CE311 Final Exam Study Guide
Exam Date: Wednesday, December 14th, 2016
Exam Time: 8am to 11am
Acopian 315

You are allowed to use the AISC steel manual, a calculator, and writing equipment, only.
The exam is designed for 3 hours. A maximum of 4 hours will be permitted.

Final Exam Coverage:
Every Lesson in the course is examinable, as are problems that relate to your laboratory analyses.
Subtracting exam days, etc., there are 34 lessons in the course. Consequently, each lesson may expect to represent approximately 3% of the final exam. However, Lessons 37 through 39 have not been covered on earlier exams. Yet, they will receive equal weight for the course grade. This means that Lessons 37 through 39 will have greater representation on the final exam, relative to earlier lessons; approximately 15% of the final exam will come from lessons 37 through 39, with the remaining percentage coming from the earlier lessons.

This Study Guide Consists of two major components:
- New Material: Lessons 37 through 39 Questions
- Samples from previous exams, covering earlier material in the course.

Given:
Ductility in the ACI (American Concrete Institute) Code:

\[ \rho = \frac{A_s}{bd} < 0.75 \beta_1 \left( \frac{0.85 f'_c}{f_y} \right) \left( \frac{87000}{b' + f_y} \right) \] (psi units must be used)

\( \beta_1 \) Factor:
The \( \beta_1 \) factor empirically relates \( a \) to \( c \). \( c \) is the “depth to neutral axis”. \( a \) is the “effective depth to plastic neutral axis”

\[ c = \frac{a}{\beta_1} \]

\( \beta_1 \) depends on the strength of the concrete, as follows (based on testing.):
If \( f'_c < 4 \) ksi, \( \beta_1 = 0.85 \)
If \( f'_c > 8 \) ksi, \( \beta_1 = 0.65 \)
If \( f'_c \) is between 4 and 8 ksi, then \( \beta_1 = 0.65 + 0.05(8 - f'_c) \) (units are ksi)

\[ a = \frac{A_s f_y}{0.85 f'_c b} \]

Reference – Standard U.S. Bar Sizes (note: a “number 3 bar” has a 3/8” diameter, a “number 4 bar” has a 4/8” diameter, etc).

<table>
<thead>
<tr>
<th>Bar size designation</th>
<th>Nominal cross section area, sq. in.</th>
<th>Weight, lb per ft</th>
<th>Nominal diameter, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3</td>
<td>0.11</td>
<td>0.376</td>
<td>0.375</td>
</tr>
<tr>
<td>#4</td>
<td>0.20</td>
<td>0.666</td>
<td>0.500</td>
</tr>
<tr>
<td>#5</td>
<td>0.31</td>
<td>1.043</td>
<td>0.625</td>
</tr>
<tr>
<td>#6</td>
<td>0.44</td>
<td>1.502</td>
<td>0.750</td>
</tr>
<tr>
<td>#7</td>
<td>0.60</td>
<td>2.044</td>
<td>0.875</td>
</tr>
<tr>
<td>#8</td>
<td>0.79</td>
<td>2.670</td>
<td>1.000</td>
</tr>
<tr>
<td>#9</td>
<td>1.00</td>
<td>3.400</td>
<td>1.128</td>
</tr>
<tr>
<td>#10</td>
<td>1.27</td>
<td>4.303</td>
<td>1.270</td>
</tr>
<tr>
<td>#11</td>
<td>1.56</td>
<td>5.313</td>
<td>1.410</td>
</tr>
<tr>
<td>#14</td>
<td>2.25</td>
<td>7.650</td>
<td>1.693</td>
</tr>
<tr>
<td>#18</td>
<td>4.00</td>
<td>13.600</td>
<td>2.257</td>
</tr>
</tbody>
</table>
New Material: Lessons 37 to 39

1. (8 points) Determine the design strength for bending moment, $\phi M_u$, for positive bending of the reinforced concrete beam, shown, using ACI methods. Given: $f'_c = 3000$psi, $f_y = 60000$psi. Assume that the beam is underreinforced.

![Beam Diagram]

2. (12 points) Use an exact indeterminate analysis to plot the moment diagram for Frame A (standard sign convention: plot on the compression side).

   Given: An analysis of Frame B determined that joint C would move 15.1" to the right. An analysis of Frame C determined that joint E would move 1.57" to the left. All frames have the same EI.

![Frame Diagrams]

3. (10 points) Determine the vertical deflection at point B due to the 10 kip point load at point D.

   Given: A is a pinned support. C is a roller support. $EI = 30,000,000$ kip-in²

![Deflection Diagram]

4. (15 points) Determine the vertical deflection at point D due to the uniformly distributed load of 1 kip per foot. Given: A is a pinned support. C is a roller support. $EI = 30,000,000$ kip-in²

![Uniform Load Diagram]

5. (15 points) Classic Steel Bridge Competition Problem: An 1/8" x 1" steel plate is connected with an 1/8" connection eccentricity on each end, as shown. First, calculate the extension of this 40" long member due to axial extension, then, use the Principal of Virtual Work to determine the extension that takes place due to the bending caused by eccentricity. Then, determine the total extension.

   Hint: $PL/AE$; determine the moment diagrams for the 40" long plate and apply virtual work.
6. (18 points) Compute the vertical deflection at point C due to the point loads. The beam is fixed at A, has a pin-connection at C and is supported by a roller at E. Beams ABC and CE are both W16x26 steel beams, bent about their strong axes.

![Diagram of the beam with loads and deflections]

**FINAL ANSWER**
Vertical $\Delta_c = \text{_________ inches}$

7. (10 points) Determine the horizontal displacement of point B. All connections are pins. All bars are aluminum ($E=10000\text{ksi}$) with areas $A = 1\text{ in}^2$.

Answer: ________inches

8. (15 points) Compute the vertical deflection at point A due to the 10 kip load at point D. $E = 29000\text{ ksi}$, $I = 10\text{ in}^4$.

![Diagram of the beam with load and deflection]

**Solution:**

Equivalent to:

500 lbs
500 lbs
1/8" 1/8"

40"

10' 10' 5' 5'

A

B

C

D

E

500 lbs
500 lbs
500 lbs

100"

100"

A

B

C

D

10 kips

6' 12' 8'
REAL MOMENT DIAGRAM (PAGE 2):

1. \( \Delta x_1 \)
2. \( x_2 \)
3. \( x_3 \rightarrow -1 \)

A-B: \( M(x_1) = 0 \)
B-C: \( M(x_2) = -6.667x \)
D-C: \( M(x_3) = -10x \)

VIRTUAL FORCE @ A:

\[
\begin{align*}
A & \rightarrow B \quad 144'' \\
B & \rightarrow C \quad 96'' \\
C & \rightarrow D \quad 72''
\end{align*}
\]

\[
\begin{align*}
\Sigma M_A &= (72) + 144y_C \quad \Rightarrow \quad y_C = -0.5x \\
\Sigma F_y &= 0 \quad \Rightarrow \quad y_C = 1.5 \quad (y_C = 0.5x)
\end{align*}
\]

MOMENT FUNCTION:

\[ m_{AB}(x) = \text{irrelevant} \quad \text{b/c} \quad M_{AB}(x) = 0 \]

\[ m_{AC} : \text{draw shear & moment diagrams} \]

\[
\begin{align*}
V &= 0.5x \\
M &= -72x + 0.5x
\end{align*}
\]

\[ m_{CD} = 0 \]

\[
\Delta_A = \frac{1}{EI} \int_0^{144} (-6667x)(-72 + 0.5x) \, dx = \frac{1}{EI} \int_0^{144} 480x - 3333x^2 \, dx
\]

\[
= \frac{1}{290000} \left[ 480 \left( \frac{144}{2} \right)^2 - 3333 \left( \frac{144}{3} \right)^3 \right] = \frac{16598800}{290000} \approx 5.72''
\]

\[ \Delta_A = 572'' \text{ DOWN} \]
9. (17 points) Use the Principal of Virtual Work to compute the vertical deflection of point C on the structure shown below, considering flexural virtual work.

Given: Assume that the self-weight of the frame is negligible.
A is a fixed foundation. B is a rigid beam-column connection. E=29000 ksi, I = 100 in²
A 10 kip horizontal force is applied at point B, as shown.

10. (20 points) Determine the vertical deflection of joint B. For each member A = 1.5 in², E=29000 ksi. All members are pin-connected. (ans: 0.0132")

11. (20 points) Use the Principal of Virtual Work to compute the vertical deflection of point C on the structure shown below.
Given: A is a fixed foundation. B is a rigid beam-column connection. E = 29000 ksi; I = 1382 in⁴

12. (22 points) Use an exact method of indeterminate structural analysis to plot the moment diagram for the indeterminate beam shown. EI is constant.
13. (2 points) What condition(s) must be met for an arch to have no internal bending moment?

14. (2 points) Circle all of the funicular arches.

15. (4 points) What is the Principal of Virtual Work?

16. (2 points) TRUE or FALSE. The external virtual work is the work done by a real force, as this real force moves through a virtual displacement.

17. (3 points) What does it mean if a steel section is non-compact?

18. (3 Points) Circle the correct answer. If all connections are simple, non-moment-resisting:
   A. The frame is stable and determinate.
   B. The frame is unstable.
   C. The frame is stable and indeterminate.
   D. The frame is unstable and indeterminate.

19. (3 points). What is KL for the buckling of column AB, for the illustrated plane?
   Given: all connections are pinned. Columns are W12x58. Beams are W21x57. Axis orientations as shown.

20. (2 points) TRUE or FALSE. The M_p/Ω values that are reported in the “Z-Table” (Table 3-2, AISC) take into account the reduction in strength that may be caused by local buckling (if applicable).

21. (2 points) TRUE or FALSE. The Maximum Total Uniform Load Tables (Table 3-6, AISC) account for the reduction in strength that is attributable to lateral-torsional buckling.

22. (2 points) TRUE or FALSE. For the Building One shown on the next page, the columns at grid location 1A are considered to be unbraced.

23. (2 points) TRUE or FALSE. An A992 W16x36 shape is non-compact for strong-axis bending.

24. (7 points) For the Building One on the next page, determine the magnitude of axial force that is in the brace along column line A, between the 2nd and 3rd floor, for wind directed from West to East.

25. (13 points) For the Building One on the next page, use ASD specifications to select the lightest W10 column for grid location B2, between the ground and 2nd floor.

26. (10 points) For the Building One below, select a typical main floor (i.e., not the roof) girder along column line 2 using ASD, considering bending moment, only (assume that shear and deflection are to be checked by others).
BUILDING ONE

- Simple-braced building: all connections are simple, non-moment-resisting. The building is braced by the three braced frames shown (highlighted on color, for clarity). The braces are considered to be redundant tension-only braces. The floors consist of concrete slabs (not shown, for clarity) on metal decking, welded to the tops of the beams and girders. The floors are considered to be diaphragms.

- Loads:
  - Dead Loads = 50 psf for all floors
  - Main Floor Live Loads = 100 psf
  - Roof Snow Loads = 50 psf
  - Wind Loads = 20 psf
27. (2 points) **True or False.** Lateral-torsional buckling cannot occur in the column because it is continuously braced with respect to lateral-torsional buckling.

28. (2 points) **True or False.** $L_b = 4'$ for member AB.

29. (2 points) **True or False.** $KL_x = 4'$, $KL_y = 16'$ member AB.

30. (5 points) Determine the maximum bending moment on the column due to wind.

31. (7 points) If the column is a W18x35, determine its allowable axial compressive force $P_n/\Omega$.

32. (15 points) Determine if the W10x33 A992 shape is adequate per ASD.

**Given:** Pin-ended, 18-ft length, no other braces
- Axial Compression $P = 100\text{kips}$
- Equal end moments $M = 15\text{ ft-kips}$, with sign as indicated
- Assume second order effects can be neglected
- $C_b = 2.27$
- Ignore self-weight.
33. (2 points) TRUE or FALSE. Local buckling cannot occur if a beam is bent about its weak axis.

34. (5 points) List all of the failure mechanisms that must be checked for the following double-L4x4x1” tension member and its bolted connection (do not list limit states for the gusset plate)

35. (2 points) TRUE or FALSE. Whereas members in indeterminate structures will have built-in internal stresses if member sizes are incorrect, demanding that members be forced into position, determinate structures do not have this problem.

Consider this Moment Capacity chart for two laterally unsupported wide-flange beams for the following questions:

36. (3 points) Which beam has a larger strong axis plastic modulus Zx?
   a). Beam A
   b). Beam B

37. (3 points) Which beam probably has the larger weak axis moment of inertia Iy?
   a). Beam A
38. (3 points) Describe why cable structures are structurally efficient (e.g., can carry heavy loads using relatively little steel).

39. (2 Points) Explain the difference between the plastic moment $M_p$ and the yield moment $M_y$ of a structural steel beam.

40. (2 Points) Explain the difference between the plastic moment $M_p$ and the residual moment $M_r$ of a structural steel beam.

41. (2 points) True or False. A $\frac{3}{4}''$ A325-SC (slip critical) bolt will have a higher allowable strength than a $\frac{3}{4}''$ A325-N (threads Not excluded) bolt, though the bolts are installed in the same manner.

42. (2 points) True or False. Local buckling can be prevented through the use of bracing that prevents lateral movement or twist of the section.

43. (4 points) Describe the role of the roof diaphragm in resisting the lateral loads on a building.

44. (6 points) The single-story building shown has a rigid roof diaphragm, whose all member connections are pinned. For the 20 psf wind pressure in the y-direction shown, the magnitude of the horizontal component of force in the brace at column A4 is (circle one):
   a. 2.5 kips
   b. 0 kips
   c. 20 kips
   d. 1.67 kips
   e. 5 kips
   f. 10 kips
   g. 3.33 kips

45. (2 points) TRUE or FALSE. The allowable compressive force for column AB will become greater if beam BC is increased in size (moment of inertia). All connections are simple pins.
46. (3 points) What is the effective length factor $K$ for Column AB in the frame below?
   Given: A is a pinned foundation, B is a rigid beam-column connection, C is a pinned connection, D is a pinned
   foundation. Beam BC is an ordinary beam (neither very large nor very small).

   \[ \text{Circle the best answer:} \]
   A). $K = 1$
   B). $1 \leq K \leq 2$
   C). $K \leq 1$
   D). $K \geq 1$

47. (5 points) Draw the moment diagram for the column shown, using the standard convention of plotting the moment
   diagram on the compression side of the structure. There is an applied moment of 100 kip-ft at point C, but no other
   applied forces or moments. A and B are both pinned foundations. The column is 12-feet long, and point C is at the
   midheight.

48. (2 points) TRUE or FALSE. In both LRFD and ASD, the nominal column buckling strength $P_n = F_{cr}A$, where $F_{cr}$ is the
   buckling stress and $A$ is the cross-sectional area.

49. (2 points) TRUE or FALSE. A non-compact steel section is one that will fail in local buckling at a moment that is
   greater than the residual moment $M_r$ but less than the plastic moment $M_p$.

50. (10 points) Compute the maximum compressive stress acting anywhere on the W10x33 beam-column due to the
   eccentrically applied 100 kip load, as well as the beam’s self-weight.
   Given: The load is applied at a level that exactly corresponds with the top of the flange. The beam is pin
   and roller supported. Use the exact (decimal) dimensions of the W10x33.

   Solution:
51. (7 Points) Select the lightest simply-supported A992 W-shape for strong-axis bending if it supports two point loads of 95 kips each at its one-third points, as shown, with lateral bracing at the point loads and supports, only. Assume the beam’s self-weight is negligible and do not consider shear or deflection.

\[
M = P_c + M_{SW} = (100 \times 4.865) + \left(0.033 \frac{(12)^2}{6}\right) = 493.6''
\]

\[
\sigma = \frac{P}{A} = \frac{100}{9.71''} + \frac{493.6}{3.5''} = 10.3 + 14.1 = 24.4 ksi
\]

Answer:

\[
\sigma = 24.4 \text{ ksi}
\]

52. (7 points) An A992 W12x58 column is 24' long. It is pinned at each end for both strong and weak-axis buckling. In addition, the weak axis has a mid-height brace, as shown. Determine the allowable (ASD) axial load \( P_{all} \).
53. (7 Points) Select the lightest possible A992 W-shape as a typical interior fill beam for the floor below, considering bending moment, only (assume the beam is adequate for shear and deflection). Given:
- The simply-supported, equally-spaced fill beams continuously support a 5” thick concrete slab (concrete unit weight= 150 lb/ft³),
- Dead Load = slab weight, beam self-weight
- Live Load = 100 psf

Answer:

54. (10 points) A circular 3-pinned arch spans 100’, subjected to a point load of 10 kips, as shown. Ignoring self-weight, what is the bending moment at point A, located 10’ right of the left support and 30’ above the left support? Is compression due to bending on the outside or the inside of the arch?
55. (5 points) An A992 W12x96 column is 24' long. It is pinned at each end for both strong and weak-axis buckling. Determine the LRFD design axial strength $\phi P_n$.

Circle the closest answer

A) 635 kips  
B) 1020 kips  
C) 980 kips  
D) 184 kips

56. (5 points) What is the (ASD) allowable moment $M_{all}$ for an A992 ($F_y = 50$ ksi) W16x26 beam bent about its strong axis by equal end moments, if it is simply-supported over a span of 12’, with lateral bracing at the ends and at midspan?

57. (20 points) Compute the ASD allowable tensile load $T_{all}$ for fracture, bolt shear, and yielding, only. The member consists of two 4”x4”x ¼” angles:
- A36 steel is used ($F_y=36$, $F_u=58$)
- The three bolts are \( \frac{3}{4}" \) A325-N bolts in standard holes
- Use a shear lag factor of 0.85

58. (3 points) What is the degree of indeterminacy for the frame shown?

59. (10 Points) Use ASD to select the lightest simply-supported A992 W-shape for strong-axis bending if it supports two point loads of 50 kips each at its one-third points, as shown, with lateral bracing at the point loads and supports, only. For simplicity, assume that the beam’s self-weight is negligible and do not consider shear or deflection.

60. (10 Points) Consider the roof plan below for a single story building with a story height of 15 feet. Select the lightest 6” x 6” Square HSS column that will safely support the loads for grid location C3, using ASD.
Given:
- All connections are simple, non-moment-resisting
- Column C3 is concentrically loaded; \( KL_x = KL_y \); no bending moment is present
- Dead Load = 40 psf
- Roof Snow Load = 100 psf.
61. (2 points) TRUE or FALSE. In both LRFD and ASD, the nominal column buckling strength $P_n = F_{cr}A$, where $F_{cr}$ is the buckling stress and $A$ is the cross-sectional area.

62. (3 points) What is the degree of indeterminacy of the structure below?

63. (2 points) If the tensile yield strength of a ductile steel bar is 100 ksi, what is the approximate (2 digits precision) shear strength of the steel bar, in units of ksi?

64. (3 points) Determine if the structure below is stable. If it is stable, report its degree of indeterminacy. Note: all connections and foundations are pinned.

65. (10 points) Determine the effective length $KL$ for column AB, for buckling within the plane shown. Given: All connections are rigid, moment-resisting connections. All beams have $I=1000$ in$^4$. All columns have $I=500$ in$^4$. All bays are 30’ long. All story heights are 12’.
66. (12 points) Determine the nominal block shear strength $R_n$ of the single angle below.

**Given:** A single L4x4x3/8" A36 angle, connected to a ½"-thick gusset plate with (3) ¾” A325-N bolts in standard round holes at 3” spacing. Do not analyze the gusset plate. Consider block shear, only.

![Diagram of a single L4x4x3/8" A36 angle](image)

67. (17 points) Determine the ASD allowable load $P_a = P_n / \Omega$ if the column is an A992 W16x77.

**Given:** The column is 36 feet long, but has 5 equally-spaced intermediate braces that prevent movement along one axis, as shown, above.

![Diagram of a column with braces](image)

68. (13 points) Use ASD to determine if the 14-foot-long A992 W10x33 shape is safe.

**Given:**
- The section is subjected to a distributed load of 250 plf (already includes self-weight), causing bending moment about its weak-axis
- The section is subjected to an axial load of 160 kips.
- No strong-axis bending.
- The shape is considered compact.
- The shape is pinned at its ends. There are no other braces
- Assume that second-order effects are very small and can be ignored.

![Diagram of a W10x33 shape with load](image)
TRUE OR FALSE QUESTIONS (1 point each)
1. TRUE or FALSE. The buckling stress for a steel column is always less than its corresponding tensile yield stress.
2. TRUE or FALSE. For the rigid frame below, the K value for the columns is less than one.

A rigid frame with rigid beam-column connections, but a pinned base.

3. TRUE or FALSE. For the previous rigid frame, the column K-value would become infinite if the beam was replaced with a cable – something with $E I = 0$.
4. TRUE or FALSE. There is no internal bending moment anywhere in ABCD, below.

6. Situation: you have a summer job working with some guy who went to Lehigh. He designed the compression member, connected as shown. Explain or show why this is bad.

Because the web sideplates connect very little of the member, it is considered a pin.

MULTIPLE CHOICE (3 POINTS EACH)
7. Situation: you need to select a column that will be continuously braced about its weak axis, but will be braced every 40' for strong-axis buckling. Qualitatively, which column shape is best suited, assuming that they have equal area and equal cost per pound?

- (a) $I_x = 2000 \text{ in}^4$, $I_y = 300 \text{ in}^2$
- (b) $I_x = 1000 \text{ in}^4$, $I_y = 1000 \text{ in}^2$
- (c) $I_x = 1200 \text{ in}^4$, $I_y = 600 \text{ in}^2$
- (d) $I_x = 300 \text{ in}^4$, $I_y = 300 \text{ in}^2$
7. (3 points) Which columns have the larger K-value? A or B?

Frame A

Frame B

7. Answer (Circle A or B)

A. Frame A

B. Frame B

10. Two square tube members are connected to one another as shown below. The tube on the left has two side-plates welded to it, while the tube on the right is bolted to the side plates with a single bolt. Circle the correct answer.

**Side View**

Left Tube

Hole through side plates and right tube for connection

Right Tube

**Top View**

Side plates, welded to left tube

Hole through side plates and right tube for connection

**Isometric View**

Circle the correct answer

A). The connection is moment-resisting for both axes of bending.

B). The connection is non-moment-resisting for both axes of bending.

C). The connection is moment resisting for bending about the y-axis, but non-moment-resisting for bending about the x-axis.

D). The connection is moment resisting for bending about the x-axis, but non-moment-resisting for bending about the y-axis.
11. Consider the floor plan shown below and circle the correct answer:

A). Edge Fill Beam tributary width = 12'
   Interior Girder tributary width = 12'

B). Edge Fill Beam tributary width = 4'
   Interior Girder tributary width = 12'

C). Edge Fill Beam tributary width = 4'
   Interior Girder tributary width = 24'

D). Edge Fill Beam tributary width = 8'
   Interior Girder tributary width = 12'

4. (7 points) A W16x26 beam is simply-supported over a 20' span, bent about its weak axis by self-weight only. Determine the maximum, (unfactored) extreme-fiber bending stress on the beam.

Answer:
Maximum Extreme Fiber Bending Stress:

\[
M = \frac{(0.026)(20^2)}{8} = 1.3 \text{ k-ft}
\]

\[
\sigma = \frac{M}{I} = \frac{M}{S} = \frac{15.6}{3.49} = 4.47 \text{ ksi}
\]
1. (20 points) Compute the vertical deflection of Point C, due to the distributed load of 0.1 kips/inch, shown. The structure has rigid beam-column connections at points B and D, pinned foundations at A and E and an internal hinge at C. All members are W18x35's, bent about their strong axis.

**Final Answer**

Vertical $\Delta_c = 2.71$ inches