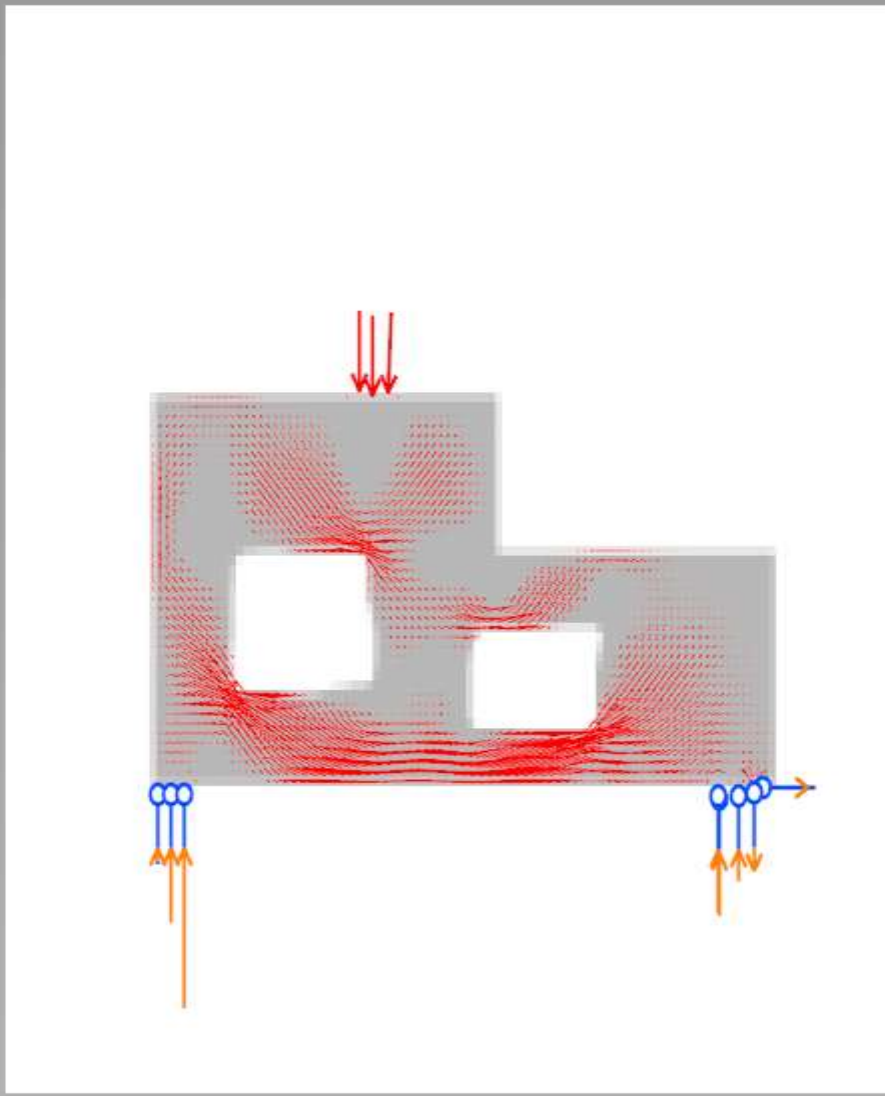
F (N)  
1000



Finished.

Stop



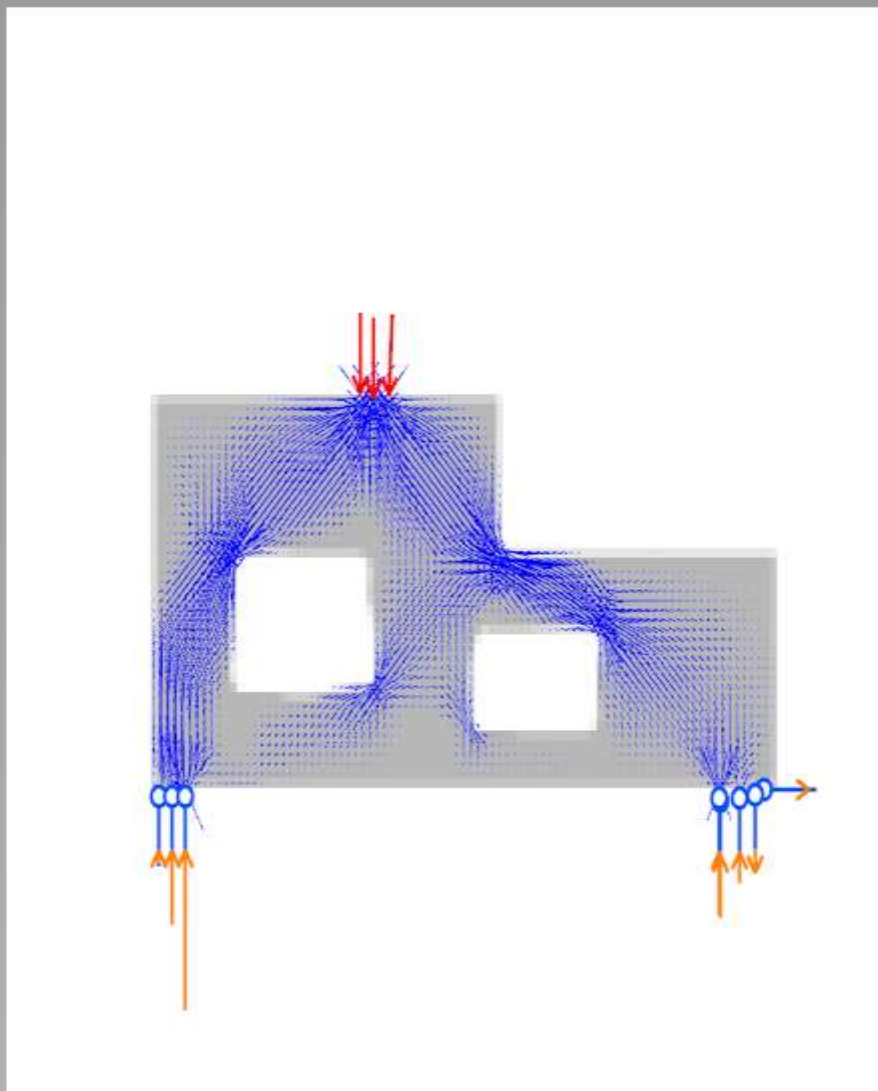


Finished.

Stop



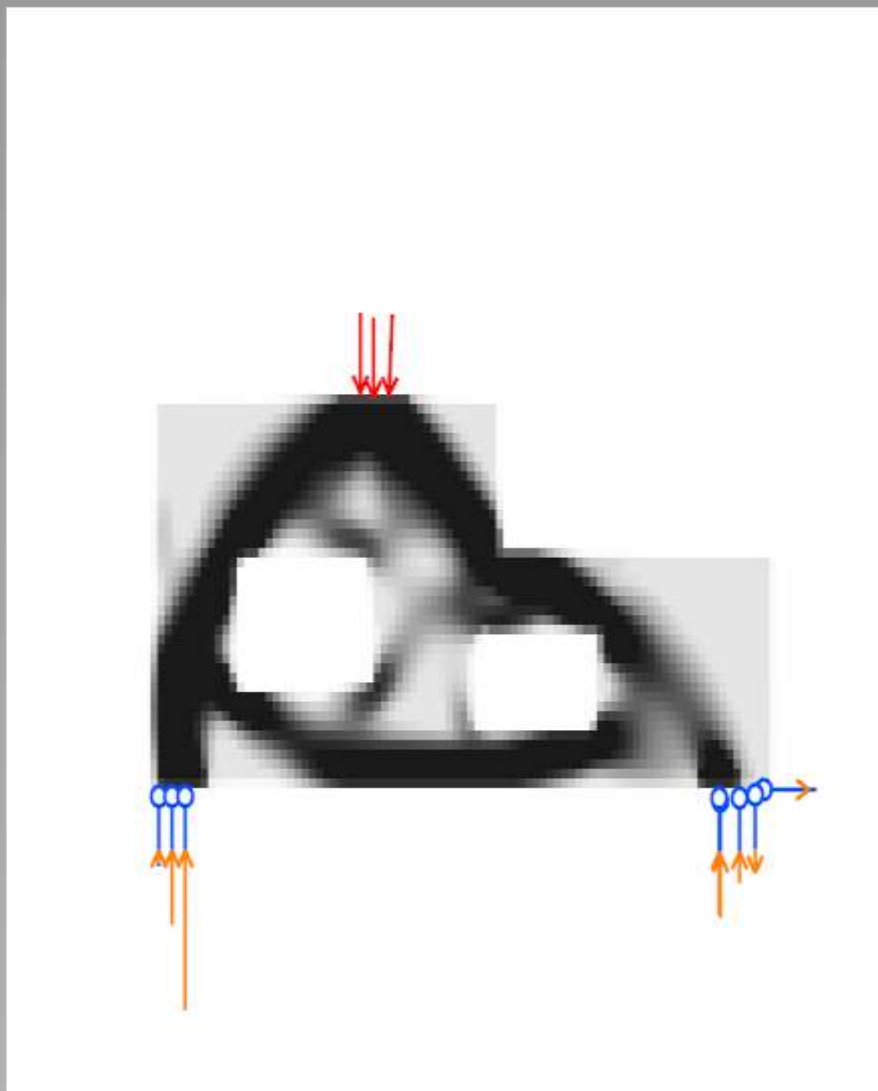




Finished.

Stop

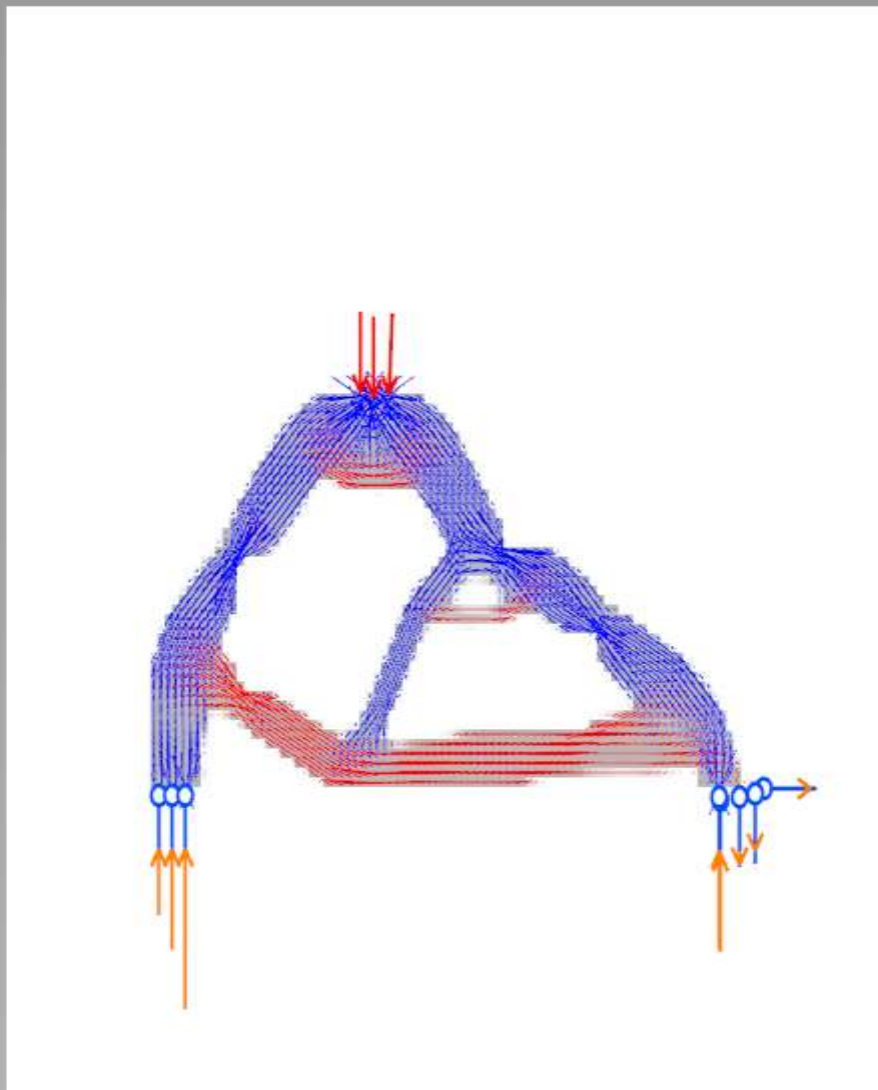




Objective function and sensitivity.

Stop



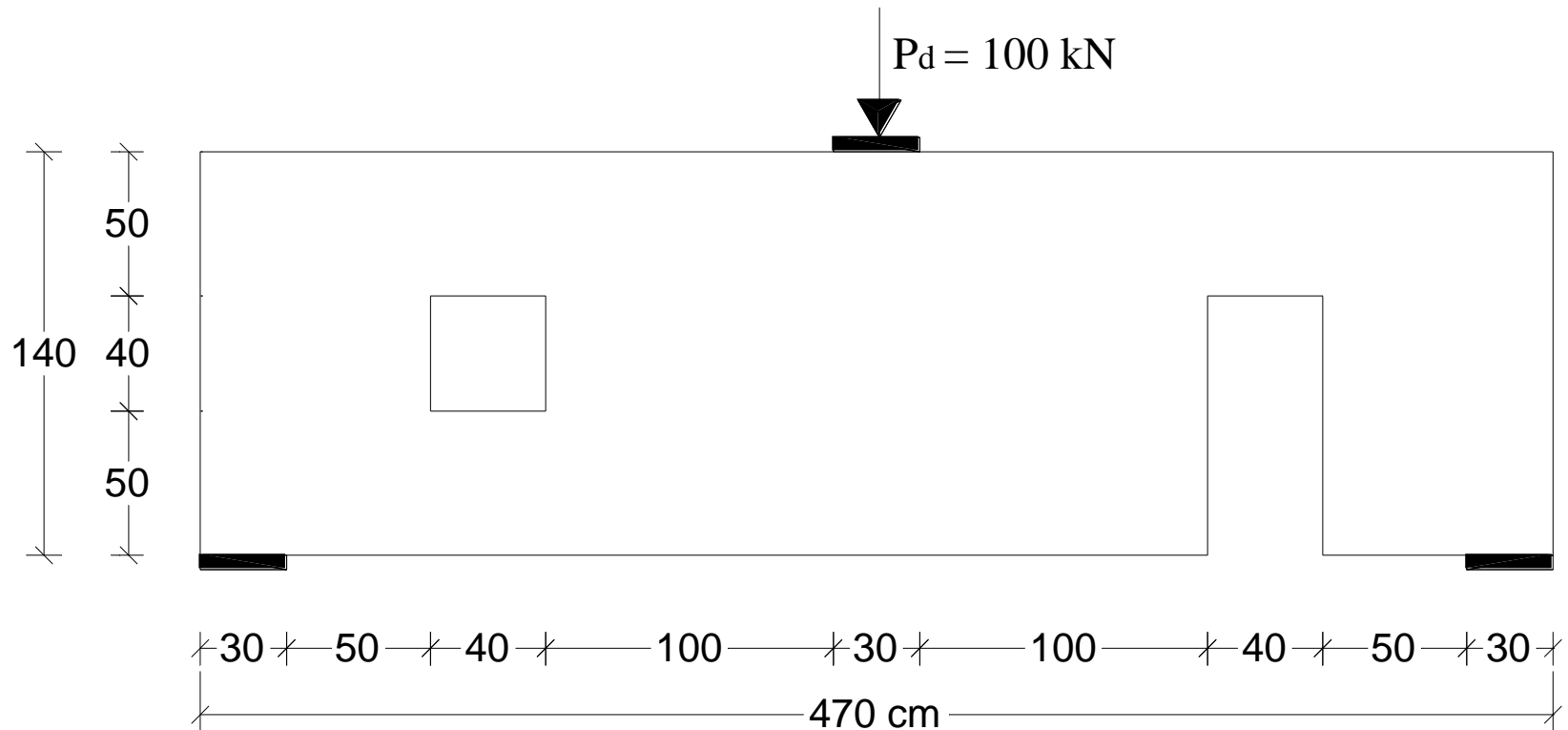


Finished.

Stop



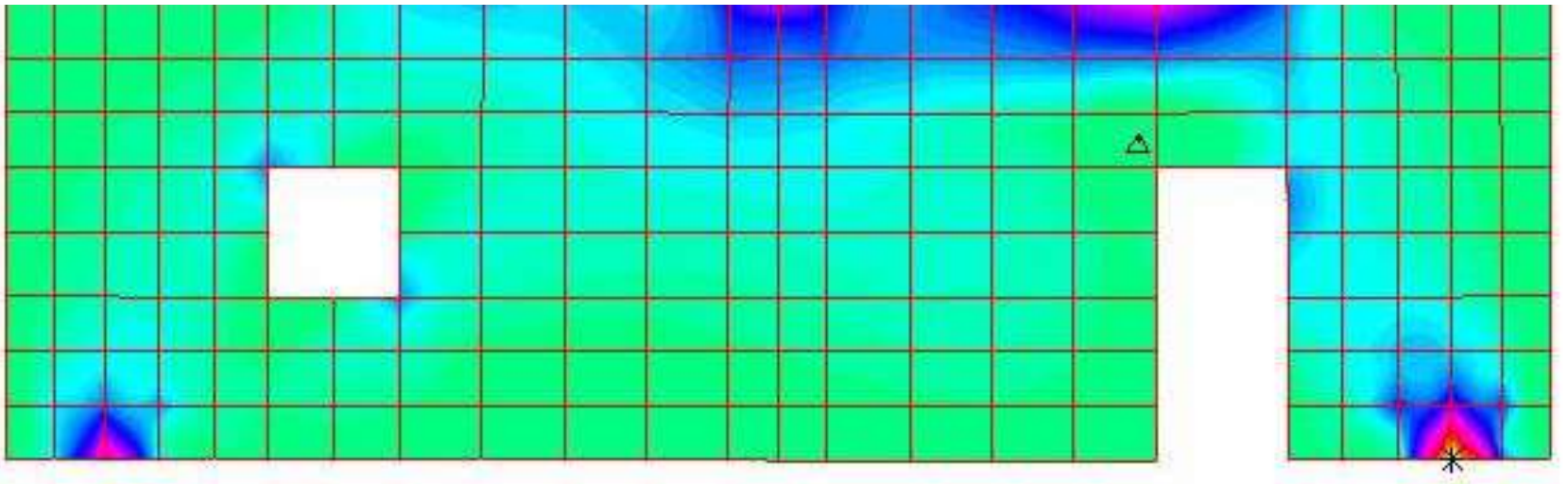
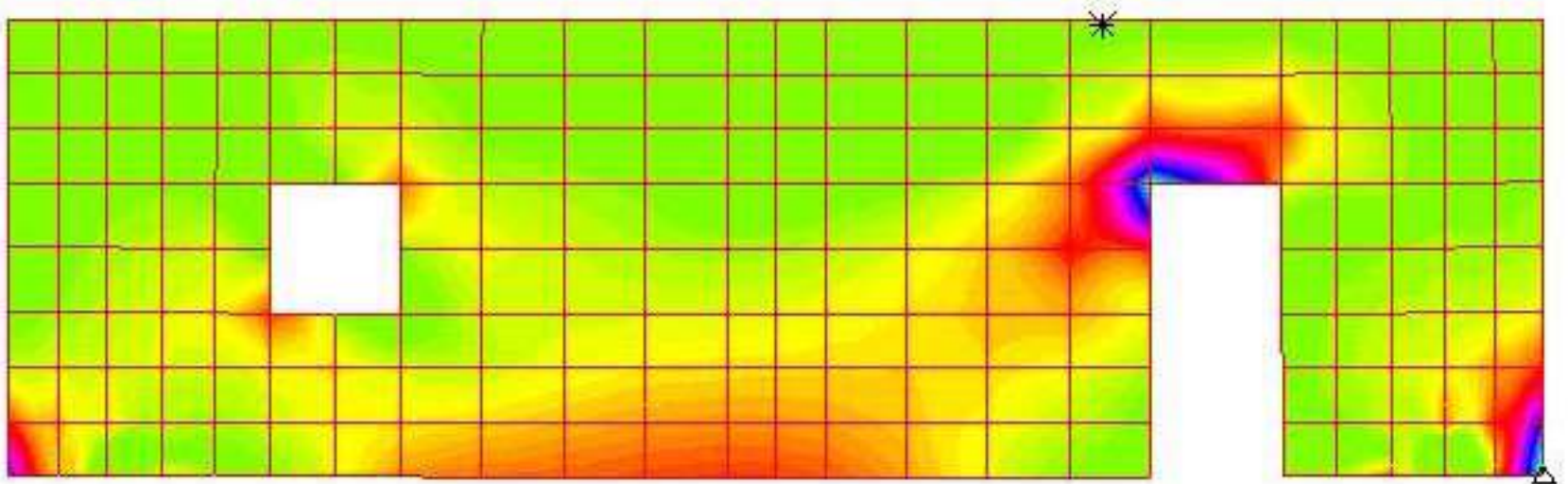
# Análise Elástica



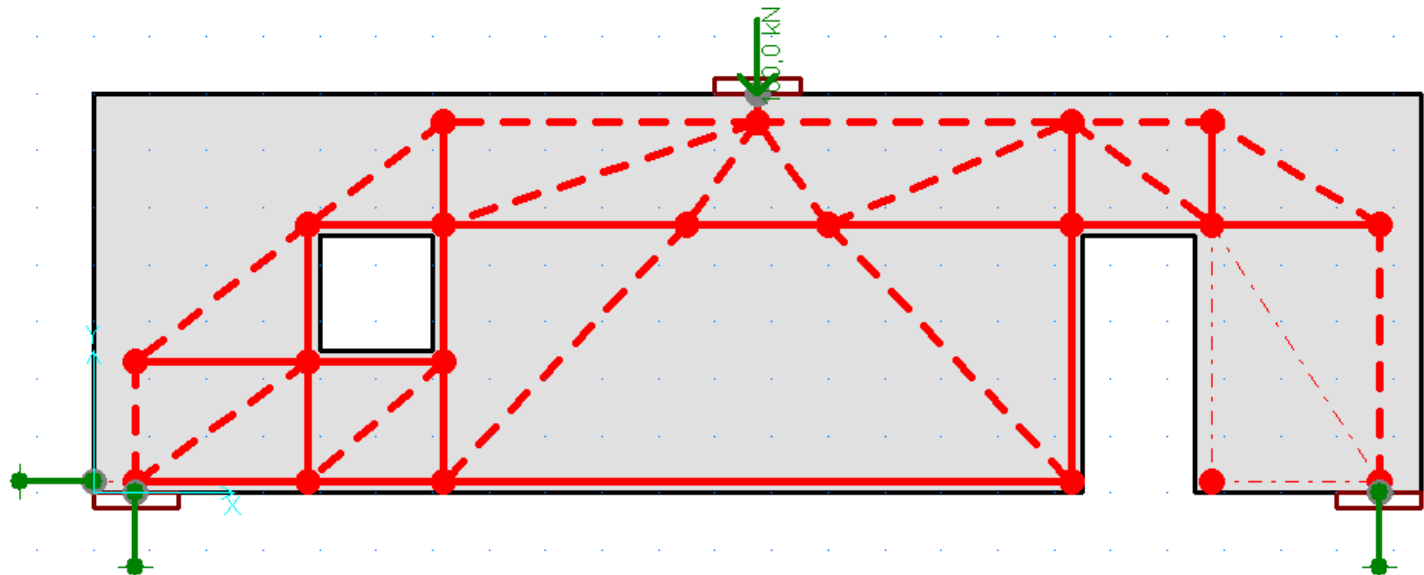
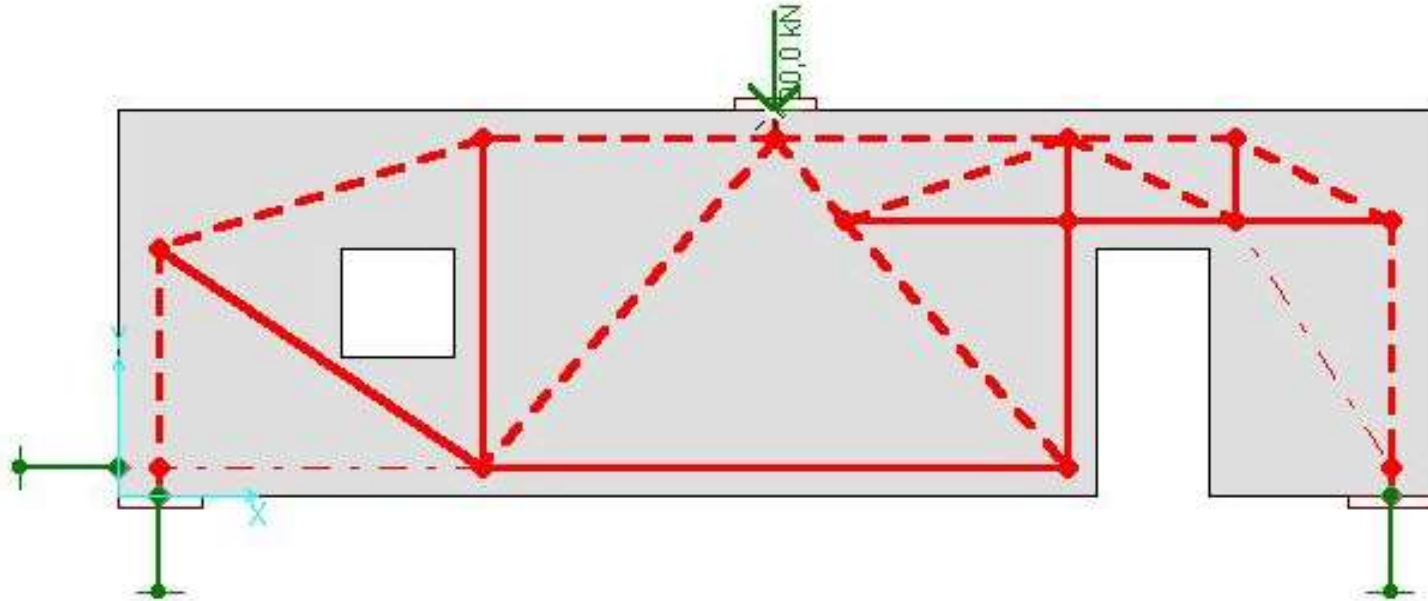
Viga-Parede Complexa Submetida a Descontinuidades Estáticas e Geométricas

Hipótese: Ruína devido ao Escoamento da Armadura:  $Pr > 1,4 * 1,15 = 1,61$   
Desprezada malha de armaduras mínimas!

# Análise Elástica



# Análises Elásticas



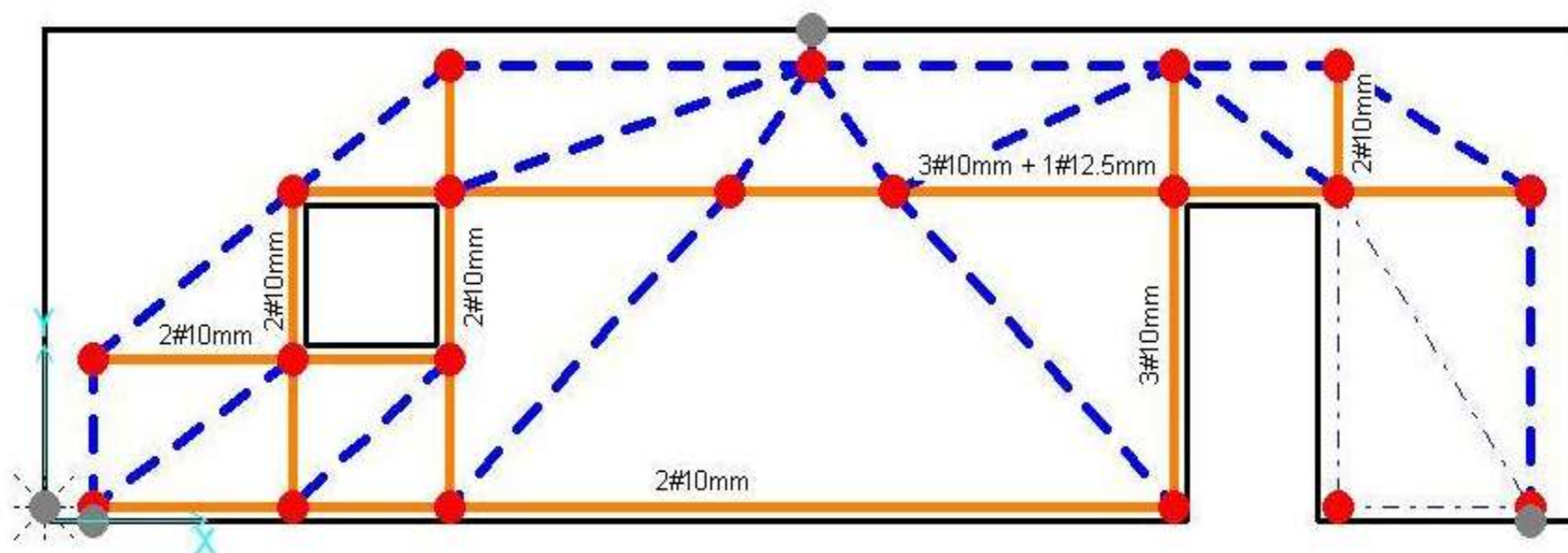


# Análises Elásticas

Determinação das armaduras resistentes para o "Modelo B"

Tirante	Posição do Tirante	Esforço (kN)	Armadura Adotada
N1	Face inferior da viga	72,8	2 $\phi$ 10 mm
N2	Abaixo da abertura esquerda	43,1	2 $\phi$ 10 mm
N3	Acima da abertura direita e esquerda	151,4	3 $\phi$ 10 mm + 1 $\phi$ 12,5 mm
N4	A esquerda da abertura esquerda	17,2	2 $\phi$ 10 mm
N5	A direita da abertura esquerda	32,8	2 $\phi$ 10 mm
N6	A esquerda da abertura direita	76,2	3 $\phi$ 10 mm
N7	A direita da abertura direita	50,0	2 $\phi$ 10 mm

\*Obs: Os esforços apresentados são apenas os maiores valores de cada armadura discretizada. De maneira a evitar armaduras diferenciadas ao longo da estrutura, tomou-se o maior esforço e dimensionou-se a armadura de cada tirante com bitola constante.

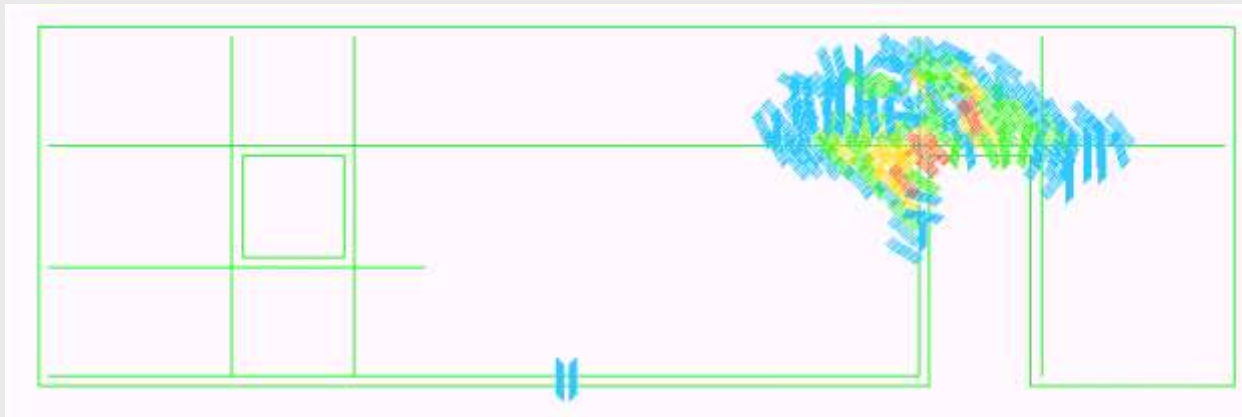


# Análise Não-Linear



Viga sem armadura em malha

$\lambda_u = 2,06 > \lambda_c = 1,61 \rightarrow$  Boas condições de segurança.



Viga com armadura em malha

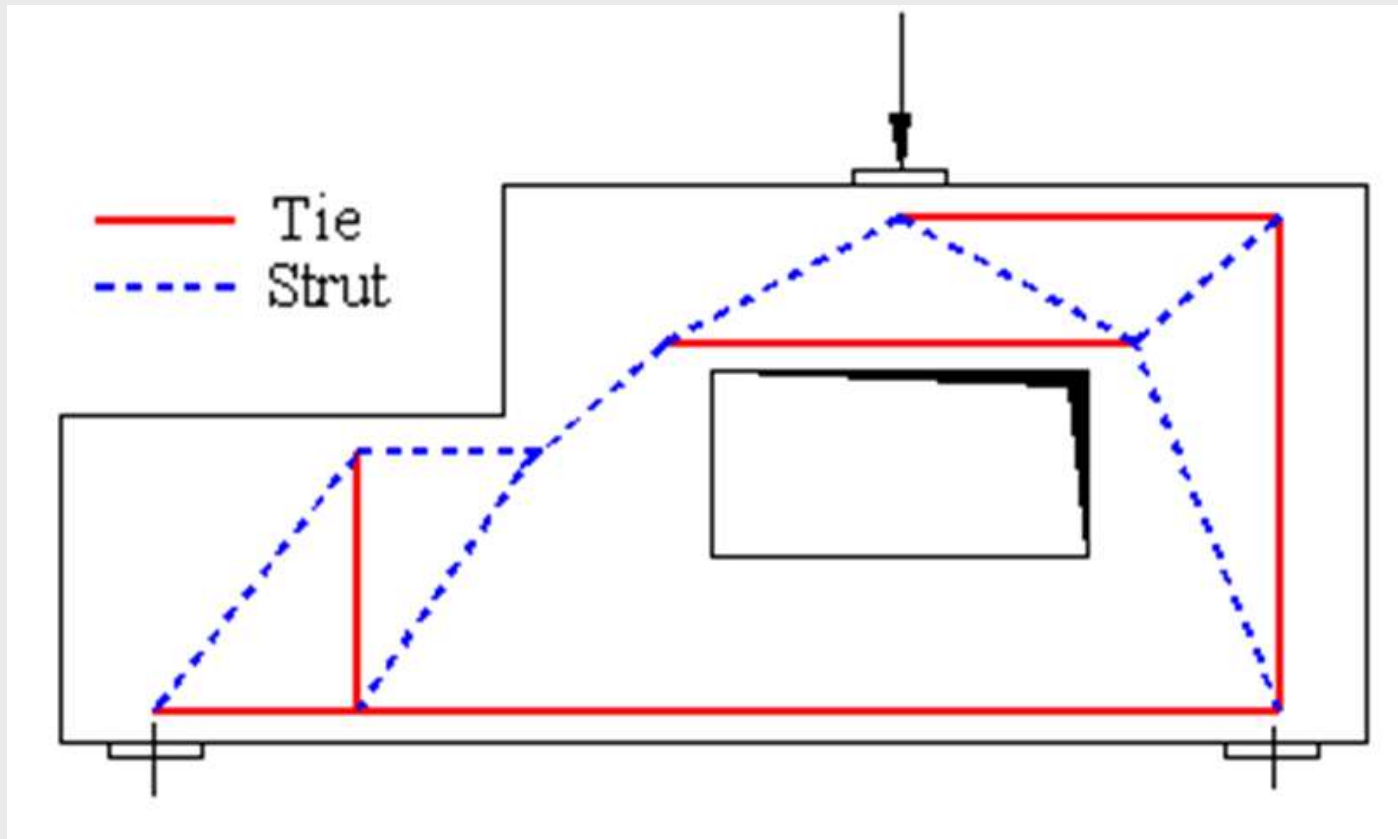
$\lambda_u = 2,92 > \lambda_c = 1,61 \rightarrow$  Boas condições de segurança.

**MODEL 8**  
 **$f_c' = 35 \text{ MPa}$**   
 **$d = 150 \text{ mm}$**



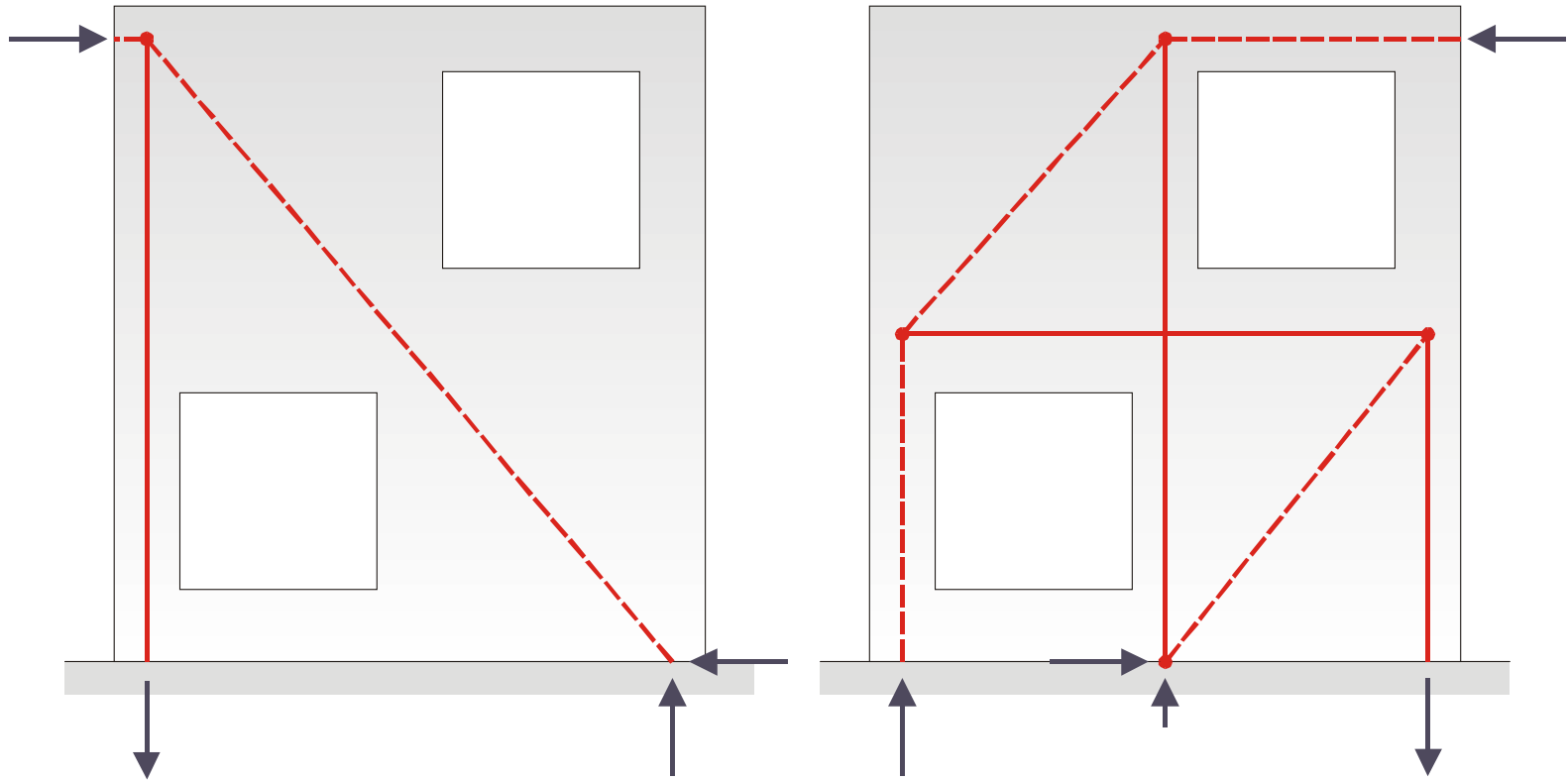
# Forças em Modelos Hiperestáticos

✓ Difícil determinar as forças em modelos hiperestáticos uma vez que estas dependem da rigidez definida para cada elemento:



# Combinação de Carregamentos

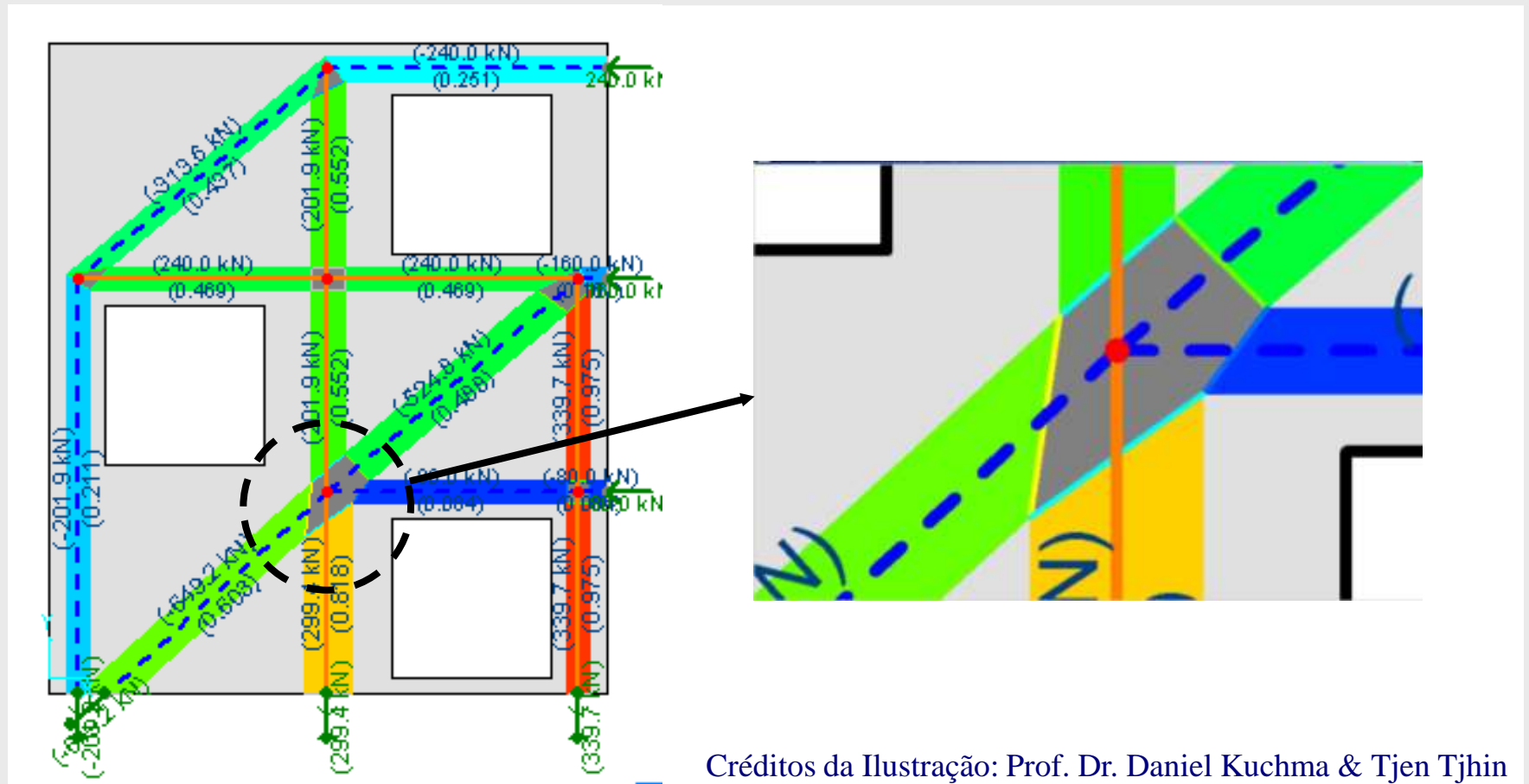
✓ Diferentes treliças surgem para cada caso de carregamento. Qual será a mais representativa?



Créditos da Ilustração: Prof. Dr. Daniel Kuchma & Tjen Tjhin

# Incerteza Sobre as Regiões Nodais

✓ A forma das regiões nodais e o estado de tensão atuante é complicado se não for hidrostático.

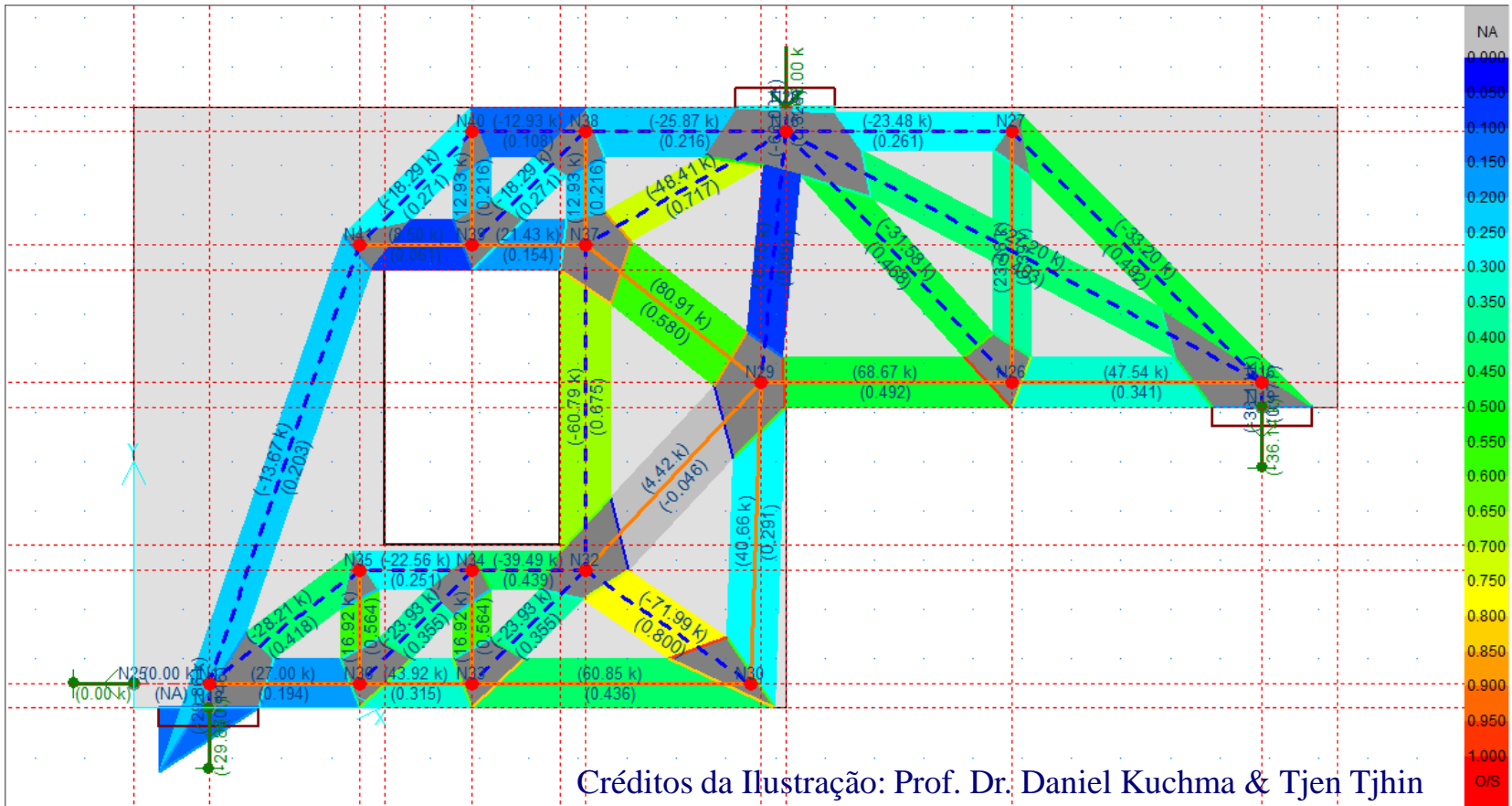


Créditos da Ilustração: Prof. Dr. Daniel Kuchma & Tjen Tjhin

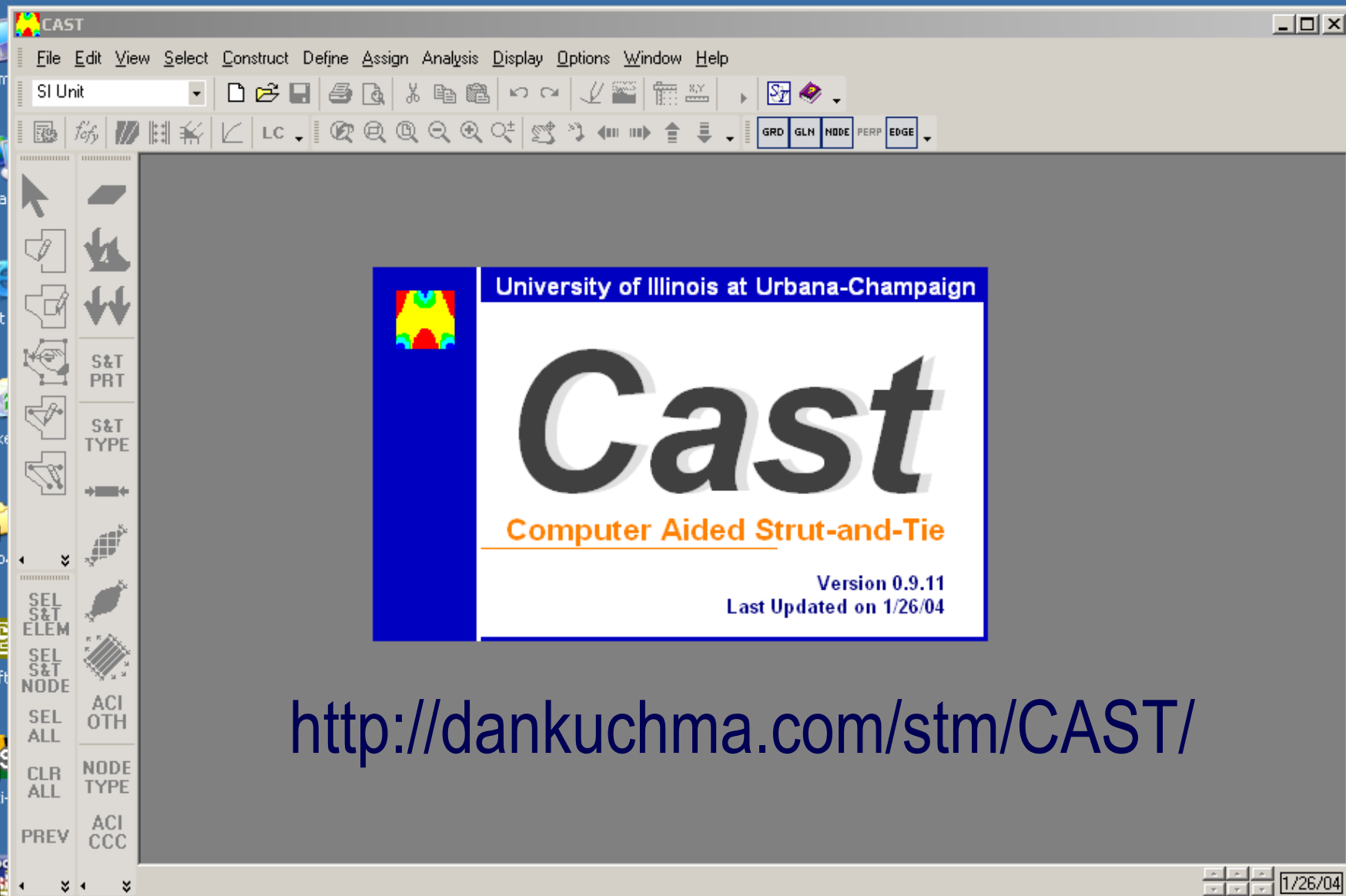


# Cálculo Manual e Comportamento em ELS

✓ O cálculo manual é praticamente inviável para alguns tipos de estruturas. Difícil avaliar comportamento em ELS;

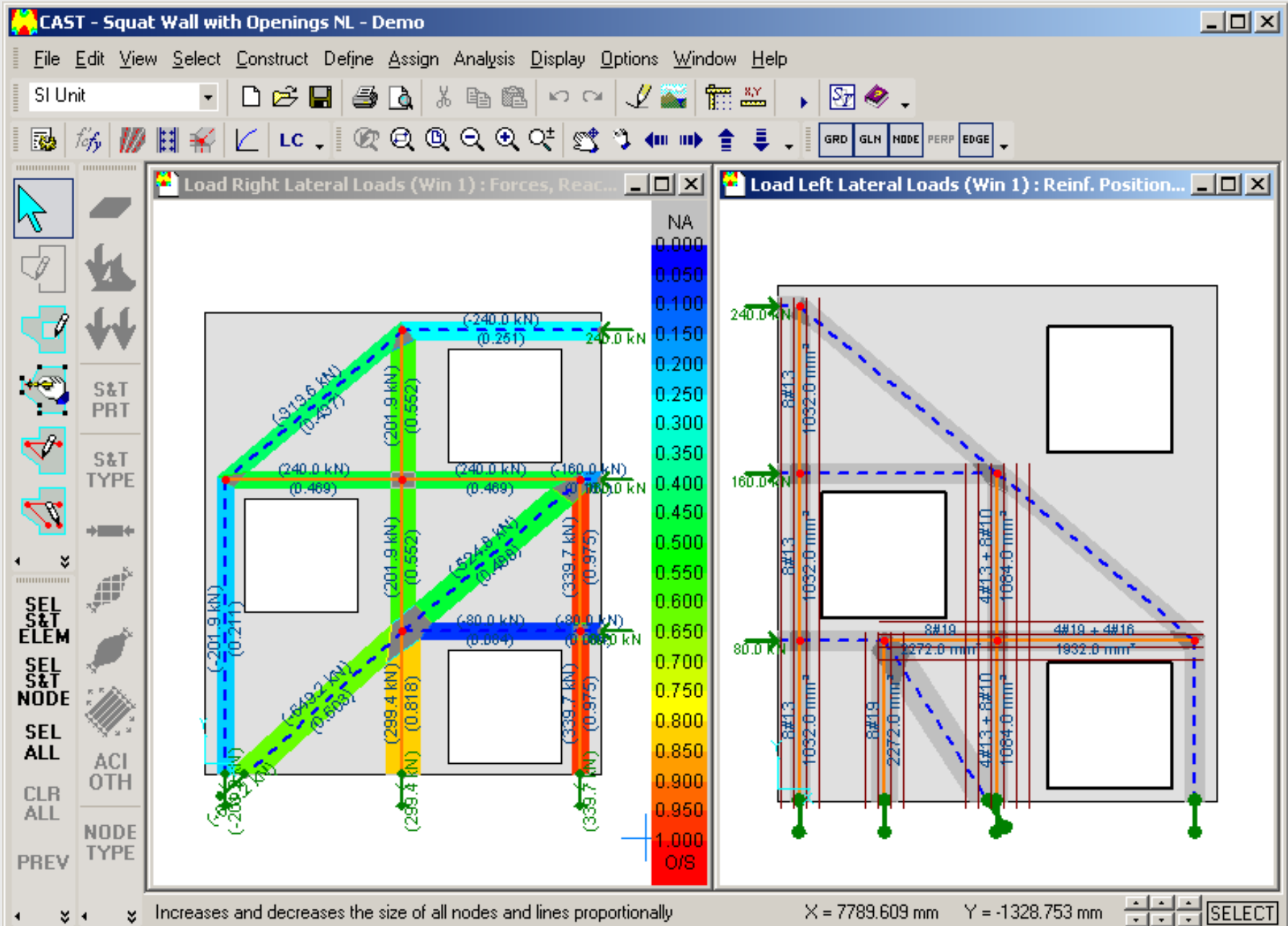


# CAST ( Computer Aided Strut And Tie)



<http://dankuchma.com/stm/CAST/>

# CAST (Computer Aided Strut And Tie)



# Dimensionamento das Escoras

**Define Concrete Strut Types** [?] [X]

**Type List**

Name  
Bottle-Shaped

Defined Types  
Bottle-Shaped  
Prismatic Strut

Add  
Modify  
Delete

**Note:** This type cannot be deleted because it has been assigned to STM Elements.

**Type Properties**

Concrete Compressive Strength,  $f_c$   
35,00 MPa Modify...

Concrete Strut Strength

Strut Equation Method

☐ Code-Based Equations:  
(1) ACI Bottle-Shaped Struts w/ Steel

☒ User-Defined or Other Methods:  
(0) User-Defined

Efficiency (between Strength and Stress)  
(1) Nielsen (1978)  
(2) Ramirez & Breen (1983)  
(3) Marti (1985)  
(4) Schlaich (1987) Uncracked Strut  
(5) Schlaich (1987) Strut w/ Reinf/Tensile Strain Perp to Its Axis  
(6) Schlaich (1987) Strut w/ Skew Reinf/Tensile Strain to Its Axis  
(7) Schlaich (1987) Strut w/ Severe Crack Width

OK Cancel

# Dimensionamento dos Tirantes

Define Non-Prestressed Reinforcement Tie Types

Type List

Name

Tie

Defined Types

Tie

Add

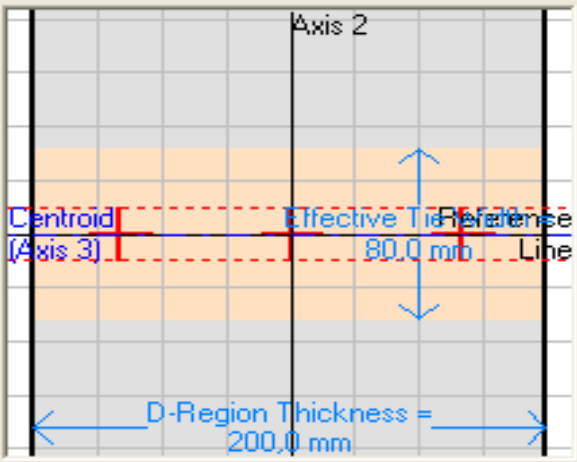
Modify

Delete

Note:

This type cannot be deleted because it has been assigned to STM Elements.

Cross Section



Type Properties

Yield Strength,  $f_y$

500,00

MPa

Modify...

Number of Bar Layers

1

Standard

☐ ASTM A615/A615M

☒ User-Defined

Bar Layer Data (User-Defined)

Layer Number

1

:

Bar Area

50

mm<sup>2</sup>

Number of Bars

3

Distance from Reference Line

0

mm

Summary

Total Steel Area

150,0

mm<sup>2</sup>

Strength Reduction Factor (between 0 and 1)

0,87

Use Default

Yield Overstrength Factor (not less than 1)

1

Use Default

Yield Force

65,3

kN

Tension Zone Extension

40

mm

Minimum Effective Width

80,0

mm

Tip:

In addition to using 'Layer Number' updown control above to select a bar layer, you can also do it by clicking a bar layer from the image to the left or by click on the image using the left mouse button. Alternatively, click the image and then press Up, Down, Left, Right, Page Up, Page Down, Home, or End key.

OK

Cancel

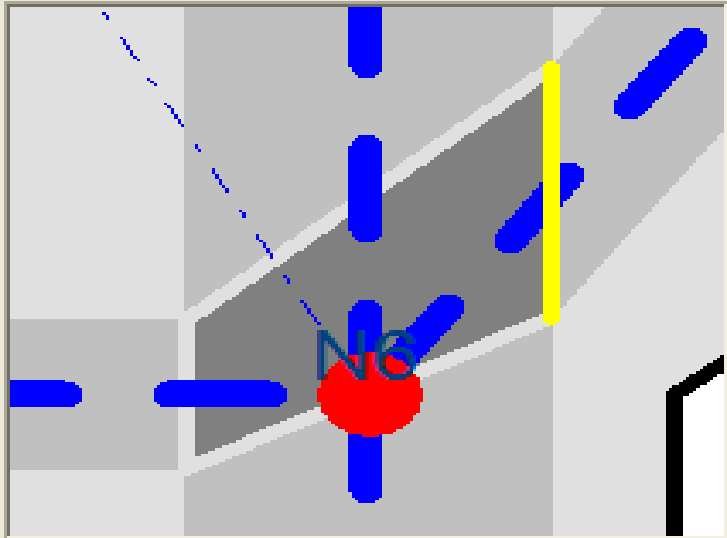
# Dimensionamento das Regiões Nodais

**STM Node Info (Load LC1)** ? X

**General Info**  
ID   
Function   
Connectivity

**Coordinates**  
X  mm  
Y  mm  
Local Axis 1 Orientation  deg.

**Properties and Results of Design Calculations**  
Thickness   
Scale Factor   
Node Type:    
Stress Limit  MPa  
Node Side:    
Strut Force  kN  
Node Stress  MPa  
Stress Ratio   
f'c Ratio   
Beta Ratio



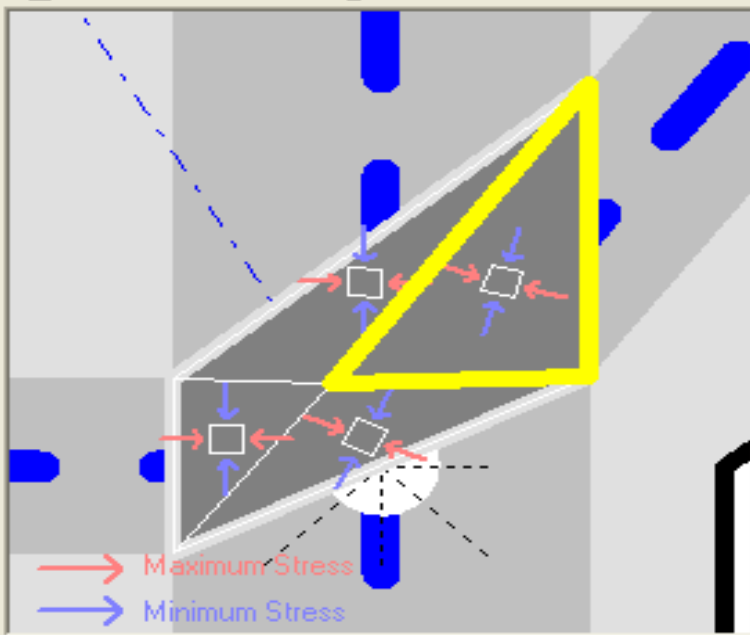
**Tip:** To obtain info of node side stresses, click the light gray lines surrounding the node (if any) from the above image.



# Dimensionamento das Regiões Nodais

**Detailed Nodal Zone N6 Stress Info**

**Constant Stress Triangles**



→ Maximum Stress  
→ Minimum Stress

**Tip:** Click on a Constant Stress Triangle from the above image to obtain its stress info displayed in 'Triangle Stress Info' frame.  
Click on a side of the selected triangle from the above image to obtain its stress info displayed below.

**General Info**

Load Condition: LC1

Node ID: N6

Strength Info...

**Triangle Stress Info**

Triangle 1

Show Table...

**Principal Stresses**

Maximum -2,92 MPa

Minimum -27,60 MPa

Direction -16,09 deg.

Stress Ratio 1,237 (0/S)

Show Detail...

**Options for Constant Stress Triangles**

☒ Show Principal Stresses

☐ Show Triangle IDs

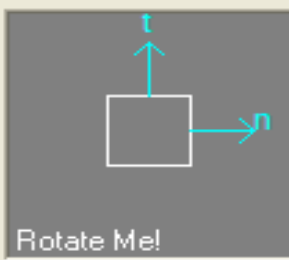
☐ Show Stress Ratio Contour

☐ Show Stress Ratio

Save As Defaults

Reset Defaults

**Interactive Stress Analysis for Triangle 1**



Rotate Me!

Plane n Direction 0 deg.

**Stress Values**

Normal to Plane n -4,82 MPa

Normal to Plane t -25,71 MPa

Shear -6,57 MPa

Alternate Triangles

Force Unbalance...

OK

Cancel

# ***Método Biela e Painel***

# Método Biela e Painel (Stringer-Panel)

✓ Método muito tradicional na Dinamarca, porém pouco divulgado ao redor do mundo;

## Limit Analysis and Concrete Plasticity

T H I R D E D I T I O N

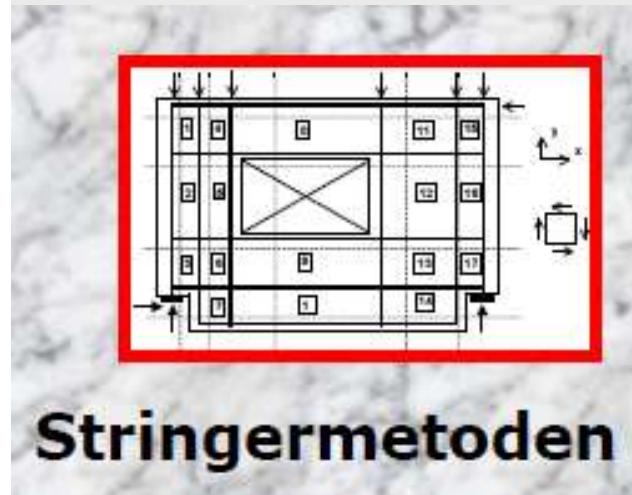
**M. P. Nielsen**

Professor Emeritus, Dr. Techn.  
Department of Civil Engineering  
Technical University of Denmark

**L. G. Hoang**

Professor, Ph.D.  
Department of Industrial and Civil Engineering  
University of Southern Denmark

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Taylor & Francis Group, an informa business



## BETON ELEMENT BYGGERIERS STATIK

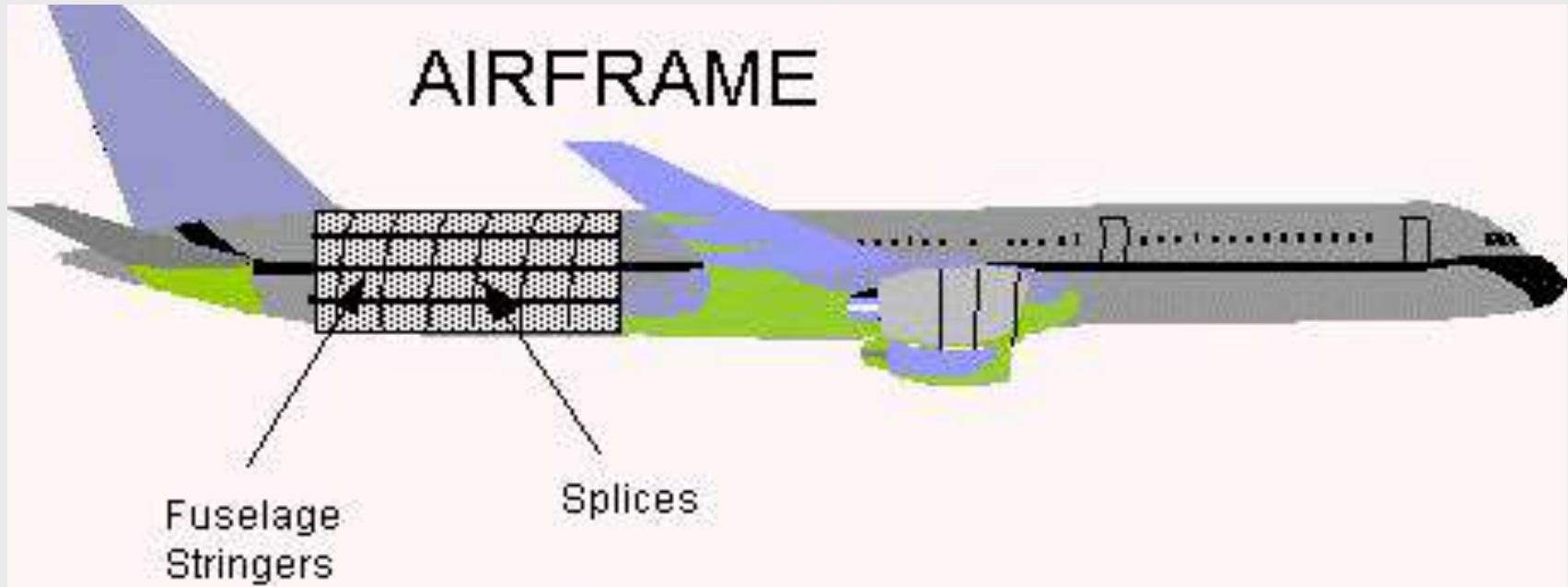
Redigeret af Jesper Frøbert Jensen

 **Polyteknisk**  
Forlag

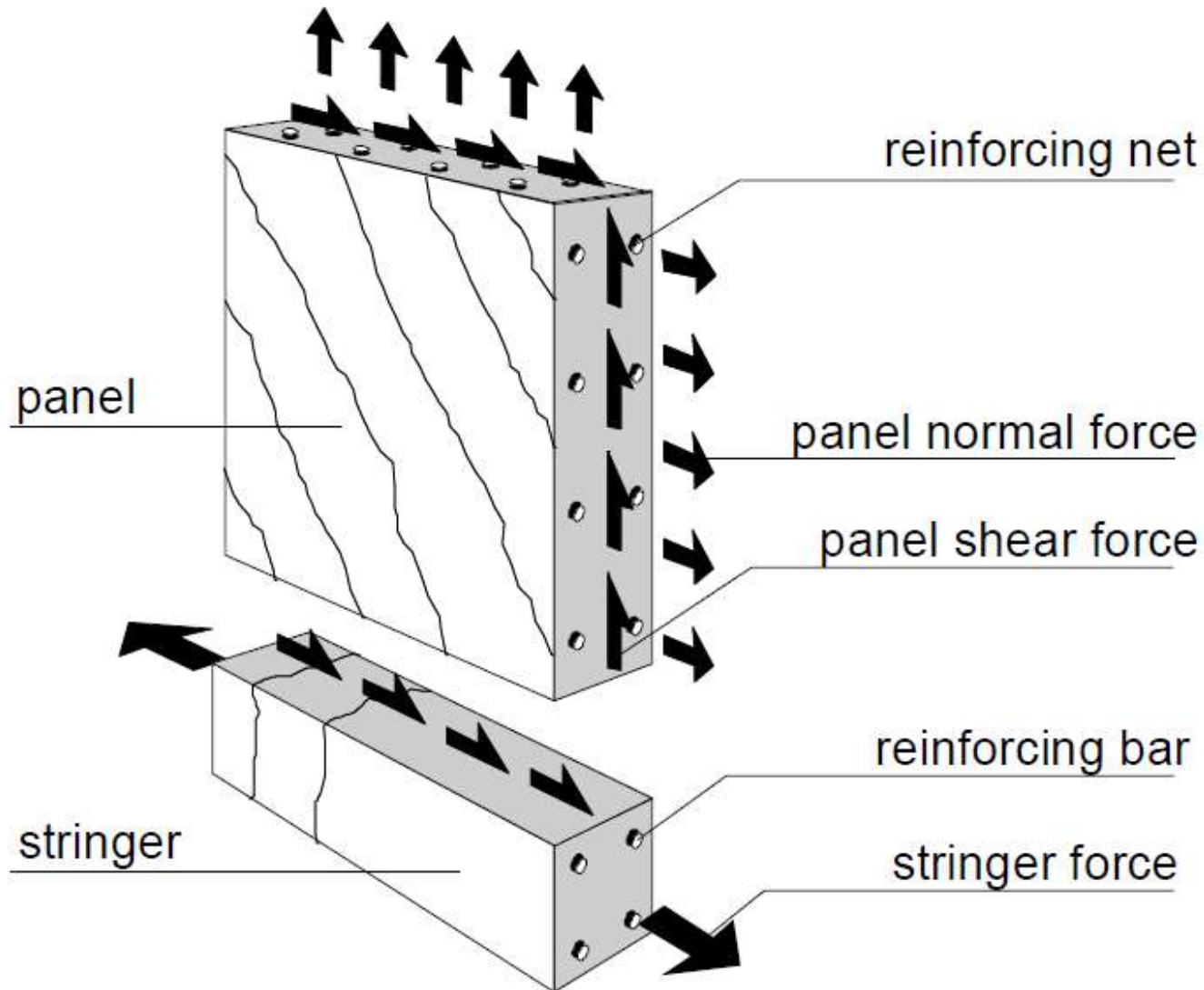
# Método Biela e Painel (Stringer-Panel)

- Modelo utilizado desde a década de 30 na indústria aeronáutica para a modelagem de fuselagem de aviões. Teorema Inferior da Teoria da Plasticidade;
- Baseado na idéia de que uma estrutura pode ser modelada dentro de um sistema de bielas (“stringers”) e painéis (“panels”). Recomendações no CEB e DNS;
- As bielas são responsáveis por absorver força normal, enquanto os painéis são utilizados para absorver cisalhamento;

# Modelagem com o Método



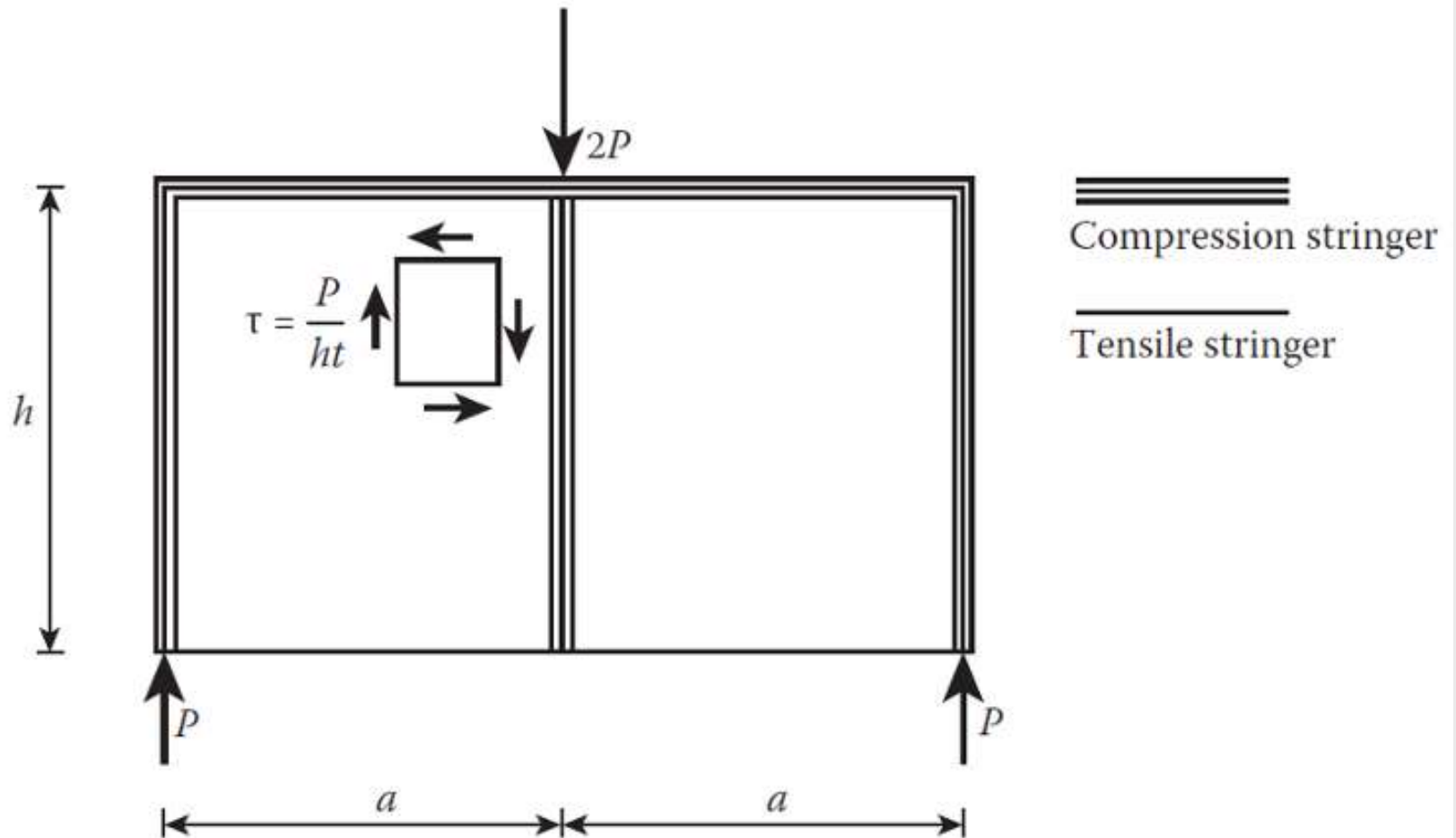
# Modelagem com o Método



Créditos da Ilustração: Prof. Dr. Pierre Hoogenboom

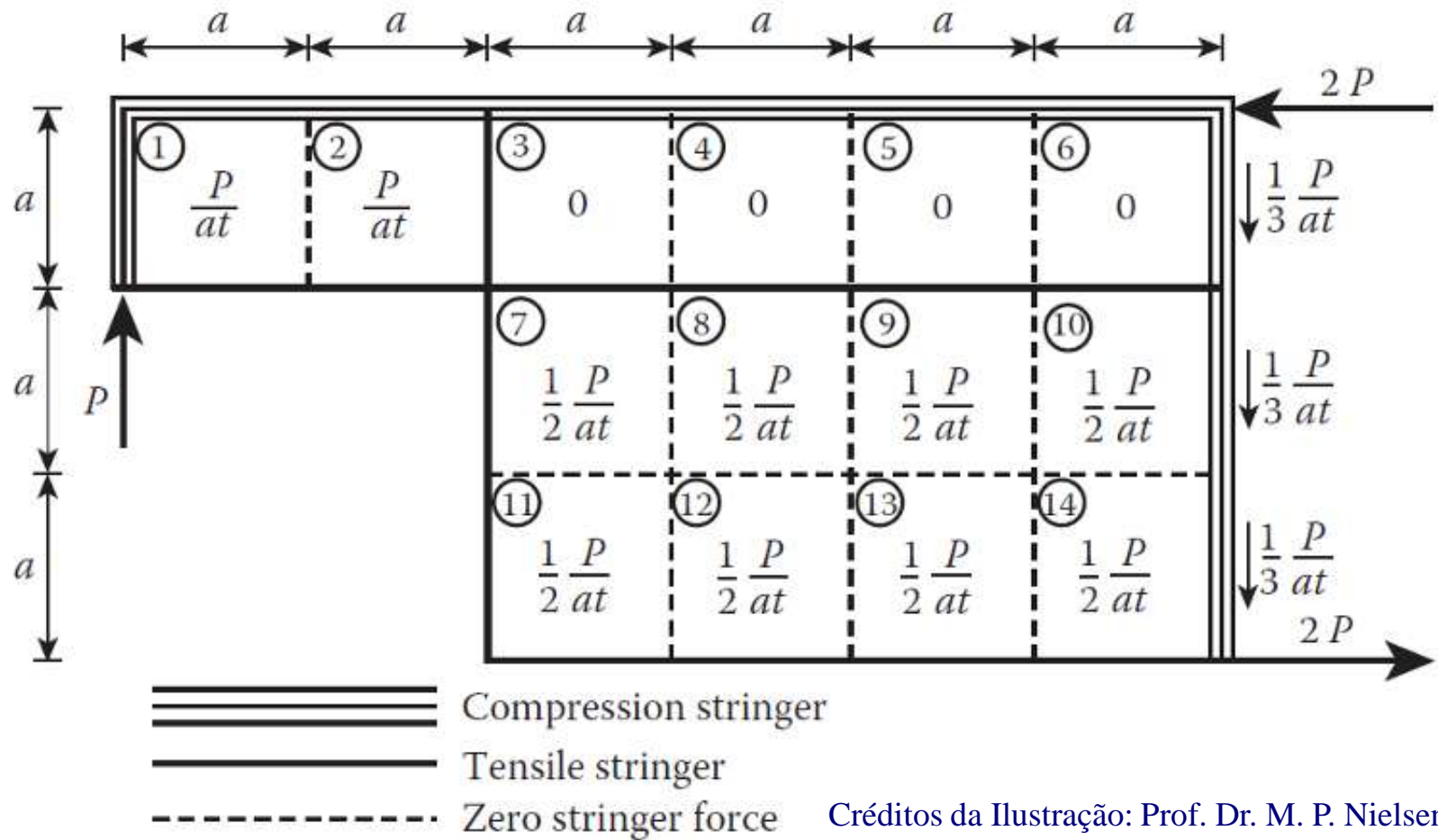


# Modelagem com o Método



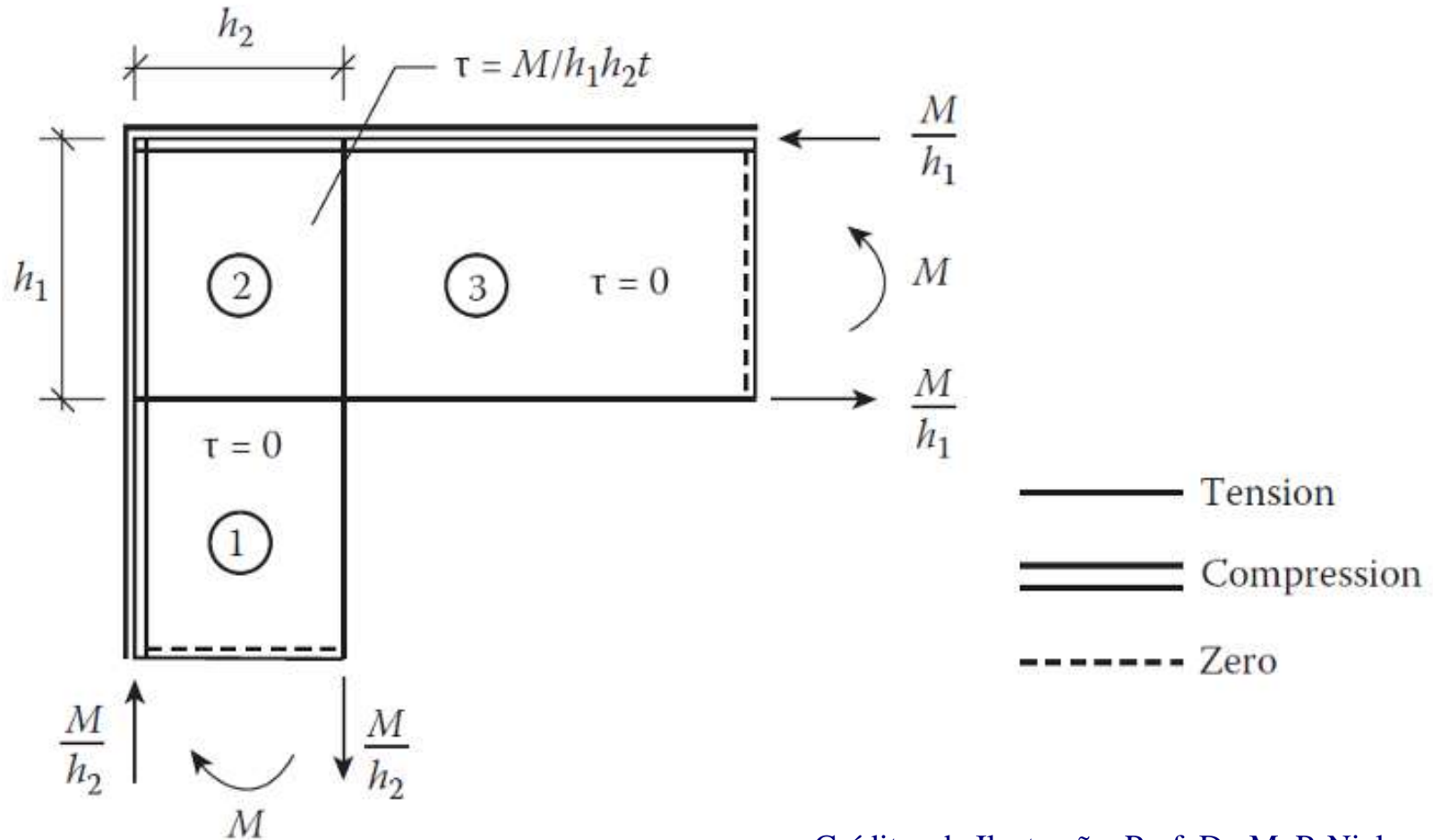
Créditos da Ilustração: Prof. Dr. M. P. Nielsen

# Modelagem com o Método



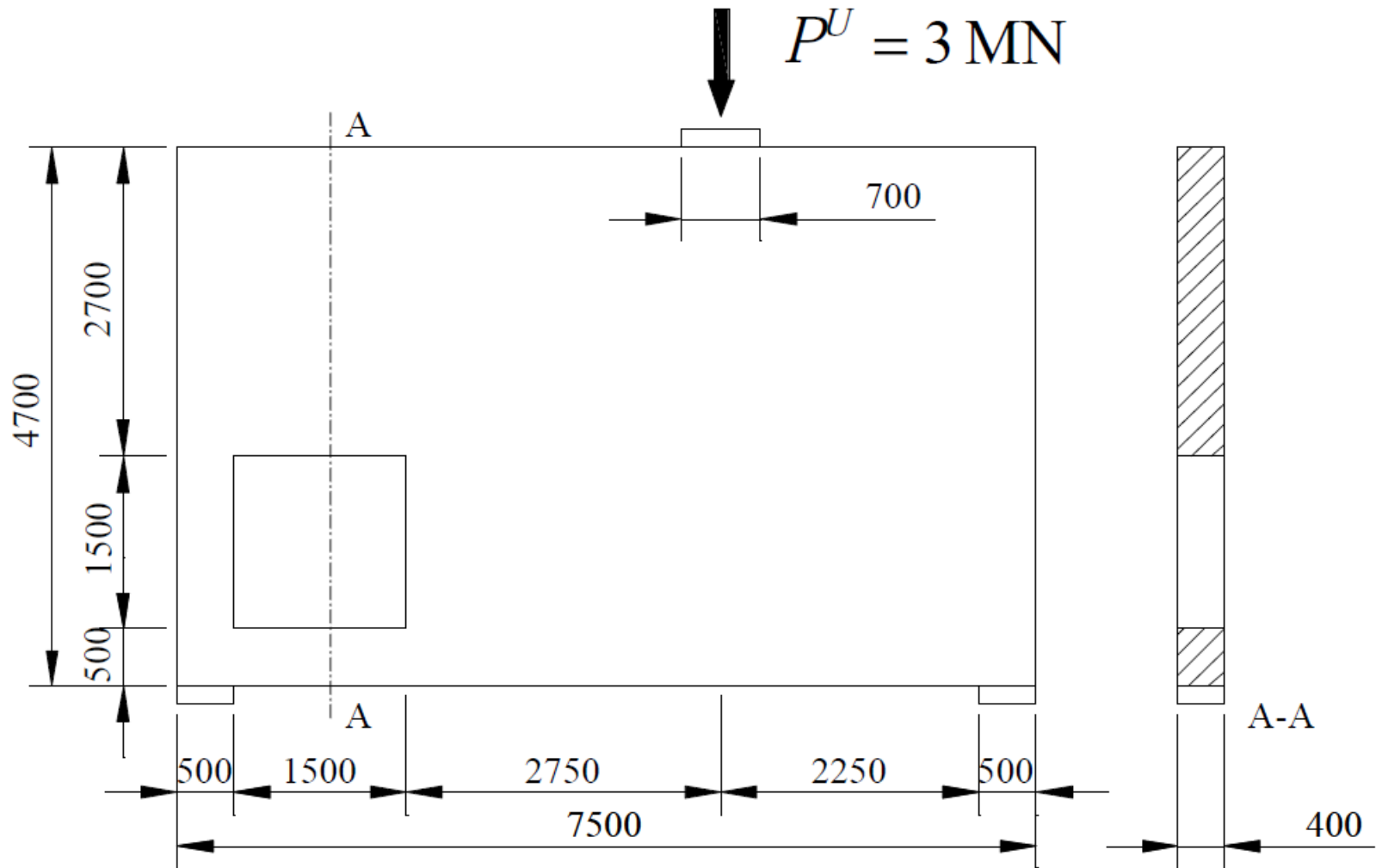
Créditos da Ilustração: Prof. Dr. M. P. Nielsen

# Modelagem com o Método

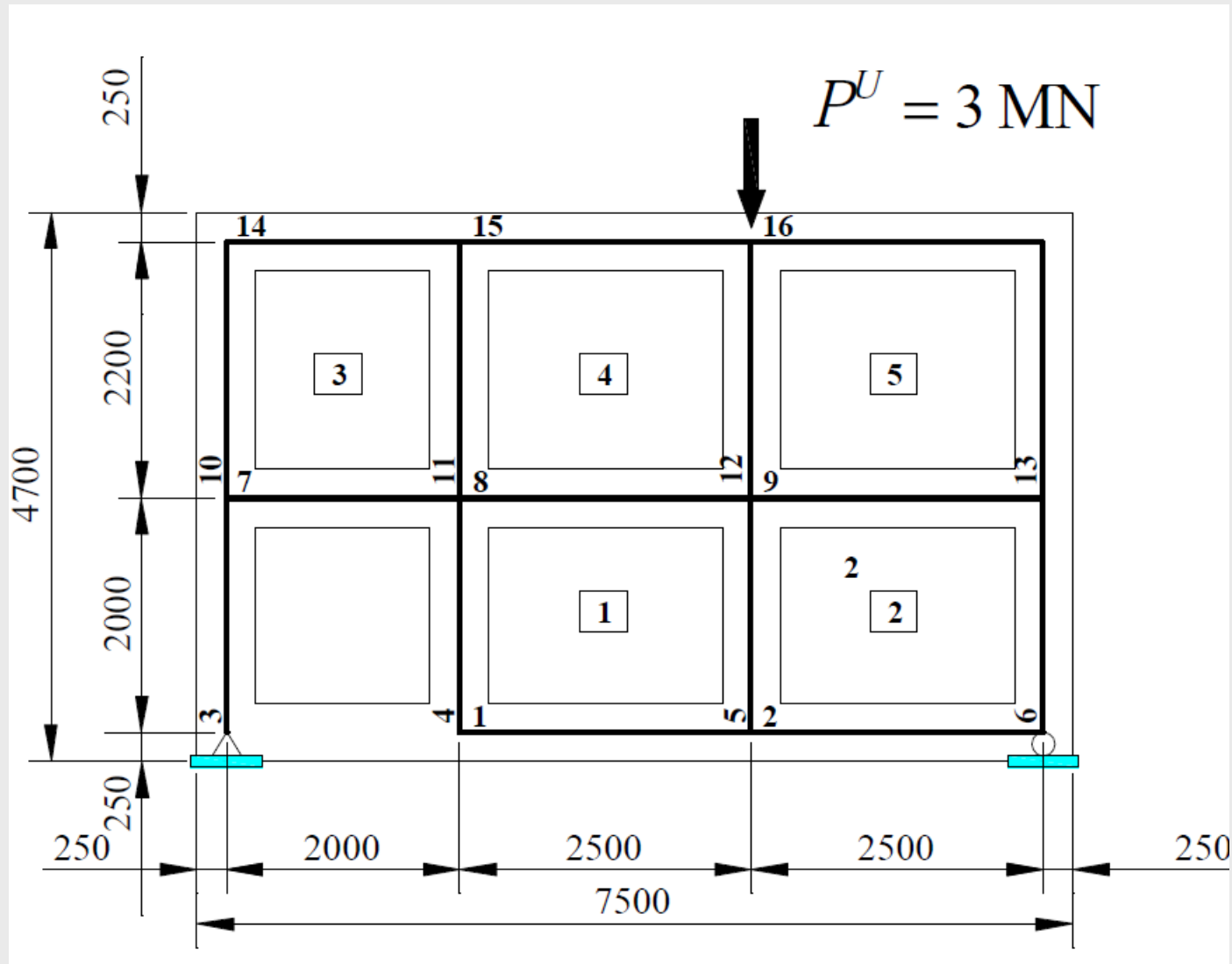


Créditos da Ilustração: Prof. Dr. M. P. Nielsen

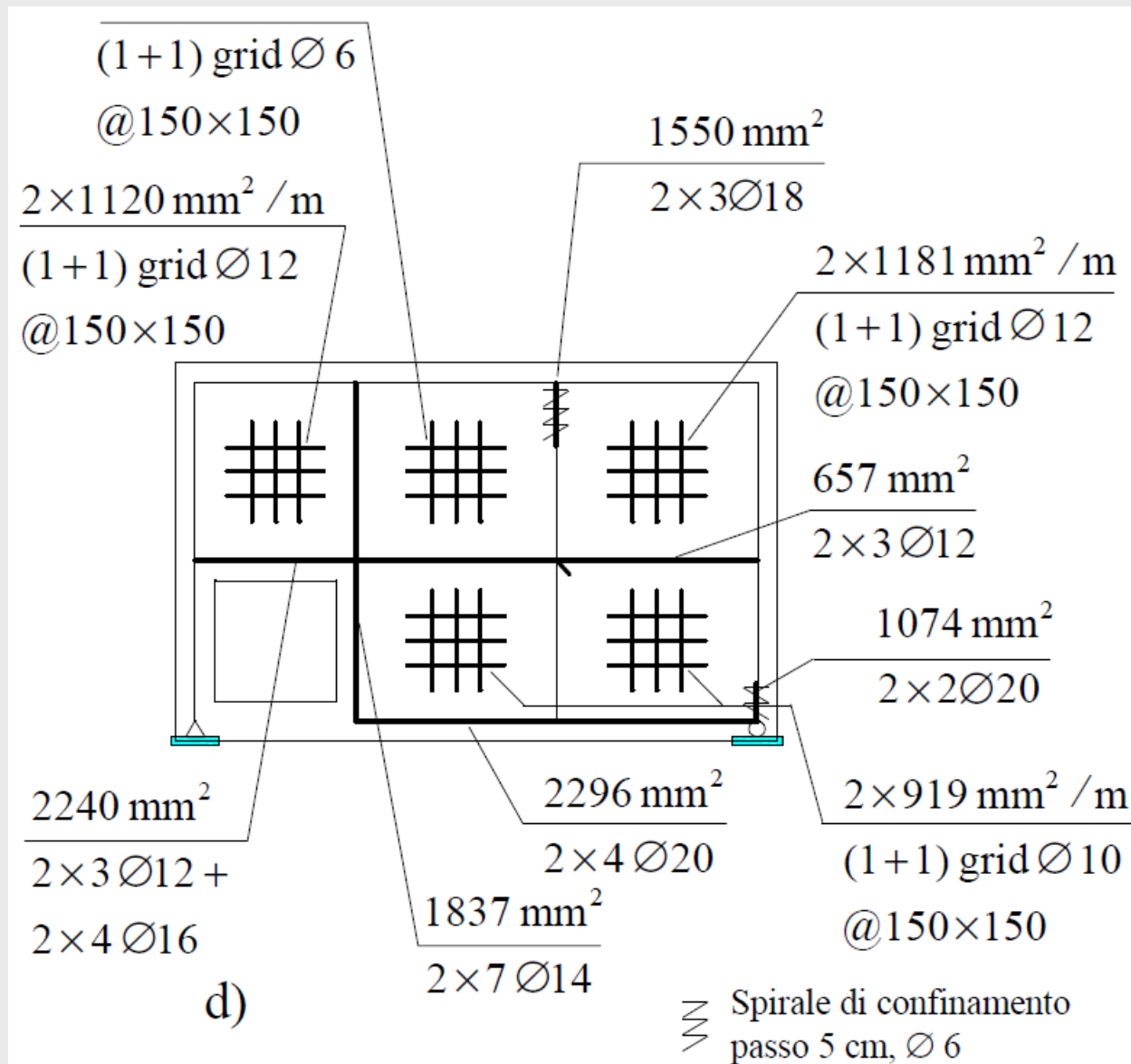
# Modelagem com o Método



# Modelagem com o Método



# Modelagem com o Método

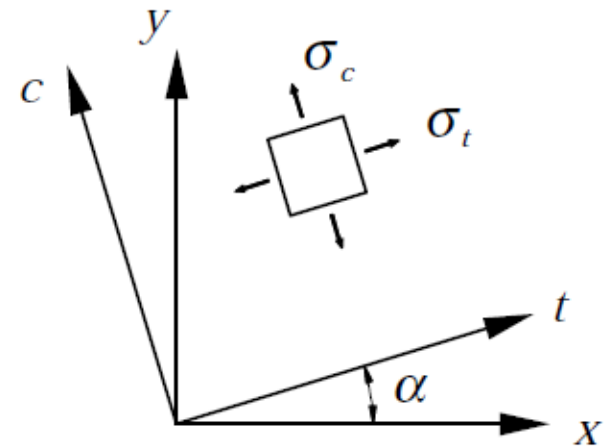
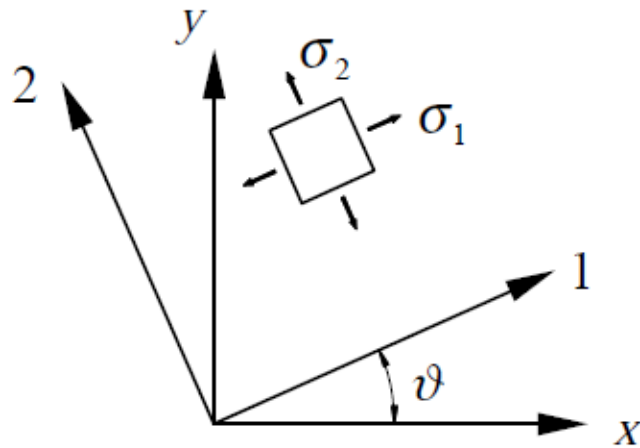
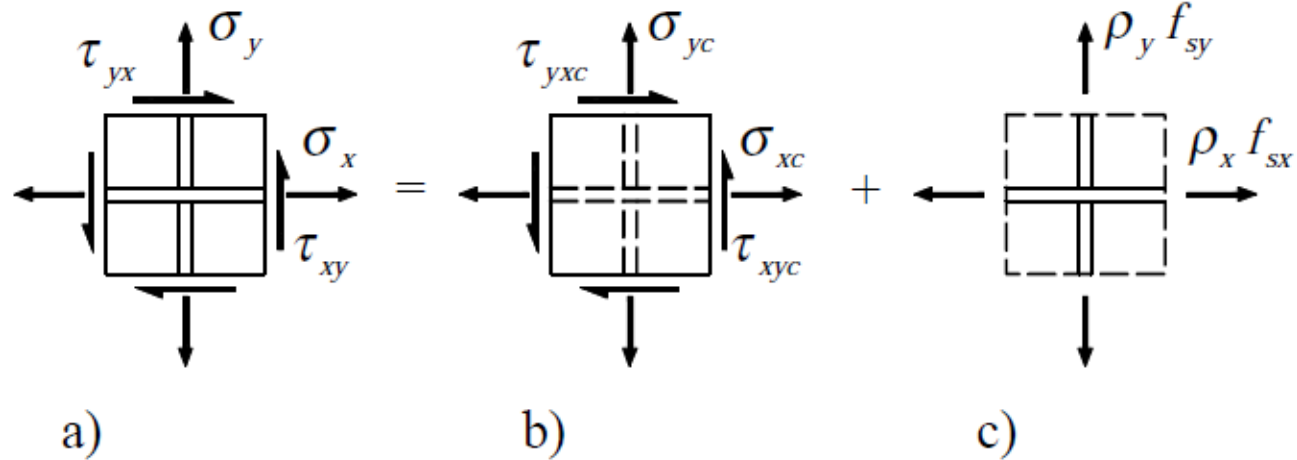


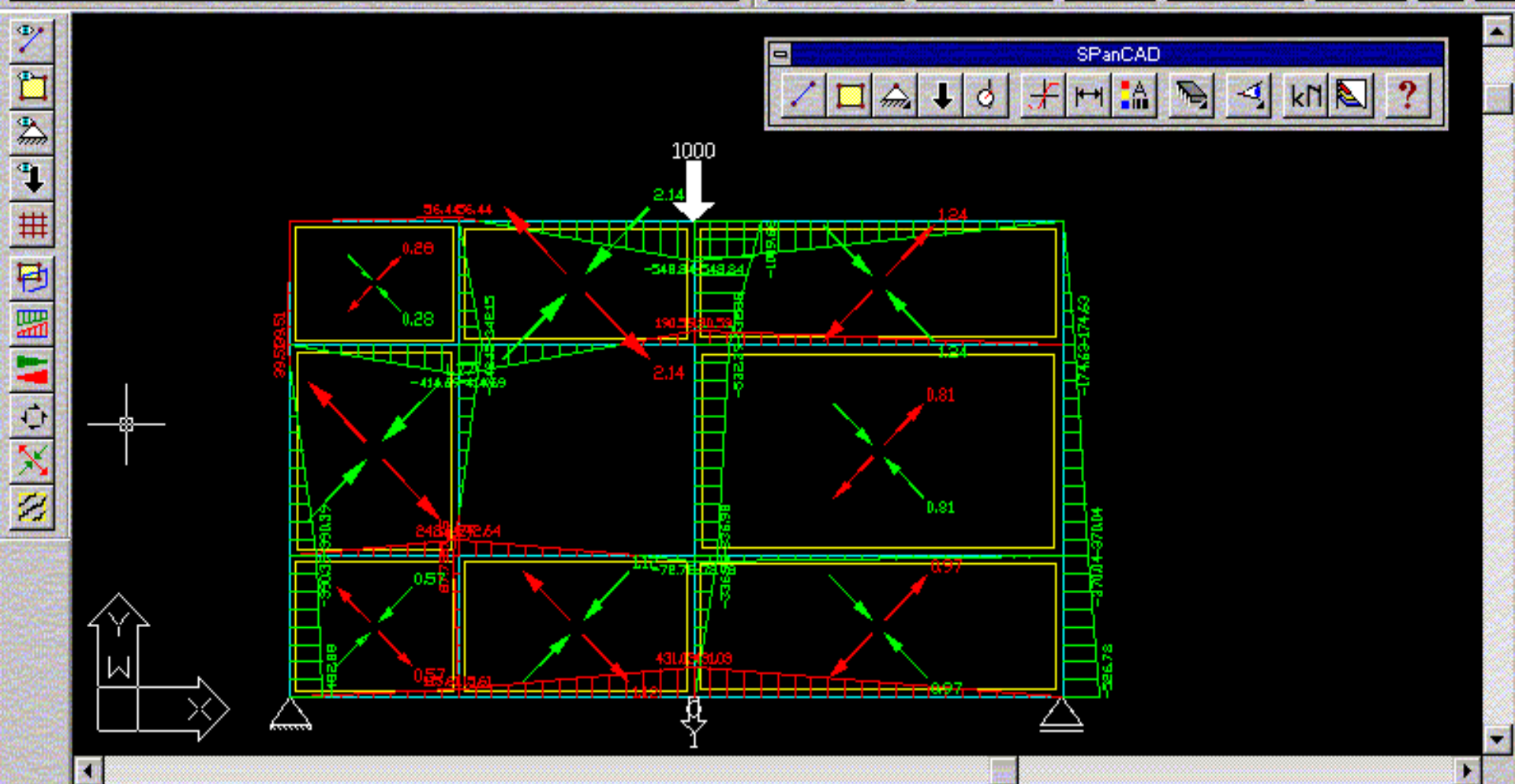


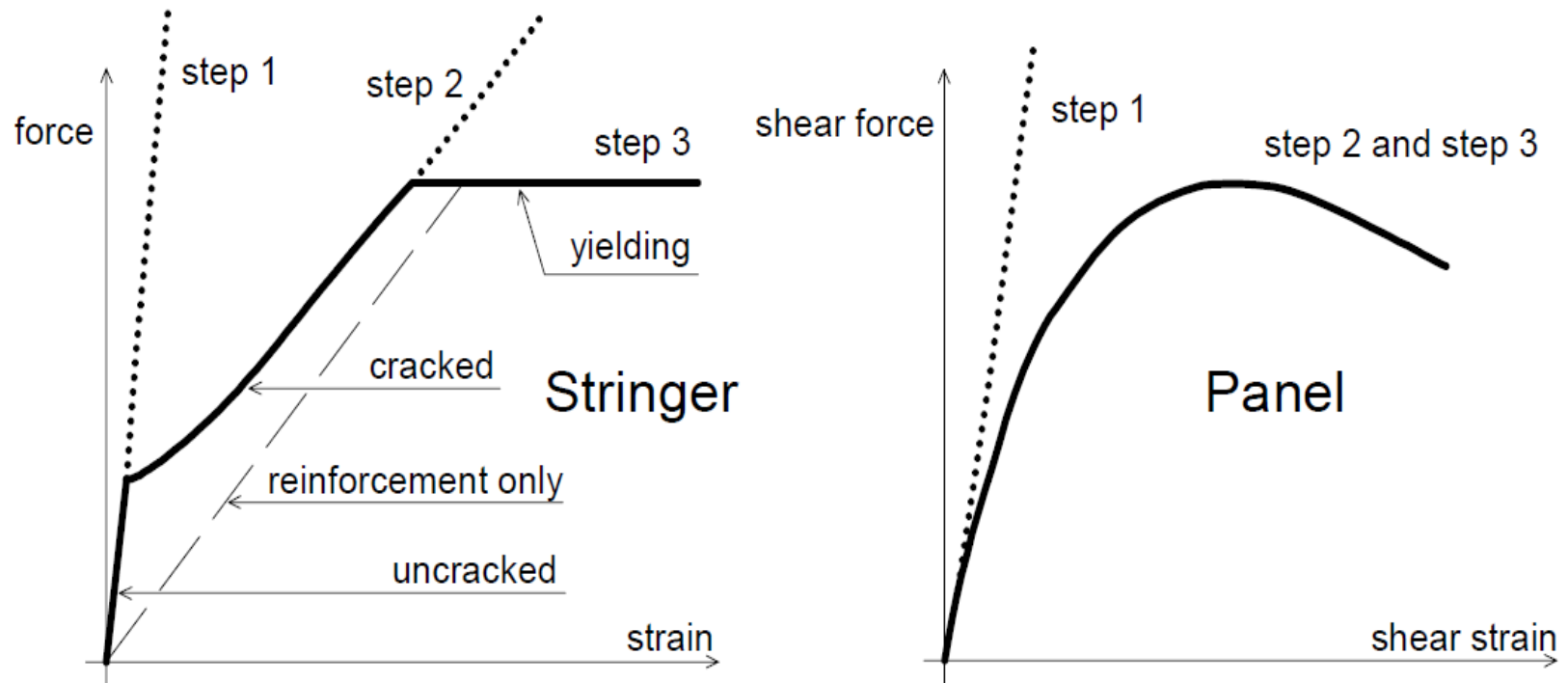
# Dimensionamento das Bielas

- ✓ Responsáveis pelas forças axiais, podendo resultar tracionadas, comprimidas ou parcialmente tracionadas e comprimidas;
- ✓ O dimensionamento das armaduras (no caso de tração) e a verificação do concreto (no caso de compressão) semelhante àquela utilizada no Método das Bielas.

# Dimensionamento dos Painéis

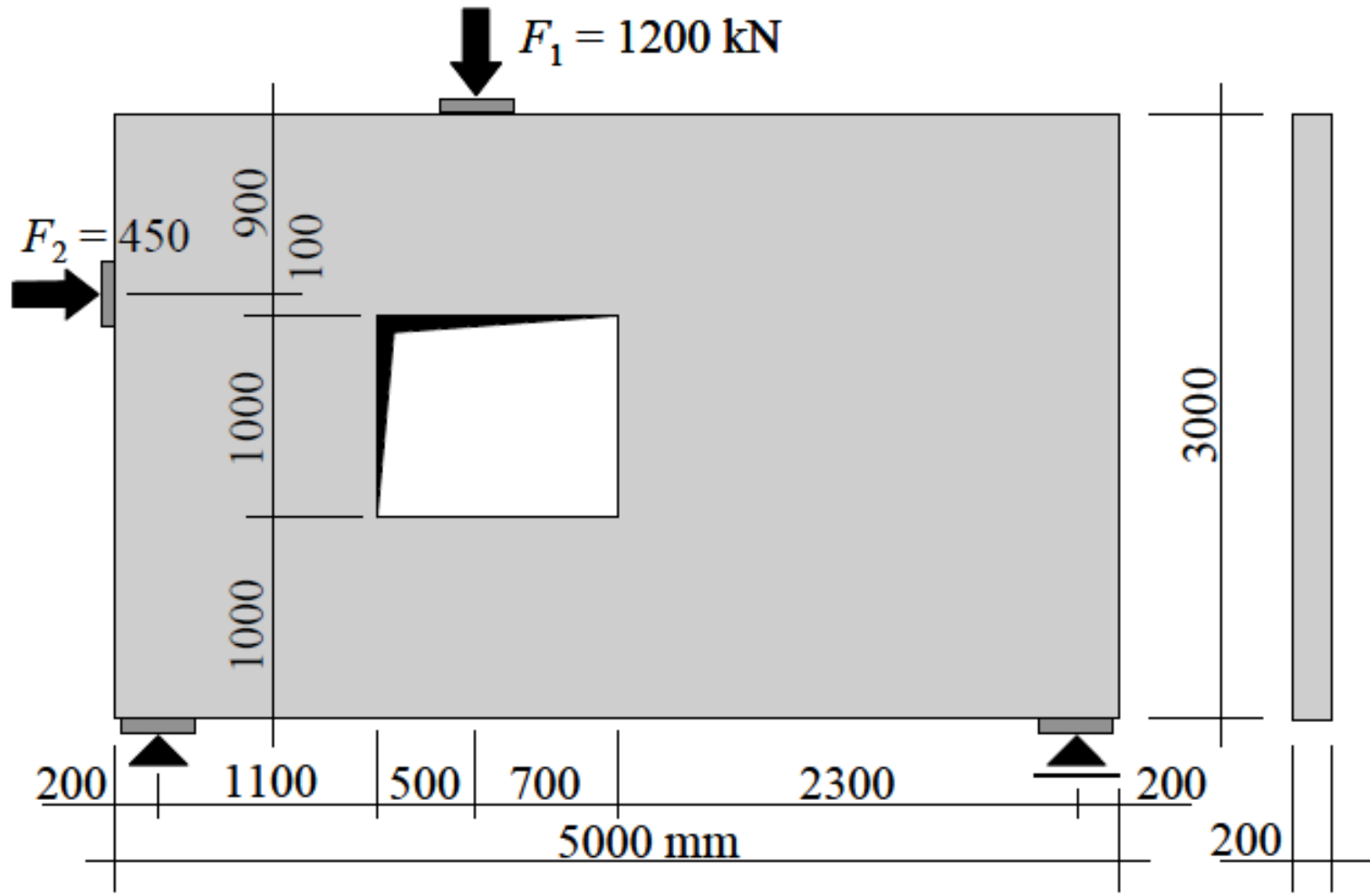




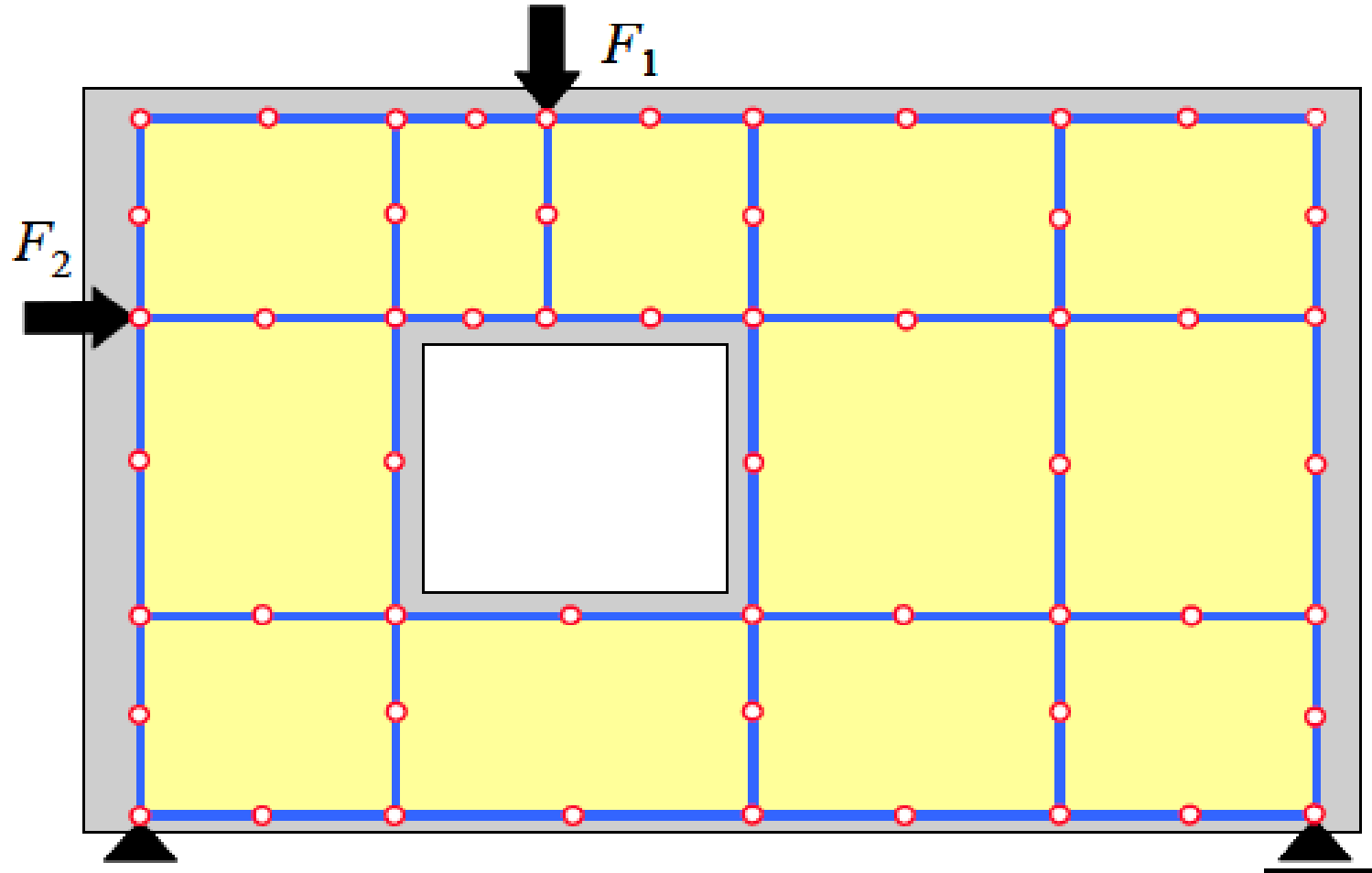


**Fig. 2** Non-linear constitutive behaviour of stringers and panels in SPanCAD

# Modelagem com o Método

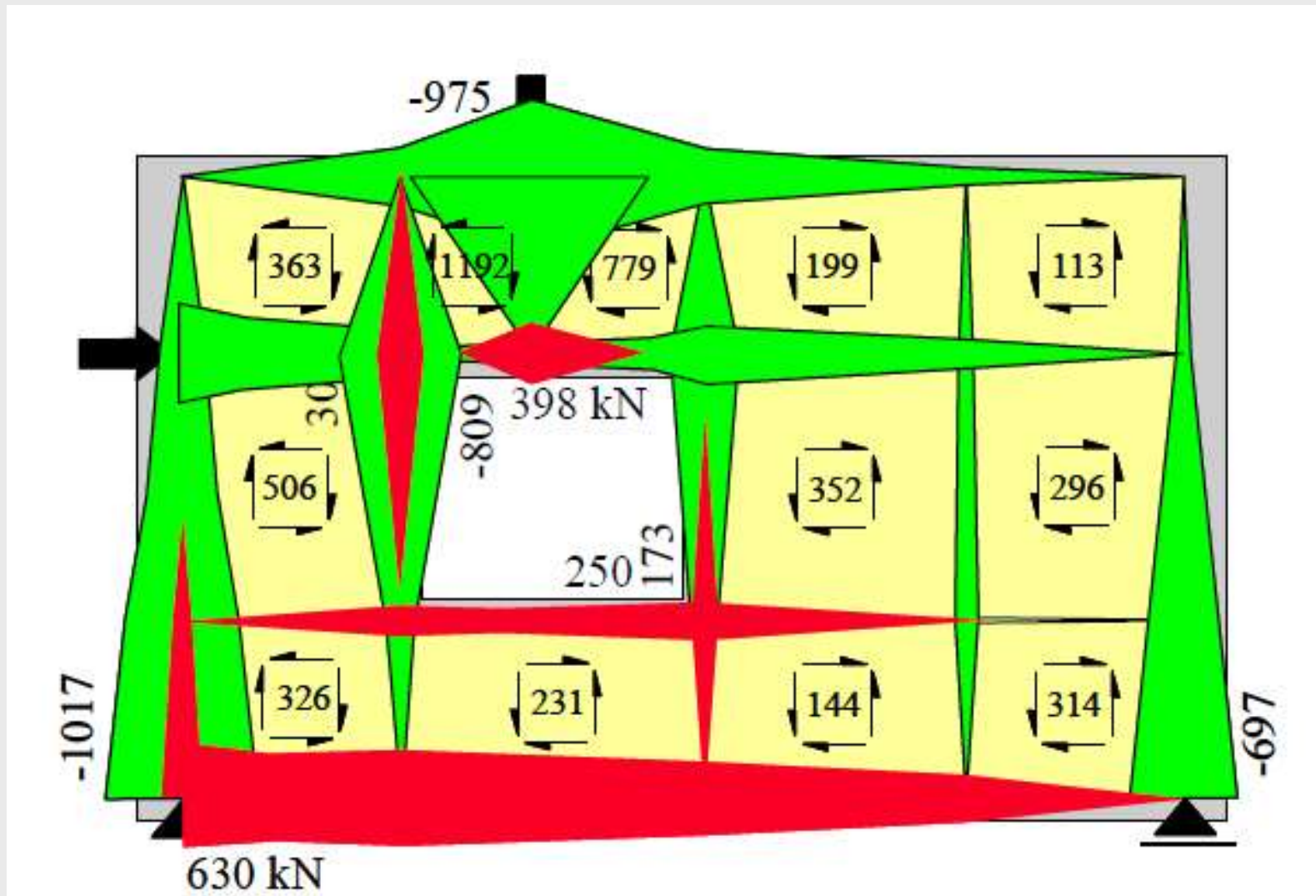


# Modelagem com o Método

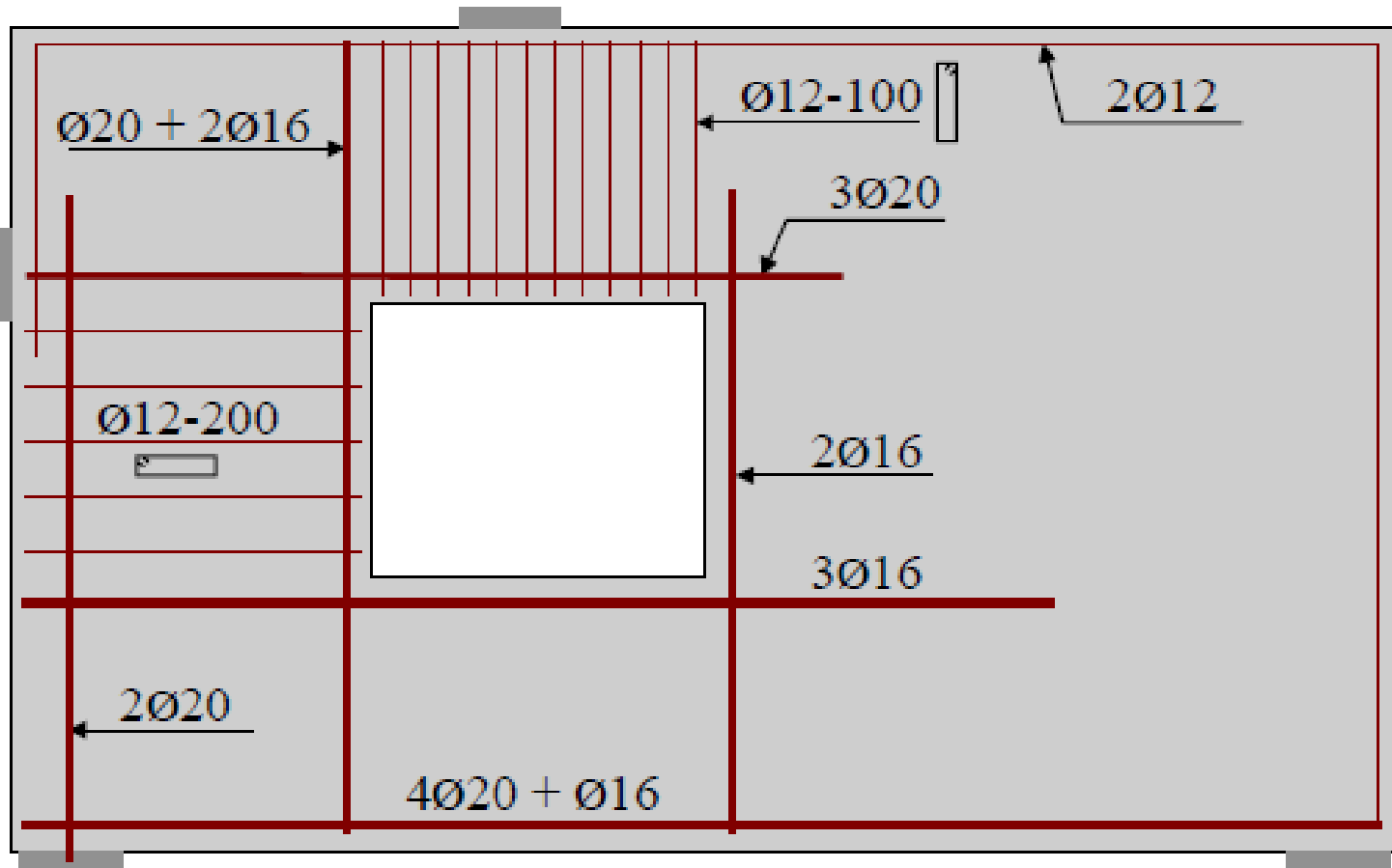




# Modelagem com o Método

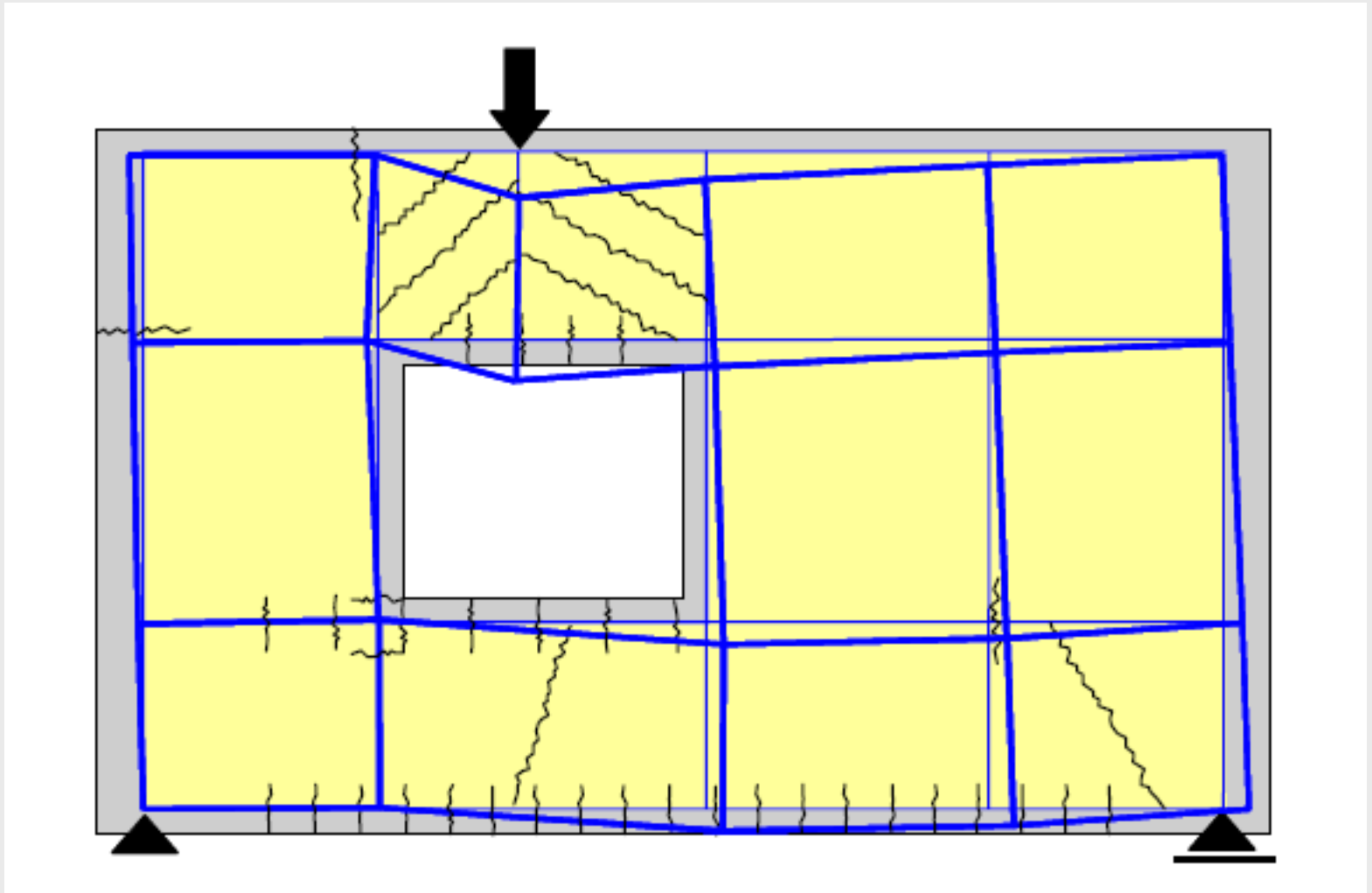


# Modelagem com o Método

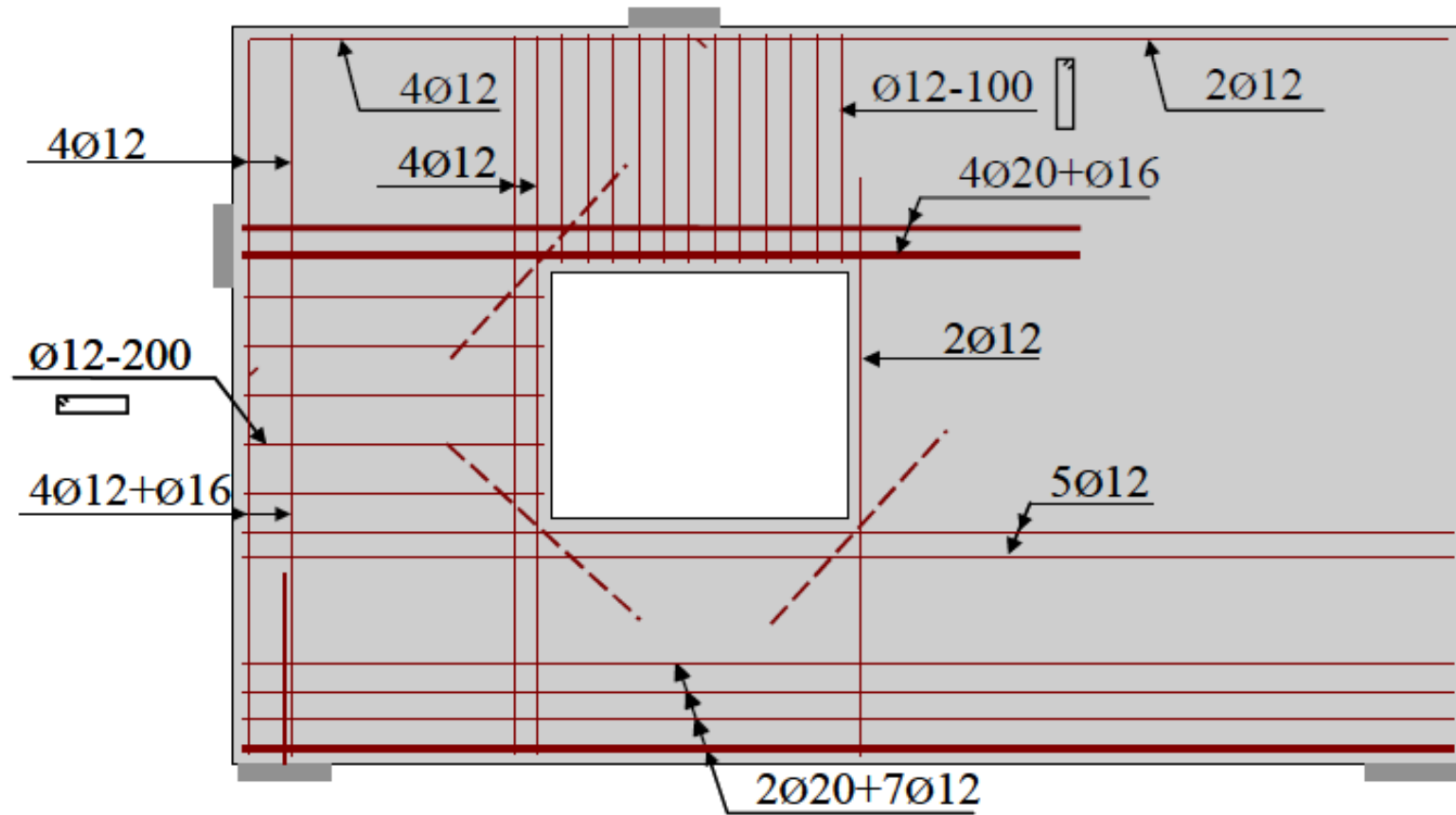


Créditos da Ilustração: Prof. Dr. Pierre Hoogenboom

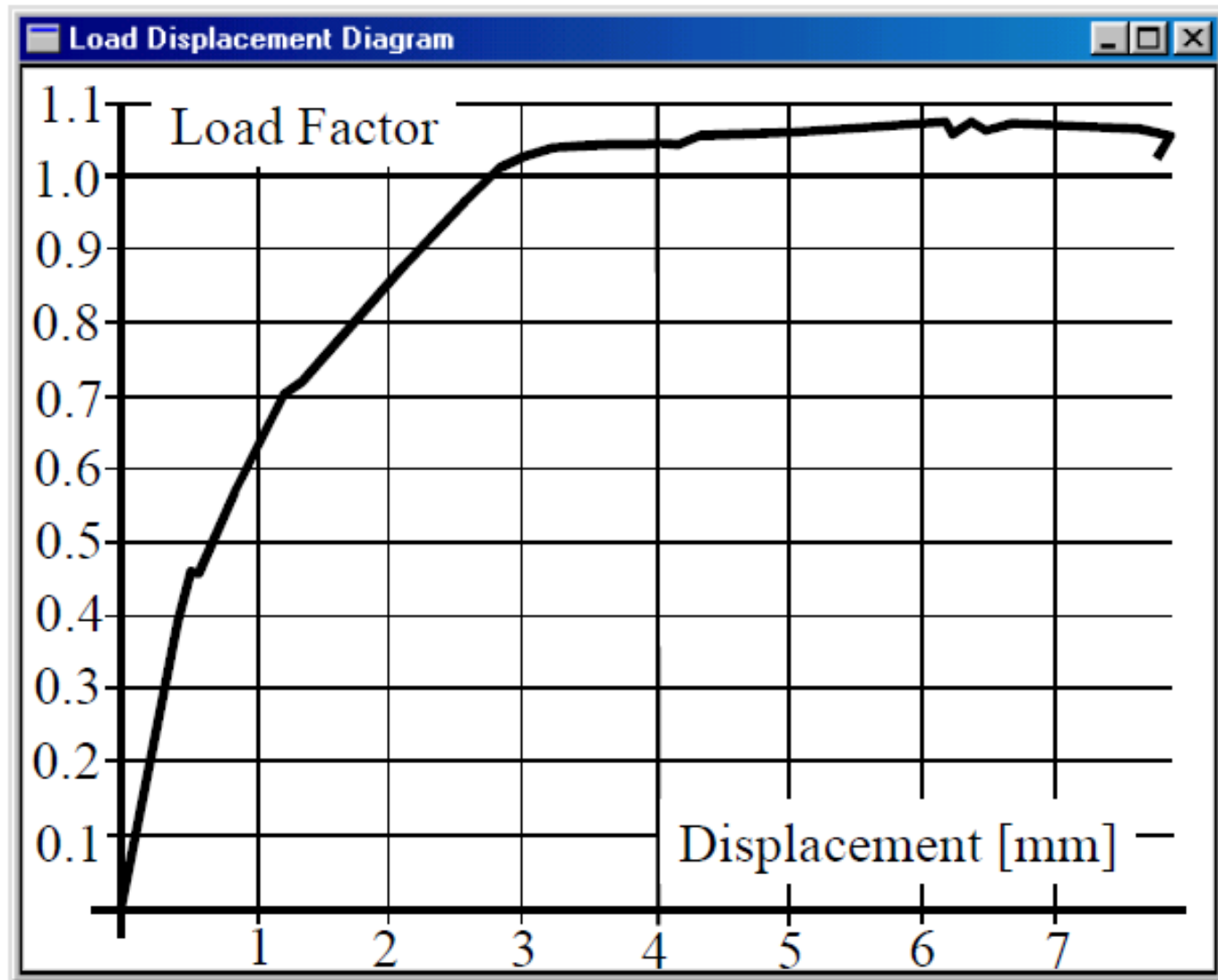
# Modelagem com o Método



# Modelagem com o Método



# Modelagem com o Método



# Conclusões

- A disseminação de programas computacionais tem tornado a prática profissional cada vez mais cômoda, diminuindo cada vez mais as verificações manuais;
- O Método dos Campos de Tensões pode ser uma excelente alternativa para dimensionamento de estruturas complexas, sendo o Método das Bielas praticamente uma simplificação do referido método;
- O Método Biela e Painel pode ser uma excelente alternativa para abordagens manuais, fornecendo uma importante ferramenta para estruturas complexas modeladas com o Método dos Elementos Finitos.



# Agradecimentos



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