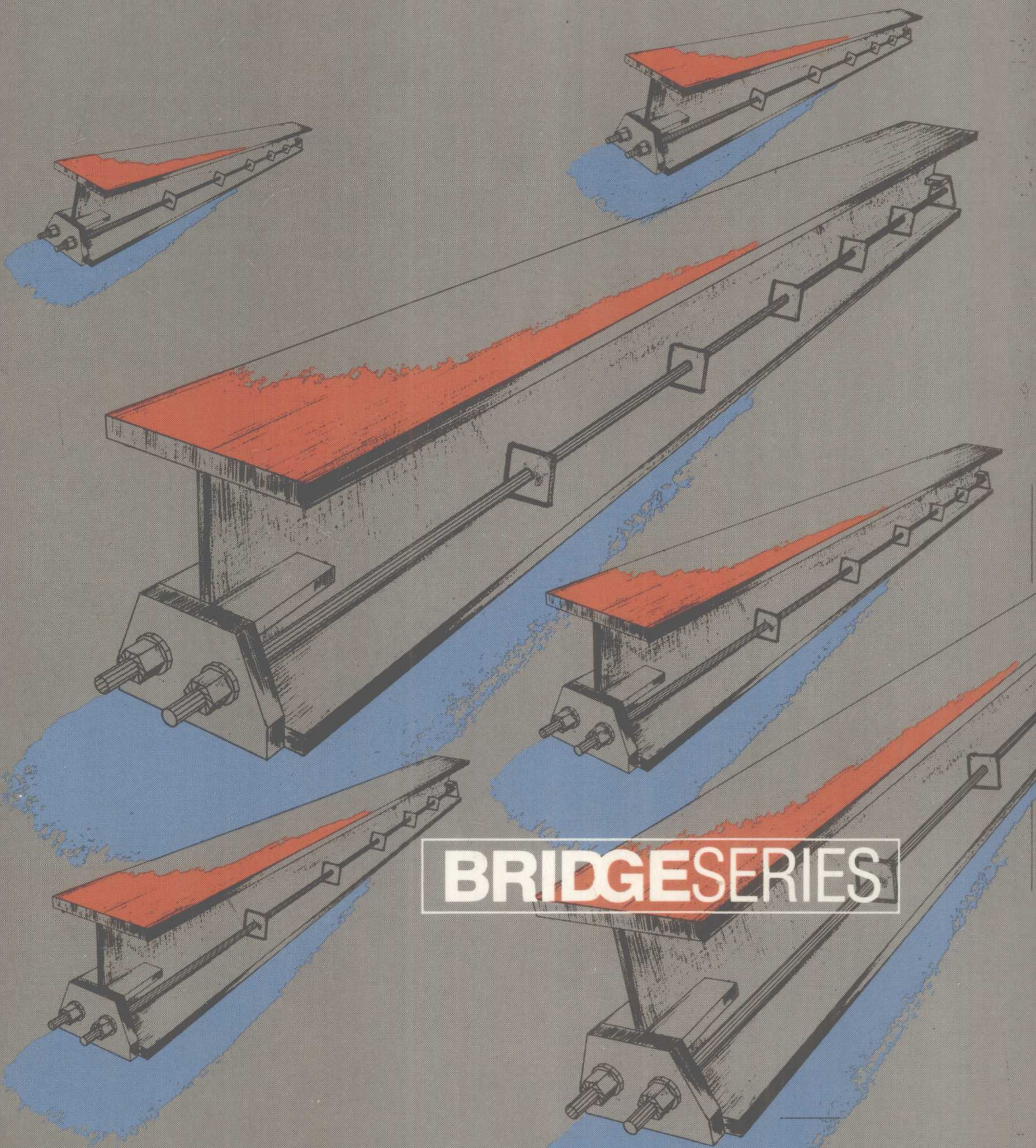
PRESTRESSED STEEL BRIDGES

Theory and Design

M. S. TROITSKY



BRIDGESERIES

PRESTRESSED STEEL BRIDGES THEORY AND DESIGN

M. S. Troitsky, D.Sc
Professor of Engineering
Concordia University
Montreal

BRIDGESERIES

VAN NOSTRAND REINHOLD COMPANY
New York

Library of Congress Catalog Card Number 89-16479
ISBN 0-442-31922-3

Printed in the United States of America

Van Nostrand Reinhold
115 Fifth Avenue
New York, New York 10003

Van Nostrand Reinhold International Company Limited
11 New Fetter Lane
London EC4P 4EE, England

Van Nostrand Reinhold
480 La Trobe Street
Melbourne, Victoria 3000, Australia

Nelson Canada
1120 Birchmount Road
Scarborough, Ontario M1K 5G4, Canada

16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging-in-Publication Data

Troitsky, M. S.
Prestressed steel bridges : theory and design / by M. S. Troitsky.
p. cm.
Includes bibliographies and index.
ISBN 0-442-31922-3
1. Bridges, Iron and steel—Design and construction.
2. Prestressed steel construction. I. Title.
TG380.T76 1990
624'.25—dc20 89-16479
CIP

PRESTRESSED STEEL BRIDGES
THEORY AND DESIGN

To the memory of my parents
Lydia and Serge

Foreword

During the nineteenth century timber, stone, and masonry were the common materials for bridge construction. Then iron, steel, concrete, and reinforced concrete emerged successively as favorite materials, culminating with the use of prestressed concrete in the twentieth century. For many years, in the long span bridge field, structural steel was the dominant material of choice, it might even be said that structural steel had a monopoly on long span bridges. However, after World War II, starting in about the 1950s in Europe and later in about the 1970s in the United States, two new concepts evolved. These were the emergence of the cable-stayed and the prestressed concrete segmental type of bridge construction.

Today's implementation of concrete cable-stayed bridges and prestressed concrete segmental bridges has not only penetrated the long span bridge market, but also threatens to replace structural steel as the dominant material of choice. The only totally structural steel cable-stayed bridge in the United States was the Luling Bridge in Louisiana, completed in 1983. Since then the so-called steel cable-stayed bridges have been, in reality, composite structures. Aside from the cable stays, structural steel is only found in the longitudinal edge girders and floor beams. The application of prestressing to steel bridges, as presented in this volume, will provide increased competitiveness for structural steel and, in all probability, emerge as a major technological advancement in the next decade.

In order for the reader, whether a seasoned veteran or a novice, to comprehend the theory and design of prestressed steel bridges requires a basic understanding of the concept of prestressing. The basic principle of prestressing is that of the introduction of internal stresses of such magnitude and distribution that the stresses resulting from given external loadings are counteracted to a desired degree. That is to say, the theory of prestressed design provides for the elimination of undesirable stresses in a load carrying structure or member by introducing into it artificial stresses which are directly opposed to those to which it will be subjected when the load is imposed. The key word is "principle." There are obvious differences in the application of the principle to various materials, however, the principle remains valid regardless of what material is being used. There is an apparent "mental block" tendency which considers prestressing as being applicable only to concrete. In fact, it has been and is being applied to structural steel. Prestressing is being used for timber structures, and in theory could be applied to other materials such as plastics. Prestressing is a basic principle of design for structures of all kinds and materials.

In the case of prestressed steel bridges the elimination of these undesirable stresses makes possible savings in the quantity of structural steel required to support a given load, as compared with conventional structural steel design. The savings in structural steel weight has been estimated to be in a range of approximately 10 to 30 percent, depending on the specifics of application in a particular design or project.

The concept of prestressing steel structures has been traced back to Squire Whipple who, in 1837, overcame the brittleness of cast iron tension members in trusses by prestressing them. During the late 1800s and early 1900s bridge designers, undoubtedly without the realization of the principles of prestressing, strengthened bridges by the use of the king and queen post trussed floor beams. Starting in about the mid 1930s, F. Dischinger in Germany, Gustave Magnel in Belgium and others in Europe began to study, investigate, test, and construct prestressed steel structures.

Magnel in an article titled "Precompressed Structural Steel Construction" published in the June 1950 issue of *L'Ossature Metalique* (Brussels) urged United States engineers to explore the use of prestressed steel. In another article titled "Prestressed Steel Structures" published in *The Structural Engineer* (November 1950) he stated:

> The specialists in structural steel have the great advantage of having at their disposal proper means of prestressing. The girder tested in our laboratory has been prestressed with the same sandwich cable, which we are using for prestressed concrete and with the same jacks. This fortunate fact will allow prestressed steel to make much quicker progress than has been possible in prestressed concrete.

Numerous articles and papers have appeared in the technical literature. Rudolph Szilard wrote "Strengthening Steel Structures by Means of Prestressing" (*The Engineering Journal* (Canada), October 1955) and "Design of Prestressed Composite Steel Structures" (*Journal of the Structural Division*, ASCE, November 1959). Subcommittee 3 on Prestressed Steel of Joint ASCE-AASHO Committee on Steel Flexural Members published a report on the "Development and Use of Prestressed Steel Flexural Members" in the ASCE *Journal of the Structural Division* (September 1968). Two articles by Homer M. Hadley in the ASCE *Civil Engineering Magazine* (May 1960 and May 1966) describe the design and construction of two prestressed steel bridges in the state of Washington.

The June 1960 issue of *Transportnoye Stroitelstvo* describes a prestressed steel bridge over the River Tom in western Siberia. This bridge consists of five spans, one of 240 ft., three of 358 ft. and one span of 240 ft., and was designed for vehicular traffic as well as for use as a temporary railway siding. The use of prestressed steel bridges of this magnitude had not previously been attempted in the Soviet Union. The reader will note from the examples and references in this book that the Soviets are undoubtedly the leaders in this technology.

The reader will also note that all of the developmental activity in prestressed steel parallels, at least in the time period under consideration, the development of prestressed concrete and may question why the prestressing of steel structures never reached a stage of exploitation similar to that of prestressed concrete. Certainly there is no technological reason why the concept of prestressing steel structures should not have advanced further than it has. Within the context of the historical time period, it must be remembered that structural steel was the dominant material and reinforced concrete was not very competitive, at least in the medium to long span range of bridges. From a commercial point of view, the use of prestressing for steel bridges would only reduce the amount of structural steel necessary, and thus be of no commercial advantage to the steel industry. The rapid technological advances of prestressed concrete, coupled with the concepts of segmental and cable-stayed bridge construction of the last two decades in the United States, have placed prestressed concrete in a very strong competitive position against structural steel, and recent trends may have made it the more dominant material. This course of events represents a classical example of a dominant competitor underestimating its competition.

The resurrection of the concept of prestressed steel bridges can reverse this trend, or at least make structural steel much more competitive than it has been in recent times. If this is true, then we must consider how the prestressing of steel can be used to best advantage. In the bridge construction field there are two broad areas where the prestressing of steel can be used to advantage: the design and construction of new longer span bridges, and the strengthening and rehabilitation of existing structures.

There is a definite trend in new structures to increasing span lengths. In the case of bridges crossing navigable waterways there are several valid reasons for spans longer than what would be required strictly for the navigation channel width. Removal of bridge piers from the waterway to the river bank, or at least to shallower water, reduces construction cost which would be greater when using deep water piers. Longer spans reduce the hazard of ship impact with the piers from errant vessels which could produce a potential failure with attendant loss of life or environmentally objectional cargo spills. Removal of the piers from the confines of the river eliminates the potential of pier scour. Longer achievable spans with prestressed steel bridges, consistent with geotechnical constraints, would require fewer piers and thus minimize impact upon environmentally or ecologically sensitive areas. Where pier locations are based upon other constraints it may be possible to reduce the span-to-depth ratio, by the use of prestressing, so that the length of the approach structure or approach embankment is reduced, thus providing economies.

The 1989 *Report of the Secretary of Transportation to the United States Congress on the Status of the Nation's Highways and Bridges* indicates that of the number of bridges inventoried and classified (577,710), approximately 26 percent (151,330) are or should be load posted. Bridges that require load posting fall into two groups. One group includes structurally deficient bridges that have deteriorated to such a condition that they cannot carry the load for which they were designed. The second group includes functionally obsolete bridges that are in good condition, but whose current state legal load exceeds the original design load and therefore, the bridges require posting.

Numerous states in the United States are confronted with the problem that many of the steel beam composite concrete deck bridges constructed between 1940 and 1960 are not in compliance with today's bridge standards. This condition results from an increase in legal load limitations, changes in specifications, and increased dead weight from resurfacing with concrete overlays. There are three possible solutions to this problem. The first solution is bridge replacement, which would be extremely expensive, not only because of the tangible cost of reconstruction, but also because of the intangible costs of inconvenience to the traveling public, longer time and additional distance traveled as a result of detours, and increased fuel consumption. The second solution is posting load restrictions, on higher type primary roads; trucks with loads exceeding the limits would be required to take alternative routes, with attendant intangible costs as indicated in the first solution. The third solution is to strengthen these existing bridges by prestressing. This can be an extremely cost-effective method.

The objective of this book is to summarize in one volume the current state-of-the-art of design and construction methods for all types of prestressed steel bridges, and thus to serve as a ready reference source for engineering faculties, practicing engineers, contractors, sub-contractors, and local, state, and federal bridge engineers. It presents guidelines for the structural analysis and design of prestressed steel bridges such as plate girders, trusses, arch bridges, cable-truss bridges, and guidelines for the rehabilitation and strengthening of existing bridges.

Chapter 1 is a quick review of the historical evolution of the subject to the current state-of-the-art. It offers the reader an appreciation of the way in which prestressing of steel bridges developed, the basic concepts of design and analysis as well as economies that are achievable by prestressing.

Chapter 2 discusses the methods of achieving prestress in a structure or in individual members, and provides examples of applications, while Chapter 3 discusses the all important subject of the prestressing tendons and anchorages through which the prestressing is induced into the structure.

Chapters 4 through 6 deal essentially with plate girder bridges, including composite girder bridges, and discusses such parameters as tendon geometry, optimum cross-sections, stress conditions, the effect of creep and shrinkage of the composite concrete deck, and continuous prestressed girders. Prestressing of steel box girders is considered in Chapter 7.

Although Chapters 4 through 7 deal with girder type bridges, prestressing can effectively be applied to other types of steel bridges. The analysis, design, and application of prestressing to trusses, tied arches, and cable-truss type bridges are treated in Chapters 8, 9 and 10, respectively.

The important topic of the application of prestressing to the strengthening and rehabilitation of existing steel bridges is presented in Chapter 11.

Perhaps the most important feature of this book, aside from the presentation of the theory and application of prestressing to steel bridges, is the authors effective utilization, throughout the book, of numerous illustrations, examples of practical applications and detailed design examples. In this way, the author has presented to the designer and engineer a series of guidelines for the successful application of the concept of prestressing to steel bridges.

There has been considerable change in bridge design and construction in the last decade, much of which has been evolving since the 1950s. As we progress into the next decade, there must be a conscious awareness of change. Research is being conducted to improve materials that may have a dramatic impact on the industry; and application of new systems to existing bridge types, along with new and improved types of bridge structures, is being attempted. Many of the improved materials and new concepts will reach practical application, others will be abandoned for technical or economic reasons. Improvements in materials, and new types of bridge structures that are currently unknown, are certain to evolve in the next decade. The next decade promises to be one of excitement and challenge.

Engineers must be constantly open to new concepts and ideas that will technically and economically improve the structures they build. However, they must also anticipate a new generation of problems that changes in methodology are certain to bring. In particular, they must avoid the trap of over-sophistication in design at the expense of simplicity in construction, and thus at the expense of economy.

As we strive for longer spans and improved means of constructing bridges, it would be well to remember the words of F. Stussi, an eminent Swiss engineer;

> The problem of long spans has always fascinated the specialist as well as the layman. The realization of a bridge with a length of span hitherto unattained, not only requires great technical knowledge and capability, but also intuition and creative courage; it signifies a victory over the forces of nature and progress in the battle against human insufficiency.

This philosophy not only applies to the achievement of longer spans, but also, to the changing technology of the future. The next decade will continue to provide technological change and advancement, foremost among these technological advances will most assuredly be the concept of prestressed steel bridges. Professor Troitsky's Herculean effort in producing this book surely represents his contribution to the great technical knowledge, intuition, and creative courage that will be required to design and build the innovative and cost effective bridges of the future. It only remains for the rest of us to exploit this effort.

Walter Podolny, Jr.
Bridge Division
Office of Engineering
Federal Highway Administration

Preface

The prestressing of steel bridges is one of the best methods of providing economy in steel and reducing construction costs. The technical and economical usefulness of prestressing has been influenced widely by its application in prestressed concrete, but has seen relatively slow development in prestressed steel structures. The usefulness of prestressing in steel structures consists mainly in the economy of the material in the construction of new bridges as well as in the strengthening of old ones.

In contrast to the cross sections of concrete members, which cannot take tensile stresses, steel cross sections do not require special stress distribution. In addition, in steel structures the prestressed tendons do not cause substantial losses due to friction as do the tendons in prestressed concrete. However, the development of prestressed concrete structures indicates that, generally, similar principles of analysis may be applied to prestressed steel structures.

The modern development of prestressed steel structures started more than three decades ago, when Dischinger and Magnel initiated the application of prestressed steel structures. This new technique developed very quickly in highly industrialized countries such as the United States, the USSR, England, Belgium, and Germany, as well as in other parts of the world. As a result of this wide experience in the design of prestressed steel structures, they are no longer subject to tests and are equal in quality to conventional steel structures.

This book presents a guideline for the structural analysis and design of prestressed steel bridges, such as plate girders, box-type structures, arches, and cable trusses. In this text, methods of prestressing steel structures, including the widely used method of tendons, are discussed.

The successful development of prestressed steel bridges has created a need for comprehensive presentation of the theory and design of this structurally efficient and economical method. Until now, such information has been available mainly in technical journals, industrial bulletins, and various scattered publications, most of them foreign.

This text is an attempt to summarize experience with this method of structural design for constructing new prestressed steel bridges and strengthening old bridges and to produce an up-to-date practical reference book on the subject. It is also intended to provide designers of prestressed steel bridges and postgraduate students having a special interest in this subject with criteria and methods for the design of such structures.

The material contained in this book is presented in the following chapters:

Chapter 1	provides an introduction to the subject and brief historical development.
Chapter 2	discusses the methods of prestressing and application of prestressed steel structures.
Chapter 3	treats tendons and different types of anchorages.
Chapter 4	presents the analysis and design of prestressed steel plate girders using straight, parabolic, and polygonal types of tendons.
Chapter 5	discusses the analysis and design of prestressed composite steel girders having concrete slabs.
Chapter 6	treats continuous prestressed steel girders of large spans.
Chapter 7	is concerned with prestressed steel box-type girders.
Chapter 8	treats analysis and design of prestressed steel trusses.
Chapter 9	discusses prestressed tied arch steel bridges.
Chapter 10	provides analysis of prestressed cable truss bridges.
Chapter 11	treats rehabilitation of steel bridges.

It must be recognized that this text is by no means complete. However, it gives in a systematic form, as much as possible, the state of knowledge available at the time of the preparation of this book.

Since many variables affect the analysis and design presented in the book, the author would appreciate having called to his attention any errors that have escaped the author's editing efforts.

Contents