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

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Reference Bridge Code – AASHTO LRFD 8th Edition, 2017

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BRIDGE PROBLEMS FOR THE STRUCTURAL ENGINEERING (SE) EXAM: LATERAL LOADS

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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. ☺

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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!

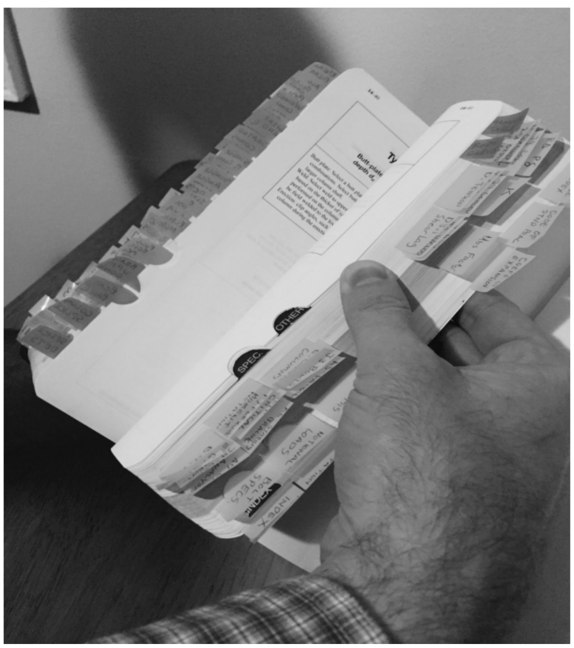
- The SE Exam is a 16-hour test split into vertical and lateral loads over two days. The vertical loads test is on Friday and the lateral loads test is on Saturday. But luckily for us, NCEES does not require that these components be taken on the same weekend. (See their website for more information.) 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.

- *Bridge Problems for the Structural Engineering (SE) Exam: Vertical Loads*
  by David Connor, SE
  This book was written by me and is the companion book to this one. It contains 40 multiple choice bridge problems dealing with vertical loads.

- *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 procedure for calculating reinforcement tension development length has been refined and clarified. See Section 5.10.8.2.4.
- Similar to concrete resistance factors, steel resistance factors (ϕ) have also been revised in some instances. See Section 6.5.4.2.

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:

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 plan area of bearing pad (in^2)
- A_c core cross sectional area (in^2)
- A_g gross cross sectional area (in^2)
- A_n net cross sectional area (in^2)
- A_{sp} cross sectional area of spiral reinforcement (in^2)
- A_S peak seismic ground acceleration coefficient modified by short-period site factor (%g)
- A_v area of shear reinforcement (in^2)
- B width of pier (in.); backfill slope angle (degrees)
- b_v concrete member width resisting shear (in.)
- C_D wind or stream drag coefficient (s^2 lbs./ft^4)
- C_L lateral drag coefficient
- C_{sm} elastic seismic response coefficient
- DC dead load of superstructure and structural components (kips)
- D_c core diameter (in.)
- D_g gross diameter (in.)
- d diameter; depth (in.)
- d_b bar diameter (in.)
- d_v effective shear depth (in.)
- E modulus of elasticity (ksi)
- E_c modulus of elasticity of concrete (ksi)
- e_X eccentricity about x-x axis (ft.)
- e_Y eccentricity about y-y axis (ft.)
- F force (kips)
- F_a site factor for short-period range of acceleration response spectrum
- $F_{elastic}$ elastic transverse base shear (kips)
- F_{hinge} inelastic hinging force (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_v site factor for long-period range of acceleration response spectrum
- F_y steel yield strength (ksi)
- f'_c 28-day compressive strength of concrete (psi/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_{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_{rt} total elastomer thickness (in)
- i backfill slope angle (degrees)
- I_e effective moment of inertia (in^4)
- I_g gross moment of inertia (in^4)
- K stiffness (k/in)
- K_1 correction factor for source aggregate
- 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_z pressure exposure and elevation coefficient
- k_a active lateral earth pressure coefficient
- 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)
- LL+IM live load + impact load (kips)
- L_{AERO} length at which wind-induced motion is to be investigated (ft)
- L_{angle} length of angle (ft)
- l_{hb} hooked bar development length (in.)
- M_{DC} unfactored moment due to dead load (k-ft)
- M_{Design} factored design moment (k-ft)
- MHW mean high water (elevation)
- MM Multimode Elastic Method (seismic analysis)

Nomenclature

M_{LAT} moment about lateral bridge axis (k-ft)
M_{LONG} moment about longitudinal bridge axis (k-ft)
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)
$M_{pierLAT}$ pier design moment in lateral direction (k-ft)
$M_{pierLONG}$ pier design moment in longitudinal direction (k-ft)
M_p plastic moment capacity (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)
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_{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)
MSE mechanically stabilized earth
N support length (in)
$\overline{N}$ average SPT blow count (blows/ft)
$(N_1)_{60}$ SPT blow count (blows/ft)
P_A lateral earth pressure (k/ft)
P_{AE} retaining wall dynamic lateral earth force (k/ft)
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_{seis} retaining wall seismic lateral force (kips)
P_r tensile resistance (kips); axial resistance (kips)
P_u ultimate compressive or gravity load (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_Z design wind pressure (ksf)
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_{ciN} CPT tip resistance (ksf)
R seismic response modification factor
R_d factor for calculation of seismic displacements due to inelastic action

Nomenclature

R_p	hole reduction factor; equal to 1.0 for welded connections
R_{pier}	pier reaction (kips)
S	pier skew relative to lateral bridge axis (degrees)
SM	Single-Mode Elastic Method (seismic analysis)
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_X	bearing modulus about x-x axis (ft^3)
S_Y	bearing modulus about y-y axis (ft^3)
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	period of vibration (s)
TH	Time History Method (seismic analysis)
T_m	period of vibration (s)
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)
U	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_{CROSS}	design lateral shear capacity of cross-frame diaphragm (kips)
V_{DC}	unfactored shear due to dead loads (kips)
V_{LL}	unfactored shear due to live load (kips)
V_n	nominal shear resistance (kips)
V_p	component in the direction of the applied shear of the effective prestressing forces. Zero for reinforced concrete.
V_r	nominal shear resistance of wall type pier (kips)
V_s	nominal shear resistance of steel (kips)
V_{s1}	shear wave velocity (fps)
V_{SEIS}	seismic shear force (kips)
V_{STREAM}	stream velocity (ft/s)
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 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)
$\bar{x}$	connection eccentricity (in.)
Z	height above low ground or water level (ft)

Nomenclature

α	angle of inclination of transverse reinforcement (degrees); 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_{p}	load factor for permanent loading
γ_{soil}	back fill soil density (psf)
Δ	displacement (in.)
Δ_{e}	elastic seismic displacement (in.); elastomer shear deformation (in.)
ϕ	strength resistance factor; soil friction angle
ϕ_{min}	minimum soil friction angle
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)

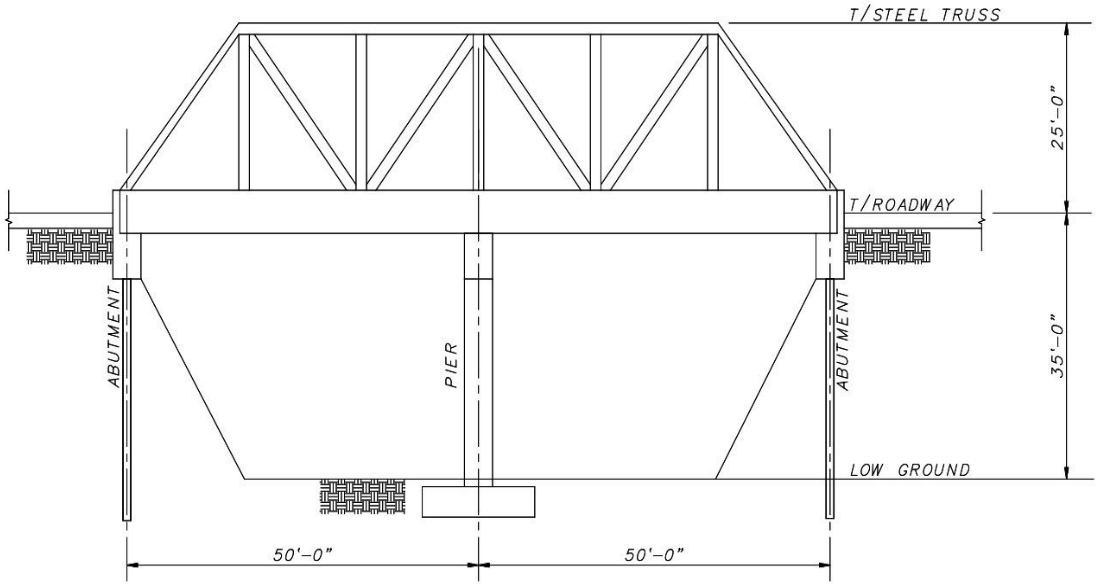
Bridge Problems for the Structural Engineering (SE) Exam: Lateral Loads 40 Problems

Answer Sheet

1 Ⓐ Ⓑ Ⓒ Ⓓ	11 Ⓐ Ⓑ Ⓒ Ⓓ	21 Ⓐ Ⓑ Ⓒ Ⓓ	31 Ⓐ Ⓑ Ⓒ Ⓓ
2 Ⓐ Ⓑ Ⓒ Ⓓ	12 Ⓐ Ⓑ Ⓒ Ⓓ	22 Ⓐ Ⓑ Ⓒ Ⓓ	32 Ⓐ Ⓑ Ⓒ Ⓓ
3 Ⓐ Ⓑ Ⓒ Ⓓ	13 Ⓐ Ⓑ Ⓒ Ⓓ	23 Ⓐ Ⓑ Ⓒ Ⓓ	33 Ⓐ Ⓑ Ⓒ Ⓓ
4 Ⓐ Ⓑ Ⓒ Ⓓ	14 Ⓐ Ⓑ Ⓒ Ⓓ	24 Ⓐ Ⓑ Ⓒ Ⓓ	34 Ⓐ Ⓑ Ⓒ Ⓓ
5 Ⓐ Ⓑ Ⓒ Ⓓ	15 Ⓐ Ⓑ Ⓒ Ⓓ	25 Ⓐ Ⓑ Ⓒ Ⓓ	35 Ⓐ Ⓑ Ⓒ Ⓓ
6 Ⓐ Ⓑ Ⓒ Ⓓ	16 Ⓐ Ⓑ Ⓒ Ⓓ	26 Ⓐ Ⓑ Ⓒ Ⓓ	36 Ⓐ Ⓑ Ⓒ Ⓓ
7 Ⓐ Ⓑ Ⓒ Ⓓ	17 Ⓐ Ⓑ Ⓒ Ⓓ	27 Ⓐ Ⓑ Ⓒ Ⓓ	37 Ⓐ Ⓑ Ⓒ Ⓓ
8 Ⓐ Ⓑ Ⓒ Ⓓ	18 Ⓐ Ⓑ Ⓒ Ⓓ	28 Ⓐ Ⓑ Ⓒ Ⓓ	38 Ⓐ Ⓑ Ⓒ Ⓓ
9 Ⓐ Ⓑ Ⓒ Ⓓ	19 Ⓐ Ⓑ Ⓒ Ⓓ	29 Ⓐ Ⓑ Ⓒ Ⓓ	39 Ⓐ Ⓑ Ⓒ Ⓓ
10 Ⓐ Ⓑ Ⓒ Ⓓ	20 Ⓐ Ⓑ Ⓒ Ⓓ	30 Ⓐ Ⓑ Ⓒ Ⓓ	40 Ⓐ Ⓑ Ⓒ Ⓓ

Problem #1

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



Design Data and Assumptions:

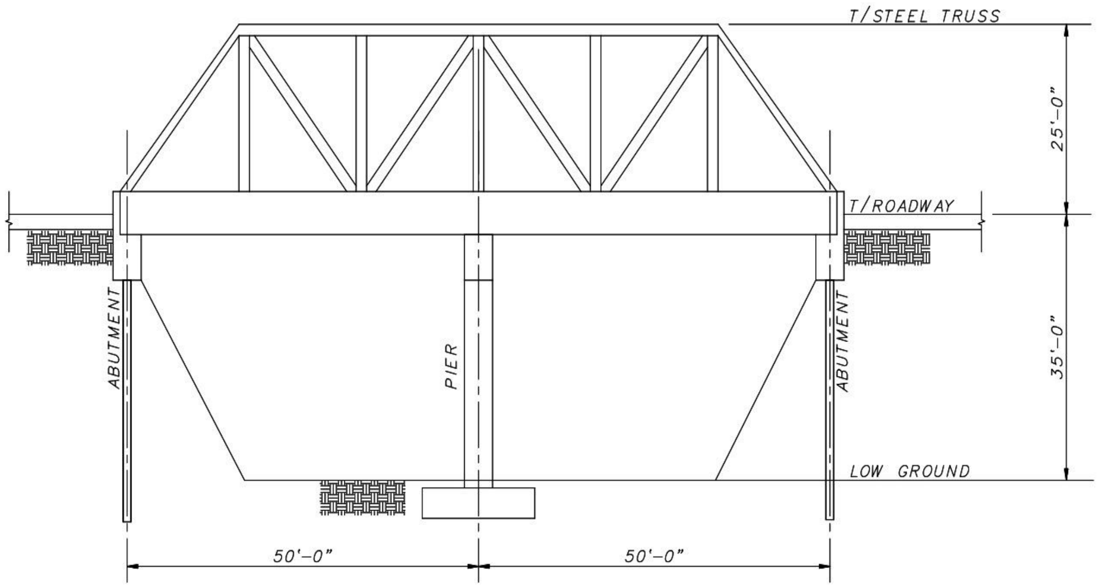
- The pier and abutments are not skewed
- The truss profile has the same projection in windward and leeward wind directions
- The truss members consist of sharp-edged steel members
- Design 3-second gust wind speed, V = 115 mph from Figure 3.8.1.1.2-1
- Wind Exposure Category - C
- Skew Angle of Wind = 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:

(A) .077 ksf
(B) .086 ksf
(C) .099 ksf
(D) .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.

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.

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

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°. 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°.
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.