

Design of Structural Concrete: Impact of Limit Analysis

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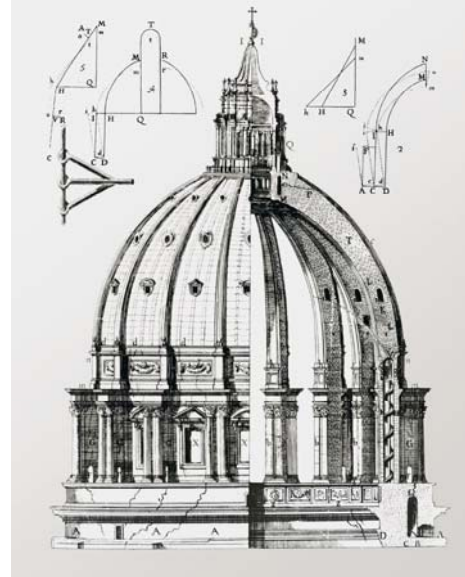
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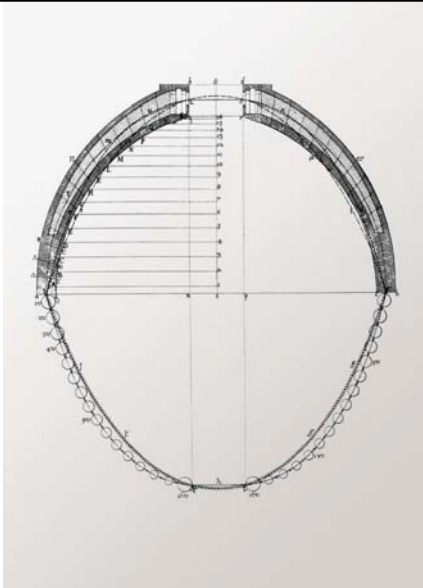
1 Historical Background



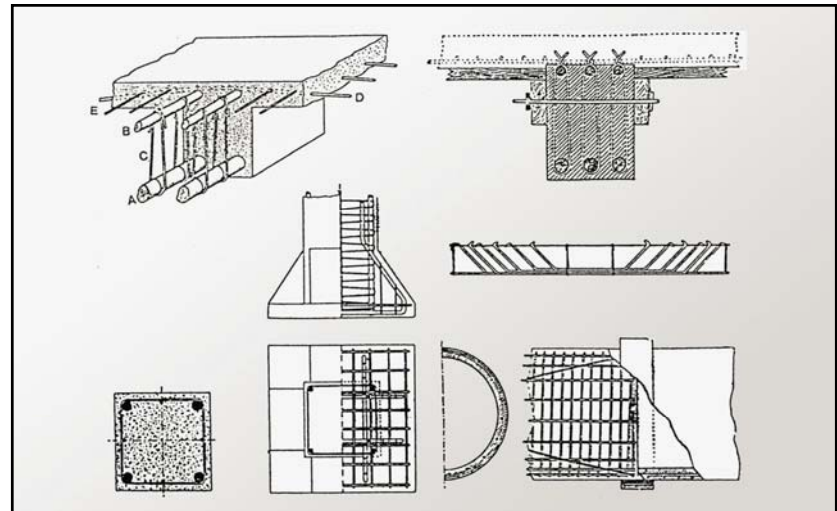
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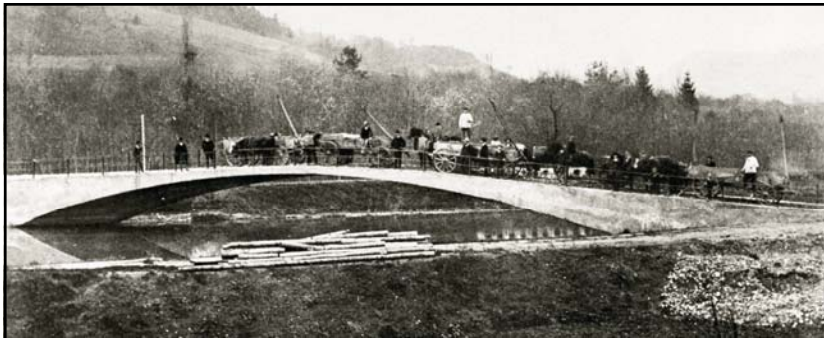
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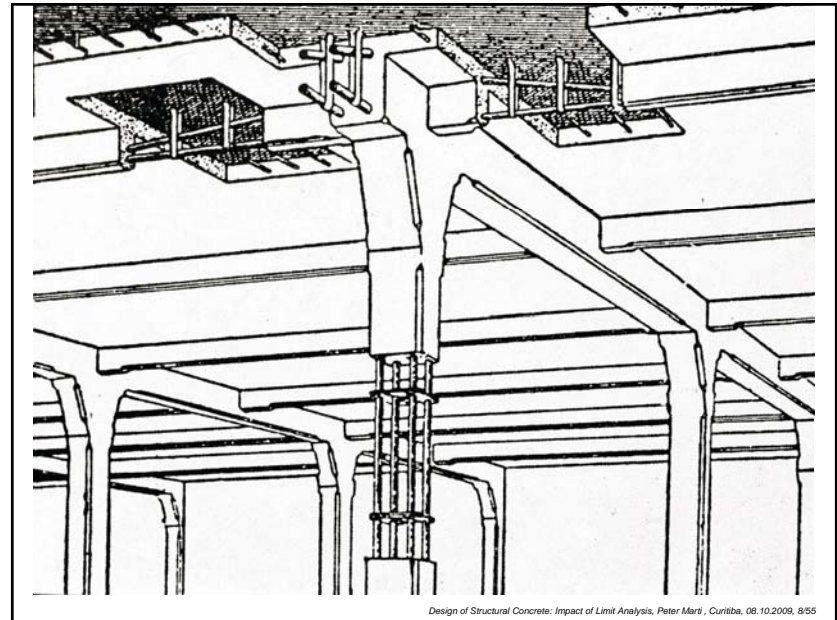
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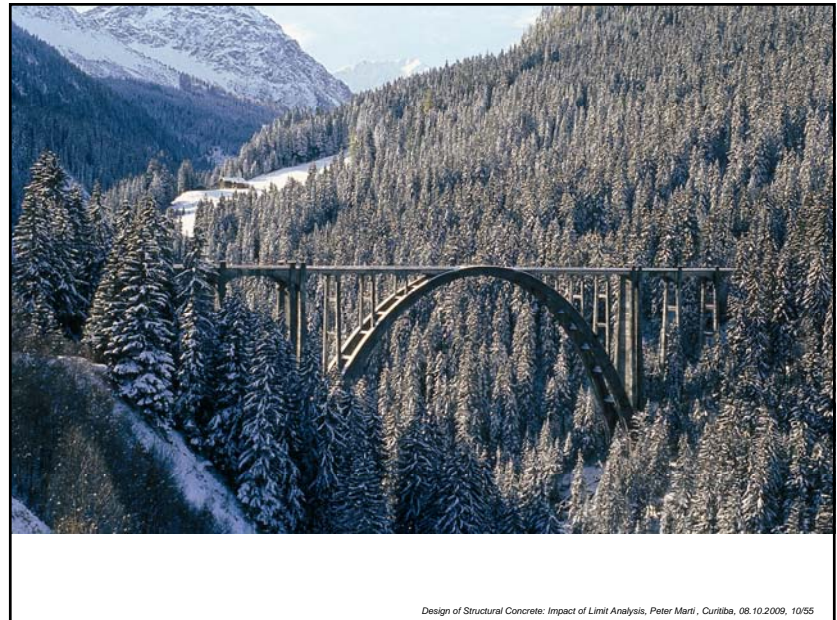
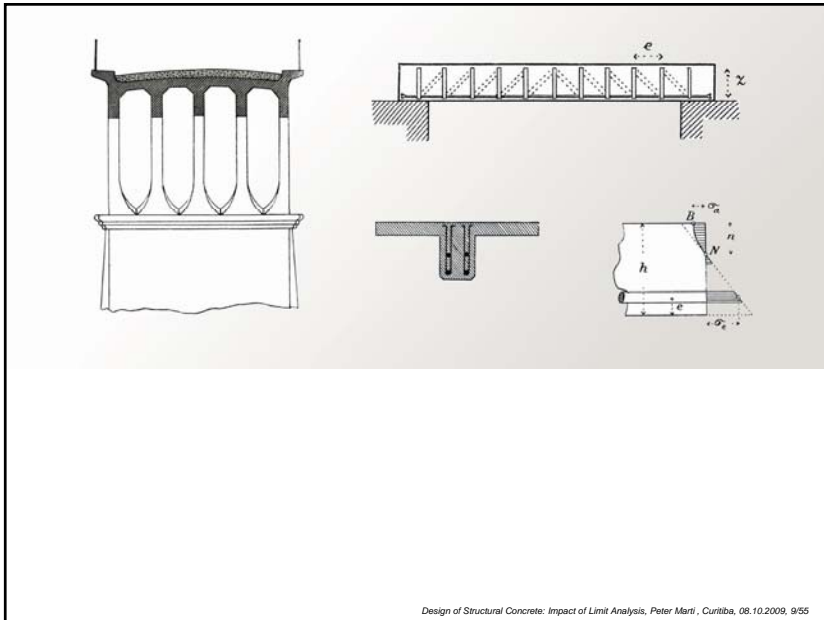
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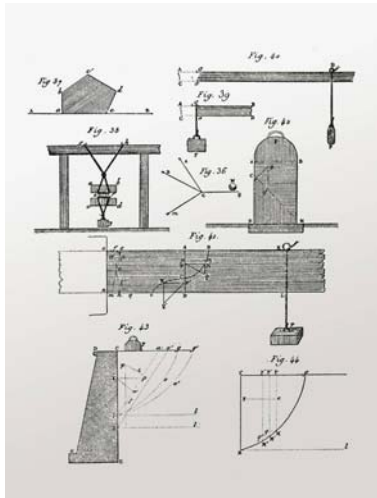


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2 Modelling of Structural Concrete



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Scientific Models - One

- Aim at representing reality
- Means of describing certain ranges of experience / developing associated terminologies
- Basis of predicting future behaviour
- Essential aspects emphasised / secondary aspects neglected

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Scientific Models - Two

- **Realistic** → consistent interpretation of past behaviour
→ accurate prediction of future behaviour
- **Powerful** → large range of experience
- **Consistency / accuracy / generality**

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Scientific Models - Three

- **Subject to permanent evolution**
- **Improve consistency, accuracy and generality**
- **Continuous verification in the light of new (experimental) evidence**
- **If necessary, models have to be adapted and terms have to be newly defined**

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Structural Engineering

- Designing, realising and managing (complex) structures based on scientific knowledge and practical experience
- Design of new / examination of existing structures
- Modelling is an important structural engineering activity

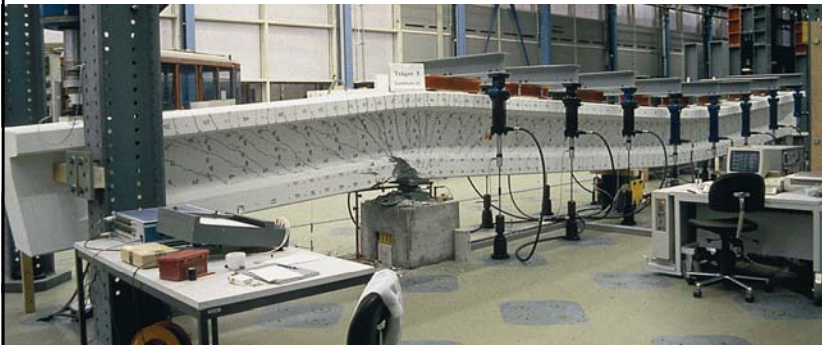
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Models for Structural Concrete

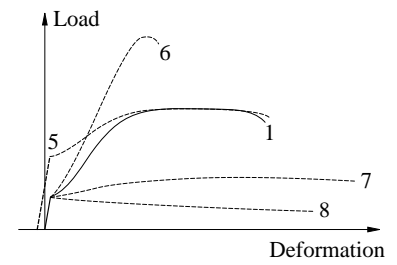
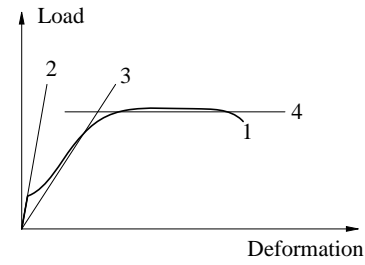
- Scientific models → consistency, accuracy, generality
- Engineering models → simplicity, transparency
- Conceptual design → combined use of simplified models
- Detailed design → more advanced and comprehensive models
- Classical models / recent extensions
- Consistent framework for the treatment of the entire load-deformation response
- Coherent approach to conceptual design, structural analysis, dimensioning and detailing

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3 Behaviour of Structural Concrete

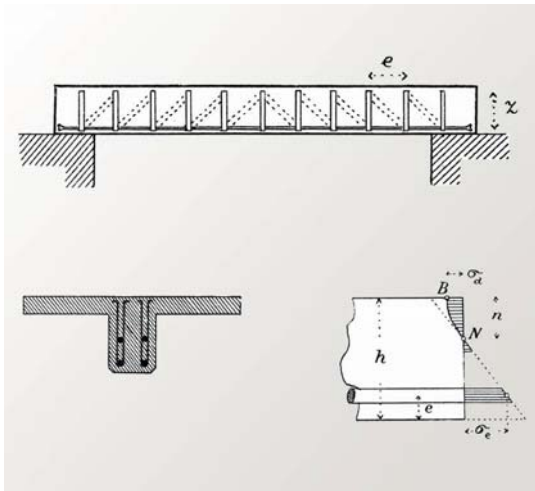


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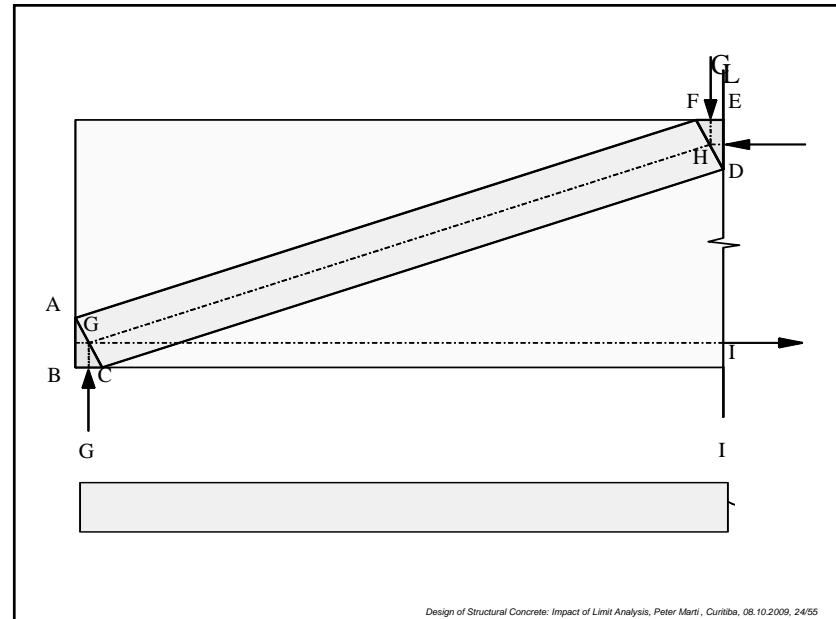


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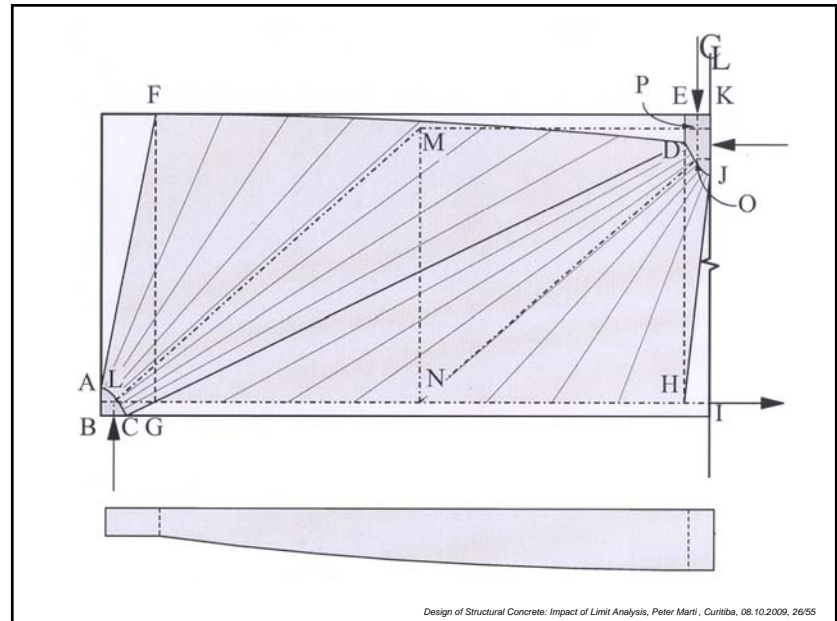
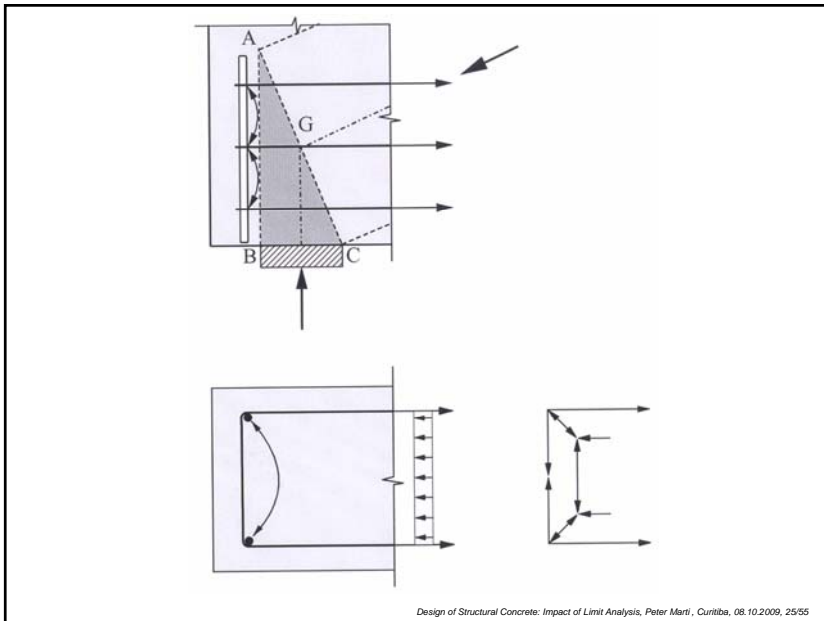
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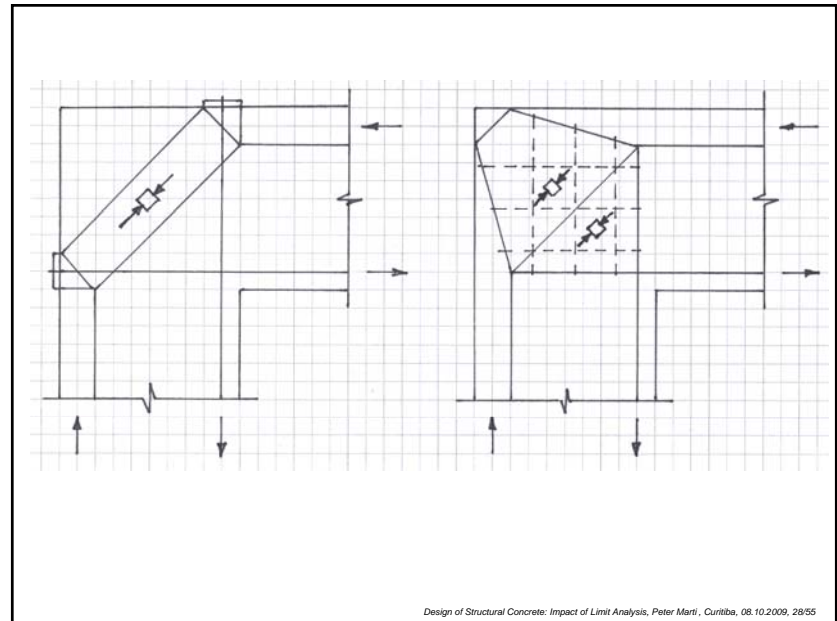
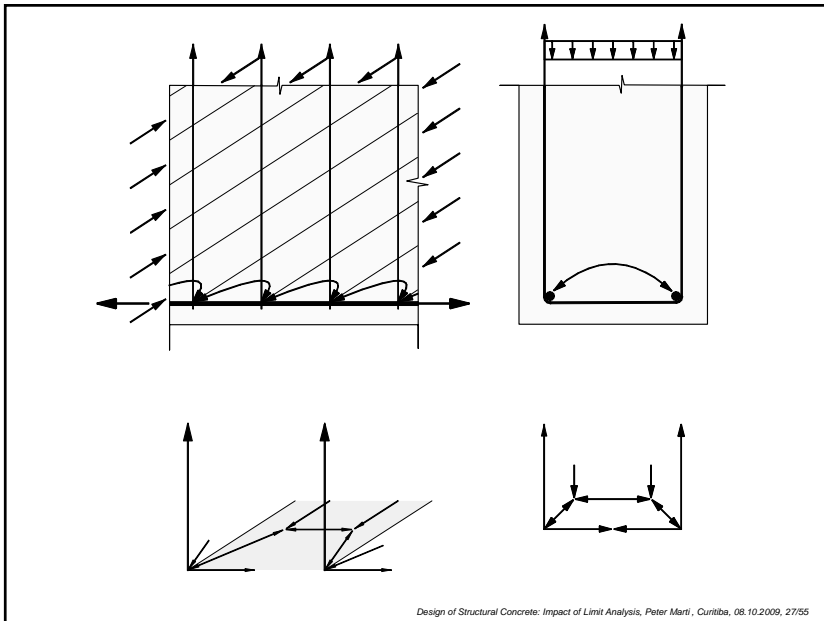


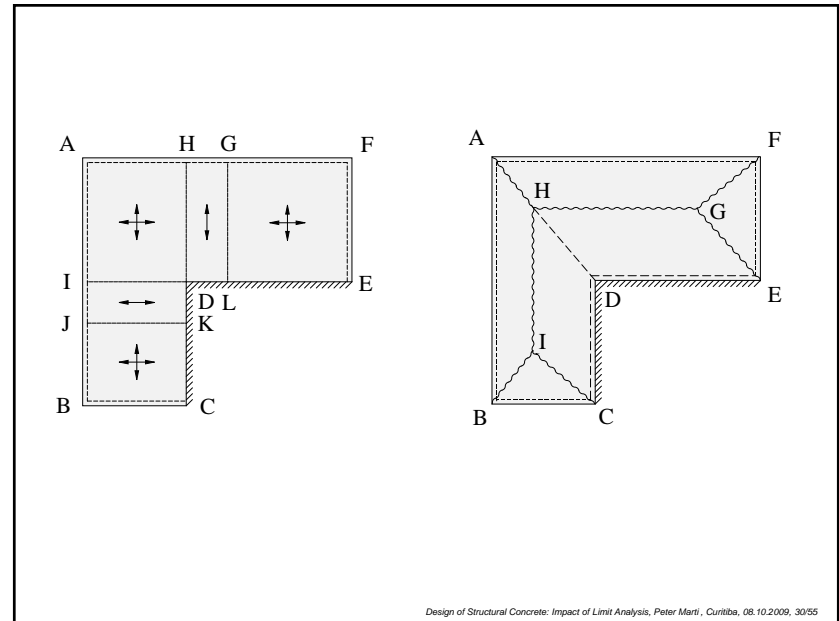
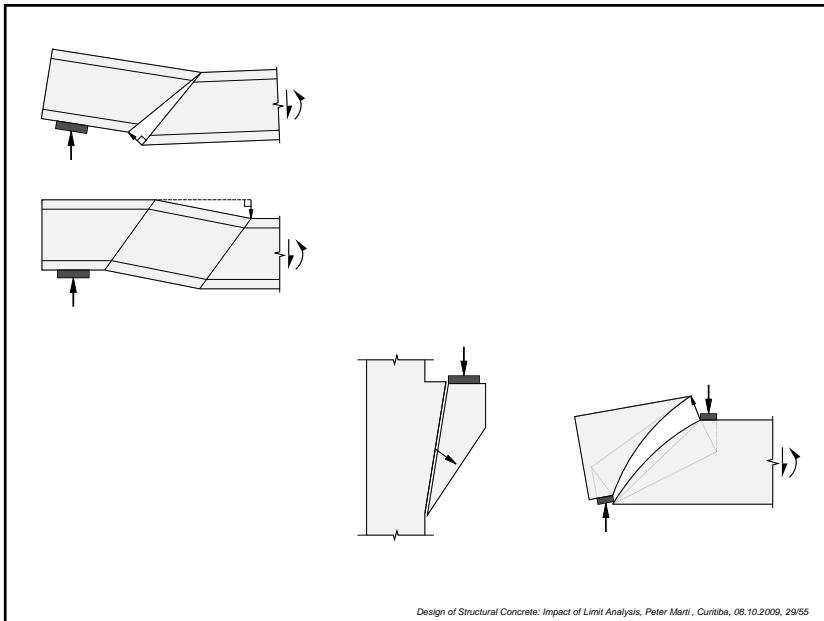
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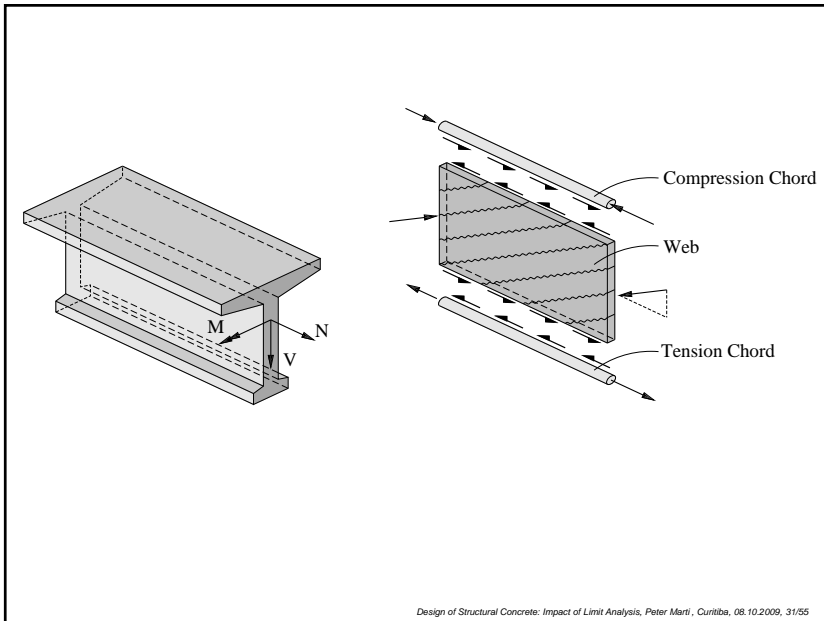


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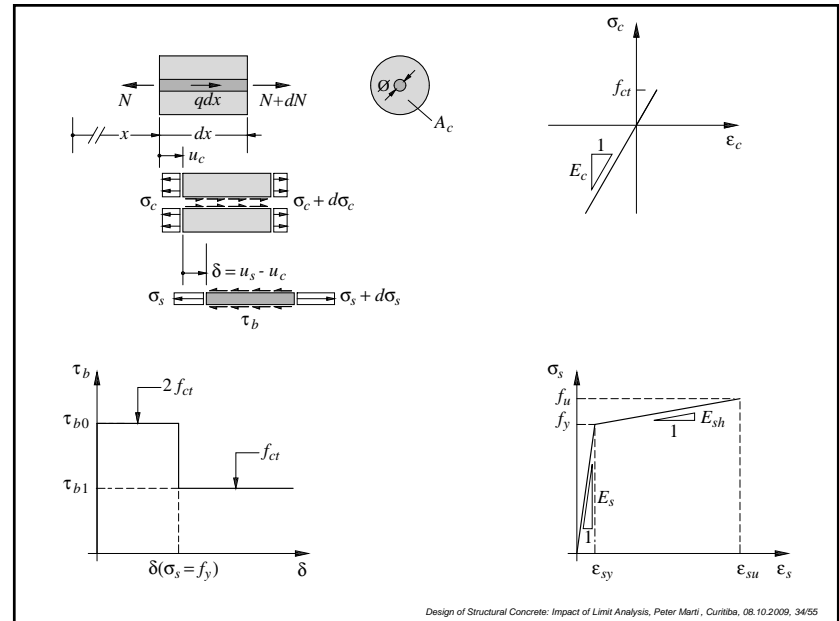
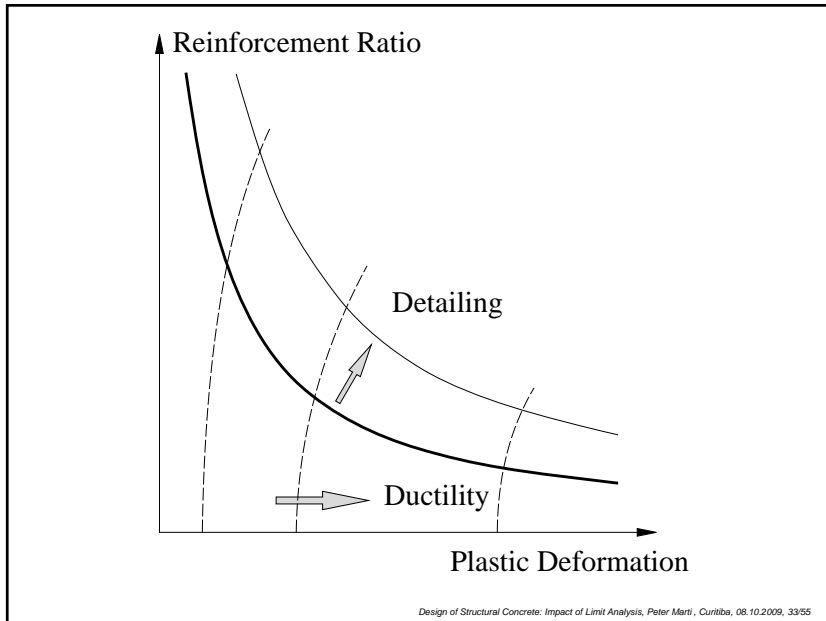


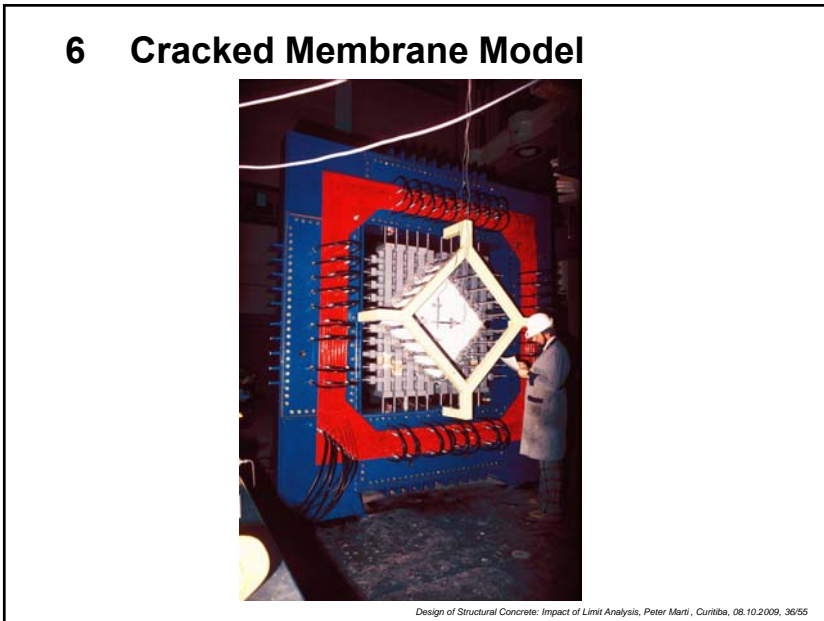
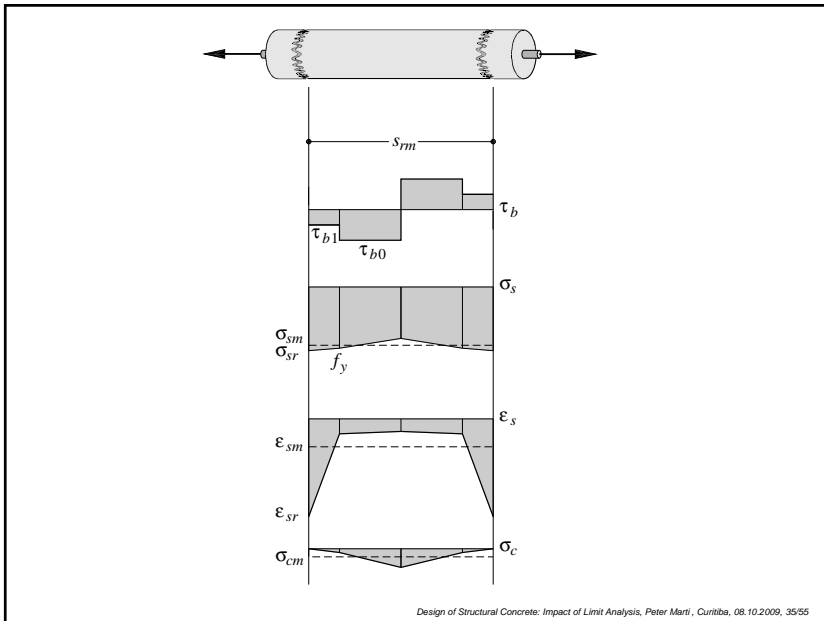
5 Tension Chord Model

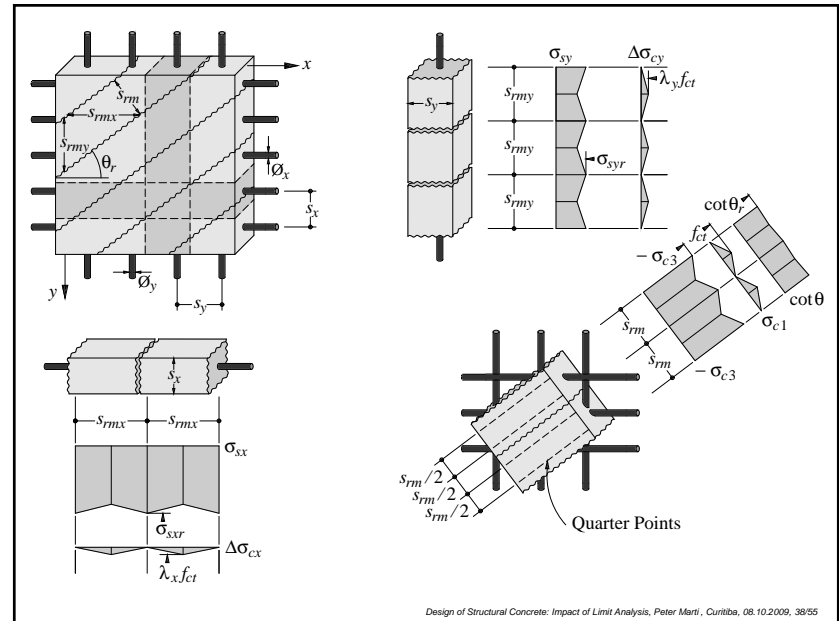
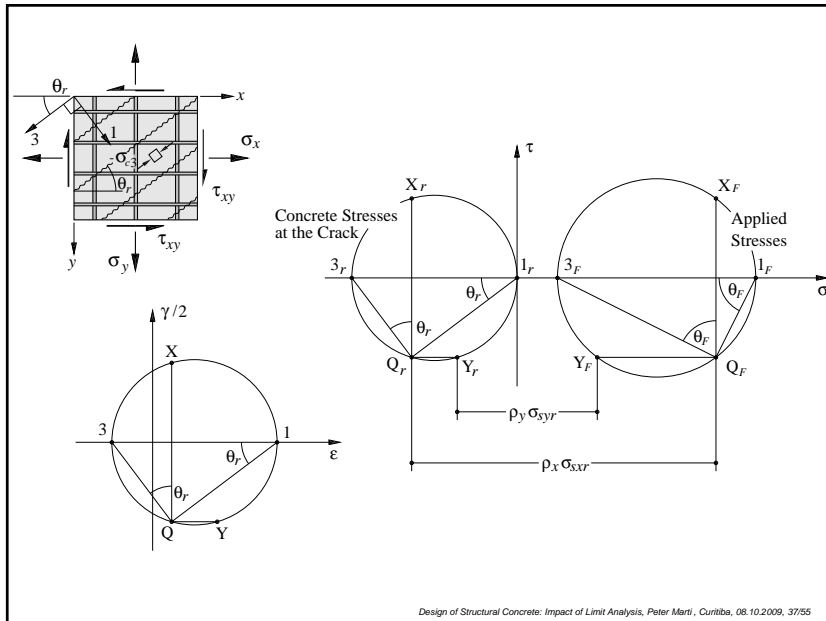
Z1 Laststufe 2

Z9 Laststufe 3

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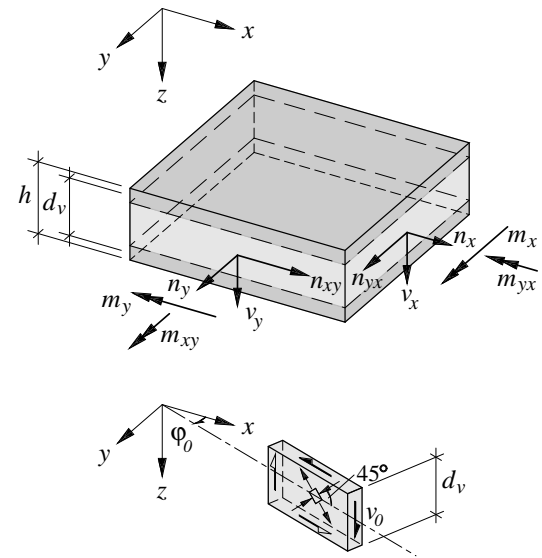




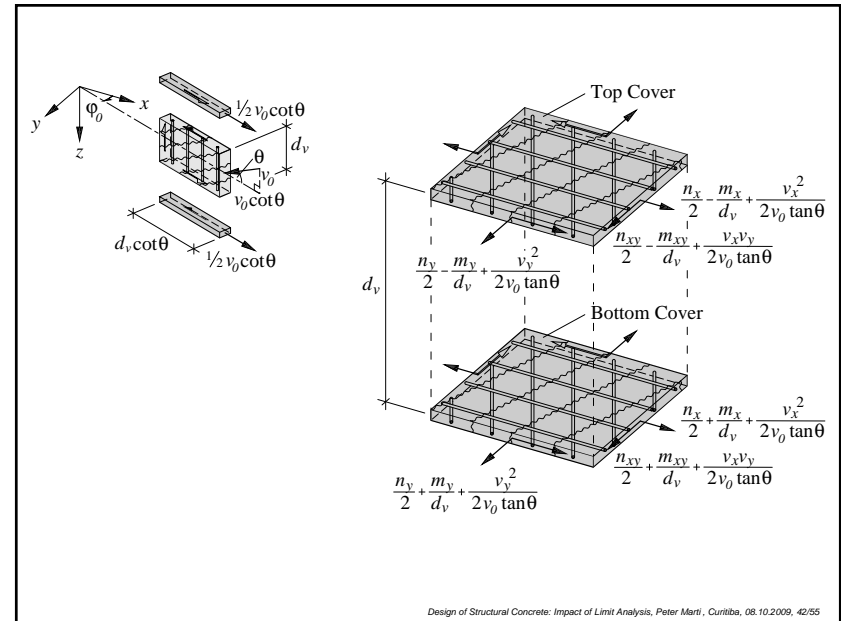
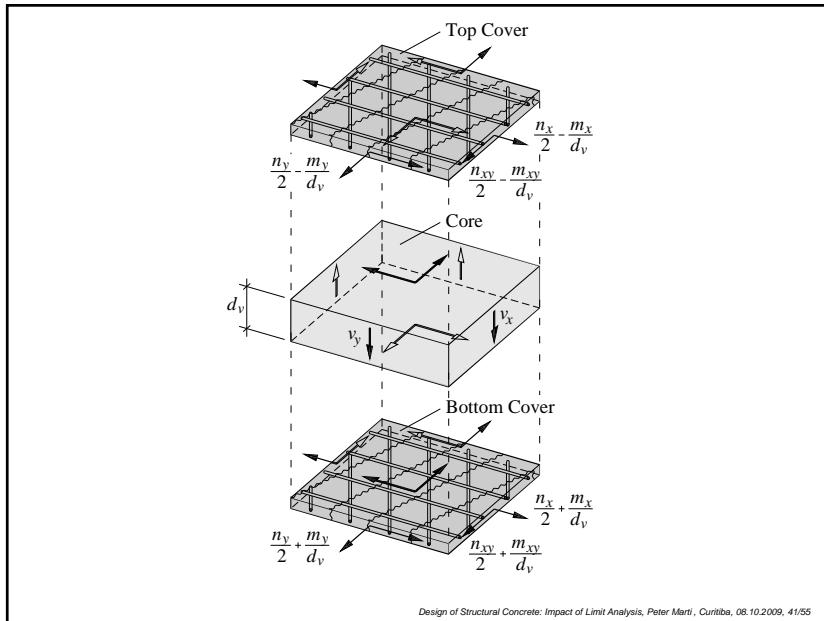
7 Sandwich Model

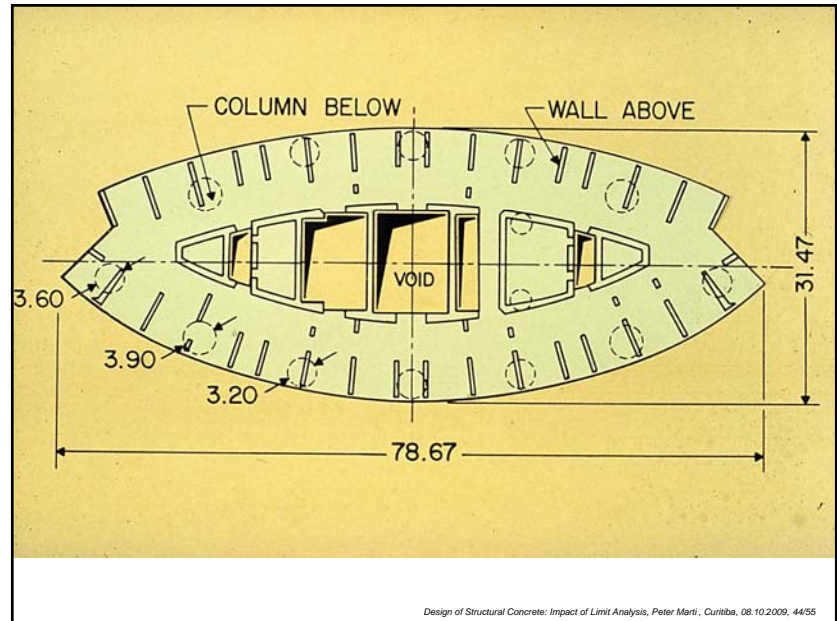
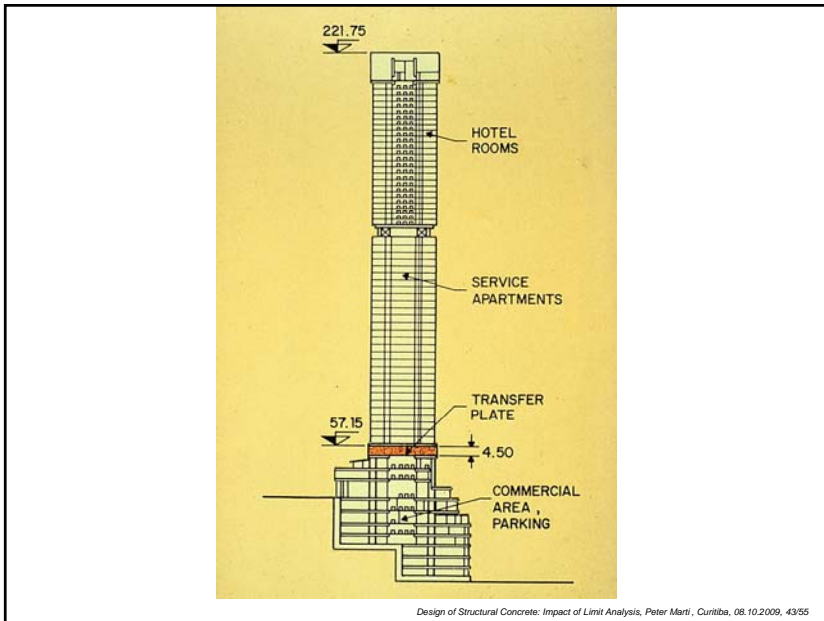


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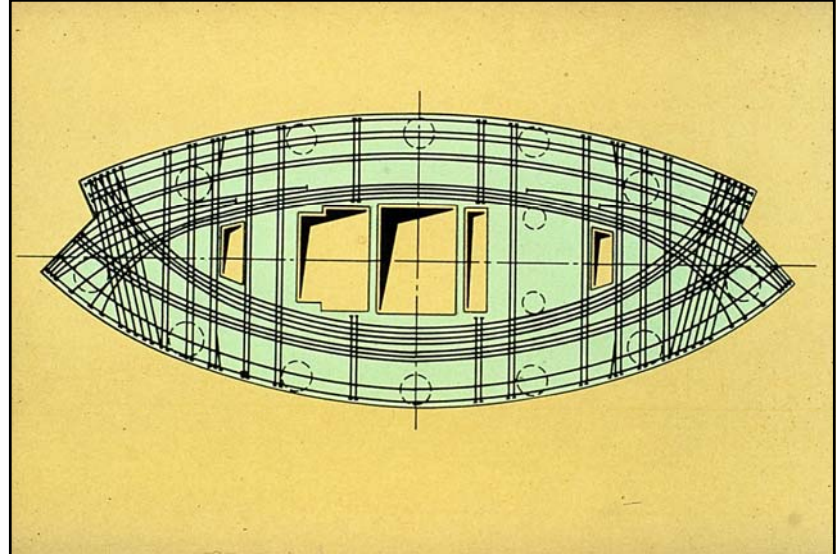
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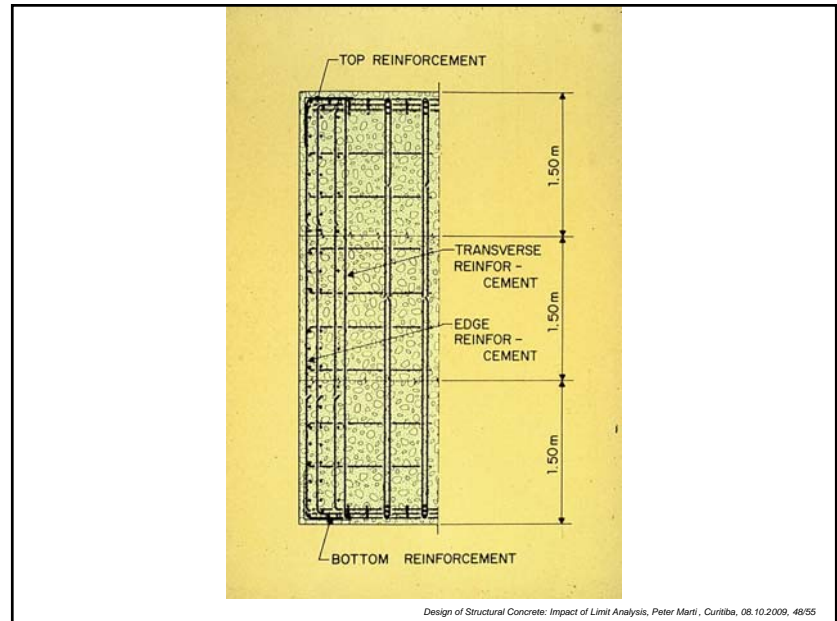
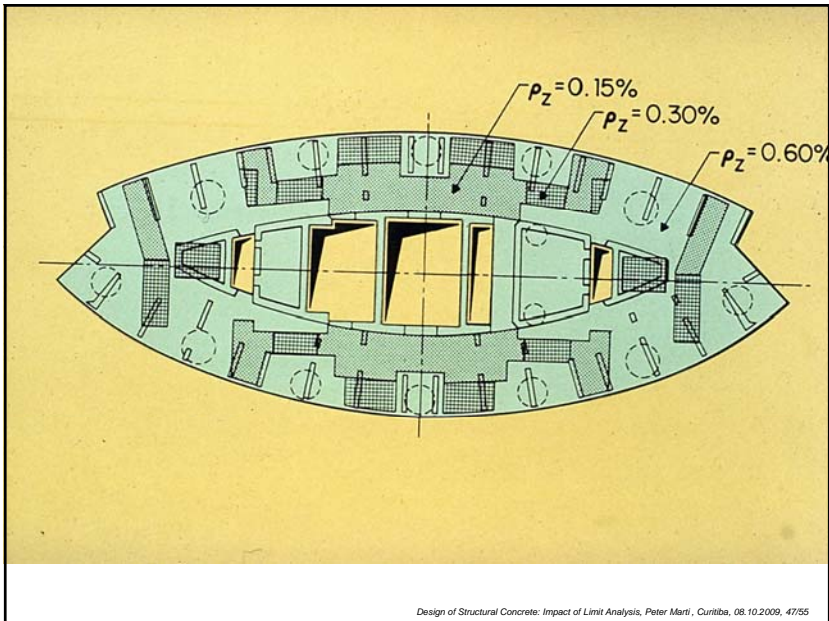




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8 Structural Design and Code Development



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Code Development

- **Recognised principles of construction**
- **Codes should be simple, clear, understandable and practical**
- **Codes must be reliable**
- **A code is a necessary evil, not an end in itself**
- **Basis of fair competition**
 - **consistent terminology**
 - **restricted to a minimum of rules**
 - **liberal towards innovation, no hindrance to creativity**

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Structural Quality

- **Mainly dependent on**
 - conceptual design
 - detailing
 - execution
- **Importance of structural analysis and numerical verifications often overestimated**

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Conceptual Design

- **Essential qualities: economy / integration / configuration**
- **Economy mainly influenced by chosen structural system / envisaged methods of construction**
- **Basic design requires a synthesis:**
 - follow force flow
 - account for execution
 - avoid ballast by reducing / prestressing members
 - **Efficient raw design / more or less uniform stresses**
- **Refined design to improve integration / configuration**

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Representative Stress Design

- Partial factors unsuitable for conceptual design
- Representative stresses (service load level)

$$\begin{aligned} |\sigma_s| &\leq \sigma_{s,rep} = 0.62 f_{sk} \\ \sigma_p &\leq \sigma_{p,rep} = 0.62 f_{p0.1k} \\ -\sigma_c &\leq \sigma_{c,rep} = 5 f_{ctm} \\ \tau_b &\leq \tau_{b,rep} = 0.65 f_{ctm} \\ \tau_c &\leq \tau_{c,rep} = 0.25 f_{ctm} \end{aligned}$$

- **N.B. :** $f_{sd} = f_{sk} / \gamma_s$; $\sigma_{s,rep} = f_{sd} / \gamma_F$
 $f_{cd} \approx 6.9 \cdot f_{ctm}$; $\sigma_{c,rep} = f_{cd} / \gamma_F$
 $\gamma_F \approx \frac{2}{3} \gamma_G + \frac{1}{3} \gamma_Q = 1.4$

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8 Conclusions

- Limit analysis
 - simple, rational and general framework for ULS design of structural concrete
- Supplementary deformation considerations
 - tension chord model
 - cracked membrane model
 - sandwich model
- Representative stress design method
 - suitable for conceptual design
 - similar to allowable stress design
 - integration of achievements of limit analysis

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Thank You



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