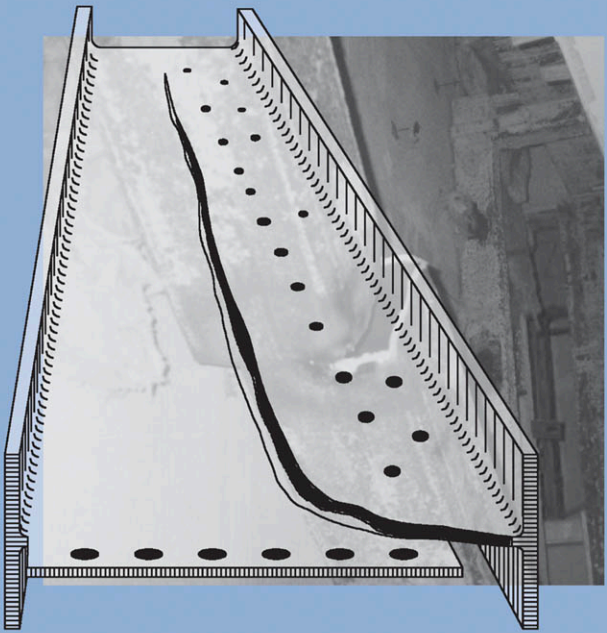
Reducing Brittle and Fatigue Failures in Steel Structures



Peter Maranian, P.E., S.E.

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Technical Council on Forensic Engineering (TCFE)
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Foreword

After the Northridge (California) Earthquake of 1994, many engineers and researchers took a careful look at failures caused by that major seismic event. In 1995, the Kobe (Japan) Earthquake revealed similar problems, principally in steel moment-frame structures. Among the experienced and talented engineers looking at these problems were many members of ASCE.

Within ASCE, the Technical Council on Forensic Engineering (TCFE) is comprised of members from across the country who came together years earlier around common elements of their practices in forensic engineering. Principal among the TCFE tenets has always been the desire to help prevent future failures by reporting as much as could be learned about previous failures. It is not enough to learn from our own mistakes, we progress as a profession when we also learn from the mistakes of others.

Within TCFE, the Committee on Practices to Reduce Failures (CPRF) includes several structural engineers who practice in California, and who engaged in the post-earthquake examination and review of damaged steel structures. Henry Huang and Peter Maranian, two of the engineers intimately involved with the analysis of the damaged steel structures, both came to realize how much they had learned through their investigations. From this shared experience came the idea for a book that would record their thoughts, point others to relevant references, and provide a first step in an engineer's search for a deeper understanding of the problems of fatigue and brittle fracture. During Henry's time as chair of the CPRF, he encouraged Peter to put their newfound knowledge into a publication for ASCE.

This book represents the culmination of Peter's work to date. He drew heavily from his and Henry's own experiences, but as his acknowledgments reflect, he also benefited from the tangible contributions of many colleagues, and from the support of CPRF and TCFE. Many fellow committee members have reviewed this document at various stages during its development. However, the work is principally Peter Maranian's, and represents a milestone in his journey. We trust that it will provide the reader with an excellent primer on the subject of brittle and fatigue failures in steel structures. We are honored to have played a small part in bringing this book to press.

Leonard J. Morse-Fortier, PhD, SECB
Chair, TCFE

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Preface

Structural steel has proven to be an excellent and versatile building material that has enabled small to very large structures to be constructed for the great benefit of society. However, there have been repeated failures associated with fracture and/or fatigue mechanisms.

Failures of steel moment frame connections in the 1994 Northridge Earthquake in California, USA and the 1995 Kobe, Japan are well documented. The 1994 Northridge Earthquake led to a significant amount of rethinking, testing and research by the Structural Engineers Association of California (SEAOC), the Applied Technology Council (ATC) and California Universities for Research in Earthquake Engineering (CUREe), called the SAC Joint Venture for the Federal Emergency Management Agency (FEMA) [which resulted in the publication of several documents including FEMA 350 (2000), 351 (2000), 352 (2000), 353 (2000) and other documents] and several other independent organizations. As a result, many engineers have not only questioned seismic designs for steel moment frames, but also other steel seismic resisting systems (e.g. braced frames and eccentric braced frames) along with buildings subjected to high winds. Although at the time of writing this publication, the causes of the Mississippi River Bridge collapse in August 2007 are not known, it highlighted concerns for the life of bridge structures particularly with regard to fatigue and corrosion.

The problems of brittle and fatigue failures in steel along with corrosion have gone on for the most part of the last century. Factors and issues affecting failures have been, in many cases, well researched and documented over several decades. However, these factors and issues have not always been translated into state of the art design practices. Experiences with failures found in one industry, which may have resulted in changes in that industry, have not always affected changes in related industries.

The intention of this book is to describe the characteristics of steel and associated fabrication processes identifying many of the potential problems that can lead to fracture. It is hoped that the publication will help give engineers a better understanding of steel, its limitations and applications, in order to reduce brittle and fatigue failures.

Chapter 1 discusses examples of failures, most of which took place in the last century. Chapter 2 gives a brief introduction to fracture mechanics including the concepts behind the need for design considerations to minimize stress and strain concentrations, quality control and assurance, and adequate material properties. Chapter 3 discusses steel as a material including the processes, chemistry, and mechanical properties. Chapter 4 discusses fabrication and connections including the

effects of fabrication procedures, welding, bolting, and riveting on the finished product. Chapter 5 gives a discussion and recommendations regarding addressing brittle and fatigue failures in steel buildings. Also included in Chapter 5 are discussion on the issues and recommendations for current practice.

It should be noted that this document primarily addresses brittle and fatigue type of failures and issues associated with corrosion. This document does not address failures of steel structures due to instability and erection procedures. Further reading of the topics in this document is encouraged. Recommended reading is provided at the end of each section and references at the end of the document.

Peter Maranian, S.E.

Acknowledgments

This publication was carried out for the Committee on Practices to Reduce Failures (CPRF) which is one of the committees of the American Society of Civil Engineers' Technical Council for Forensic Engineering (TCFE). It has taken several years of effort to compile, and could not have been carried out without the significant contributions, consultation, advice and support of many. My very sincere thanks to all involved.

In particular, I wish to acknowledge the major contribution made by Andrew Metzger who helped write most of the very important discussion on Fracture Mechanics given in Chapter 2. Andrew Metzger's fine contribution and knowledge on this key subject is so very much appreciated.

I also wish to acknowledge Eric Stovner, who made an important contribution to the case histories given in Chapter 1, describing the Mianus River Bridge failure. Eric, when chair of CPRF, also played a key role in progressing the document including carrying out an extensive review of the manuscript.

Furthermore, I can not thank enough both Leonard Morse-Fortier, chair of TCFE from 2008 to 2009, along with Susan Sheldon Smith for their great efforts in transforming the final original manuscript and the collection of figures into the book you see here. Leonard's great abilities, leadership and devotion to the task along with Susan's significant talents all were applied in the final compilation and editing of the document. Their contributions were immeasurable.

The document was the brain child of Henry Huang with whom I have worked for many years on various committees. Henry, at the time, was chair of CPRF. He and I worked together investigating problems with steel structures damaged by the 1994 Northridge (California) Earthquake. Henry saw the important need to have a document on structural steel that would convey the concerns that we shared after those experiences. His great vision and understanding of the issues effecting the profession were an inspiration to me.

I had the benefit of some excellent and constructive review comments from several members of CPRF. These included Rubin Zallen, whose thorough and critically constructive review is sincerely appreciated. Michael Lester, John Gross, and Ron Schneider also provided important reference material. I appreciate the thorough review comments from members of the TCFE's executive committee, including those by Norb Delatte, Anthony Dolhon and David Peraza. Michael Lester, who took over the chair of CPRF after Eric Stovner, also greatly assisted in the administrative aspects of developing the manuscript.

Along with Henry Huang, there were several others who shared many of their concerns regarding steel issues and gave invaluable support. The late Dr. Warner Simon was a major inspiration to me providing much insight on the problems. Although well into his eighties, I was privileged to work with him during his final years, throughout which he dedicated himself to the pursuit of investigating past failures and resolving welding issues. I was also greatly privileged to have the opportunity to assist Dr. James Anderson at the University of California, Los Angeles, on several steel moment frame connection tests carried out during the 1990's from which I gained invaluable knowledge. Dr. Praful Patel provided excellent knowledge on issues associated with heat affected zones and assisted with reviewing the document. I also had the significant benefit of working with Daniel Luna, a welding consultant, who has become a valuable resource on welding procedures and processes. I was also very fortunate to have Robert Lyons as a colleague, both at the company I work with, and in committees. His help included taking on the burden of articulating many of the issues through committees. Ashwani Dhalwala, particularly during recent years, has been a great resource, providing much insight, knowledge along and encouragement on addressing the issues of brittle failures. Others who have helped by providing invaluable documents include James Partridge, Raphael Franco, Dr. Patxi Uriz, Saif Hussain and Don Strand. Throughout all of these efforts, Dr. Gregg Brandow, President at Brandow & Johnston Inc, gave me constant support, encouragement and also helped provide some important references.

There are several people whose hard work much helped to produce the document and are much appreciated. They include Agnes Gonzalez who carried out the typing dealing with countless drafts, Sema Akyurek who carried out most of the sketches and illustrations along with Marco Ramirez, Gabriel Lopez who assisted in organizing the sketches, Dr. Navid Nastar who provided much assistance in reviewing and checking the document and Bhahti Dhalwala who carried out an editorial review of the document.

Finally, I wish to thank my wife, Srpuhi, for her patience and understanding in tolerating endless weekends during which I worked on the document.

Peter Maranian, S.E.

List of Figures