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Cover photograph by Erik Ruggeri: Crew lifting the middle phase to Catenary 2, Nebraska, 2008

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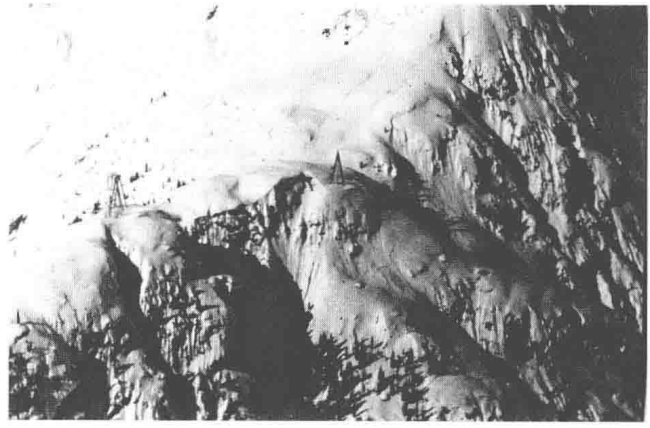
Structural Engineering of Transmission Lines

There are reasonable places for transmission lines and there are useful but unreasonable places for transmission lines. Some are challenging and fun to engineer and some are yawners. Here's hoping that some of your days require tackling the unreasonable ones because they're fun!



Crossing Twin Peaks in British Columbia with the Kemano–Kitimat transmission line, 1950s. (Courtesy of H. Brian White)

This book is dedicated to the teachers and mentors that have influenced my work, most notably H. Brian White, and to the younger engineers who show a keen interest in the work and on whose intelligence, curiosity and pursuit of excellence relies the future of the engineering of transmission lines.

Brian (right) and I conferred at the initial stages of several projects. It was always useful

Foreword

Fellow students, I often wonder why it is that only a small subset of engineers are attracted to electrical transmission lines. What is even more interesting is the passion that this small group has for these seemingly simple facilities, while the rest of the engineering community spend their careers, some even becoming famous, on tall buildings, long-span bridges and flying machines of one sort or another.

Maybe most engineers, and the community at large, overlook transmission lines because they are as common to the landscape as highways, farm tractors and fast food restaurants, plus, and most importantly, seem to do their job without fail, in all types of weather and all without moving parts. Probably every type of major infrastructure has its engineering 'fanatics'; however, it seems as if the transmission line engineering fanatics are the smallest and closest knit group of engineering colleagues. As support for this statement, I suggest that there are only two and at most three degrees of separation between any two people doing real transmission line design anywhere around the world. For us students of transmission line engineering, it seldom takes more than one conversation to put ourselves on the trail of the state-of-the-industry technical solution to whatever problem we are facing.

Why are we so enamoured with transmission lines? On the surface they appear so simple, sets of wires, spanning the globe, held up by steel, wood or concrete structures in a wide variety of configurations. In fact, when my daughter was in grade school, I often remarked that the reason transmission line design engineers get so little respect is that transmission lines appear simple enough to design and construct that my daughter could do it ... and it would certainly carry electricity ... at least for a day. In all seriousness, for those of us who have seen the light, we realise that transmission lines can be simple and straightforward, but most are not. Most are complicated structural systems that are asked to do their job of powering the world economy over all types of terrain and in all types of weather.

I offer two thoughts on what attracts us to transmission line design. Firstly, the structural system is surprisingly complex. Although when viewing a transmission line all components seem static, in reality there is a never-ending balancing act in progress, all components delicately balanced so that the line appears motionless. Understanding this delicate balance and then applying this knowledge to design such that the system stays

balanced and intact for more than 50 years is no simple feat of engineering.

Secondly, each span and/or each structure location presents its own unique engineering challenges. Although there is most often a common set of criteria for the entire line, on every project there is at least one structure or span (most often many more) that will challenge even the most talented of engineers. The exceptional engineers handle the easy sections of the project routinely, employing time-tested techniques and tools to quickly dispatch these straightforward sections such that talent, energy and enthusiasm can be focused on the generally small number of challenging (most often described as 'fun') parts of the project.

My final thought on why some of us are so enamoured with transmission lines is that I suppose the transmission line design industry is a little like being in a secret club. Our specialty is out there for all to see, yet only a few of us know the secrets that make these simple-looking systems perform so well. In this book, Peter describes some of the 'secrets' (many of them learned the 'hard way') that will enable our club to grow.

Most of this book is focused not on the benign sections of the transmission line but on the unique locations/spans where terrain, weather, restricted access, jurisdictional constraints and any number of other hazards conspire to challenge the design engineer to find elegant, yet technically sound and cost-effective, solutions. This book is not only a resource and a reminder of things important but should be used to further your education in the pursuit of personal improvement for the benefit of your project, your company and the transmission line design industry.

I believe that transmission lines are a thing of joy and beauty to behold forever. So, behold the beauty, even if only you can see it, embrace the joy of solving thousands of unique problems during each design, be better on each project, give back to an industry that has given so much to you, and finally be grateful to those who have gone before.

Enjoy and put into practice the experience, insight and enthusiasm that Peter and his co-authors (those named and those that provided influence) have brought to life. Good luck, be safe and be good!

Ronald J. Carrington PE
Student, transmission line design

Preface

To a few people, this book may be considered a long time coming. These people would be those that saw or possess a much lesser scope document that I first put together in 2000. I dared to call it a book because I did have the intention, even then, of making it into something broader in scope and presumably of actual value. I am relieved to have waited, because I keep learning useful things. But, the time has come, and the result is this.

The fundamental purpose of this book is to lay down my thoughts on the structural engineering of transmission lines. I believe that the book can provide to you a take on the subject that is not covered by other publications. There is a plethora of papers that are constantly being written for our industry by a very wide-ranging population of experts. Many of those papers are insightful and useful. Many are not. Far too many are regional in understanding and value. So, herein I offer a sideways view of things that I intend to be complementary and supplemental to all other things written. I have tried with this book to provide timeless truths and certain basic insights with limited commentary on issues of this day.

This book does not dwell on the elementary, in that we dive right into our industry's lingo without much concern for consistently providing the reader with definitions of all the terms that we present. I assume the reader has had reasonable exposure to the business and is armed with at least elementary knowledge of our industry's lingo. In other words, I am not trying to introduce the completely uninitiated to the business of engineering transmission lines. Rather, I am offering to take reasonably experienced engineers to a higher level of understanding of that which they already have some knowledge.

For the less initiated, I hope that, by reading the book, you sense the challenging nature of the work and the joy that committed engineers can feel upon accomplishing good things within the business. In other words, I hope that the book helps spark your interest in the business and that it becomes a valued reference for you for years to come.

Early in my own career, I had the pleasure to work with newer and younger engineers. I learned early on that, as much as I enjoyed doing this work, I got much greater satisfaction helping these young entrants to our industry improve their game – to be better next year than they are

today. This book is designed to provide to me that satisfaction of being of real help to you.

The end result of this effort could have been a book that is purely technical in style such as any textbook, but I chose another style. This book includes injections in a first person style. Throughout, you are occasionally subjected to my experiences written as personal accounts. I hope this makes it just a bit more interesting to read than the subject naturally begets. It certainly made it easier to write.

During my third year in high school, I wrote all literary exercises assigned to me in the style of John Lennon's *In his Own Write* and *Spaniard in the Works*. It was exhilarating to write everything as fanciful nonsense riddled with words with at least triple entendre. Most of my friends would say that I still think and talk that way. My English teacher that year was a Brit on exchange from his homeland. He was a fish out of water in several ways, and that probably led him to appreciate my style. Maybe he lived down the street from John Lennon when he was a kid. I don't know. He kept saying how much he enjoyed the writing that I handed in, but counselled me that the style would probably not work well later in life in the real world. I warn you that I have not entirely vacated the style. I hope that you find this book very useful as a resource for your engineering career, but I also hope you enjoy reading it. I like unorthodox things!

I can count four men who have shaped my life and career to the extent that I would call them my mentors. In order of their appearance, they were my father, the aforementioned John Lennon, Frank Mackay and H. Brian White.

Only one of these four should beg a question, that being: *who is Frank Mackay?* Frank showed up in my life when I entered this business at the age of 28 at a small integrated utility. He was their VP of All Things That Matter with 42 years under his belt with the organisation. He was a dynamic, life-loving, short, fast-moving whirling dervish with a booming voice and a full head of bright white hair. I loved him!

I was in the business for only a few months and had been assigned a line design to develop beyond the point to which it had been taken by the new incoming company president. Two days after I started that job, the only other engineer with civil/structural engineering knowledge of lines or substations had a heart attack. He

recovered sort of, but never really returned to work. I was alone! I needed guidance, and went to Frank the VP with an opinion regarding that line's design, 'I'm not sure this is going to work and I think we should do it another way.' His answer was, 'Well, if that's what you think then let's do it.' That comment to me, the brand new untested engineer, lay a foundation of confidence and a recognition of responsibility within me that I have carried with me ever since. In turn, I have tried to treat the young(er) kids that I meet on the job over the years with the same respect for the same reason.

> I got into this business because the band broke up. I love that line but it's not true. The band sucked. My employer back then was offering a stint in the Algerian desert, and I chose to 'stay in town'. A friend suggested the local utility, and I was excited to go work on dams, fast-flowing rivers and the like. On day 2, I found myself standing ankle deep in mud on a thing called a right-of-way, looking at 115 kV lines above me and asking myself, 'Why are there always three wires?' I was that dumb.

That was 1977. I stood in that same place as a line engineer several months ago (2012). I worked at that utility for just under 4 years, but have been consulting to it from afar since 1988. It is my *alma mater*. Lesson one: don't burn bridges!

You can imagine that from a father and from John Lennon, I learned what to do, how to behave and what matters, but also what not to do and not to say. Not all valuable mentoring is a positive directive. After all, we do learn the best lessons from mistakes, and it is lovely when they are the mistakes of others. This is, in fact, the reason that the chapter on line failures is so important to the book and for the reader.

Of these four named individuals, Brian White is the name that you should pay attention to, given our subject at hand. Brian entered the transmission line engineering business in the early 1950s. He was going strong when I met him in 1985, and was still whacking at the piñata when 87 years old. His reputation in the industry is such that we need only refer to him by his first name.

Brian became a very good friend and mentor to a great many people in this business on many continents over the years. A number of my colleagues and I myself consider ourselves to be students of Brian. This book is deeply marinated in Brian's view of transmission line

engineering, and it is primarily to Brian that I make the teacher and mentor reference in the Dedication.

This book actually began as a joint effort with Brian about 5 years ago. I wanted it in part to be a vehicle for getting Brian's wonderful teachings out to the new generation of transmission line engineers. Brian had a passion for this work like no one else. Sadly, the collaboration did not make it to the end of the effort, but you will find considerable amounts of Brian's work within. Sometimes, the words are his and other times they are my version of his thinking. Then, I hope that I have taken subjects to an even further level for you in some areas.

Brian passed away on 8 December 2012 at the age of 90. He was described by a colleague as a phenomenon of nature. His passion for this work and his dedication to the profession of engineering were the reasons that he spent a great deal of time teaching and shaping many young engineers in the business, including myself.

Brian's written and teaching efforts always came under the heading of 'understanding transmission line behaviour'. It would be a suitable title for this book, but the phrase belongs to Brian. Although transmission lines exist for the primary reason of transporting electricity, this book says very little of value about electricity. Instead, the focus is on the structural nature of these lines and on the business of conducting business under the heading of 'projects'.

> I have often said, 'I don't care if there is electricity in the conductors, my job is to design something that will not fall down.'

A very fundamental message of this book is that it takes much more than an engineer's efforts to create a transmission line but that the engineer's work is essential to a successful, well-behaved outcome. I have often said 'a person will never be good at something unless he or she enjoys doing it'. Brian spun the table and added, 'a person will never be good at anything without doing the hard work of learning the subject – after that, the satisfaction that comes from accomplishments is the source of the happiness'. Later, I described this flipped description to a colleague, and he suggested that the relationship between hard work, competence and satisfaction may be a circle, and describing that one comes first is futile. The presence of the three matters is something that you should ensure occurs in your career.

Good luck with that. Then, I'll suggest that if their presence is not happening for you, do something else, as in: *make it happen* for you.

Throughout the book, I will provide you with comments, observations, stories and even calculations that show you that perfection is not to be defined by the technically minded engineer but by the collaboration of all players. I will also pound the drum trying to tell you what I believe matters and what I believe does not matter. After all, we all want to be effective in what we do, so my objective is to point you in a direction away from what does not matter. I also believe that nothing will ever change for the better unless somebody thinks outside the box and charts new paths for others to follow. Certainly, the opportunities for improvement in our field of endeavour are plenty. Be the adventurer!

Over the years, I have gathered the quotes and phrases that impressed me and express my sentiments about what matters. The first and last two are long-standing mantras of Brian's.

> It is the mark of an educated mind to rest satisfied with the degree of precision that the nature of the subject admits, and not to seek exactness where only an approximation is possible.
>
> Aristotle

> That your only tool is a hammer does not mean that all of your problems can be treated successfully as if they are nails.
>
> Anon.

> Everything in nature and all events have a relationship with other things that involve opposing factors. These natural things and events are also in a continual state of change. The ideal state is when these opposing forces are in relative balance. Do not believe in absolutes or in the ideal, rather that everything is relative, flexible and changeable.
>
> A paraphrase of yin and yang

> It is an easy and fatal step to think that the accuracy of our arithmetic is equivalent to the accuracy of our knowledge about the problem at hand. We suffer from 'delusions of accuracy.' Once an enthusiast gets this disease, he and all who depend on his conclusions for

their welfare are damned. [alternative ending: ~~are damned~~. will continually find the wrong answers with great precision.]

M. J. Moroney, *Facts from Figures* (Penguin, 1951)

If at first the idea is not absurd, then there is no hope for it.

Albert Einstein

Look for the effect of these quotes on my thoughts as you read this book. Whether you find it acceptable to adopt any of these principles as guides for yourself is up to you. Regardless, it is my hope that you will find the contents of the book useful, worth reading and understandable.

Peter Catchpole PEng

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