Bridge Problems for the Structural Engineering (SE) Exam: Vertical 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: VERTICAL 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!

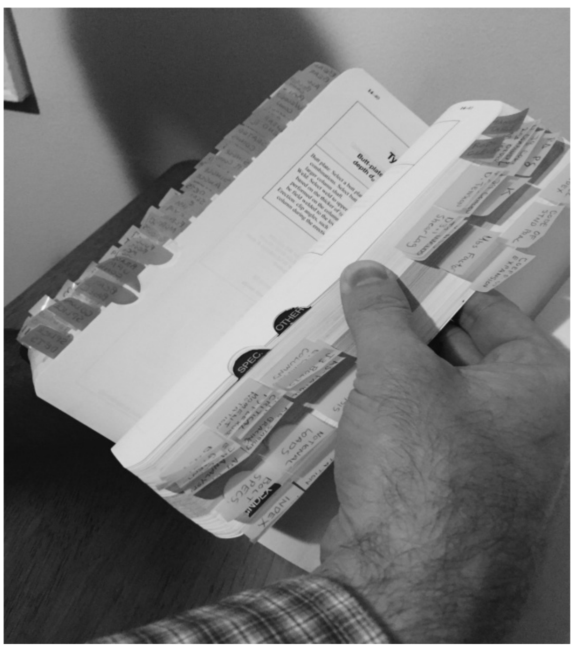
- The SE Exam is a 16-hour test split into vertical and lateral loads over two days. The vertical loads test is on Friday and the lateral loads test is on Saturday. But luckily for us, NCEES does not require that these components be taken on the same weekend. (See their website for more information.)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

- 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:

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

This is nearly half of the problems contained in this book.

Nomenclature

A fatigue detail category constant
A_b cross sectional area of bolt (in^2)
A_{cv} area of concrete section resisting shear transfer (in^2)
A_e effective area (in^2)
A_g gross cross sectional area (in^2)
A_{girder} cross sectional area of girder (in^2)
A_n net area (in^2)
A_{ps} cross sectional area of prestressing strands (in^2)
A_s cross sectional area of steel member (in^2)
A_{sc} headed stud cross-sectional area (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)
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 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 cohesion factor (ksi)
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_M wet-service factor
C_v volume factor
CV vessel collision force (kips)
CVN Charpy V-Notch
C_λ time effect factor
D plate girder web depth (in.)
DC dead load of superstructure and structural components (kips)
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.)
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)
F strut or tie force
F* pullout friction factor
F_b adjusted design flexural strength of wood (ksi)
F_{bo} design flexural strength of wood (ksi)
FCM fracture-critical member
F_p total radial force in concrete deck (kips)
F_u steel tensile strength (ksi)
F_{ub} tensile strength of bolt (ksi)
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)

Nomenclature

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)
H humidity (%); wall height (ft)
HL-93 AASHTO truck loading (kips/kips per ft)
h_{eq} equivalent height of soil (ft.)
h_{wall} height of wall (ft.)
I_{cr} cracked moment of inertia (in^4)
I_e effective moment of inertia (in^4)
I_g gross moment of inertia (in^4)
l_{hb} hooked bar development length (in.)
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
K_g longitudinal stiffness parameter
K_h hole size factor
K_s surface condition factor
K_1 fraction of concrete strength available to resist interface shear
K_2 limiting interface shear resistance (ksi)
L span length, deck span length (ft); bearing pad use has limited applications
L_b anchor bonded length (ft)
L_e length of MSE wall reinforcement (ft)
LL_{DIST} live load distribution factor
L_p arc length between an end of the girder and an adjacent point of maximum positive live load plus impact moment (ft.)
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_{LL} unfactored moment due to live load (kip-ft)
M_{LL+IM} unfactored moment due to live load + impact (kip-ft)
M_n nominal moment capacity (k-ft)
M_{nx} nominal X-X (strong) axis flexural resistance (k-in)
M_p plastic moment capacity (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_{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)
$M_{75\%}$ 75% of the member flexural resistance (k-ft)
MSE mechanically stabilized earth
m multiple presence factor; bearing area modification factor; confinement modification factor
N number of stress range cycles
N_s number of shear planes
P total nominal force in concrete deck (kips)
P_a lateral earth pressure (psf)
P_c permanent net compressive force (kips); composite force in bottom flange steel (kips)
P_{design} design force or pressure
P_e elastic critical buckling resistance (kips)
P_{fy} flange design yield resistance (kips)
P_{DH} deck house impact force (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)

Nomenclature

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_r bearing resistance (kips); axial 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)
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_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
R_{AL} axle load correction factor
R_{base} base reaction (kips)
R_C concrete strength correction factor
R_c reinforcement coverage ratio
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_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
S_b bottom fiber section modulus (in^3)
S_t top fiber section modulus (in^3)
S_x elastic section modulus (in^3)
S_v vertical spacing of MSE wall reinforcement (in)
SW classification designation for well graded sand
s spacing of shear reinforcement (in)
T unfactored tension force (kips/kips per ft)
T_{MAX} maximum tension in MSE wall reinforcement (plf); maximum design temperature (^oF)
T_{MIN} minimum design temperature (^oF)
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
V stream velocity (ft/s)
V_c nominal shear resistance of concrete (kips)
V_{cr} shear buckling resistance (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); plastic shear force in steel (kips)

Nomenclature

V_{pier} pier extreme event force (kips)
V_{ri} factored interface shear resistance (kips/ft)
V_s nominal shear resistance of steel (kips)
V_{stream} unfactored stream pressure force (kips)
V_{super} superstructure extreme event force (kips)
WA water load or stream pressure (kips)
w/c water/cementitious ratio
y_{bot} distance to girder centroid from bottom (in)
$\bar{Y}$ distance from top of concrete deck to plastic neutral axis (in.)
Z_x plastic section modulus (in^3)

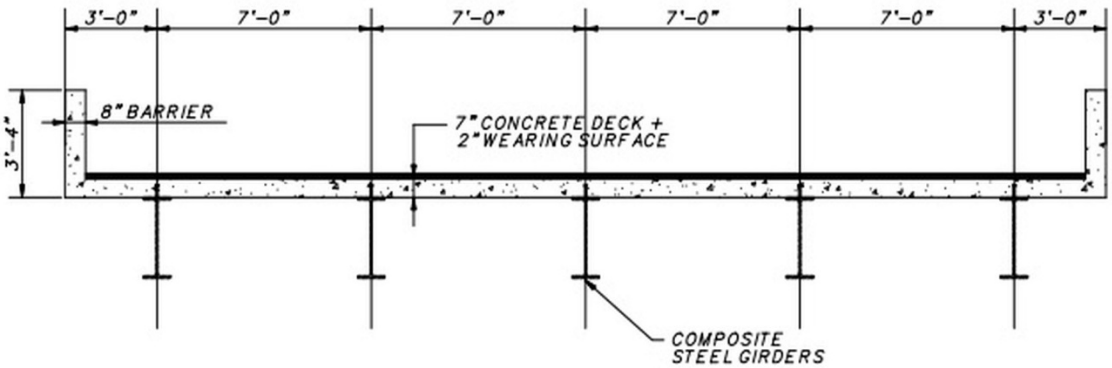
α angle of inclination of transverse reinforcement (degress); MSE wall scale effect correction factor; coefficient of thermal expansion (in/in/^{o}F)
Δ deflection (in.)
$(\Delta F)_n$ nominal fatigue resistance (ksi)
$(\Delta F)_{TH}$ constant amplitude fatigue threshold stress (ksi)
Δf live load stress 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.)
Δlt_g long term deflection based on gross moment of inertia (in.)
Δ_T thermal expansion (in)
ϕ strength resistance factor
ϕ_c axial compression strength resistance factor
ϕ_f flexural strength resistance factor
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_v shear 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
γ load combination factor
γ_h correction factor for relative humidity
γ_s back fill soil density (psf)
γ_{st} correction factor for specified concrete strength at time of prestress transfer to the concrete member
μ coefficient of friction
ν concrete efficiency factor
η_ι ductility, redundancy, and operational classification factor
θ angle of inclination of diagonal compressive stresses (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:

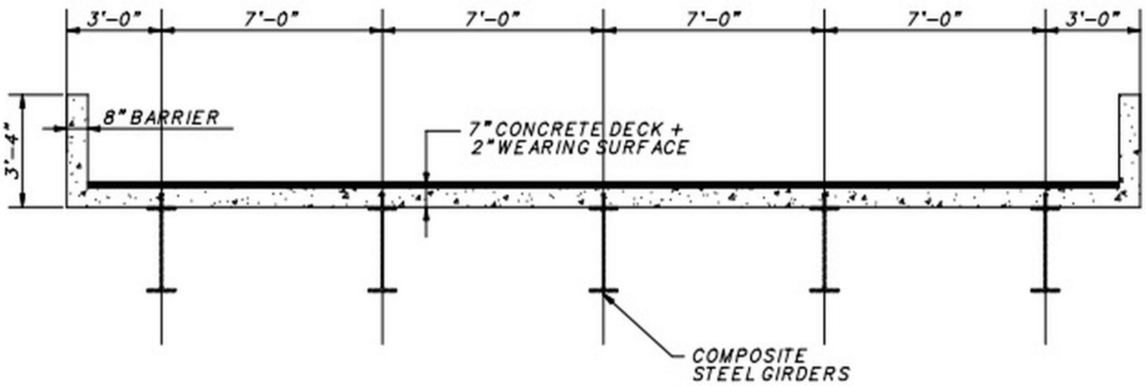
- Beam span = 50'-0"simple span
- Total Dead Load of Superstructure (DC) – 3.0 kips/ft
- Total Dead Load of Wearing Surface (DW) – 0.5 kips/ft
- HL-93 Design Truck Static Moment – 628 kip-ft
- HL-93 Design Lane Load – Per AASHTO
- Ductililty, Redundancy, and Operational Classification factor η_i = 1.0
- 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:

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.

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.

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.

VERTICAL SOLUTIONS

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.