

# Contents

Preface	iii
<b>Examples</b>	
<b>1 Solving structural design problems with strut-and-tie models</b>	<b>1</b>
<i>Sebastián Dieste Ballestrino, José Romo Martín, Eduardo García Díaz, Hugo Corres Peiretti</i>	
The strut-and-tie method has been demonstrated to be a powerful tool for the modelling and design of structural concrete. In the conceptual and the structural design stage, the method allows study of different resistant models and evaluation of the most suitable one. In the analysis stage, this method enables the stresses in the structure to be adequately evaluated, allowing calculation of the amount of reinforcement and verification of the stress level of concrete. Additionally, it is especially useful in identifying the critical zones and organizing the reinforcement layout.	
This Example 1 provides a set of application examples for the strut-and-tie method that allows us to understand the creation of the models and the verification of the elements, struts, ties and nodes. Simple structural elements have been chosen, as they are usually designed according to certain traditional rules that are often applied without clear justification. These examples are: Example 1–1: Footing under uniaxial bending; Example 1–2: Footing under biaxial bending; Example 1–3: Pile cap for precast concrete piles; Example 1–4: Diaphragm of a box girder bridge.	
For those facing the design with strut-and-tie models for the first time these examples are intended to be a guide and a reference for similar cases. For those with more experience in structural design, some refinements and possible difficulties in applying the method are discussed.	
<b>2 Precast corbels fitted to columns</b>	<b>31</b>
<i>Jean-Marc Voumard</i>	
In a repair work new corbels had to be fitted to existing columns with post-tensioned bars. The new corbels are made of two precast “C”-shaped concrete elements. A simple and a more refined strut-and-tie model is presented, and a check performed of the transfer of forces by friction across the interface between corbel and column.	
<b>3 Lift shaft substructure</b>	<b>37</b>
<i>Stein Atle Haugerud, Karolin Reineck</i>	
The example demonstrates the application of strut-and-tie model approach for the design of a lift shaft substructure in a 7-story office building. The design with the aid of strut-and-tie models, widely based on the FIP Recommendations (1999), is presented in detail for a deep beam subjected to concentrated loads from intersecting members. The example deals with issues related to concentrated loads near support and detailing aspects of indirect supports. The development of the strut-and-tie model is outlined followed by capacity checks and consequent detailing of critical anchorage zones.	
<b>4 Continuous deep beam</b>	<b>45</b>
<i>Miguel S. Lourenço, João F. Almeida, Rui Boia</i>	
This example shows the application of strut-and-tie models to the design and detailing of a continuous deep beam in an office building. It is a simple model, although some special aspects are worth mentioned, namely the support stiffness, minimum reinforcement disposals and detailing in node regions. A strut-and-tie model is developed for the whole region and the node regions are checked. Finally, the detailing is presented following closely the developed strut-and-tie model.	
<b>5 Shear wall in office building</b>	<b>53</b>
<i>Eudovít Fillo, Vladimír Benko</i>	
A twenty-storey office building was designed for Vienna, Austria. This 76 m tall structure has plan dimensions of 17 m (30 m) × 54 m. A transverse shear wall of varying dimensions was designed with strut-and-tie models for a combination of seismic, permanent and imposed loads.	
<b>6 Deep beam with an opening</b>	<b>67</b>
<i>Tjen Tjhin, Sukit Yindeesuk, Daniel Kuchma</i>	
A large load transfer beam is designed to support a heavy concentrated load and a lighter distributed loading. This storey deep beam is simply supported at its left edge, while the right side frames into a shear wall. The design is complicated by the presence of a rectangular opening between the concentrated load and the shear wall.	

- 7 **Anchorage block for external prestressing tendon – comparison with test results** 77  
*Toshio Ichihashi, Hiroshi Shiratani*  
 An anchorage block on a concrete bridge deck, arranged on the thin slab or web and subjected to prestressing force of external tendons, is a typical D-region problem for concrete structures. In this example, a three-dimensional strut-and-tie model is applied to an actually implemented loading test using a 1/2 size model of an anchorage block. The anchorage block was analysed according to FIP Recommendations (1999) in order to estimate its capacity. The calculated capacity has been compared with the test result. It was concluded that the strut-and-tie model has proved to be useful for estimating the anchorage capacity.
- 8 **Suspended precast RC member** 85  
*Eudovít Fillo, Jaroslav Halvoník*  
 The bridge links two parts of the shopping centre “Avion” divided by busy street in Bratislava, Slovakia. Heavy traffic forced authorities to keep opened the street during construction works. Contractor was forced to offer a semi-precast solution that allowed building bridge without significant disturbances of the traffic. This was reason to use suspended precast reinforced concrete members. Special shape, support and loads of this prefabricated shell offer the possibility for analysis by strut and tie models.
- 9 **Connection between prefabricated beams** 95  
*Miguel S. Lourenço, José N. Camara*  
 This example shows the application of strut-and-tie models for the design of the connection between prefabricated beams of a viaduct. Two different models were developed for the design, considering both construction and service loads. The nodal regions close to the prestress anchorage zones were checked and the detailing is presented following the performed design models.
- 10 **Clamped support of large prefabricated T-girder** 103  
*Hannes Ludescher*  
 In the example, the clamped support of a large T-girder in a connection composed of shear panels is illustrated. The beam with a span of about 35 m is placed as prefabricated girder and consecutively integrated into the structure in order to establish a clamped support. In the operational phase, the connection has to resist to large closing and minor opening moments. The example illustrates the design for the closing moment, starting with the definition of section forces and qualitative modelling. As a result, tendon layout is amended and main reinforcement intensities are outlined.
- 11 **Abutment shear wall of Viaduct 1 on Algarve Highway** 117  
*Miguel S. Lourenço, João F. Almeida*  
 This example shows the application of strut-and-tie models for the design of a viaduct fixed abutments shear walls subject to seismic and permanent loads. Seismic actions conduce to several load conditions, though different strut-and-tie models were performed. Concrete stresses at node regions were checked assuming simplified considerations for the compression strength subject to reverse and cyclic loads. Local third plane models were developed to improve the detailing of critical anchorage zones and load support regions.
- 12 **Designing D-regions of the Enmedio stream bridge** 133  
*Santiago Perez-Fadón Martínez, Carlos J. Bajo Pavia*  
 This example presents the design of five discontinuity regions (D-regions) of the Enmedio Stream Bridge using strut-and-tie models. It is shown that even or especially for very complex D-regions the strut-and-tie models are an appropriate and excellent design tool, which explains the flow of forces and thus leads to a better understanding of the structure.
- 13 **D-regions of the pylons of a cable-stayed bridge** 155  
*Duc Thanh Nguyen*  
 In this example the check of two typical D-regions in Pylons of a cable-stayed bridge using strut-and-tie models are presented. These are the regions where the loads from the stiffening beam are transferred to the pylons and to their cross beams. It shows that strut-and-tie models can follow clearly the flow of forces and, therefore, are excellent tools for the check and de-tailing of such complicated D-regions.

14 Design of T-connections in an offshore terminal 163

*Hannes Ludescher, Stein Atle Haugerud*

The design of off-shore terminals is characterised by a high number of loading situations. They result from various load phases, starting with construction including post-tensioning, assembling, transportation, installation, operation and accidental situations. In order to cover all critical situations in every section of the structure, a systematic and highly automated design process has been developed. Modern computers enable to verify structural safety and serviceability for hundreds of design combinations in all sections. Contrary to sectional design of B-regions, design of D-regions cannot be automated. Engineering judgement is required to identify and delimit these regions, establish design criteria for the various elements and develop models that allow verification of these criteria. This article presents the design process adopted for the design of connections in an off-shore terminal, mainly of T-shaped connections.

**Papers**

15 Strut-and-tie models utilizing concrete tension fields 185

*Karl-Heinz Reineck*

In codes the utilization of the concrete tensile strength has often been denied and explicitly been ruled out. Yet, the bond and anchorage of reinforcement in concrete members cannot be explained without the action of the concrete tensile strength. However, this is covered by using shear stresses for the bond strength. Likewise, the ultimate capacity of members without shear reinforcement has been defined in terms of shear stresses, for which empirically derived formulae are given. However, such equations do not give any insight in the structural behaviour and the flow of the forces within the member.

This paper describes the shear transfer in members without shear reinforcement and derives a simple truss model with inclined concrete ties. However, the ultimate capacity cannot be explained by the concrete ties attaining the concrete tensile strength but it is determined by the limited capacity of the friction along the cracks and the dowel action. This model also explains the transition from B- to D-regions in members without shear reinforcement and enables the design of the D-regions, as demonstrated by an example.

16 Gaining experience with strut-and-tie models for the design of concrete structures 197

*Karl-Heinz Reineck, Miguel S. Lourenço, João F. Almeida, Stein Atle Haugerud*

Author information 217

**Editorial Comments**

In the drawings of strut-and-tie models the following well known convention is used:

for struts: dashed lines      and for ties: solid lines.

The notation follows that of the CEB-FIP Model Code 1990 respectively that of the FIP Recommendations 1999 “Practical design of structural concrete.

For the spacing of reinforcing bars various symbols were used in the examples according to the different traditions in the various countries:

á      @      at      c      s =      /      //      -      #

In the calculations the decimal symbol is a comma (,), and for the thousands separator a point (.) is used. However, due to different conventions in CAD programs, in some figures the decimal point used instead of a comma; in such cases a note has been added the relevant figure caption.