Bridge Problems for the Structural Engineering (SE) Exam

David Connor, SE, PE
Website: www.davidconnorse.com
Email: davidconnorse@gmail.com

Reference Bridge Code – AASHTO LRFD 8th Edition, 2017

VIEW THE ERRATA FOR THIS BOOK AT:

www.davidconnorse.com

PLEASE REPORT ERRORS OR SEND COMMENTS TO:

davidconnorse@gmail.com

Your help in making this publication error free and easy to understand is much appreciated!

Thank you for purchasing this book.

BRIDGE PROBLEMS FOR THE STRUCTURAL ENGINEERING (SE) EXAM

Current Printing of this edition: 1st
Reference Bridge Code: AASHTO LRFD 8th Edition, 2017

Copyright © 2021 by David Connor, SE, PE
All rights reserved.

No part of the publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of the author. Contact the author via e-mail at davidconnorse@gmail.com for inquiries.

This publication shall be used for educational purposes only. It is not a substitute for professional and sound engineering judgment. The author does not guarantee the accuracy or completeness of any information published herein and shall not be responsible for any errors, omissions, or damages arising out of use of the information in this publication. It is understood that the author is not rendering professional engineering services via this publication.

The American Association of State Highway and Transportation Officials (AASHTO) and the National Council of Examiners for Engineering and Surveying (NCEES) were not involved in producing this publication. Any mention of these, or similar organizations, within this publication does not constitute an endorsement of the publication, nor the information published herein.

Any similarity between the problems appearing in this publication and problems published by others or that appear on the NCEES Structural Engineering (SE) Exam is purely coincidental. The subject matter of the problems was chosen based on what the author believed what may appear on future SE Exams only.

Printed by Kindle Direct Publishing, An Amazon.com Company
Purchase Additional Copies at Amazon.com

ISBN: 9781795493161

Table of Contents

Subject Matter of Each Problem: Vertical Loads i-4

Subject Matter of Each Problem: Lateral Loads i-5

About the Author i-6

Acknowledgements i-7

Preface i-8

Tips and Recommendations . . . . . i-9 –i-16

Summary of AASHTO Changes . . . . . i-17 –i-18

Nomenclature i-19-i-25

Notes i-26

Bridge Problems for the Structural Engineering (SE) Exam: Vertical Loads
40 Problems 1

Answer Sheet 2

Problems #1 through #40 . . . . . 3 - 42

Bridge Problems for the Structural Engineering (SE) Exam: Vertical Loads
Solutions 43

Answer Key 44

Problems #1 through #40 Solutions 45-84

Notes 85-86

Bridge Problems for the Structural Engineering (SE) Exam: Lateral Loads
40 Problems 87

Answer Sheet 88

Problems #1 through #40 . . . . . 89 - 128

Bridge Problems for the Structural Engineering (SE) Exam: Lateral Loads
Solutions 129

Answer Key 130

Problems #1 through #40 Solutions 131-170

Subject Matter of Each Problem: Vertical Loads

Problem #1 – Design Moment for Bridge Girder
Problem #2 – Design Shear for Bridge Girder
Problem #3 – Concrete Deck Live Load Moment
Problem #4 – Pier Stream Pressure and Vessel Impact
Problem #5 – Superstructure Vessel Impact
Problem #6 – Lateral Earth Pressure at Abutment
Problem #7 – Anchored Wall Tension
Problem #8 – Anchored Wall Bonded Length
Problem #9 – MSE Wall Reinforcement
Problem #10 – Retaining Wall Forces
Problem #11 – Expansion Joints
Problem #12 – Braking Force and Moment
Problem #13 – Long-Term Concrete Deflection
Problem #14 – Concrete Column Axial Resistance and Biaxial Flexure
Problem #15 – Support Bearing Resistance
Problem #16 – Shear Resistance of Prestressed Girder
Problem #17 – Interface Shear Resistance
Problem #18 – Prestressed Girder Stresses
Problem #19 – Prestressed Girder Losses
Problem #20 – Development Length
Problem #21 – Concrete Deck Reinforcement Cover
Problem #22 – Concrete Piles
Problem #23 – Pile Caps
Problem #24 – Strut and Tie Method
Problem #25 – Steel Fatigue
Problem #26 – Steel Piles
Problem #27 – Fracture-Critical Member Charpy V-Notch (CVN) Testing
Problem #28 – Steel Girder Moment Capacity
Problem #29 – Plate Girder Dimensions
Problem #30 – Plate Girder Web Shear Capacity
Problem #31 – Plate Girder End Bearing Capacity
Problem #32 – Composite Girder Headed Studs
Problem #33 – Use of Slip Critical Connections
Problem #34 – Bolted Connection Shear Resistance
Problem #35 – Bolted Connection Slip Resistance
Problem #36 – Bolted Splice
Problem #37 – Wood Decking
Problem #38 – Drilled Shafts
Problem #39 – Concrete Relieving Slab
Problem #40 – Use of Bearing Type

Subject Matter of Each Problem: Lateral Loads

Problem #1 – Superstructure Wind Loads in Transverse Direction
Problem #2 – Superstructure Wind Loads in Longitudinal Direction
Problem #3 – Superstructure Wind Loads on Sign/Sound Barrier
Problem #4 – Simultaneous Substructure Wind and Stream Loads
Problem #5 – Usual Girder and Slab Bridge Wind Loads
Problem #6 – Wind Loads on Vehicles
Problem #7 – Superstructure Wind Loads – Skewed Pier
Problem #8 – Substructure Wind Loads – Skewed Pier
Problem #9 – Pier Analysis Subject to Wind Loads
Problem #10 – Wind-Induced Motion
Problem #11 – Lateral Stream Pressure
Problem #12 – Soil Bearing Pressures Due to Lateral Loads
Problem #13 – Seismic Site Specific Hazard Analysis
Problem #14 – Seismic Response Spectrum
Problem #15 – Determination of Elastic Seismic Response Coefficient
Problem #16 – Pier Seismic Design Moments
Problem #17 – Pier Foundation Seismic Design Moments
Problem #18 – Pier Foundation Seismic Design Moments
Problem #19 – Longitudinal and Lateral Seismic Design Moments
Problem #20 – Pier Seismic Shear Force
Problem #21 – Hold-Down Device Uplift
Problem #22 – Seismic Analysis Methods for Bridges
Problem #23 – Single-Mode Spectral Method of Seismic Analysis
Problem #24 – Uniform Load Elastic Method of Seismic Analysis
Problem #25 – Minimum Support Width
Problem #26 – PΔ Compliance
Problem #27 – Concrete Column to Footing Connections – Seismic Provisions
Problem #28 – Concrete Column Longitudinal Reinforcement Development – Seismic Provisions
Problem #29 – Concrete Column Shear Reinforcement – Seismic Provisions
Problem #30 – Wall-Type Pier Reinforcement – Seismic Provisions
Problem #31 – Steel Cross-Frame Diaphragm Capacity
Problem #32 – Deck Flexibility vs. Rigidity
Problem #33 – Deck Seismic Shear Force
Problem #34 – Site Liquefaction Characteristics
Problem #35 – MSE Wall Grid Reinforcement Seismic Capacity
Problem #36 – Proper Use of Mononobe-Okabe Method
Problem #37 – Conventional Retaining Wall Seismic Forces
Problem #38 – MSE Wall Seismic Inertial Forces
Problem #39 – Elastomeric Bearing Pad Lateral Shear
Problem #40 – Sound Barrier Wind Loads

About the Author

David Connor, SE, PE is currently a structural engineer for Haines, Gipson, and Associates in Lawrenceville, Georgia and resides in Greenville, SC with his wife, Amy. He earned his Bachelor's Degree in Civil Engineering, structural emphasis, from the Georgia Institute of Technology and his Master's Degree in Civil Engineering, structural and geotechnical emphasis, from the University of South Carolina. He has been a registered Professional Engineer (PE) in Georgia since 2002, and passed the 16-hour NCEES Structural Engineering (SE) Exam in 2014 on his first try. He is registered as a PE in other states as well, and a registered SE in Illinois.

His structural engineering experience is primarily with buildings; however, his firm has performed the structural engineering for numerous bridges. He was involved in the design of a 5-span, prestressed concrete girder bridge located in Gwinnett County, GA and has provided engineering support to co-workers on other bridges. Additionally, he has performed structural engineering for buildings located across the U.S. including areas of high seismic and wind loads. The types of buildings he has worked on include retail, institutional, and industrial facilities. His curriculum vitae along with additional information may be found on his website (www.davidconnorse.com).

David has also been known to enjoy a craft beer every now and then after a bike ride around the Appalachian foothills in Greenville. ☺

Acknowledgements

I'd like to thank the following people who have helped me in not only writing this book, but throughout my life and career.

- My wife, Amy, who is my foundation (pun intended) and has been there for me through thick and thin.
- My parents, Bob and Rosie, who raised a son they could be proud of and my sister, Elizabeth, who put up with me during those years growing up in Meridian, MS.
- Randy Gipson, PE, principal at Haines, Gipson, and Associates. Randy gave me my first structural engineering job (and 5th). He is the best structural engineer and boss I have ever had the pleasure to work with.
- My other employers who provided me with employment and further education during the lean years in our industry. These include Owen Steel Company in Columbia, SC, Michael McCauley of MJM Engineering in Dallas, GA, and O'Neal, Inc. in Greenville, SC.
- The professors at Georgia Tech and the University of South Carolina who taught me the art of structural engineering and analysis. Especially Drs. Leroy Emkin and Lawrence Kahn at Georgia Tech and Dr. Juan Caicedo at the University of South Carolina.
- My fellow co-workers who have given their time and knowledge to help me edit this book. Especially those who were studying for the SE Exam while this book was being written.
- To all of my friends and family not listed here who have supported me over the years.

Preface

This book is written assuming that the reader generally knows the format of the NCEES Professional Engineering Structural (SE) Exam. For instance, Vertical Loads Component vs. Lateral Loads Component, and Buildings Exam vs. Bridges Exam. If you are not familiar with the format of the exam, please refer to the NCEES website (www.ncees.org). It should be said however, that the morning (multiple choice) section of each exam component is the same for both Buildings and Bridges Exams. *Therefore, everyone who takes the SE Exam will have to show a minimum level of proficiency in performing structural engineering for both buildings and bridges.* This book was primary written for the "building" structural engineer to help them with the multiple choice bridge questions on the SE Exam. The "bridge" structural engineer may also use this book as a review of concepts that may not be commonly encountered in practice, and a refresher on the "fundamentals."

So…….

Why is a "building" structural engineer writing a study guide for the SE Exam on bridges? The simple answer is because there is a need for it, but there is more to it than that. When I was studying for the SE Exam, I purchased a few of the study guides that are out on the market. (See the Tips and Recommendations section for more information on the study guides that I recommend.) The books that I purchased either had very little or no bridge content which was disconcerting for a structural engineer that predominantly works on building projects. The publications that did have bridge content had it in proportion to the amount of bridge problems that you would encounter on the SE Exam. It is commonly assumed that this is about 25% of the multiple choice problems. A study guide that represents a sample SE Exam covering buildings would contain 80 multiple choice questions and 8 essay questions; however, only 20 of the multiple choice questions in the entire book would cover bridges. Other study guides would have 1 chapter out of 10 covering bridges or no bridge content at all.

In looking at the recent volume of SE Exams taken as published by NCEES, about 80-85% of those taking the SE Exam take the Buildings Exam. Most of those "building" structural engineers probably have minimal experience in bridge design. Therefore, there is a need for more study materials that concentrate on bridges vs. buildings because these structural engineers most likely do not work on bridges on a day-to-day basis. That is where this book comes in. This book is meant to "bridge the gap" between the study guides currently on the market and the fact that they mostly concentrate on structural engineering for buildings.

Tips and Recommendations

SE Exam Study Tips:

The tips listed below are geared specifically for the SE Exam and are based on my experience in taking the exam. These are not the "typical" test taking tips that everyone at this point in their lives should know. For instance, get a good night of sleep before the exam. This goes without saying, but if you are anything like me you probably won't get the best night of sleep due to nervousness, so be ready for that. Anyway, on with the tips!

- The SE Exam is a 16-hour test split into vertical and lateral loads over two days. The vertical loads test is on Friday and the lateral loads test is on Saturday. But luckily for us, NCEES does not require that these components be taken on the same weekend. (See their website for more information.) If you are a glutton for punishment, feel free to take both components the same weekend, but I recommend that only one component be taken at a time. This is especially true if it's the first time you are taking the exam so you can familiarize yourself with its difficulty, instead of spending $1000 only to find that the exam is more difficult than you thought. And yes, the exam is difficult with pass rates in the 30%-50% range. Go easy on yourself and your brain.

- Print out a calendar and plan out your time for study of various subjects. As discussed above, I recommend taking each of the exam components separately with the process of studying and taking the exam being a year-long ordeal. On my website (www.davidconnorse.com), I have a copy of the study calendar that I used. The amount of time allotted to each subject is in proportion to the SE Exam subject specifications as shown on the NCEES website. It should be noted there is usually 3-4 additional weeks between the April and October exams, than between the October and April exams.

- The first thing you should do when you decide to take the SE Exam is to gather together all of the current building and material codes that the SE Exam will cover. Again, you can find this information on the NCEES website. Don't underestimate this task. It could take a couple of weeks and if your firm or colleagues do not have copies of the codes, it could cost a significant amount of money.

Tips and Recommendations

- After you have gathered together all of the codes, “tab” them. Solving problems quickly is paramount to passing the SE Exam and the use of tabs will help you to quickly find the code information you need. This process will also help you get familiar with the layout of the codes and you may even find information in the codes that is useful in your day-to-day work experience. Again, don’t underestimate the time it will take to perform this task. It took me the better part of 2 weeks to tab my codes. Be selective with your tabbing. If you “overtab,” you could have the reverse effect of making it more difficult to find information quickly. Also, leave a gap without tabs in the middle of the page edges to make flipping through the pages easier and so that your thumb does not get caught on the tabbed pages. See the photo below.

This photo shows “overtabbing” at the front of the book and correct tabbing with a gap between the tabs at the back of the book.

- This may sound like common sense and trivial, but the best way to study is to work out problems step-by-step, by hand. Obviously, this is how you will need to solve the problems on the exam as well. The reason I mention this is because, many if not all, structural engineers today depend on the use of spreadsheets and structural engineering software to perform the sometimes repetitive structural engineering and analysis tasks. Solving problems by hand will help you to identify the best ways to solve a problem, where in the code to find the information, and where you may get tripped up.

Tips and Recommendations

- Don't be afraid to write things down in the codes, provided they are your own copies, of course. Many times, codes will reference other sections of the code and flipping through pages to find this information can be time consuming. For instance, in AASHTO the design equations will refer to the strength reduction factors (ϕ) that are typically listed toward the beginning of their respective chapters. To save the time it would take to flip to the beginning of the chapter to find the correct ϕ factor, write down the value of ϕ on the page where the design equation is. This can also apply to design coefficients, material properties, etc.

- Based on diagnostic reports from colleagues that did not pass the SE Exam, you will need to show that you have minimum competence in *ALL* of the subjects that are tested. NCEES lists these subjects on their website and they include analysis, loads, code methods, structural systems, steel, concrete, wood, masonry, bridges, foundations, etc. The strategy of studying hard for one subject to "ace" it will not help you if you answer too many questions wrong in another subject. This is part of the reason why I wrote this book with the "building" structural engineer in mind.

- In practice, analysis and design for lateral loads tends to be the more challenging part of the structural engineering profession, therefore you may think the vertical forces component of the SE Exam would be easier than the lateral forces component. However, do not underestimate the difficulty of the vertical forces exam. I personally found it more difficult to study for the vertical forces exam because the types of questions that could be asked cover a broad spectrum. You may want to consider taking the lateral forces component first and passing it before moving on to the vertical forces component. Additionally, pass/fail rates for each component are about the same.

- Use the calculator that you will use on the test when you study. The allowed calculators are listed on the NCEES website and generally cost less than $20. I used the TI-36X Pro calculator and liked it so much I now use it in day-to-day practice. A common test day tip is to bring an extra set of batteries for your calculator. However, since the allowed calculators are fairly cheap, I recommend bringing a 2nd identical calculator, both with fresh batteries in case there is a technical malfunction. You will now have a spare calculator once you are done with the exam.

Tips and Recommendations

Day of Test Tips:

There are numerous "day of test" tips that could be listed here and are generally easy to find in other study guides and on the internet. Below are some additional tips that became apparent to me during preparation for the SE Exam and should hopefully make your exam experience more pleasant and save you time in answering questions.

- You will find that between all of the codes and study materials gathered during your studies that you will need some way of physically transporting these references into the exam site. I recommend using 2 large plastic containers that can be bought at most home improvement or "big box" stores. One of the plastic containers that I used is shown here:

I used 2 of these large plastic containers to bring my codes and reference materials to the SE Exam site.

  You will need 1 container for the codes, and the other container for your other study materials like study guides and text books. 1 container won't be enough for all of your references. However, if you need 3 containers, you are probably bringing too much and will probably use more time looking for references during the exam. Finally, you will need a dolly to carry the containers as they will be very heavy.

- This book references the *AASHTO LRFD 8th Edition, 2017* code and is the latest AASHTO code available at the time of this writing. It is important to remember the following regarding the units used in the AASHTO code. For material properties and strength equations, units are always in kips, inches, and ksi. (Don't use f'_c = 3000 psi in a square root, etc. Use f'_c = 3 ksi.) Moments from analysis are usually determined in units of kip-ft. Do not forget to convert the design strengths from kip-in to kip-ft where necessary.

Tips and Recommendations

- The convention used in this book, and typically on the exam, is that "design" capacities or loads should consider all adjustment factors (ϕ, etc.) or apply the appropriate load combinations. If the question asks for "nominal" capacities or "service" loads then do not apply capacity adjustment factors or factor the loads per the load combinations.

- For the morning session of each exam, there will be 40 multiple choice questions. I recommend reading through all of the questions first and putting each question into a category. Spend 15-30 seconds on each problem. This process will not only let you get an overall feel for the exam, but is meant to be a time saver. Generally each of these categories will require the use of a single code or reference, maybe 2 at the most. Grouping the questions together based on these categories will keep you from having to move from one code to another after each question. Write the categories down on the first page of the exam and as you skim the questions put the question number next to the appropriate category. The categories that I recommend are as follows:

  Analysis
  Loads (IBC/ASCE 7 Codes)
  Foundations
  Steel (AISC Codes)
  Reinforced Concrete (ACI 318 Code)
  Masonry (ACI 530 Code)
  Wood (NDS Code)
  Light Gage Steel (AISI Code)
  Bridges (AASHTO Code)
  Inspections/Construction Methods/Miscellaneous
  "Word Problems"

  The category "word problems" are problems that don't require calculations and can be quickly answered. If you come across one of these during your initial reading of the questions, go ahead and answer it. The remaining questions would then be answered going from one category to the next. Start with the category you know best and save the category you are least familiar with for last. Hopefully after you are finished studying this book your last category won't be bridges. ☺

Tips and Recommendations

Recommended Study Guides:

Below is a list of study guides that are currently out on the market that I recommend you use to aid in your studies for the SE Exam. I also give a brief reasoning for each recommendation. Of course, these are in addition to the codes that the SE Exam tests.

- *Steel Design for the Civil PE and Structural SE Exams*
  by Frederick S. Roland, PE
  Published by Professional Publications, Inc. (www.ppi2pass.com)
  This is a clear and concise book covering steel design. It mostly covers subjects you will see on the vertical forces component exam.

- *Concrete Design for the Civil PE and Structural SE Exams*
  by C. Dale Buckner, PhD, PE
  Published by Professional Publications, Inc. (www.ppi2pass.com)
  This book is similar to the Steel Design book put out by PPI but for concrete design. It mostly covers subjects you will see on the vertical forces component exam, but also has some good information on seismic design.

- *Timber Design for the Civil PE and Structural SE Exams*
  by Robert H. Kim, PE and Jai B. Kim, PE with Parker E. Terrill
  Published by Professional Publications, Inc. (www.ppi2pass.com)
  This is a book that PPI has since discontinued publishing. If you can find it on Amazon or another on-line book seller it is a good study guide for timber design. *Design of Wood Structures* by Donald Breyer is the go-to timber design textbook.

- *2015 Design of Reinforced Masonry Structures*
  by the Concrete Masonry Association of California and Nevada (www.cmacn.org)
  This book contains numerous design examples with full explanation and reference to the masonry code, design tables and charts, and 3D details. This should be the only book you need to study for masonry. At the time of this printing the book was FREE, but you will have to pay shipping.

Tips and Recommendations

Recommended Study Guides:

- *2018 IBC: SEAOC Structural/Seismic Design Manual Vol. 1: Code Application Examples*
  by Structural Engineers Association of California and the International Code Council
  Published by Structural Engineers Association of California
  This is your "go to" book for study of the lateral seismic loads for buildings and ASCE 7. The examples are very much like what you may see on the SE Exam.

- *2018 IBC: SEAOC Structural/Seismic Design Manual Vols. 2-4*
  by Structural Engineers Association of California and the International Code Council
  Published by Structural Engineers Association of California
  Part of the series described above put out by SEAOC. Volume 2 covers light-frame, tilt-up, and masonry buildings. Volume 3 covers concrete buildings. Volume 4 covers steel buildings. The examples are "full building" examples and are very thorough. They are great for studying for the essay portion of the lateral building exam.

- *Seismic Design of Building Structures*
  by Michael R. Lindeburg, PE and Kurt M. McMullin, PE
  Published by Professional Publications, Inc. (www.ppi2pass.com)
  This is another good guide for seismic analysis and design. It is a good companion to the SEAOC Seismic Design Manuals.

- *Wind Loads: Guide to the Wind Load Provisions of ASCE 7*
  by Kishor C. Mehta, Ph.D, PE and William L. Coulbourne, PE
  Published by ASCE Press (www.asce.org)
  The lateral load component of the SE Exam mostly covers seismic loads, but it also covers wind loads. The guide will help in your lateral wind load studies.

Tips and Recommendations

Recommended Study Guides:

- *16-Hour Structural Engineering (SE) Practice Exam for Buildings*
  by Joseph S. Schuster, SE, PE
  Published by Professional Publications, Inc. (www.ppi2pass.com)
  Like the title says, this is a full SE practice exam for buildings. It contains 40 multiple choice questions and 4 essay questions for an example vertical forces exam and an example lateral forces exam (80 total multiple choice questions and 8 total essay questions). It also has fully explained solutions for all of the questions and essay problems. This book's best asset is that is a close representation in difficulty to the actual SE Exam. For those taking the bridge SE Exam, the multiple choice questions provide a good example of what will be seen on the exam, unfortunately, the essay questions will be of minimal use.

- *SE – Structural Engineering Sample Questions + Solutions*
  by NCEES
  This is also a full SE practice exam, but has essay questions for buildings and bridges. It contains a total of 80 multiple choice questions covering vertical loads and lateral loads. The essay questions cover: building vertical loads (4 questions), bridge vertical loads (3 questions), building lateral loads (4 questions), and bridge lateral loads (3 questions). It also has solutions for all of the questions and essay problems. When studying for the SE Exam, I found that the examples in this book were somewhat easier than the actual exam, however, given that it is published by the organization giving the exam it is probably a good idea to pick it up. There were a few questions on the SE Exam that closely resembled questions in this book, maybe as a "thank you" from NCEES for purchasing their book.

  And for when you need to take a study break…….

- *Cycling Greenville, South Carolina*
  by Wendy Lynam, Foreword by George Hincapie
  A guide book to road biking around Greenville, SC

Summary of AASHTO Changes

Below is a brief summary of the changes to the AASHTO LRFD Bridge Design Specifications from the 7th edition, 2014 to the 8th edition, 2017. An exhaustive summary of all of the sections that were changed is not itemized below because the changes for this edition were numerous. However, many of these changes have made AASHTO better organized and easier to use. Additionally, some of the revisions to the AASHTO code were made so that it more closely aligns with provisions in "building" codes (ACI, AISC, ASCE 7, etc.). Listed below are some of the changes that were made to the AASHTO code that resulted in revision of some of the problems in this book. The chapters and sections that were affected are also listed where applicable.

- The method for determining wind loads has been completely revamped and is now closely aligned with the method used in ASCE 7 for determining wind loads on buildings. Additionally, wind loads are now calculated at strength level. This is reflected in changes to the load combination factors that involve wind.
- Chapter 5 – Concrete Structures has been completely reorganized. A new Section 5.11 – Seismic Design and Details has been added. In past editions, seismic design and details was contained in the sections for limit states, details of reinforcement, etc. There have been some minor conceptual changes made, and these are discussed below, but the reorganization of this Chapter is the biggest change.
- There have been revisions to concrete Section 5.5.4.2 – Resistance Factors (ϕ). In particular the resistance factors for normal weight and lightweight concrete are now equal for each particular limit state.
- The method for determining the shear resistance of a prestressed concrete girder is now similar to that of a conventionally reinforced concrete girder. The calculation of V_{ci} and V_{cw} is no longer necessary. See Section 5.7.3.4.2.
- The procedure for calculating reinforcement tension development length has been refined and clarified. See Section 5.10.8.2.4.
- The allowed concrete compressive stresses in strut and tie models have been revised. See Section 5.8.2.
- Steel fatigue load combination factors have been made more conservative. See Table 3.4.1-1 & Section 6.6.1.
- Similar to concrete resistance factors, steel resistance factors (ϕ) have also been revised in some instances. See Section 6.5.4.2.
- The provisions and values used for the design of bolted connections have been revised to more closely align with the provisions of the AISC specification. The reduction factor for the bolted connection length has also been changed to 38 inches to align with AISC.
- The provisions for the design of splices have been revised. Generally speaking, the design approach is based on the capacity of the members being spliced, as opposed to the forces and stresses determined by structural analysis.

Summary of AASHTO Changes

As described above, this is not an exhaustive list of all of the changes because there were many changes. To put it in perspective, the following problems had to be revised or completely rewritten to comply with AASHTO 8th edition, 2017 from previous editions:

Vertical Problems:
Problem #13 – Long-Term Concrete Deflection
Problem #14 – Concrete Column Axial Resistance and Biaxial Flexure
Problem #15 – Support Bearing Resistance
Problem #16 – Shear Resistance of Prestressed Girder
Problem #17 – Interface Shear Resistance
Problem #18 – Prestressed Girder Stresses
Problem #19 – Prestressed Girder Losses
Problem #20 – Development Length
Problem #21 – Concrete Deck Reinforcement Cover
Problem #22 – Concrete Piles
Problem #24 – Strut and Tie Method
Problem #25 – Steel Fatigue
Problem #27 – Fracture-Critical Member Charpy V-Notch (CVN) Testing
Problem #31 – Plate Girder End Bearing Capacity
Problem #34 – Bolted Connection Shear Resistance
Problem #35 – Bolted Connection Slip Resistance
Problem #36 – Bolted Splice
Problem #38 – Drilled Shafts
Lateral Problems:
Problem #1 – Superstructure Wind Loads in Transverse Direction
Problem #2 – Superstructure Wind Loads in Longitudinal Direction
Problem #3 – Superstructure Wind Loads on Flat Surface
Problem #4 – Simultaneous Substructure Wind and Stream Loads
Problem #5 – Usual Girder and Slab Bridge Wind Loads
Problem #6 – Wind Loads on Vehicles
Problem #7 – Superstructure Wind Loads – Skewed Pier
Problem #8 – Substructure Wind Loads – Skewed Pier
Problem #9 – Pier Analysis Subject to Wind Loads
Problem #10 – Wind-Induced Motion
Problem #12 – Soil Bearing Pressures Due to Lateral Loads
Problem #26 – PΔ Compliance
Problem #27 – Concrete Column to Footing Connections – Seismic Provisions
Problem #28 – Concrete Column Longitudinal Reinforcement Development – Seismic Provisions
Problem #29 – Concrete Column Shear Reinforcement – Seismic Provisions
Problem #30 – Wall-Type Pier Reinforcement – Seismic Provisions
Problem #40 – Sound Barrier Wind Loads
This is nearly half of the problems contained in this book.

Nomenclature

A	fatigue detail category constant; plan area of bearing pad (in^2)
A_b	cross sectional area of bolt (in^2)
A_c	core cross sectional area (in^2)
A_{cv}	area of concrete section resisting shear transfer (in^2)
A_g	gross cross sectional area (in^2)
A_{girder}	cross sectional area of girder (in^2)
A_n	net cross sectional area (in^2)
A_{ps}	cross sectional area of prestressing strands (in^2)
A_s	cross sectional area of steel member (in^2);
A_S	peak seismic ground acceleration coefficient modified by short-period site factor (%g)
A_{sc}	headed stud cross-sectional area (in^2)
A_{sp}	cross sectional area of spiral reinforcement (in^2)
A_{st}	cross sectional area of reinforcement (in^2)
A_v	area of shear reinforcement (in^2)
A_{vf}	area of reinforcement for interface shear between concretes of slab and beam (in^2)
A_1	load area (in^2)
A_2	area of the lower base of the largest frustrum of a pyramid contained wholly within the support and having for its upper base the loaded area (A_1) and having side slopes of 1 vertical to 2 horizontal (in^2)
$ADTT_{SL}$	average daily truck traffic over design life – single lane (trucks/day)
AEP	apparent earth pressure (psf/ksf)
B	width of pier (in.); backfill slope angle (degrees)
BR	vehicular braking force (kips)
b_f	flange width (in.)
b_s	composite effective width of concrete deck (in.)
b_t	projecting width of bearing stiffener (in.)
b_v	concrete member width resisting shear (in.); prestress girder web width (in.)
C	MSE wall reinforcement surface area geometry factor; ratio of shear buckling resistance to the shear specified minimum yield strength
C_D	wind or stream drag coefficient (s^2 lbs./ft^4)
C_d	deck factor
C_F	size factor
C_{fu}	flat use factor
C_i	incising factor
C_{KF}	format conversion factor = 2.5/ϕ
C_L	lateral drag coefficient
C_{sm}	elastic seismic response coefficient
C_M	wet-service factor
C_v	volume factor
CV	vessel collision force (kips)
CVN	Charpy V-Notch
C_λ	time effect factor
c	cohesion factor (ksi)
D	plate girder web depth (in.)
DC	dead load of superstructure and structural components (kips)
D_c	core diameter (in.)
D_g	gross diameter (in.)
DW	dead load of wearing surface (kips)
DWT	dead weight tonnage of ship (tonnes)
D_p	distance from top of concrete deck to the neutral axis of the composite section at the plastic moment (in.)
D_t	total depth of composite section (in.)
d	diameter; depth; distance from extreme compression fiber to centroid of tensile steel (in.); diameter; depth (in.)
d_b	bar diameter (in.)
d_o	web stiffener spacing (in.)
d_v	effective shear depth (in.)
E	modulus of elasticity of steel (ksi)
E_c	modulus of elasticity of concrete (ksi)
E_{ci}	modulus of elasticity of concrete at transfer (ksi)
E_{ct}	modulus of elasticity of concrete at transfer or time of load application (ksi)
E_p	modulus of elasticity of prestressing tendons (ksi)
EH	horizontal earth pressure load (psf/ksf)
EV	vertical pressure from dead load of earth fill (psf/ksf)
e_X	eccentricity about x-x axis (ft.)
e_Y	eccentricity about y-y axis (ft.)
F	force (kips); strut or tie force (kips)
F*	pullout friction factor

Nomenclature

F_a site factor for short-period range of acceleration response spectrum

F_b adjusted design flexural strength of wood (ksi)

F_{bo} design flexural strength of wood (ksi)

FCM fracture-critical member

$F_{elastic}$ elastic transverse base shear (kips)

F_{hinge} inelastic hinging force (kips)

F_p total radial force in concrete deck (kips)

F_{pga} site factor at zero-period on acceleration response spectrum

F_{px} transverse seismic shear force in deck (kips)

$F_{PIERLAT}$ wind load normal to pier longitudinal axis (kips)

$F_{PIERLONG}$ wind load parallel to pier longitudinal axis (kips)

F_{SUBLAT} substructure wind force applied along bridge lateral axis (kips)

$F_{SUBLONG}$ substructure wind force applied along bridge longitudinal axis (kips)

$F_{SUPERLONG}$ force applied to pier along bridge longitudinal axis (kips)

$F_{SUPERLAT}$ force applied to pier along bridge lateral axis (kips)

$F_{SUPERLONG}$ force applied to pier along bridge longitudinal axis (kips)

F_u steel tensile strength (ksi)

F_{ub} tensile strength of bolt (ksi)

F_v site factor for long-period range of acceleration response spectrum

F_y steel yield strength (ksi)

F_{yf} steel yield strength of flange (ksi)

F_{yw} steel yield strength of web (ksi)

F_{ys} steel yield strength of stiffener (ksi)

f'_c 28-day compressive strength of concrete (psi/ksi)

f'_{ci} compressive strength of concrete at strand release (psi/ksi)

f_{cgp} concrete stress at the center of gravity of prestressing tendons that results from the prestressing force at transfer and the self-weight of the member at sections of maximum moment (ksi)

f_{pbt} stress in prestressing steel immediately prior to transfer (ksi)

f_{pc} compressive stress in concrete after all prestress loss has occurred (ksi)

f_{pe} effective stress in the prestressing steel after losses (ksi)

f_{pi} prestressing steel stress immediately prior to transfer (ksi)

f_{pu} prestress strand tensile strength (ksi)

f_{py} prestress strand yield strength (ksi)

f_y steel yield strength (ksi)

G gust effect factor; shear modulus (ksi)

g acceleration of gravity = 32.2 ft/s^2

H wall, pier, or column height (ft)

H humidity (%); wall height (ft)

HL-93 AASHTO truck loading (kips/kips per ft)

H_{bu} elastomeric bearing pad shear force (kips)

H_{WS} transverse wind load (kips)

H_2 effective soil mass height considering slope of backfill (ft)

h_{eq} equivalent height of soil (ft.)

h_{rt} total elastomer thickness (in)

h_{wall} height of wall (ft.)

i backfill slope angle (degrees)

I_{cr} cracked moment of inertia (in^4)

I_e effective moment of inertia (in^4)

I_g gross moment of inertia (in^4)

I_{hb} hooked bar development length (in.)

K stiffness (k/in)

K_A static active earth pressure coefficient

K_{AE} seismic active earth pressure coefficient

K_{COL} column stiffness (k/in)

K_{PIER} pier stiffness (k/in)

K_g longitudinal stiffness parameter

K_h hole size factor

K_s surface condition factor

K_Z pressure exposure and elevation coefficient

K_1 correction factor for source aggregate; fraction of concrete strength available to resist interface shear

K_2 limiting interface shear resistance (ksi)

k lateral earth pressure coefficient; web stiffener spacing factor

k_a active lateral earth pressure coefficient

k_c ratio of the maximum concrete compressive stress to the design compressive strength of concrete. Equals 0.85 for $f'_c < 10$ ksi

Nomenclature

k_h horizontal seismic acceleration coefficient
k_{h0} horizontal seismic acceleration coefficient at zero displacement
k_v vertical seismic acceleration coefficient
L span length, deck span length (ft); bearing pad use has limited applications
LL+IM live load + impact load (kips)
L_{AERO} length at which wind-induced motion is to be investigated (ft)
LL_{DIST} live load distribution factor
L_{angle} length of angle (ft)
L_b anchor bonded length (ft)
L_e length of MSE wall reinforcement (ft)
L_p arc length between an end of the girder and an adjacent point of maximum positive live load plus impact moment (ft.)
l_{hb} hooked bar development length (in.)
M_a maximum service moment (k-ft)
M_{avg} average of the member flexural resistance and factored flexural loads (k-ft)
M_{BR} unfactored moment due to braking forces (k-ft)
M_{cr} cracking moment (k-ft)
M_{DC} unfactored moment due to dead load (k-ft)
M_{Design} factored design moment (k-ft)
MHW mean high water (elevation)
M_{IM} unfactored moment due to dynamic impact (kip-ft)
M_{LAT} moment about lateral bridge axis (k-ft)
M_{LL} unfactored moment due to live load (kip-ft)
M_{LL+IM} unfactored moment due to live load + impact (kip-ft)
M_{LONG} moment about longitudinal bridge axis (k-ft)
MM Multimode Elastic Method (seismic analysis)
M_n nominal moment capacity (k-ft)
$M_{N\text{-}LAT}$ nominal moment capacity in lateral direction (k-ft)
$M_{N\text{-}LONG}$ nominal moment capacity if longitudinal direction (k-ft)
M_{nx} nominal X-X (strong) axis flexural resistance (k-in)
M_p plastic moment capacity (k-ft)
$M_{pierLAT}$ pier design moment in lateral direction (k-ft)
$M_{pierLONG}$ pier design moment in longitudinal direction (k-ft)
M_{PBOT} plastic moment capacity at bottom of column, not multiplied by seismic overstrength factor (k-ft)
M_{PTOP} plastic moment capacity at top of column, not multiplied by seismic overstrength factor (k-ft)
M_{POVER} plastic moment capacity multiplied by seismic overstrength factor (k-ft)
$M_{POVERBOT}$ plastic moment capacity at bottom of column multiplied by seismic overstrength factor (k-ft)
$M_{POVERTOP}$ plastic moment capacity at top of column multiplied by seismic overstrength factor (k-ft)
MSE mechanically stabilized earth
M_r factored flexural resistance (k-ft)
M_{rx} factored flexural resistance about x axis (k-ft)
M_{ry} factored flexural resistance about y axis (k-ft)
M_{self} moment due to self weight (k-ft)
$M_{strands}$ moment due to prestress force (k-in)
M_{ux} factored moment about x axis (k-ft)
M_{uy} factored moment about y axis (k-ft)
$M_{U\text{-}LAT}$ design moment in lateral direction (k-ft)
$M_{U\text{-}LONG}$ design moment in longitudinal direction (k-ft)
$Mdesign_{hi}$ design moment at high water (k-ft)
$Mdesign_{low}$ design moment at low water (k-ft)
$Mwater_{hi}$ water pressure moment at high water (k-ft)
$Mwater_{low}$ water pressure moment at low water (k-ft)
$Mwind_{hi}$ wind pressure moment at high water (k-ft)
$Mwind_{low}$ wind pressure moment at low water (k-ft)
$Mwind_{low}$ wind pressure moment at low water (k-ft)
M_X moment about x-x axis (ft^3)
M_Y moment about y-y axis (ft^3)

Nomenclature

$M_{75\%}$	75% of the member flexural resistance (k-ft)
m	multiple presence factor; bearing area modification factor; confinement modification factor
N	number of stress range cycles
N	support length (in)
$\overline{N}$	average SPT blow count (blows/ft)
N_s	number of shear planes
$(N_1)_{60}$	SPT blow count (blows/ft)
P	total nominal force in concrete deck (kips)
P_a	lateral earth pressure (psf)
P_{AE}	retaining wall dynamic lateral earth force (k/ft)
P_c	permanent net compressive force (kips); composite force in bottom flange steel (kips)
P_D	design wind pressure (ksf)
P_{design}	design force or pressure
P_e	elastic critical buckling resistance (kips)
P_{DH}	deck house impact force (kips)
PGA	peak seismic ground acceleration (%g)
P_{ir}	MSE wall horizontal inertial force caused by acceleration of reinforced backfill and wall facing (k/ft)
P_{IR}	horizontal inertia force due to seismic loading at retaining wall or MSE wall (k/ft)
P_{LAT}	load in lateral direction (kips)
P_{LONG}	load in longitudinal direction (kips)
P_{MT}	mast impact force (kips)
P_o	nominal axial resistance at 0.0 eccentricity at concrete (kips); equivalent nominal yield resistance at steel (kips)
P_p	longitudinal force in the concrete deck at the point of maximum live load plus impact moment (kips)
P_{pi}	prestress force of strands at release
P_n	nominal compressive or bearing resistance (kips)
P_{seis}	retaining wall seismic lateral force (kips)
P_r	bearing resistance (kips); axial resistance (kips); tensile resistance (kips)
P_{rb}	composite force in the bottom concrete deck reinforcement (kips)
P_{rt}	composite force in the top concrete deck reinforcement (kips)
P_{rx}	factored axial resistance in flexure about x-axis (kips)
P_{ry}	factored axial resistance in flexure about y-axis (kips)
P_{rxy}	factored axial resistance in biaxial flexure (kips)
P_s	composite force in concrete deck slab concrete (kips)
$P_{strands}$	prestress force (kips)
P_{stream}	stream pressure (ksf)
P_{ship}	ship collision force (kips)
P_t	composite force in top beam flange steel (kips); minimum required bolt tension force (kips)
P_u	ultimate compressive or gravity load (kips)
P_w	composite force in beam web steel (kips)
P_{WSHOR}	column uplift due to horizontal wind load (kips)
P_{WSUP}	total column uplift due to wind load (kips)
P_{WUP}	column uplift due to uplift wind load (kips)
p_e	equivalent uniform static seismic loading per unit length of bridge that is applied to represent the primary mode of vibration (kips/ft)
$P_e(x)$	intensity of equivalent static seismic loading that is applied to represent the primary mode of vibration (kips/ft)
p_o	uniform lateral load set equal to 1.0 (k/ft)
p_{stream}	stream pressure (ksf)
Q_n	nominal anchor resistance (kips); nominal shear connector resistance (kips)
Q_R	factored anchor resistance (kips)
Q_r	factored shear connector resistance (kips)
q_{ciN}	CPT tip resistance (ksf)
q_p	nominal unit tip resistance (ksf)
q_s	nominal unit side resistance (ksf)
R	radius of curvature (ft.); bearing pad use may be suitable but requires special considerations or additional elements; seismic response modification factor
R_{AL}	axle load correction factor
R_{base}	base reaction (kips)
R_C	concrete strength correction factor
R_c	reinforcement coverage ratio
R_d	factor for calculation of seismic displacements due to inelastic action

Nomenclature

R_{DH}	deck house impact force factor
R_f	relieving slab factor applicable for box structures where the span is less than 26 ft. = 1.2
R_p	nominal tip resistance of drilled pier (kips)
R_p	hole reduction factor; equal to 1.0 for welded connections
R_{pier}	pier reaction (kips)
R_R	factored axial compression resistance (kips)
R_r	factored resistance of bolts (kips)
R_s	nominal side resistance of drilled pier (kips)
R_n	nominal shear resistance of bolts (kips)
r	radius of gyration (in.)
S	longitudinal girder spacing (ft); bearing pad use is suitable; pier skew relative to lateral bridge axis (degrees)
S_b	bottom fiber section modulus (in^3)
S_{DS}	horizontal response spectral acceleration at 0.2s period modified by short-period site factor (%g)
S_{D1}	horizontal response spectral acceleration at 1.0s period modified by long-period site factor (%g)
S_S	horizontal response spectral acceleration coefficient at 0.2s period (%g)
S_t	top fiber section modulus (in^3)
S_x	elastic section modulus (in^3); bearing modulus about x-x axis (ft^3)
S_v	vertical spacing of MSE wall reinforcement (in); bearing modulus about y-y axis (ft^3)
SM	Single-Mode Elastic Method (seismic analysis)
SW	classification designation for well graded sand
S_1	horizontal response spectral acceleration coefficient at 1.0s period (%g)
s	spacing of shear reinforcement (in)
$\bar{s}_u$	average undrained shear strength (ksf)
T	unfactored tension force (kips/kips per ft); period of vibration (s)
TH	Time History Method (seismic analysis)
T_m	period of vibration (s)
T_{MAX}	maximum tension in MSE wall reinforcement (plf); maximum design temperature (^oF)
T_{MIN}	minimum design temperature (^oF)
T_O	reference period used to define shape of acceleration response spectrum (s)
T_S	corner period at which acceleration response spectrum changes from being independent of period to being inversely proportional to period (s)
TU	force effect due to temperature
T_u	ultimate tension load (kips)
t	plate thickness (in.); relieving slab thickness (in.)
t_b	basic thickness of relieving slab (in.)
t_f	flange thickness (in.)
t_p	bearing stiffener thickness (in.)
t_s	slab thickness (in.)
t_w	web thickness (in.)
U	bearing pad use is unsuitable; reduction factor to account for shear lag in tension connections
UL	Uniform Load Elastic Method (seismic analysis)
V	wind velocity (mph), stream velocity (ft/s)
V_c	nominal shear resistance of concrete (kips)
V_{cr}	shear buckling resistance (kips)
V_{CROSS}	design lateral shear capacity of cross-frame diaphragm (kips)
V_{DC}	unfactored shear due to dead loads (kips)
V_{DW}	unfactored shear due to wearing surface (kips)
V_{IM}	unfactored shear due to dynamic impact (kips)
V_{LL}	unfactored shear due to live load (kips)
V_n	nominal shear resistance (kips)
V_{ni}	nominal interface shear resistance (kips)
V_p	component in the direction of the applied shear of the effective prestressing force in concrete; positive if resisting the applied shear (kips) Zero for reinforced concrete; plastic shear force in steel (kips)
V_{pier}	pier extreme event force (kips)
V_r	nominal shear resistance of wall type pier (kips)
V_{ri}	factored interface shear resistance (kips/ft)
V_s	nominal shear resistance of steel (kips)

Nomenclature

V_{SEIS} seismic shear force (kips)
V_{STREAM} stream velocity (ft/s)
V_{stream} unfactored stream pressure force (kips)
V_{super} superstructure extreme event force (kips)
V_{s1} shear wave velocity (fps)
V_u ultimate design shear (kips)
V_{uLAT} ultimate design shear in lateral direction (kips)
V_{uLONG} ultimate design shear in longitudinal direction (kips)
$v_s(x)$ deformation corresponding to p_o (ft)
$v_{s,max}$ maximum seismic displacement (in)
WA water load or stream pressure (kips)
WL wind load on vehicles (ksf)
WS wind load (kips)
W bridge weight (k/ft); seismic weight as defined in problem #33 (kips)
W_{LAT} lateral wind load (k/ft)
W_{LONG} lateral wind load (k/ft)
W_{px} seismic weight as defined in lateral problem #33 (kips)
W_S weight of soil immediately above wall, including wall heel (k/ft)
W_{UP} distributed uplift wind load (k/ft)
W_W weight of wall (k/ft)
w pier wind exposure width (ft)
w_c concrete density (pcf)
w(x) unfactored dead load of bridge (k/ft)
w/c water/cementitious ratio
$\bar{x}$ connection eccentricity (in.)
y_{bot} distance to girder centroid from bottom (in)
$\bar{Y}$ distance from top of concrete deck to plastic neutral axis (in.)
Z height above low ground or water level (ft)
Z_x plastic section modulus (in^3)

α angle of inclination of transverse reinforcement (degress); MSE wall scale effect correction factor; coefficient of thermal expansion (in/in/^oF); generalized flexibility SM seismic analysis method
β factor relating effect of longitudinal strain on shear capacity of concrete, as indicated by the ability of diagonally cracked concrete to transmit tension; generalized participation factor SM seismic analysis method; backfill slope angle (degrees)
γ load combination factor; generalized mass factor SM seismic analysis method
γ_{conc} concrete density (psf)
γ_h correction factor for relative humidity
γ_s back fill soil density (psf)
γ_{soil} back fill soil density (psf)
γ_{st} correction factor for specified concrete strength at time of prestress transfer to the concrete member
Δ deflection (in.); displacement (in.)
Δ_e elastic seismic displacement (in.); elastomer shear deformation (in.)
$(\Delta F)_n$ nominal fatigue resistance (ksi)
$(\Delta F)_{TH}$ constant amplitude fatigue threshold stress (ksi)
Δf live load stress range (ksi)
Δf_{pt} total prestress losses (ksi)
Δf_{pR} estimate of relaxation loss taken as 2.4 ksi for low relaxation strands, 10.0 ksi for stress relieved strand (ksi)
Δf_{pES} prestress loss due to elastic shortening (ksi)
Δf_{pLT} prestress loss due to time-dependant losses (ksi)
Δi_e deflection based on effective moment of inertia (in.)
Δi_g deflection based on gross moment of inertia (in.)
Δlt_e long term deflection based on effective moment of inertia (in.)

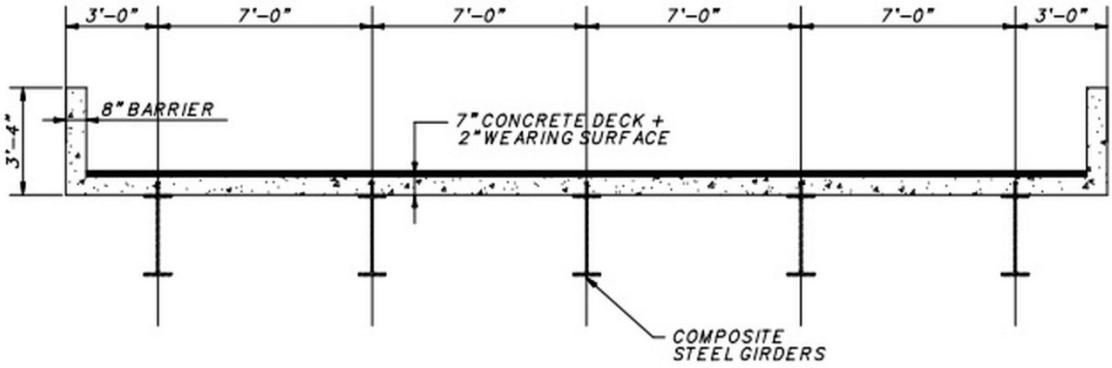
Nomenclature

Δlt_g	long term deflection based on gross moment of inertia (in.)
Δ_T	thermal expansion (in)
ϕ	strength resistance factor; soil friction angle
ϕ_c	axial compression strength resistance factor
ϕ_f	flexural strength resistance factor
ϕ_{min}	minimum soil friction angle
ϕ_{qp}	drilled shaft tip resistance factor
ϕ_{qs}	drilled shaft side resistance factor
ϕ_s	bolt shear resistance factor
ϕ_{sc}	shear connector resistance factor
ϕ_u	tensile rupture strength resistance factor
ϕ_v	shear strength resistance factor
ϕ_y	tensile yield strength resistance factor
λ	concrete density modification factor
λ_{cf}	coating factor
λ_{er}	excess reinforcement factor
λ_{rc}	reinforcement confinement factor
λ_{rl}	reinforcement location factor
μ	coefficient of friction
η_ι	ductility, redundancy, and operational classification factor
ρ_h	ratio of horizontal wall-type pier reinforcement
ρ_s	ratio of spiral reinforcement to volume of column core
ρ_v	ratio of vertical wall-type pier reinforcement
θ	angle of inclination of diagonal compressive stresses (degrees); angle (degrees)
σ_H	factored horizontal soil stress (psf)
σ_v	unfactored vertical soil stress (psf)
τ_n	nominal anchor bond stress (ksf)
ω_{self}	self weight of girder (k/ft)

Bridge Problems for the Structural Engineering (SE) Exam: Vertical Loads 40 Problems

Problem #1

Refer to the bridge deck section, design data, and assumptions below:



Design Data and Assumptions:

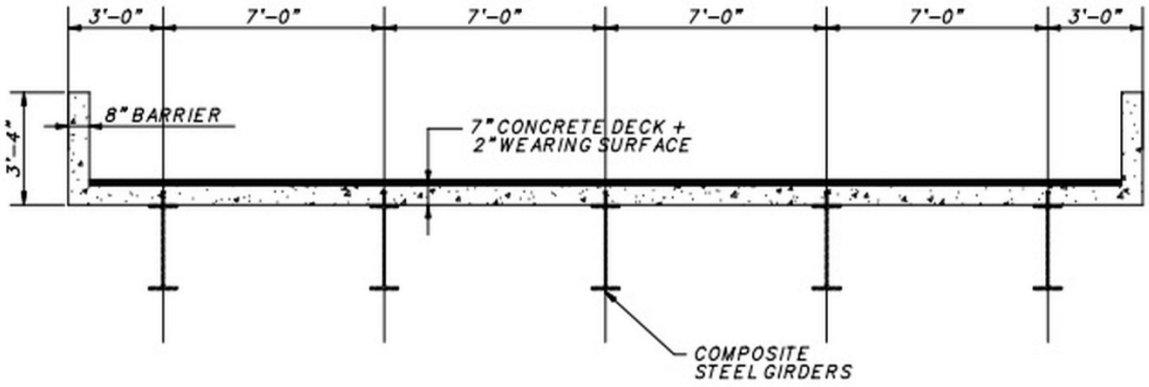
- Beam span = 50'-0"simple span
- Total Dead Load of Superstructure (DC) – 3.0 kips/ft
- Total Dead Load of Wearing Surface (DW) – 0.5 kips/ft
- HL-93 Design Truck Static Moment – 628 kip-ft
- HL-93 Design Lane Load – Per AASHTO
- Ductililty, Redundancy, and Operational Classification factor $\eta_i = 1.0$
- Bridge Stiffness Factor $(K_g/12.0Lt_s^3)^{0.1} = 1.0$
- Two design lanes loaded
- Permanent loads are distributed equally among the girders
- Loads and moments not shown are negligible or do not govern design

The maximum design moment for an interior girder is most nearly:

(A) 1200 kip-ft
(B) 1440 kip-ft
(C) 1730 kip-ft
(D) 2100 kip-ft

Problem #2

The same bridge from Problem #1 has a simple end span of 20'-0". Refer to the bridge deck section, design data, and assumptions below:



Design Data and Assumptions:

- Beam span = 20'-0"simple span
- Total Dead Load of Superstructure (DC) – 3.0 kips/ft
- Total Dead Load of Wearing Surface (DW) – 0.5 kips/ft
- HL-93 Design Live Load applies
- Ductililty, Redundancy, and Operational Classification factor $\eta_i = 1.0$
- Bridge Stiffness Factor $(K_g/12.0Lt_s^3)^{0.1} = 1.0$
- Two design lanes loaded
- Permanent loads are distributed equally among the girders
- Loads not shown are negligible

The maximum design shear for an interior girder is most nearly:

(A) 76 kips
(B) 84 kips
(C) 89 kips
(D) 96 kips

Problem #3 Correct Answer – (B)

Upon first glance, if you were not familiar with AASHTO Table A4-1 this would be a complicated continuous beam structural analysis problem. However, AASHTO has tabulated the maximum live load moments in bridge decks for "typical" bridges. This problem tests the use of Table A4-1.

Pertinent Sections and Tables –

Appendix A4 – Deck Slab Design Table A4-1 – Note: This table is located at the end of AASHTO Section 4
Section 4.6.2.1.6 – Calculation of Force Effects (Bridge Deck Approximate Analysis)

Solution –

Step 1 – Determination of location of design section:

Table A4-1 has the negative moments tabulated based on the CL to CL distance (S) between girders and the distance from the CL of girder to the design section.

TIP: Use table A4-1 to determine transverse live load deck moments, however do not multiply these values by the 1.33 impact factor. It is already included in the tabulated values.

Per AASHTO Section 4.6.2.1.6 this typical bridge deck (cross section type k in Table 4.6.2.2.1-1) design section for negative moments may be taken at a distance of 1/3 the flange width, but not exceeding 15" from the centerline of support. This is applicable to the top flange width of 3'-0" given in the illustration.

Thus the design section location is at 36"/3 = 12" from the CL of the girder.

Step 2 – Determination of negative moment:

Referring to Table A4-1 the negative moment for S = 9'-0" at 12" from CL of support –

Answer: 3.71 kip-ft/ft

Incorrect Answers –

(A) 3.31 kip-ft/ft – This is the moment at the 18" away from girder CL which would be the edge of the girder.
(B) 3.71 kip-ft/ft – This is the correct answer
(C) 4.40 kip-ft/ft – This is answer (A) multiplied by 1.33 impact factor. However, in the assumptions for use of this table, multiple presence and the dynamic load allowance is already included in the tabulated values.
(D) 4.94 kip-ft/ft – This is answer (B) multiplied by 1.33 impact factor, thus it is incorrect.

Problem #4 Correct Answer – (B)

Isn't this a lateral load problem? Yes, however the Vertical Forces exam does cover "Incidental Lateral Loads", which stream pressure and vessel impact would fall under. However, do not be surprised if a similar problem to this one is on the Lateral Forces test as well.

Pertinent Sections and Tables –

Section 3.7.3 – Stream Pressure with Table 3.7.3.1-1 – Drag Coefficient
Section 3.14.8 – Ship Collision Force on Pier
Table 3.4.1-1 - Load Combinations and Load Factors

TIP: Don't confuse ship and barge impact forces. Ship collision is per AASHTO 3.14.8 through 3.14.10. Barge collision is per AASHTO 3.14.11 & 3.14.12.

Solution –

Step 1 – Determination of stream pressure force:

Determine the pressure of flowing water using AASHTO equation 3.7.3.1-1.

$P_{stream} = C_d V^2/1000$

C_d = 1.4 (square-ended pier per Table 3.7.3.1-1

V = 22 ft/s (given)

P_{stream} = .678 ksf acting on an area 6'-0" wide (end of pier) x 20'-0" tall (depth of MHW)

V_{stream} = .678 ksf * (6'x20') = 81 kips

Step 2 – Determination of ship collision force:

Determine the ship collision force on the pier using AASHTO equation 3.14.8-1

$Pship = 8.15V\sqrt{DWT}$

V = 11 ft/s (given as ½ stream velocity)

DWT = 5000 tonnes (given in ship information)

P_{ship} = 8.15 * (11) * $\sqrt{5000}$ = 6340 kips

Step 3 – Determine the Extreme Event Force V_{pier}:

Vessel Collision Forces are determined using Extreme Event II Load Combination (Table 3.4.1-1)

V_{pier} = 1.0*(WA) + 1.0*(CV) = 1.0*(81 kips) + 1.0*(6340 kips) = **Answer: 6421 kips**

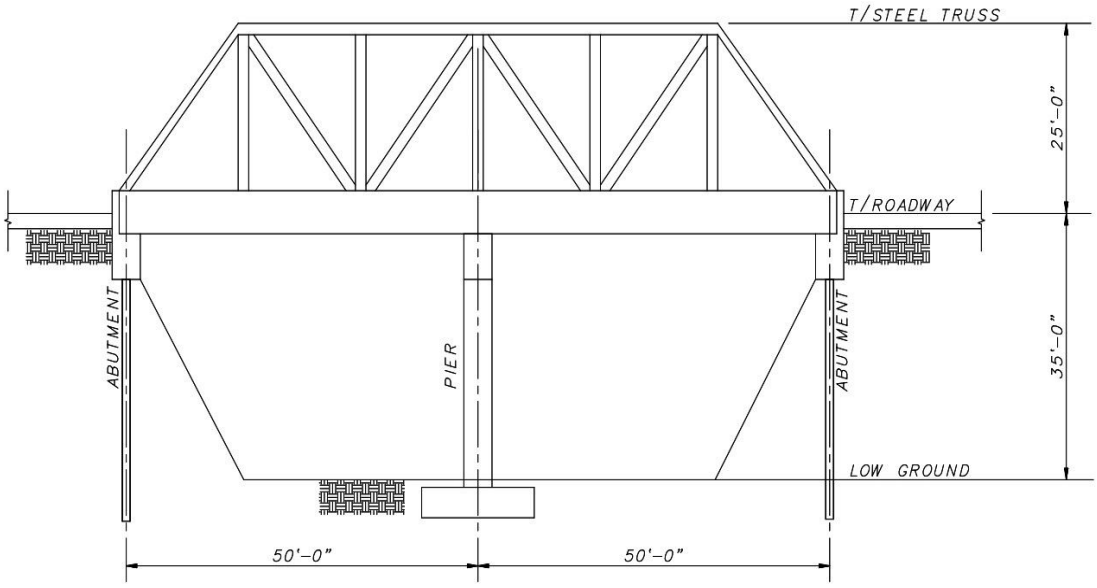
Incorrect Answers –

(A) 6340 kips – This answer does not consider the stream pressure force.
(B) 6421kips – This is the correct answer.
(C) 10,081 kips – This answer is the DWT plus stream pressure force.
(D) 12,760 kips – This answer uses the stream velocity of 22 ft/s to determine the ship collision force.

Bridge Problems for the Structural Engineering (SE) Exam: Lateral Loads 40 Problems

Problem #1

Refer to the bridge elevation, design data, and assumptions below:



Design Data and Assumptions:

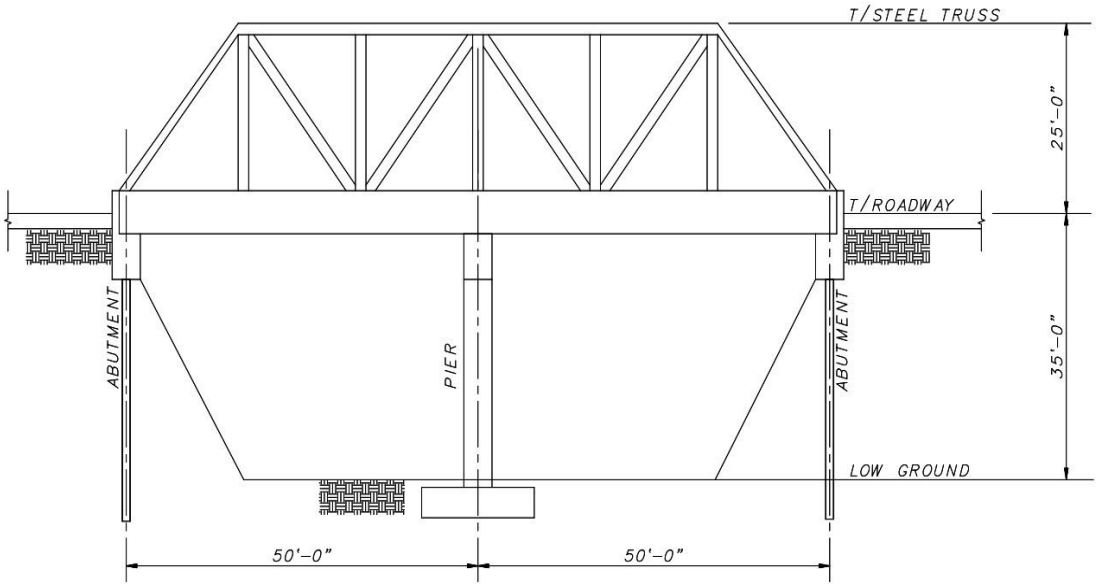
- The pier and abutments are not skewed
- The truss profile has the same projection in windward and leeward wind directions
- The truss members consist of sharp-edged steel members
- Design 3-second gust wind speed, V = 115 mph from Figure 3.8.1.1.2-1
- Wind Exposure Category - C
- Skew Angle of Wind = 0^O to 60^O
- Applicable load combination – Strength III

The maximum total design wind pressure (P_Z) that should be applied to the truss members for design of the pier, in the bridge transverse direction, is most nearly:

(E) .077 ksf
(F) .086 ksf
(G) .099 ksf
(H) .116 ksf

Problem #2

The same bridge from problem #1 is shown below with the same design data and assumptions:



Design Data and Assumptions:

- The pier and abutments are not skewed
- The truss profile has the same projection in windward and leeward wind directions
- The truss members consist of sharp-edged steel members
- Design 3-second gust wind speed, V = 115 mph from Figure 3.8.1.1.2-1
- Wind Exposure Category - C
- Skew Angle of Wind = 0^O to 60^O
- Applicable load combination – Strength III

The maximum total design wind pressure (P_Z) that should be applied to the truss members for design of the pier, in the bridge longitudinal direction, is most nearly:

(A) .029 ksf
(B) .044 ksf
(C) .066 ksf
(D) .077 ksf

Problem #3 Correct Answer – (B)

This problem tests on determining the wind loads to be applied on a sign attached to a bridge superstructure in the lateral/transverse direction. AASHTO no longer refers to "large flat surfaces" in the code, so this problem considers the sign a "sound barrier." See the TIP for additional information.

Pertinent Sections and Tables –

Section 3.8.1.2 – Wind Load on Structures: WS
Table C3.8.1.2.1-1 – Pressure Exposure and Elevation Coefficients, K_z
Table 3.8.1.2.1-1 – Gust Effect Factor, G
Table 3.8.1.2.1-2 – Drag Coefficient, C_D
Table 3.8.1.2.3a-1 – Skew Coefficients for Various Skew Angles of Attack

TIP: The wind pressure applied to sound barriers (or signs in this problem) mounted to the superstructure are determined similarly to structural components of the superstructure, however the gust effect factor (G) and drag coefficient (C_D) differ. See Tables 3.8.1.2.1-1 and 3.8.1.2.1-2 for these coefficients for sound barriers.

Solution –

Step 1 – Determine wind pressure coefficients:

The wind pressure P_Z is determined by AASHTO Eq. 3.8.1.2.1-1:

$$P_Z = 2.56x10^{-6}V^2K_zGC_D$$

From the problem statement and provisions of the AASHTO code the following values are determined:
V = 115 mph (Please take note of Table 3.8.1.1.2-1 where V may differ for other load combinations)
K_Z – To determine K_Z we need to know the Wind Exposure Category and the structure height (Z).
Per the problem statement the Wind Exposure is C, and per the AASHTO Section 3.8.1.2.1 the structure height (Z) for structure mounted sound barriers is "the height of the top of the sound barrier above low ground..." Per the illustration, the top of the sign is 60 ft. above low ground. Do not use the elevation of the sign centerline. We can use equations 3.8.1.2.1-2, 3.8.1.2.1-3, or 3.8.1.2.1-4 depending on the Wind Exposure Category, or we can use Table C3.8.1.2.1-1. Using the equations will give you the same values shown in the table. Of note, these values of K_Z closely align with the values of K_Z in ASCE 7.
Thus K_Z = 1.14
G = 0.85 (For load combination Strength III use table 3.8.1.2.1-1, the sign is considered a sound barrier)
C_D – To determine C_D we use Table 3.8.1.2.1-2. Per the problem statement the sign may be considered a sound barrier, and therefore the value of C_D = 1.2 for windward pressures and is N/A for leeward pressures.
Thus, C_D = 1.2.

Step 2 – Determine design pressure P_Z:

P_Z is determined by AASHTO Eq. 3.8.1.2.1-1 above:
P_Z = (2.56E-6)*(115^2)*(1.14)*(0.85)*(1.2) = .039 ksf
For wind pressures in the lateral/transverse direction of the bridge, the maximum wind pressure occurs at the skew angle of wind = 0^o. This is reflected in AASHTO Table 3.8.1.2.3a-1 – Skew Coefficients for Various Skew Angles of Attack. For Trusses, Columns, and Arches the maximum longitudinal skew coefficient = 1.0, at a skew angle = 0^o.
Thus Pz = (1.0)*(.039 ksf) = -→ **Answer: 0.039 ksf**

Incorrect Answers –

(A) 0.029 ksf – This answer would be determined if the value of K_Z for Wind Exposure Category B was used.
(B) 0.039 ksf – This is the correct answer.
(C) 0.045 ksf – This answer would be determined if the value of G=1.0 was used. G=1.0 for all other structures, except sound barriers. It would also be determined if Exposure Category D was used.
(D) 0.052 ksf – This answer would be determined if the drag coefficient C_D = 1.6 for bridge substructure was used.

Problem #4 Correct Answer – (C)

This problem tests on determining the design moment at the bottom of a pier due to substructure lateral loads. The pier is subjected to variable height stream and wind pressure loads. The key to correctly solving this problem is realizing that where there is stream pressure, the wind pressure will not be there because it is "blocked" by the water.

TIP: The wind loads to be applied to the substructure of bridges is determined similarly to that of the superstructure. The only difference is the drag coefficient C_D = 1.6 for the substructure vs. 1.3 for typical girder superstructure elements. See AASHTO Table 3.8.1.2.1-2.

Pertinent Sections and Tables –

Table 3.4.1-1 – Load Combinations and Load Factors
Section 3.7.3 – Stream Pressure
Section 3.7.3.1 – Longitudinal (Note: This refers to the longitudinal direction of the pier, which is typically the lateral/transverse direction of the bridge.)
Table 3.7.3.1-1 – Drag Coefficient
Section 3.8.1.2.3b – Wind Loads Applied Directly to Substructure

Solution –

Step 1 – Determination of stream and pressures:

Determine the pressure of flowing water using AASHTO equation 3.7.3.1-1.

$$p_{stream} = \frac{C_D V^2}{1000}$$

C_d = 1.4 (square-ended pier per Table 3.7.3.1-1)

V = 12 ft/s (given)

Therefore p_{stream} = .20 ksf. For a 5' wide pier the distributed load is 1 k/ft.

For substructure wind loads, we will use Eq. AASHTO Eq. 3.8.1.2.1-1, similar to the procedure in problems #1 & #2. V = 115 mph per the problem statement, and the Exposure Category is C. The substructure height is 25'-0" above low ground, thus K_Z = 1.0. G=1.0, and C_D = 1.6 per Table 3.8.1.2.1-2. Using these values we find the design wind pressure (P_Z) is equal to 0.054 ksf. The skew angle coefficient is 1.0.
For a 5' wide pier the distributed load is 0.27 k/ft.

Step 2 – Determination of pier moments at LOW water and HI water cases:

LOW water moments:
$Mwind_{LOW}$ = (0.27 k/ft)*(20')*(8'+10') = 97.2 k-ft
$Mwater_{LOW}$ = (1 k/ft)*(5')*(3'+2.5') = 27.5 k-ft
HI water moments:
$Mwind_{HI}$ = (0.27 k/ft)*(15')*(13'+7.5') = 83.0 k-ft
$Mwater_{HI}$ = (1 k/ft)*(10')*(3'+5') = 80 k-ft

Step 3 – Determine the governing design moment for the pier:

The governing load combination is the Strength III Load Combination – 1.0WA + 1.0WS
$Mdesign_{LOW}$ = 1.0*(27.5)+1.0*(97.2) = 124.7 k-ft
$Mdesign_{HI}$ = 1.0*(80 k-ft)+1.0*(83 k-ft) = **Answer: 163 k-ft GOV**

Incorrect Answers –

(A) 106 k-ft – This answer would be determined if the wind only was applied to the full height of the pier, and was chosen as the governing design moment when compared to the 80 k-ft high water pressure design moment.
(B) 125 k-ft – This is the answer determined for the low water case.
(C) 163 k-ft – This is the correct answer.
(D) 186 k-ft – This answer would be determined if the wind load was applied to the full height of the pier along with the HI water moment. The stream does not "block" the wind.

Good Luck on the Exam!

Bridge Problems for the Structural Engineering (SE) Exam

David Connor, SE, PE
www.davidconnorse.com
davidconnorse@gmail.com