Practical Use of the New Load Combinations

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During the 1980's individual load cases, such as dead load, live load and wind, were simply added together and compared to an allowable stress value. If the resulting combination included wind or seismic, a 1/3 allowable stress increase was permitted. Serviceability checks, such as deflection and drift, were directly calculated from the analysis. This simple process has served the industry well for many years. Why can't we choose to continue to use it, if we so desire?

During the last two decades, much research and revision has occurred in the areas of load probability and the use of load factor or strength design. The resulting building code load combinations have more reliable and appropriate probabilities assigned to each load case. However, Load Factor or Strength Design is the necessary basis, and converting it to the familiar Allowable Stress Design can be cumbersome. Furthermore, the basis of the magnitude of the loads has changed such that simply applying the new loads to old combinations (and with stress increases) is unsatisfactory and unconservative.

AISC ASD 1989

Wind
- D
- D+L
- (D+L+W)*
- (D+W)*
- * = 1 1/3 increase for combos with wind acting alone or in combination…

The new ASCE 7-02 load combinations, as well as some older load combinations, for comparison purposes, are listed on the accompanying figures. The following paragraphs explain important changes which have occurred, and have influenced the new load combinations. Many are frequently overlooked, and may result in unconservative and unsuitable designs.

ANSI A58.1 -1982

Wind
- D
- D+L
- .75 (D+L+W)
- .75 (D+W)
- E applied same as W

The primary model building codes of the past (UBC, BOCA and SBC) have evolved into the IBC. The IBC relies heavily on the provisions of ASCE-7 and the individual standards of the materials (e.g. AISC, ACI etc.). NFPA has also developed a new model code, and it similarly relies heavily on the above mentioned standards. The 1997 UBC, which is still in use in California, is also significantly influenced by the ASCE-7 stan-dards. The ASCE 7-02 commentary explains "The basic idea of the load combination scheme is that in addition to dead load which is considered permanent, one of the variable loads takes on its maximum lifetime value while the other variable loads assume 'arbitrary point in time' value…". Applying a 1/3 allowable stress increase to forces caused by dead load is not in conformance with that statement.

The AISC steel code and the AISC seismic provisions have focused their revisions almost exclusively on LRFD. The latest AISC steel code relies on ASCE 7 for load combinations. Certain Allowable Stress Deign load combinations in IBC 2000 allow a 1/3 increase for steel by reference to AISC ASD; however, IBC 2003 references AISC ASD Supplement Number One which no longer allows a 1/3 increase.

The ACI concrete code using Ultimate Strength design has gained acceptance. However, in an effort to accept non-material specific load factors based upon probability only, as per ASCE 7, the ACI 318-02 code has modified some of their material strength reduction factors (phi); e.g. shear phi was .85, now it is .75. It should be noted, however, that the phi for bending has not changed.

The basis of wind pressures has evolved from a fastest mile speed basis to a 3 second gust basis (ASCE 7-95). For instance, the middle of the United States has changed from 70 mph (fastest mile) to 90 mph (3 second gust). This was to modernize and better quantify wind pressures. However, the magnitude of the wind pressure loading for a specific building at a specific location did not significantly change. None the less, the formulas changed and were unfamiliar, and thus have the potential to camouflage awareness of the changes described in the next paragraph.

ACI 318-89

Wind
- 1.4D + 1.7L
- .75 (1.4D + 1.7L + 1.7 W)
  = 1.05D + 1.28L + 1.28W
- .9D - 1.3 W

ASCE 7-98 introduced a directionality factor, K_d, into the wind pressure equation. The old load factor for wind of 1.3 had incorporated a factor of .85 to account for the reduced likelihood that the building will experience the wind from the direction most unfavorable for building response. The newer ASCE 7-98 included the K_d on the wind pressure side of the equation, and therefore the load factor correspondingly changed from 1.3 to 1.6. New research has quantified the K_d factor individually for various structure types. The value for K_d is tabularized and may now be assessed for each specific structure type. However, for most structures it is still equal to .85; except for some unique structures (tanks, chimneys and trussed towers) whereby K_d = .90 or .95.

ACI 318-89

Seismic: 1.1E for W and Chapter 21:
- 1.4D + 1.7L
- .75 (1.4D + 1.7L + 1.7(1.1E))
  = 1.05D + 1.28L + 1.40E
- .9D - 1.4 E

UBC 1994 High Seismic:
- 1.4 (D+L+E)
- .9D - 1.4E

The resulting wind pressure is therefore usually 85 percent of the previous codes. It must be used with correspondingly and appropriately higher load factors. Using old building code or old ACI load factors with this wind load would be unconservative and in error. Similarly, using old Allowable Stress Design load combinations, with a 1/3 stress increase would also be unconservative and in error.

ASCE 7-95 Allowable Stress Design used a 1.0 factor for dead load to resist uplift forces. It further required that the overturning moment due to wind shall not be greater than 2/3 of the dead load resisting moment. ASCE 7-98, and -02 apply a .6 factor on dead load and have removed the 2/3 overturning text. The model codes have adopted this basis, but still allow the older alternative load combinations which list the required 2/3 factor on dead load in the section on wind loads. The engineer should take care not to omit this requirement.

W
Wind Pressure Equation

- $qz = 0.00256\ Kz\ Kzt\ Kd\ V^2\ I$
- $Kd = .85$

Older codes for seismic forces used working stress forces as a basis. The 1994 UBC equation for base shear included a response modification coefficient, R_w. It occurs in the denominator of the base shear equation and accounts for overstrength, inelastic energy dissipation and damping inherent in the lateral system. The subscript *w* indicates a working stress basis. The corresponding load factor was 1.4. The newer codes have changed from R_w to R. The difference is a factor of approximately 1.4. The basis of the equations using R is strength design and therefore a load factor of 1.0 is appropriate. Therefore a factor of 1/1.4 = .7 may be used in allowable stress load combinations. To not do so would be overly conservative. The .7 factor should not be applied to drift calculations, however.

ASCE7-02 ASD

Seismic

- D
- D + L
- D + (.7E)
- D + .75L + .75(.7E)
- .6D - (.7E)

No 1 1/3 stress increase
For IBC, use .75E, not .75(.7E)

For the response modification coefficient, R, to be appropriate for a system, the surrounding elements must be proportioned so as to perform adequately. Seismic base shear levels are based upon lateral system behaving in a desirable inelastic and energy dissipating manner. Connections or irregularities in the system must be stronger than the key inelastic element of the system. For instance, a steel braced frame dissipates energy and provided dampening through inelastic buckling of the diagonal brace. The diagonal brace is essentially a controlled weak link or fuse. Therefore, all other elements in the load path must be strong enough to deliver loads to the brace. They must be proportioned so as to not themselves be the weak link. Examples include brace end connections and collectors. These elements are specifically addressed by the code as requiring a special load combination which includes the Omega overstrength factor (typically 2.2 to 2.8). The basis of the combinations and capacity check is ultimate strength. For working stress design, the allowables may be increased by a 1.7 factor (but not a 1/3 increase (UBC 1997).

ASCE 7-02 Strength Design

Wind:

- 1.4D
- 1.2D + 1.6L
- 1.2D + 1.0L + 1.6W
- .9D - 1.6W

Seismic:

- 1.2D + 1.0L+ 1.0E
- .9D - 1.0E

E

- $E = \rho Q_E + 0.2 S_{DS} D$
- $E = \Omega_0 Q_E + 0.2 S_{DS} D$
  ASD allowables x 1.2
  (1.7 x .7=1.2)

Ω_0 = 2.2 to 2.8
$0.2 S_{DS} D$ = .03D to 0.2D

Older UBC 1994 load factors for seismic design for high seismic regions included 1.4 (dead + live + seismic). Newer load factors include a 1.2 load factor for dead loads. In an effort to minimize the impact of this change, the seismic portion of the code introduced a "vertical effect of earthquake motion" factor, E_v. In reality, this does not account for the full effect of the vertical motion; instead it was primarily intended to correct the aforementioned load factor change. The E_v is not a seismic load, but instead results in a modification to the load factor on dead load. E_v generally ranges from 1.0 to 1.2, depending on seismicity. UBC 1997 Allowable Stress Design allows this E_v to be ignored, however the "vertical component" adjustment is required in Allowable Stress Design in IBC and ASCE 7, whereby it must be included as a factor multiplied to the dead load.

ASCE7-02 ASD

Wind

- D
- D + L
- D + W
- D + .75L + .75W
- .6D – W

No 1 1/3 stress increase

UBC 1997 also added an exception to the Strength Design load factors requiring a 1.1 factor for concrete structures subjected to seismic forces. This was later deemed redundant to the aforementioned E_v; and was subsequently removed in the 1998 California Building Code adoption of the UBC.

ASCE 7-02 represents the latest and most up to date Code and Commentary. UBC, IBC, AISC and ACI use the ASCE 7 documents as their basis. ASCE 7-02 Code and Commentary is an extremely valuable and necessary resource for structural engineers.

The 18th century French philosopher Jean-Jacques Rousseau once said, "Men will always prefer a worse way of knowing to a better way of learning." Indeed it takes effort and expense to keep up with new codes. Especially since newer codes seem to add complexity; a complexity that the practitioner may deem unwarranted and undesirable. But as jurisdictions adopt new Codes, the structural engineer has little choice but to study, learn, use and embrace the current Codes as the appropriate Standard of Care.■

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Recommendations:

1. Define your code and stick with it. For instance, do not mix load combinations and 1/3 stress increases allowed in an older code (say UBC 1997) with the loads prescribed by a newer code (e.g. ASCE 7-02 with wind reduced by K_d = .85). If a code references a material standard, verify that you are using the correct edition of that standard.
2. Similarly, if you use the new ASCE 7-02 load factors, you must use the new lower ACI 318-02 phi factors for concrete design (e.g. phi shear was .85, now .75).
3. Apply a .6 factor on dead load when resisting uplift in Allowable Stress Design load combinations (ASCE 7-02). This will satisfy the older requirements of limiting the overturning moment due to wind to not greater than 2/3 of the dead load resisting moment.
4. When using Allowable Stress Design, reduce seismic base shear and other force formulas by 1.4 (or multiply by .7) as shown in the load combinations of the code you are using. To not do so is overly conservative.
5. Include the vertical seismic effects modifier to dead load, Ev, even in Allowable Stress Design (except not required by UBC).
6. Include special load combinations which include overstrength Omega where specifically required such as connections and collectors. If using Allowable Stress Design, use 1.7 times allowables, but do not use 1 1/3 stress increase.
7. Don't multiply wind by .75 for drift calculations. Don't multiply seismic load by .7 for drift calculations.
8. Book keep dead, live, wind and seismic forces separately. Check serviceability, drift, deflection etc. Consider using Strength Design load combinations and LRFD design for steel. This is especially beneficial for the new AISC Seismic 2002 which is referenced by IBC 2003 and coordinated with ASCE 7-02. It is particularly difficult to convert to Allowable Stress design.
9. Thoroughly read and study the Codes you are using. ASCE 7-02 is the current basis of the model codes and material standards. Know this document!
10. Read the Commentaries to the Codes.