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Johan Blaauwendraad

Stringer-Panel Models in Structural Concrete

Applied to D-region Design

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Preface

This book is intended for structural engineers designing concrete structures. Structural engineers are familiar with structural concrete members to which Bernoulli beam theory applies, known as B-regions. The focus of this book is particularly on the design of regions where beam theory does not apply, known in structural jargon as D-regions. They occur at supports and at locations where beams and columns meet in joints or where lumped forces are applied. The design of these regions is the subject of this book, and the method advocated is the *Stringer-Panel Model* (SPM). In fact, SPM is a companion method to strut-and-tie models (STM).

An early highly advanced application of SPM in 1998 undeservedly failed to gain the attention of structural designers or software builders. Therefore, this book takes, on purpose, a step backward in comparison with that sophisticated modelling. The lesson has been learned that it is hard to offer public access to specialist software and a challenge to keep the software up-to-date. Here, we go back to the basics of the method, reducing models to the most straightforward configuration possible and restricting ourselves to simple analysis. In most cases used, we do not need software at all and solve the problem by hand. Moreover, designers who do need software are provided here with links to free-access software.

SPM has its roots in the two entirely different subcultures of concrete plasticity and linear-elastic aeroplane analysis. These two branches of descent make SPM of interest to two distinctive groups of structural concrete designers: one focusing on durability requirements and the other in charge of safety in seismic regions with severe cyclic loading.

We would plead for the inclusion of SPM in the design of D-regions in structural concrete in forthcoming editions of the Model Code. This book aims to be a practice-oriented and easily accessible exposé of the method, making structural engineers familiar with it and hopefully enabling them to start using it.

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We are indebted to Prof. José Restrepo of the University of California at San Diego for his interest in the method itself and his promotion of the SPM in educational and structural engineering societies. We very much appreciate his contribution to the practical examples and his preparedness to read through key sections of the manuscript. Our exchange of thoughts clarified the merits of the Stringer-Panel Model for two different groups of designers: one focusing on performance requirements and the other on seismic actions. We are also greatly indebted to Pierre Hoogenboom, Assistant Professor at Delft University of Technology and the architect of a previous package of advanced SPM software. To us, he is a master of the method. His offer, for the purposes of this book, to write basic multi-purpose software as a supporting tool for more demanding applications of the model has really been a major relief to us. Moreover, our discussions and mutual considerations certainly boosted our understanding of the potential of the SPM itself and of the newly developed software. We also acknowledge with pleasure Nelson Ángel, PhD of the Universidad de los Andes in Colombia. As part of his doctoral thesis work under the supervision of Prof. José Restrepo, he brought about a dedicated application of SAP2000 and MATLAB, yielding an analysis tool which is intended to be profitable to structural engineers in the Americas. Both the software of Hoogenboom and that of Ángel is available on the Internet to interested structural designers. Finally, we express our gratitude to Wim de Bruijn, former Lecturer of Delft University of Technology and retired structural designer in engineering practice, for kindly assisting on workable reinforcement layouts.

Links to Websites

- Appendix 1: http://heronjournal.nl/42-3/SPM/
- Appendix 2: www.ideas-sas.com

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Chapter 1
Introduction to Stringer-Panel Models

Structural engineers designing reinforced concrete structures are used to distinguishing between B-regions and D-regions. All parts of structures where Bernoulli beam theory applies are B-regions, a category all structural engineers are familiar with. At supports and at locations where beams and columns meet in joints or where lumped forces are applied, however, the basic assumptions of this theory cease to be valid. In such situations, the beam theory state of stress is disturbed and discontinuities may occur. Therefore, such areas are called D-regions.

To the present day, structural designers rely mostly on the *Strut-and-Tie Model* (STM) for the design of D-regions. Here we present a companion method on the basis of the *Stringer-Panel Model* (SPM). This model can be used in its own right, but may also be applied to determine a proper strut-and-tie model, or used in combination with the STM.

The *panels* transfer membrane shear forces which are uniform over the whole area of a panel, and the *stringers* transfer normal forces, see Fig. 1.1. Because the stringers are loaded by the uniform shear forces of the panels, the normal force varies linearly over the length of stringers. The model is inspired by the fact that real reinforcement arrangements always consist of one or more concentrated tension bands, which as a rule are situated near the edge of beams and walls and around openings, and a distributed reinforcement over the beam or wall or over large parts of it, often applied in two different directions.

For two distinct reasons, it is helpful to start with a discussion of the STM. First, much of the knowledge that there is concerning the STM also applies to the SPM, and second, this discussion will enable us to set out which difficulties in the STM are thought to be circumvented by the application of the SPM. So, we will briefly summarize the merits of the STM, discuss its development over the course of time, and list some complications.

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