

Engineering Mechanics and Design Applications



Transdisciplinary
Engineering Fundamentals

Atila Ertas

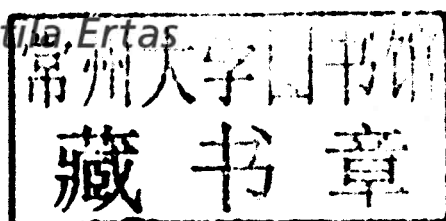


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Engineering Mechanics and Design Applications

Transdisciplinary
Engineering Fundamentals

*To my mentors, Professor C. V. Ramamoorthy and Dr. Raymond T.
Yeh, dearest friends, who inspired me to write this book.*

Preface

In the last decade the number of complex problems facing engineers has highly increased and the technical knowledge and understanding in science and engineering required to address and mitigate these problems has been evolving rapidly. The world is becoming increasingly interconnected as new opportunities and highly complex problems connect the world in ways we are only beginning to understand. When we do not solve these problems correctly and in a timely manner, they rapidly become crises. Problems such as energy shortages, pollution, transportation, the environment, natural disasters, safety, health, hunger, and the global water crisis threaten the very existence of the world as we know it. Recently, fluctuating fuel prices and environmental concerns have set car manufacturers in search of new zero-polluting, fuel-efficient engines. None of these complex problems can be understood from the sole perspective of a traditional discipline. The last two decades of designing large-scale engineering systems have demonstrated that neither mono-disciplinary nor inter- or multidisciplinary approaches provide an environment that promotes the collaboration and synthesis necessary to go beyond existing disciplinary boundaries and produce truly creative and innovative solutions to large-scale, complex problems. These problems not only include the design of engineering systems with numerous components and subsystems, which interact in multiple and intricate ways, but also involve the design, redesign, and interaction of social, political, managerial, commercial, biological, medical, and other systems. Furthermore, these systems are likely to be dynamic and adaptive in nature. Obtaining the solutions to such unstructured problems requires many activities that cut across traditional disciplinary boundaries, that is, transdisciplinary research and education.

The results of transdisciplinary research and education include the following: emphasis on teamwork, bringing together investigators from diverse disciplines, and developing and sharing concepts, methodologies, processes, and tools. All of these help to create fresh, stimulating ideas that expand the range of possibilities. The transdisciplinary approach creates a desire in people to seek collaboration outside the bounds of their professional experience to make new discoveries, explore different perspectives, express and exchange ideas, and gain new insights.

This book was developed completely based on the fundamentals of engineering mechanics for undergraduate students. The mathematical level is similarly limited to that found in engineering mathematics that covers calculus and differential equations. Throughout the book, discussions of theory are followed by practical examples.

Engineering Mechanics with Design Applications: Transdisciplinary Engineering Fundamentals has been written to fulfill the need for a textbook or reference book that is appropriate for use in engineering design practice. It is intended to foster a thorough understanding of the basic condensed knowledge necessary for engineering design.

A general introduction to the concept of Prevention through Design for preventing occupational injuries, illnesses, and fatalities is provided in Chapter 1. Students

should emerge from this transdisciplinary educational experience with a broad understanding of occupational safety and health needs in the design process that will prevent or minimize work-related hazards.

A condensed introduction to engineering statics is provided in Chapter 2, followed by engineering dynamics in Chapter 3. Chapter 4 deals with solid mechanics, which covers many design applications, and Chapter 5 covers failure theories and dynamic loadings. Finally, Chapter 6 integrates knowledge gained from the previous chapters for real-life design analysis and applications. In this chapter, two tragic accidents that occurred in 2010 are discussed. These two disasters killed many workers and caused property damages worth millions of dollars as well as widespread environmental damage. Therefore, the Prevention through Design (PtD) concept and some related concerns are also discussed.

This book is also geared for graduate classes covering engineering fundamentals for nonengineering students and for review by engineering students who have been out of school for several years. It will also be a valuable source for engineering students preparing for the Fundamentals of Engineering Exam and for non-mechanical engineers collaboratively working on large-scale projects. Finally, this book can be used as a textbook for non-mechanical engineering disciplines such as industrial engineering, electrical engineering, and chemical engineering.

Acknowledgment

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Contents

Preface.....	xiii
Acknowledgment	xv

Chapter 1	Prevention through Design: A Transdisciplinary Process	1
1.1	Introduction	1
1.2	Transdisciplinarity and PtD.....	1
1.2.1	Discipline	1
1.2.2	Defining Transdisciplinarity	1
1.2.3	Multidisciplinary, Interdisciplinary, and Transdisciplinary Case Studies	3
1.2.4	Why Is Prevention through Design a Transdisciplinary Process?.....	7
1.2.5	PtD Considerations for the Design Process	8
1.2.5.1	Generic Design Process.....	8
1.2.5.2	PtD Process.....	10
1.3	Prevention through Design	13
1.3.1	PtD Program Mission.....	14
1.3.2	PtD Process	15
1.3.3	Stakeholder Input	15
1.3.4	Strategic Goal Areas	18
1.3.5	Business Value of PtD	20
1.4	Case Studies.....	21
1.4.1	Case Study 1: Chemical Containment.....	21
1.4.1.1	Description of Operation	21
1.4.1.2	Hazard Identification	21
1.4.1.3	Hazard Intervention	21
1.4.1.4	Impacts of the Intervention.....	21
1.4.1.5	Financial Metrics	22
1.4.1.6	Lessons Learned	22
1.4.2	Case Study 2: Automated Baler	22
1.4.2.1	Description of Operation	22
1.4.2.2	Hazard Identification	22
1.4.2.3	Hazard Intervention	22
1.4.2.4	Impacts of the Intervention.....	22
1.4.2.5	Financial Metrics	23
1.4.2.6	Lessons Learned	23
1.4.3	Case Study 3: Carbon Monoxide Control	23
1.4.3.1	Background.....	23
1.4.3.2	Hazard Identification	23

1.4.3.3	Hazard Intervention	24
1.4.3.4	Impacts of the Intervention	24
1.4.3.5	Financial Metrics	24
1.4.3.6	Lessons Learned	24
1.4.4	Case Study 4: Metal Removal Fluid Management Control Plan	24
1.4.4.1	Description of Operation	24
1.4.4.2	Hazard Identification	25
1.4.4.3	Hazard Intervention	25
1.4.4.4	Impacts of the Intervention	25
1.4.4.5	Financial Metrics	26
1.4.4.6	Lessons Learned	26
1.5	PtD and Sustainability	26
1.5.1	Transdisciplinary Sustainable Development	27
1.5.2	Contaminated Environment	28
1.5.2.1	Air Pollution	29
1.5.2.2	Groundwater Contamination	29
1.5.3	Making “Green Jobs” Safe: Integrating Occupational Safety and Health into Green Jobs and Sustainability	30
1.5.4	Going Green during Construction	32
1.6	Conclusion	33
	References	33

Chapter 2	Static	37
2.1	Introduction	37
2.2	Fundamental Concepts	37
2.2.1	Weight and Mass	37
2.2.2	Rigid Body	37
2.2.3	Force	37
2.3	Force as a Vector	37
2.3.1	Definition	39
2.3.2	Trigonometric Solution	39
2.4	Force Components in Space	42
2.4.1	Force Vector Defined by Its Magnitude and Two Points on Its Line of Action	44
2.5	Moments	47
2.6	Free-Body Diagram	47
2.6.1	Equilibrium of a Particle	49
2.6.2	Equilibrium of a Rigid Body	49
2.6.3	Equilibrium of a Two-Force Member	49
2.6.4	Equilibrium of a Three-Force Member	50
2.6.5	Equilibrium of a Pulley System	50
2.6.5.1	Simple Pulley	50

2.6.5.2	Fixed Pulley	51
2.6.5.3	Fixed- and Free-Pulley Arrangement	52
2.6.6	Moment of a Force about a Given Axis	54
2.6.7	Moment of a Couple	56
2.7	Structures in Three Dimensions	56
2.8	Trusses	62
2.8.1	Method of Joint	63
2.8.2	Method of Section	66
2.9	Machines and frames	67
2.10	Friction	73
2.10.1	Coefficient of Friction	73
2.10.2	Angles of Static and Kinetic Friction	74
2.11	Properties of Plane Areas	77
2.11.1	Parallel Axis Theorem for Areas	79
2.11.2	Radius of Gyration of Area	79
2.11.3	Moment of Inertia of Composite Areas	80
	Problems	84
	Bibliography	90
Chapter 3	Dynamics	91
3.1	Introduction	91
3.2	Kinematics of a Rigid Body	91
3.2.1	Translation	91
3.2.1.1	Velocity in Translational Motion	91
3.2.1.2	Acceleration in Translational Motion	92
3.2.2	Fixed-Axis Rotation	93
3.2.2.1	Angular Components of Fixed-Axis Rotation	93
3.2.2.2	Tangential and Normal Components of Fixed-Axis Rotation	94
3.2.3	General Plane Motion	98
3.2.4	Absolute and Relative Velocity in Plane Motion	99
3.2.5	Instantaneous Center of Zero Velocity (IC)	104
3.2.5.1	Determining IC	105
3.2.6	Absolute and Relative Acceleration in Plane Motion	106
3.3	Kinetics of a Rigid Body	110
3.3.1	Translation	110
3.3.2	Fixed-Axis Rotation	114
3.3.3	General Plane Motion	120
3.4	Rolling Problems	121
3.5	Planar Kinetic Energy and Work	124
3.5.1	Principle of Work and Energy	125
3.5.2	Conservation of Energy	126

3.5.3	Principle of Linear Impulse and Momentum	127
3.5.4	Principle of Angular Impulse and Momentum	128
3.5.5	Impact.....	128
3.5.5.1	Direct Central Impact	128
3.5.5.2	Oblique Central Impact	129
	Problems.....	133
	Bibliography	139

Chapter 4	Solid Mechanics	141
4.1	Introduction	141
4.2	Stress Analysis.....	141
4.2.1	Uniform Normal Stress and Strain.....	141
4.2.1.1	Uniform Normal Stress.....	141
4.2.1.2	Uniform Normal Strain	142
4.2.2	Uniform Shear Stress and Strain.....	145
4.2.3	Thermal Stress and Strain	145
4.2.4	Normal Bending Stress in Beams	146
4.2.5	Shear Stress in Beams.....	149
4.2.6	Stress in Thin-Walled Pressure Vessels	155
4.2.7	Combined Stress.....	156
4.3	Stress-Strain Analysis.....	156
4.3.1	Plane Stress	157
4.3.2	Stress on an Inclined Plane	158
4.3.3	Mohr's Circle of Stress	159
4.3.4	Principal Stresses in Three Dimensions	161
4.4	Strain Measurement and Stress Calculations	165
4.5	Deflection and Stiffness of Beams	168
4.5.1	Spring Rates	169
4.5.2	Torsion.....	169
4.5.2.1	Power Transmission through Rotating Shaft	170
4.5.3	Lateral Deflections of Beams.....	173
4.5.3.1	Method of Integration	173
4.5.3.2	Elastic Energy Method (Castigliano's Method).....	175
4.5.3.3	Statically Indeterminate Structures: Solution of Reactions and Deflections by Castigliano's Method	183
4.6	Buckling of Columns.....	186
4.6.1	Eccentrically Loaded Column	189
4.6.2	Prestressed Concrete Column	189
	Problems.....	192
	Reference.....	197
	Bibliography	197

Chapter 5	Failure Theories and Dynamic Loadings.....	199
5.1	Failure Theories and Safety Factor	199
5.1.1	Maximum Normal Stress Theory	199
5.1.2	Maximum Shear Stress Theory	199
5.1.3	Distortion Energy Theory	200
5.2	Fatigue Failure.....	204
5.2.1	Fatigue Strength Correction Factors	208
5.2.1.1	Surface Finish Correction Factor.....	209
5.2.1.2	Size Correction Factor	209
5.2.1.3	Temperature Correction Factor.....	210
5.2.1.4	Reliability Correction Factor	210
5.2.1.5	Fatigue Stress Concentration Correction Factor	211
5.2.1.6	Miscellaneous Correction Factor.....	212
5.3	Fluctuating Stresses.....	214
5.3.1	Fatigue Analysis for Brittle Materials.....	214
5.3.2	Fatigue Analysis for Ductile Materials	218
5.4	Cumulative Fatigue Damage	221
5.5	Design Analysis Using Fracture Mechanics	224
5.5.1	Stress State in a Crack (Mode I)	225
5.5.2	Elliptical Crack in an Infinite Plate.....	227
5.5.3	Critical Crack Length.....	230
5.5.4	Leak-before-Break.....	230
5.5.5	Fatigue Crack Propagation	235
5.6	Vibrations in Design.....	238
5.6.1	Knowledge of Vibrations and Design Engineers	238
5.6.2	Terminology in the Field of Vibration.....	239
5.6.3	Natural Frequency of Spring–Mass System.....	239
5.6.3.1	Derivation of Natural Frequency	240
5.6.4	Dynamic Displacements and Stresses.....	243
5.6.5	Forced Vibration of a Single-Degree-of- Freedom Linear System	244
5.6.5.1	Vibration Isolation and Transmissibility.....	247
5.6.6	Response of a Single-Degree-of-Freedom System under Random Excitation	252
5.6.7	Number of Zero Crossing.....	255
	Problems.....	256
	References	263
	Bibliography	264
Chapter 6	Design Analysis and Applications	265
6.1	Introduction	265
6.2	Design Analysis and Application I.....	265
6.2.1	Pipeline System Design.....	265

6.2.2	Related Design Problem.....	266
6.2.2.1	Calculation of Beam Dynamic Stress.....	269
6.2.2.2	Calculation of Dynamic Stress	271
6.2.2.3	Fatigue Life Calculation	271
6.2.2.4	Questions as Closure.....	272
6.3	Design Analysis and Application II	272
6.3.1	Offshore Drilling.....	272
6.3.2	Related Design Problem	274
6.3.2.1	Derivation of Equations	274
6.3.2.2	Operation Chart Design.....	279
6.3.2.3	Calculation of Constants Used in Computation	280
6.3.2.4	Calculation of Cumulative Fatigue Damage	281
6.3.2.5	Offshore Platform Concrete Column Design	285
6.3.2.6	Design Analysis of the Drill Pipe Holder Mechanism.....	289
6.3.2.7	Safety Concerns for Drilling Mud Pumps	292
6.3.2.8	Shaft Design	293
6.3.2.9	Questions as Closure.....	294
	References	294
	Appendix 1: Tables	295
	Appendix 2: Figures	309
	Index.....	317

1 Prevention through Design

A Transdisciplinary Process

1.1 INTRODUCTION

The main objective of this chapter is to introduce the concept of Prevention through Design (PtD) to prevent occupational injuries, illnesses, and fatalities. Students should emerge from this transdisciplinary educational experience with a broad perspective on occupational safety and health needs in the design process that will prevent or minimize work-related hazards.

1.2 TRANSDISCIPLINARITY AND PtD

1.2.1 DISCIPLINE

Since the 1950s the integration of research methods and techniques across disciplines has been of great interest in the social and natural sciences [1]. A particular area of study is called a “discipline,” provided it has cohesive tools, specific methods, and a well-developed disciplinary terminology. As disciplines inevitably develop into self-contained shells, interaction with other disciplines is minimized. However, practitioners of a discipline develop effective intra-disciplinary communication based on their disciplinary vocabulary. Many distinguished researchers and educators have contributed to the development of transdisciplinary education and research activities [2–18].

Multidisciplinary activities involve researchers from various disciplines working independently, each from their own discipline-specific perspective, to solve a common problem. Although multidisciplinary teams cross discipline boundaries, they remain limited to the framework of disciplinary research.

In interdisciplinary activities, researchers from diverse disciplines collaborate by exchanging methods, tools, concepts, and processes to find integrated solutions to common problems. Both multidisciplinary and interdisciplinary activities cross discipline boundaries, but their goal remains within the framework of disciplinary research.

1.2.2 DEFINING TRANSDISCIPLINARITY

In German-speaking countries, the term *transdisciplinarity* is used for integrative forms of research [19]. Transdisciplinary education and research programs take collaboration across discipline boundaries a step further than do multidisciplinary

and interdisciplinary programs. The transdisciplinary concept is a process by which researchers from diverse disciplines work together to develop and use a shared conceptual framework to solve common problems. A distinctive characteristic of transdisciplinary research is the loosening of theoretical models and the development of a new conceptual synthesis of common terms, measures, and methods that produce new theories and models [20]. The three terms—multidisciplinary, interdisciplinary, and transdisciplinary—are often defined differently by researchers and educators.

Nicolescu [21] stated that transdisciplinarity concerns that which is simultaneously between the disciplines, across the different disciplines, and beyond all disciplines.

Klein [8] defined the above-mentioned three terms as follows: "Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, in encyclopedic alignment. ...

Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues, questions, or problem. ... Theories of interdisciplinary premised on unity of knowledge differ from a complex, dynamic web or system of relations.

Transdisciplinary approaches are comprehensive frameworks that transcend the narrow scope of disciplinary world views through an overarching synthesis, such as general systems, policy sciences, feminism, ecology, and sociobiology. ... All three terms evolved from the first OECD international conference on the problems of teaching and research in universities held in France in 1970."

Hadorn et al. [22] stated, "Transdisciplinary research is research that includes cooperation within the scientific community and a debate between research and the society at large. Transdisciplinary research therefore transgresses boundaries between scientific disciplines and between science and other societal fields and includes deliberation about facts, practices and values."

Peterson and Martin [23] stated that interdisciplinary research has not produced a combination or synthesis that would go beyond disciplinary boundaries to produce innovative solutions to policy questions. However, they proposed that transdisciplinary approaches call for a synthesis of research at the stages of conceptualization, design, analysis, and interpretation by using integrated team approaches.

Stokols et al. [24] defined transdisciplinary science as collaboration among scholars representing two or more disciplines in which the collaborative products reflect an integration of conceptual and/or methodological perspectives drawn from two or more fields.

Petts et al. [25] stated, "One of the broadly agreed characteristics of transdisciplinary research is that it is performed with the explicit intent to solve problems that are complex and multidimensional, particularly problems (such as those related to sustainability) that involve an interface of human and natural systems."

During the past decade, other approaches of transdisciplinarity have been developed and described by several researchers and educators. Common phrases in the definitions above include collaboration, shared knowledge, unity of knowledge, distributed knowledge, common knowledge, integration of knowledge, new knowledge generation, integrated disciplines, beyond discipline, complex problems, and societal fields. Although a precise definition of transdisciplinarity is debatable, by reviewing

the above approaches, definitions, and common phrases, the following definitions can be put forward [18]:

Transdisciplinarity is the development of new knowledge, concepts, tools, and technologies shared by researchers from different disciplines (social science, natural science, humanities, and engineering). It is a collaborative process of organized knowledge generation and integration by crossing disciplinary boundaries to design and implement solutions to unstructured problems.

Transdisciplinary knowledge is a shared, common, collective knowledge derived from diverse disciplinary knowledge cultures (engineering, natural science, social science, and humanities).

The transdisciplinary research process is the collaboration among scholars from diverse disciplines to develop and use integrated conceptual frameworks, tools, techniques, and methodologies to solve common unstructured research problems. Transdisciplinary research creates new paradigms and provides pathways to new frontiers.

The fundamental characteristics of transdisciplinary research are

- Use of shared concepts, frameworks, tools, methodologies, and technologies to solve common unstructured research problems
- Elimination of disciplinary boundaries for strong collaboration
- Redefinition of the boundaries of natural science, social science, humanities, and engineering by building bridges between them
- Development of shared conceptual frameworks, new knowledge, tools, methodologies, and technologies

1.2.3 MULTIDISCIPLINARY, INTERDISCIPLINARY, AND TRANSDISCIPLINARY CASE STUDIES

Wind power promises a clean and inexpensive source of electricity. It promises to reduce our dependence on imported fossil fuels and to reduce the output of greenhouse gases. Many countries are, therefore, promoting the construction of vast “wind farms” and encouraging private companies by providing generous subsidies. The goal of the U.S. Department of Energy (DOE) in 2010 was to produce 5% of the country’s electricity by wind turbine farms. The history of wind power shows a general evolution from the use of simple, lightweight devices to heavy, material-intensive drag devices and finally to the increased use of lightweight, material-efficient aerodynamic lift devices in the modern era.

During the winter of 1887–1888, Charles F. Brush built the first automated wind turbine for generating electricity. It was the world’s largest wind turbine with a rotor diameter of 17 m (50 ft) and 144 rotor blades made of cedar wood. The turbine ran for 20 years; the batteries, which were charged in the cellar of Brush’s mansion, lasted even longer [26].

Wind has been an important source of energy in the United States for some time. Over 8 million mechanical windmills have been installed in the country since the 1860s. It is interesting to note that some of these units have been in operation for more than a hundred years [27].