101 Things I Learned Since Engineering School

1. If someone tells you that they can’t do something believe them.

Everyone has things they do well, and things they don’t do so well - things they have done hundreds of times and things that they have never attempted.

Sometimes projects require tasks that were either not anticipated at the start of the project or were communicated in the contract in such a manner that the intent was not clear.

Sometimes a contractor (or even an engineer) finds that they are expected to do something that they either know they cannot do or are not confident that they can do. Sometimes the project team perceives that the party is contractually obligated to perform the work and forces them to perform the task. This often does not turn out well.

It makes no sense to force someone to do something they have already stated they cannot do. This does not mean that the task is undoable, but it does mean that some other method of getting it done should be considered.

2. The world is always right.

If there is a conflict between a theory or a design model and behavior that is observed in the real-world, then it should be assumed that something is wrong with the theory or a design model. It makes no sense to assume that there is something wrong with the world.

Engineers will sometimes describe observed behavior or conditions and then assert that the behavior or conditions cannot exist because they are not (or even cannot) be explained by theories or models that they are aware of. In some cases other theories or models may need to be applied, and in such cases this may be an indication that the design standards (the codes) being applied are ill-suited to the task. In some cases, the engineer may be misinterpreting the observed behavior.

3. You often don’t need the right answer; you just need a safe answer.

Engineers often get hung up on finding the right answer.

Engineers rarely need the ‘right’ answer and ‘right’ answers rarely exist in structural engineering. See Item 4.

The best approach is often to define a condition that is known to be worse than the condition that will actually exist and then establish that the worse condition is still safe.

4. All design is based on models, and all models are wrong.

This statement is true regardless of the source of the model. Models in textbooks are wrong. Models in building codes are wrong. Models used in computer programs are wrong.

"All models are wrong, but some are useful." ~~~ British statistician George E. P. Box.

“The eternal tension in theory – or any other abstract formula or principle – is how to make it relevant to many cases without becoming either so vague or abstract as to be useless, or so beset by qualifications for every occasion that it loses coherence.” ~~~ Michael Blastland

See Item 3.

5. Wrong models are often more useful than right models.

Much human progress was made based on the model that the Earth is flat and located at the center of the Universe.

When one builds a table or a chair or a building, it is common - and often best - to assume that the Earth is flat. Accounting for the curvature of the Earth is not necessary. The effect of the curvature is negligible. Accounting for the curvature adds complexity, time, and increases the risk that errors will be introduced with no practical gain.

6. Sum the forces at the foundations.

I was once involved with a project where the loads that had been provided for connection design did not balance and did not seem to make sense. In response to our concerns, the Engineer of Record shuffled loads around, and we (the fabricator) shuffled members and plates and bolts and welds around, but each iteration made as little sense as the previous one.

Finally, I took the drawings home and over a weekend summed the forces at each floor (as best I could) and compared them to the forces we had been provided. The two sets of forces could not be reconciled. After some uncomfortable discussions with the Engineer of Record, it turned out that after the initial design the framing had changed and the engineer had stopped a column short and designed a large plate girder to carry the load from shortened column. However, the engineer had neglected to account for this load in the transfer trusses that carried the girder.

Calculating the loads along a column and comparing it to the load at the base of the column is a simple way to catch BIG problems.

7. Sometimes everyone is right.

Everyone has their own set of experiences. These experiences frame our perceptions and result in biases.

It is not uncommon for people to view the same situation from different perspectives. Since there can be multiple causes and multiple solutions for any given problem, it is possible that each party can be correct.

When parties all assert that a problem is someone else’s fault, they can all be correct.

8. Sometimes everyone is wrong.

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It is not uncommon for people to view the same situation from different perspectives. Since there can be multiple causes and multiple solutions for any given problem, it is possible that each party can be wrong.

When parties all assert that a problem is not their fault, they can all be wrong.

One of the most common situations where everyone is wrong involves the galvanizing of complex, welded frames. It is well-known and well-documented that such frames are prone to warping. Everyone involved could know this and could take steps to prevent, minimize, or anticipate the warping. However, in many cases no one does and then after the fact everyone wants to know who is responsible for the twisted, unserviceable frame that exists in the world. It seems the only reasonable answer is that everyone is.

9. If everyone is responsible, then sometimes no one will take responsibility.

Ideally every task should have a specific home.

If something needs to get done on a project, but it is not assigned to anyone, the possibility exists that it simply will never get done.

The best situations are when the task that does not get done interferes with the completion of other tasks. In such cases the task, that might otherwise have been forgotten, must be completed – by someone - for the project to proceed.

More insidious are tasks that can be left undone without interfering with the completion of the work. Unfortunately, such tasks often directly interact with the design intent.

Design checks can go unperformed with no outwards sign of the deficiency in the members or connections and with no impact on erection. Since engineering is rarely done by a single individual, this risk exists even when a single engineering company performs all the design, but is perhaps even more likely when connection design (or other aspects of design) is delegated.

Bolts can be placed, but not tensioned, and this can accelerate fatigue which could go unnoticed for years before a failure. This sort of thing is more likely to occur where structural steel elements interface with other metal elements.

10. Things can be simple and conservative. Things can be complex and efficient. Things are rarely simple and efficient.

When an engineer employs a simple model in design, including the simple models provided in design standards, the model will often incorporate conservative simplifications. Something will be left on the table.

It is often the case that “better” models will result in more efficient designs.

Even the simplest design or most common assumption can be expanded into a months-long project. Trade-offs are inevitable.

11. Don’t start problems at the beginning and work to the end. Start in the middle and work out. (Be the member).

I hate flowcharts and checklists.

Checklists can be used as quality assurance to ensure nothing obvious is overlooked.

Flowcharts can be useful if one is writing computer programs, or if a non-engineer is performing what borders on engineering work.

As a society we have decided – for now anyway – that people are responsible, not cars or computers or design standards. Engineers should perform engineering work as engineers, not as automatons or button pushers, or a linguist. The engineer should adopt the perspective of the member or the force in the member and think about the behavior that is desired and acceptable.

12. Anything is possible if you’re willing to spend enough money.

This is perhaps a bit of an overstatement, but it is generally true, and not a bad assumption to start with.

Folks sometimes do not get what they want, not because what they want is impossible but rather because what they want is impossible for the price that they are willing to pay.

If cost is not a consideration, then one will usually find someone willing to do the work.

However, cost is rarely not a consideration.

Even when cost is not a limitation, convincing others that this is true can be a challenge.

13. If someone has been doing something for 30 years, then you should listen to them.

Everyone has their own experiences and areas of expertise. Some lessons are best learned from books. Some lessons are best learned in practice.

Designing and constructing a building is a complex and difficult task. Generally, I can use all the help I can get.

If someone knows something I do not and is willing to share the information, then I am going to listen. I am not necessarily going to act on the information, but I am never going to dismiss it out-of-hand.

14. You’re the Engineer of Record. You can do anything you want.

Design standards cannot address every condition. The Preface to the AISC *Specification* states this: “The intention is to provide design criteria for routine use and not to provide specific criteria for infrequently encountered problems, which occur in the full range of structural design.”

Sometimes engineers must solve problems based on their own knowledge, experience, and judgment. The AISC *Specification* permits this: “Where conditions are not covered by this *Specification*, designs are permitted to be based on tests or analysis, subject to the approval of the authority having jurisdiction. Alternative methods of analysis and design are permitted, provided such alternative methods or criteria are acceptable to the authority having jurisdiction.”

In some cases, alternative methods are not only permitted, but required.

15. The Engineer of Record can have anything he or she wants – but not for free.

Our society has chosen to assign an Engineer of Record to projects and make this individual responsible for the safety of the project.

To turn a common saying on its head, “With great responsibility comes great power.”

The AISC Code of Standard Practice states, “The owner’s designated representative for design is the final authority in the event of a disagreement between parties regarding the design of connections to be incorporated into the overall structural steel frame.”

The Engineer of Record (the owner’s designated representative for design) can require anything at any time that the Engineer of Record feel is necessary to ensure the safety of the structure. However, if a requirement changes the contract, then adjustments to the contract may have to be made.

16. Communication is more important than calculation.

Engineers do not build structures. Engineers produce documents that guide the construction of structures.

Even the best design, if it exists only in the mind of the engineer or on the engineer's computer, is worthless.

Design must be communicated if it is to be reflected in real-world structures.

17. Equilibrium must exist among folks building the structure just as it does in the structure they are seeking to build.

The lower bound theorem of plastic analysis in effect indicates that elements will take all they can take in terms of load, and then will yield (lose stiffness) and distribute (or shed) additional loads to other stiffer (unyielded) elements.

The Code of Standard Practice states, “The fabricator shall provide field connection details that are consistent with the requirements in the contract documents and that will, in the fabricator’s opinion, result in economical fabrication and erection.” What is most economical for the fabricator may not always be what is most economical for the erector – or the owner.

"From each according to his ability, to each according to his needs"
~~~ Karl Marx

“A manly assertion by each of his individual rights, and a manly concession of equal rights to every other man, is the boast and the law of good citizenship.”
~~~ Benjamin Harrison

“It is not from the benevolence of the butcher, the brewer, or the baker, that we expect our dinner, but from their regard to their own interest. We address ourselves, not to their humanity but to their self-love, and never talk to them of our own necessities but of their advantages.”
~~~ Adam Smith
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18. Practice makes perfect – or hopefully at least adequate.

Ideally every mundane engineering task that is undertaken in ‘engineering practice’ should be preparing you to make the right engineering decisions under pressure.

If your modus operandi is to be sloppy and illogical and to rely on words in books rather than engineering principles, then when problems arise which are burning daylight and money and you are in the critical path, you will tend to return to form. You will tend towards ‘strong but wrong’ behaviors. You will do what you have trained to do - be sloppy and illogical and to rely on words in books rather than engineering principles.

If instead you routinely (no one will ever always) think carefully about assumptions, boundary conditions, load paths (draw free-body diagrams), and behaviors, then when you are under pressure you will return to form. You will tend towards logical, first-principles-based decisions.

“Under pressure, you don't rise to the occasion, you sink to the level of your training.” ~~~ Often attributed to a Navy SEAL

19. All I Really Need to Know I Learned in Kindergarten – or in Statics and Strength of Materials

Design courses related to specific materials - steel, concrete, wood, masonry, etc. serve two purposes:

1. They reinforce what is learned in Statics and Strength of Materials courses.

2. They make sure students are aware that different materials behave differently and therefore must be designed differently – which I suppose is simply reinforcing what is learned in a Strength of Materials course.

20. What is happening in- and out-of-the-page often matters more than what is happening on the page. (stability)

It is surprisingly common to see designs that seem to be stable only because the paper they are drawn upon do not allow them to move out-of-plane.

“I’d rather be in an over-braced and under-designed building, than in an over-designed, underbraced building.” ~~~ Jim Fisher

21. If you have a good design standard and reasonable knowledge of engineering principles, then you don’t need a Manual.

I once gave a series of lectures on seismic connection design in Canada – based on the Canadian codes. I had never used the Canadian codes, so before I accepted the contract, I purchased a copy of CSA S16, Design of steel structures, which is similar to the AISC *Specification*. After a brief review, I decided I could work with this unfamiliar standard.

The contract required me to produce hundreds of pages of design calculations, which were then submitted to the Canadian Institute of Steel Construction (CISC) for review. After their review CISC staff requested only one change because I had sized a fillet weld in a way that was unusual based on common Canadian practice as illustrated in CISC *Handbook of Steel Construction*.

I had no way of knowing what was done in the *Handbook of Steel Construction* because I had never owned a copy.

22. Assumptions need to be justified.

We train engineers for four years (or perhaps more like 20 years) to blindly accept things, and then we release them upon the world with the expectation that they will question assumptions and apply judgment.

As certainly as the bell caused Pavlov’s dog to salivate, the mere sight of the words ‘given’ or ‘assume’ cause many engineers to perceive that the heavens have opened and delivered unto them sacred and universally useful knowledge.

Statements like “Assume the frame is braced out-of-plane,” “Assume deflection does not govern,” and “Assume the beam is loaded through the shear center” become commandments (rather than simplifications to “textbook” problems) to an engineer chomping at the bit to plug-and-chug and move on to the next task. “If it was good enough for the expert who wrote the example, then it must be good enough for me.”

When making an assumption, stop for a moment and consider whether there is any possibility at all that the assumption is actually true. Then consider how you might prove that the assumption is true or at least close enough to true to be useful.

23. "By inspection" means something.

Some engineers adopt the position that nothing can ever be evaluated "by inspection", and then proceed to make a bunch of implicit assumptions that they seemingly do not even inspect.

Some engineers seem to use "by inspection" to indicate that they have no idea how to check something, but since something must be done whatever is done is okay "by inspection" – maybe because it looks like other conditions that seem not to have failed.

"By inspection" means that the condition or assumption is obviously okay based on the knowledge, experience, and judgement of the engineer AND the engineer knows (is certain) that if pressed to do so he or she could "prove" the condition of assumption to be okay through rigorous and rational analysis.

24. Negligible means something.

Negligible means that explicit consideration of an effect will not change the final design.

If an effect is asserted to be negligible by inspection, and someone questions this conclusion, it is possible to resolve the controversy by checking the condition once neglecting the effect and then checking the condition again including the effect. If the effect is negligible, then the design will not change.

A set of detrimental and beneficial effects can be negligible even though each effect individually is significant.

Neglecting an effect or set of effects can cause the available strength to be underpredicted or the required strength to be overpredicted. The fact that the effects are neglected does not make them negligible. The assumption/decision to neglect the effects is better describe as ‘conservative’.

25. If it looks wrong; it may be wrong.

When you perform a lot of design on a project, you get a feel for what things tend to look like on that project. Since most things will be correctly designed, a feel for what things tend to look like also tends to be a feel for what things should look like. If something looks different, then it is worth a second look.

A common occurrence during shop drawing review, in my experience, is that one will encounter a condition that looks wrong, and therefore a check will be perform that may have previously (for the hundreds of previously reviewed shop drawings) been neglected. Lo and behold, the condition in question is found to be deficient based on the ‘new’ check. Inevitably a nagging feeling causes one to pull all the completed shop drawings back onto the table, so that the ‘new’ check can be performed relative to these other conditions. In my experience, it is rare that the ‘new’ check will be found to govern. One’s feel for what ‘looks wrong’ has been confirmed. This is a nice feeling.

26. If you think it needs to be checked, then check it.

Engineers must satisfy building codes, but they must more importantly satisfy themselves.

If in the judgment of the engineer something should be evaluated, then it should be checked – even if checking it is not explicitly required ‘by code’.

27. Statics. Limit states. Compatibility. Sometimes two out of three ain’t bad.

The true solution to a structural problem is found by satisfying statics, the constitutive equations (generally by considering the limit states), and strain compatibility.

A lower bound (safe) solution is found by satisfying statics and the constitutive equations.

An upper bound (unsafe) solution is found by satisfying strain compatibility and the constitutive equations.

Each solution is only as valid as the assumptions made, which of course can never be precisely correct.

Each solution can be used in design, and each solution is reflected in the *Specification* and the methods commonly used with the *Specification*.

An upper bound solution can produce conservative results if beneficial effects are neglected.

A lower bound solution can produce unsafe results if detrimental effects are neglected.

The true solution is never true relative to the actual condition.

28. Read the contract.

The purpose of a contract is to define the legal implications and obligations that each contracted party must deliver upon.

Each party must agree to the contract. Contracts cannot be changed unless each party agrees.

Contract provisions cannot be overridden by codes and standards. The AISC Code of Standard applies “in the absence of specific instructions to the contrary in the contract documents”.

Contracts cannot require violation of laws.

29. Know what you don’t know.

Engineers are prohibited from performing services outside the areas of their competence.

“…there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know. And if one looks throughout the history… it is the latter category that tends to be the difficult ones.”

~~~ Donald Rumsfeld

If engineers are to avoid performing services outside the areas of their competence, then they must maximize their knowledge of what they do not know (the known unknowns) and minimize their ignorance (the unknown unknowns). The best way to accomplish this is by seeking to know a little about a lot. The best way to accomplish this is by paying attention.

Each time an engineer expands the scope of his or her services, it should be assumed that unknown unknowns exist and these should be actively sought.
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30. Know what you know.

"…there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don't know we don't know. And if one looks throughout the history… it is the latter category that tends to be the difficult ones."

~~~ Donald Rumsfeld

There are also unknown knowns.

Things that you know, and you assume everyone else knows, so you don't bother expressing them.

Things that you know at such a visceral level that you tend not to recognize their influence on your decisions and your designs.

"Common sense is only the application of theories which have grown and been formulated unconsciously as a result of experience." ~~~ Hardy Cross
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31. Derive.

‘Nuff Said... AND Cannot Be Said Enough

32. The more you learn, the less you know.

I suspect that when I was sixteen years old and working on my car, I was pretty confident I understood how a bolt worked. After about thirty years as an engineer working with structural steel, I know that there is much more I don’t know about bolts than I do know.

Engineering is sometimes the creative application of the science, mathematical methods, and empirical evidence *that you DO know* to the innovation, design, construction, and maintenance of structures, machines, materials, devices, systems, processes, and organizations. But sometimes engineering is the creative avoidance of the science, mathematical methods, and empirical evidence *that you DON’T know* during the innovation, design, construction, and maintenance of structures, machines, materials, devices, systems, processes, and organizations. Viewed in this way, it is very beneficial to face one’s ignorance.

33. We do not know the stresses in the structures we design.

All design is based on models. All models are wrong.

Thousands of assumptions will be made. Most assumptions will be wrong.

Conditions in buildings (and most other structures) are constantly changing.

It is impossible to accurately and precisely predict the stresses in the structures we design.

This has been empirically proven. (Baker, J.F., Home, M.R. and Heyman, J. (1956), The Steel Skeleton. Vol. 2, Plastic Behavior and Design, Cambridge University Press, London.)

Most (arguably all) practical design relies on the lower bound theorem.

34. Stuff yields… or stuff breaks.

If you pull, push, or twist on something enough something will give. There are advantages to having stuff yield instead of break.

35. The *Specification* is in the eye of the beholder.

If a provision of the *Specification* is presented to three engineers, it is possible (and would not be surprising) to find among these three engineers more than three interpretations of the provision.

36. The *Specification* does not cover everything.

The Preface to the AISC *Specification* states, “The intention is to provide design criteria for routine use and not to provide specific criteria for infrequently encountered problems, which occur in the full range of structural design.”

37. Common practice is less common than you think.

Engineers tend to have limited exposure to the practices of other engineers and therefore tend to assume that all engineers do things the way they do.

Fabricators tend to have limited exposure to the practices of other fabricators and therefore tend to assume that all fabricators do things the way they do.

Fabricators tend to interact with many engineers and therefore tend to understand how much engineering practices vary from engineer to engineer.

Engineers tend to interact with many fabricators and therefore tend to understand how much fabrication practices vary from fabricator to fabricator.

38. The person who wrote the Design Example, does not know what you are designing, and you do not know what they were designing. It is unlikely that the two of you are designing the same thing.

Design examples, whether they are published in AISC Design Guides, in textbooks, in handbooks, or in conjunction with the AISC Manual, are written by individuals. The individual producing the design example must form some picture of the condition in their mind. In many cases in my experience the picture the individual has in mind relates to a specific project the individual previously worked on.

It is impossible to convey all of the details of real-world problems in the format of a design example. It is likewise impossible to convey all the assumptions made. Ultimately it is the responsibility of the user to ensure the accuracy, suitability, and applicability of the example as it relates to their design.

39. Prying action is beneficial (usually).

Engineers overwhelmingly seem to view prying action in bolted connections as a detrimental effect.

Consideration of prying action, as described in the Manual, tends to reduce, not increase, the connection elements.

Prying action is detrimental relative to fatigue and must be considered.

It is potentially unsafe to account for the beneficial effects of prying relative to sizing the plate while neglecting the detrimental effects of prying relative to sizing the bolts.

40. Steel is inherently ductile. Your job is not to screw it up.

Structural steel is an inherently ductile material.

Structures constructed of steel generally will behave in a ductile fashion – undergo significant inelastic strain while losing stiffness but not strength.

There are factors that tend to reduce ductility and promote brittle fracture. These factors include: triaxial state-of-stress, increased strain rate, strain aging, stress risers, welding residual stresses, areas of reduced notch toughness, and low-temperature service.

41. Computers do not make decisions.

This statement illustrates the limitations of language while making two points.

First, as a society we do not allow computers to make engineering decisions. If bad engineering decisions are made and bad things happen, it will not be a computer that is held responsible. It will likely be the Engineer of Record.

Second, it is not clear to what extent, or how, a computer can or does make decisions. To some extent computers that seem (or claim) to make decisions do so through a process that is incomprehensible (and not repeatable) by humans. Will humans ever fully entrust the lives of humans to computers that they cannot understand?

"The need for explainable AI has grown in importance… to add (or enhance) the capability of humans to understand the processing of deep learning techniques and/or to develop "alternative machine learning techniques that learn more structured, interpretable, or causal models". ~~~ Jonathan M. Garibaldi

"If we are able to explain and predict its behaviour or if there seems to be little underlying plan, we have little temptation to imagine intelligence." ~~~ Alan Turing

42. An intelligent computer will make mistakes.

"… if a machine is expected to be infallible, it cannot also be intelligent. There are several mathematical theorems which say almost exactly that. But these theorems say nothing about how much intelligence may be displayed if a machine makes no pretence at infallibility." ~~~ Alan Turing

A dumb machine may never make a mistake, but an intelligent person using the machine may.

43. It is impossible to teach anyone anything complex. It is only possible to provide or improve a learning environment or opportunity.

“If you teach a man anything, he will never learn.” ~~~ George Bernard Shaw

“In training a child to activity of thought, above all things we must beware of what I will call ‘inert ideas’—that is to say, ideas that are merely received into the mind without being utilised, or tested, or thrown into fresh combinations.” ~~~ Alfred North Whitehead

“… students of vocational schools have difficulties applying mathematical formulae needed for compound interest and real interest calculations. Many students do not understand the meaning of the variables and arithmetic connections involved. In many cases they simply learn the formulae by heart and apply them more or less mechanically. The selection of formulae and of specific variables often remains tied to the very surface features of the task – which may be irrelevant for solving the task…” ~~~ “Overcoming problems of knowledge application and transfer” (Stark et al., 2004)

“Students of *engineering* schools have difficulties applying mathematical formulae. Many students do not understand the meaning of the variables and arithmetic connections involved. In many cases they simply learn the formulae by heart and apply them more or less mechanically.” = “Many engineers plug-and-chug.” ~~~ Larry S. Muir

“The French curve is made so that the lowest point on each curve, no matter how you turn it, the tangent, is always horizontal.” ~~~ Richard Feynman

44. If you think you understand something, you are not looking hard enough.

See #32.

45. Spending a lot of time and effort to understand an idea does not make the idea true or useful.

Delight at having understood a very abstract and obscure system leads most people to believe in the truth of what it demonstrates. ~~~ G. C. Lichtenberg

46. The fact that an idea has been peer-reviewed does not make the idea true or useful.

The 'Monument to an Anonymous Peer Reviewer’ outside Moscow’s Higher School of Economics displays ‘Accept’, ‘Minor Changes’, ‘Major Changes’, ‘Revise and Resubmit’ and ‘Reject’ on its five visible sides.

I have participated in just about every phase of a peer-review, and I think there would be a substantial market for pocket-sized versions of such dice.

47. Nothing in the real world is simple.

Some designs are simple, but the things being designed are never as simple as the models used to design them.

Einstein is quoted as saying, “Everything should be made as simple as possible, but no simpler.”

Apparently what Einstein actually said was, “It can scarcely be denied that the supreme goal of all theory is to make the irreducible basic elements as simple and as few as possible without having to surrender the adequate representation of a single datum of experience.”

48. Everyone does not have a mortgage to pay.

Establishing the right decision to make can be difficult. Making the right decision can be harder still. Freeing oneself from financial encumbrances can be – well – freeing and can promote better decision making.

Freedom's just another word for nothing left to lose, and nothing ain't worth nothing, but it's free.
~~~ Kris Kristofferson
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49. Ensuring that a connection has adequate strength is necessary, but it is not sufficient.

Connections must be designed “consistent with the intended behavior of the framing system and the assumptions made in the structural analysis”.

Simple connections must “have sufficient rotation capacity to accommodate the required rotation determined by the analysis of the structure”.

Beam end connections must restrain beams “against rotation about their longitudinal axis” in order to satisfy the assumptions of Chapter F.

Fully restrained moment connections must “have sufficient strength and stiffness to maintain the initial angle between the connected members at the strength limit states”.

The response characteristics of partially restrained moment connections must be “documented in the technical literature or established by analytical or experimental means”. Partially restrained moment connections must “have sufficient strength, stiffness and deformation capacity at the strength limit states”.

When assessing stability the following must be considered “connection deformations that contribute to the displacements of the structure,” “stiffness reductions due to inelasticity, including the effect of partial yielding of the cross section which may be accentuated by the presence of residual stresses”, and “uncertainty in connection strength and stiffness”.

50. Consider does not mean calculate.

The *Specification* requires the engineer to consider a lot of things. It is possible and common for an engineer to consider something and then decide that it is negligible or conservative or true without performing rigorous calculations.

51. If you think you have <u>the</u> right answer, you are probably wrong.

There is rarely a single correct solution to any engineering problem.

52. Good design neglects a lot.

We also make judgments routinely until they become second nature. For example:

- We neglect forces or moments that are of minor consequence.
- We assume pinned connections when in actuality they are not pure pins.
- We neglect moments in four-bolt anchor rod bases.
- We assume steel is isotropic and homogeneous.
- We neglect secondary moments in truss chords and web members.
- We neglect small differential settlements.
- We do not calculate principle stresses.
- We neglect stresses from rolling, bending, cutting, and welding of steel members.

From “Design!” by Jim Fisher April 2006 *Modern Steel Construction*

53. The power of compounding exists in engineering, not just economics. Part 1

If you start out using good judgment to make good decisions and communicate these decisions well, then the project will likely continue in a good direction, and it will be easier to make further good decisions.

However, once you use bad judgment in a design, more bad decisions will have to be made.

“You cannot do just one stupid thing in the design.” ~~~ Mike West

54. The power of compounding exists in engineering, not just economics. Part 2

Problems on projects tend to grow if left unaddressed or addressed incorrectly. I have seen situations where a simple problem that was recognized but hidden by the Engineer of Record morphed from a simple fix to a project on the verge of collapse both structurally and financially.

“Don’t hide under your desk”. ~~~ Mike West

“Danger - if you meet it promptly and without flinching - you will reduce the danger by half. Never run away from anything. Never!” ~~~ Winston Churchill

55. Pencil lead is cheaper than steel.

It is cheaper to identify and solve problems with pencil and paper - keystrokes and electrons – than it is to identify and solve problems with steel in the real world.

The closer you get to the finished product the more expensive the problems become.

56. Least weight does not equal least cost.

57. Sometimes when something is done incorrectly it is best to leave it as-is.

Sometimes attempts to fix something - that has been fabricated or erected incorrectly - do more harm than good.

This is especially true when it comes to mislocated bolt holes. Repairing mislocated bolt holes by welding involves a complex and difficult process, which while potentially restoring strength will never return the condition to the original state. The heat of welding will cause residual stress and metallurgical changes. These potentially detrimental effects must be considered.

Since repair work is often more complex and difficult than the work that was original specified, the fact that the contractor failed to perform the original work as expected may in itself be evidence that the contractor will not complete the repairs as intended.

58. A picture is worth 1,000 words.

Pictures can convey an incredible amount of information. There are pros and cons to this.

The next time you see or include a picture in a document, recognize that of the “1,000 words” the picture might convey, only a small percentage of these were intended when the picture was included.

59. When a picture, table, graph, or equation is presented in a document, there is a good chance that few will read the accompanying text.

Pictures, tables, graphs, and equations appearing in documents should be accompanied by text discussing the intent, basis, and/or limitations of the information provided. This text is often critical to the proper use of the information presented in pictures, tables, graphs, and equations, but readers often do not read the accompanying text. It is not unusual for engineers to misapply such information in ways that are explicitly addressed in the text. It is also not unusual for engineers to ask questions - about pictures, tables, graphs, and equations – that are already addressed within text mere inches from the picture, table, graph, or equation in question.

60. Sleep on it.

Sometimes things do not go as planned on projects, and ‘fixes’ become necessary. By definition ‘fixes’ occur under less-than-ideal circumstances. Fixes often must be developed under tremendous time and financial pressures.

As a chief engineer working for a fabricator, I sometimes advised project managers who proposed fixes to imagine their spouse, or mother, or children, or dog, or car, or whatever was most important to them in the world standing under the fix when they went to sleep at night, and if in the morning they still felt the fix was a good idea, then we would try to justify it with calculations.

Allowing a cooling off period, preferably ‘sleeping on it,’ is also a good idea when sending emails.

61. The moron theory.

Some engineers respond to every uncertainty or problem by pouring ‘more on’ – making things bigger or stronger. Sometimes there is no rational justification for such actions. Sometimes they do no good. Sometimes they make things worse.

(I first heard of the more-on theory from Tom Schlafly.)

62. Building-like is defined by the user, not the *Specification*.

The AISC *Specification* “sets forth criteria for the design, fabrication and erection of structural steel buildings”. It can also be used for “other structures” if the Engineer of Record decides that the “other structures” can be “designed, fabricated and erected in a manner similar to buildings”. If the other structure cannot be “designed, fabricated and erected in a manner similar to buildings”, then the Engineer of Record must provide additional project-specific requirements.

63. In the real-world buckling is often not sudden.

"Euler determined the elastic rigidity term EI from the measured end deflection Δ at the end of a cantilever beam with an applied load W using the known relationship Δ = WL3/3(EI). The column was assumed initially straight in the derivation. The use of the Euler formula implies that the initially straight member will remain straight until the Euler load is reached, thus providing little warning of an impending failure. At the Euler load the column bends without any increase in load (small deflection theory); the column has lost its stiffness… If the column is assumed to have an initial out-of-straightness… As the applied load P approaches the buckling load, the slope of the P - ΔT relationship (stiffness) approaches zero. Since all members in a structure have some initial out-of-straightness, flexural displacements will get very large near the theoretical buckling load thus providing ample warning of impending disaster." ~~~ Joe Yura

64. There is a difference between unanticipated and un-anticipatable.

Occurrences of web sidesway buckling have been described as “unexpected failures”. Yet the behavior can be explained, and simple models can and have been developed to predict web sidesway buckling. Therefore, the behavior can be anticipated – is anticipatable. The fact that it came as a surprise during tests reflected a lack of imagination, not a lack of knowledge.

It is sometimes best to advance in baby steps to give one’s pessimism time to catch up to one’s optimism.

“Engineers should be slightly paranoiac during the design stage. They should consider and imagine that the impossible could happen. They should not be complacent and secure in the mere realization that if all the requirements of the design handbooks and manuals have been satisfied, the structure will be safe and sound.” ~~~ Lev Zetlin

65. It is unrealistic to think structures will behave as you imagine, but if they do not it is best to consider why.

All structural design is based on models, and all models are wrong. Therefore, our models will never precisely and accurately predict structural behavior.

However, very often structures that fail are first observed to behave in unexpected ways.

Unusual deflections were observed in the Quebec Bridge, the Hartford Convention Center, the West Gate Bridge, and other structures before collapse.

Attempts should be made to explain unanticipated deflections, cracks, and fit-up problems.

66. Unexpected deflections, cracks, and fit-up problems should not be treated as ‘means and methods’.

When structures behave badly there is often an inclination to blame the contractors.

Attempts should be made to explain unanticipated deflections, cracks, and fit-up problems.

“None of the explanations for the bent chord stand the test of logic. I have evolved another theory, which is a possible if not the probable one. These chords have been hit by those suspended beams used during the erection, while they were being put in place or taken down. Examine if you cannot find evidence of the blow, and make inquiries of the men in charge.” ~~~ Theodore Cooper

67. Engineers are bad businesspeople – Part 1.

Many engineering firms start with someone deciding they can do better than their boss - only to realize when it is too late that work is awarded not to the best but to the cheapest. As each existing engineering firm spawns its own competitors, a race to the bottom ensues.

68. Engineers are bad businesspeople – Part 2.

Engineers work very hard to take on tremendous risks for modest rewards.

Engineers never escape the projects they design, cannot hide behind corporate structures, and often commit suicide when designs fail – even when the failures cannot reasonable be blamed on the engineer.

69. The ‘unsafe’ theorem can be used to design safe structures.

The kinematic theorem of plastic analysis is sometimes called the upper bound theorem or the unsafe theorem. It will predict a strength that is at least as great as the actual strength of the system. In other words, it will tend to overpredict the available strength.

A yield line analysis, most commonly used in the design of rectangular HSS connections, is based on the kinematic theorem of plastic analysis. The method produces safe results because it neglects some sources of strength, such as membrane action.

70. I cannot confirm or refute someone's interpretation of the *Specification*.

Folks often want confirmation that they correctly understand the intent of the *Specification*. It is impossible to provide such confirmation.

The process involves:

1. First and foremost a committee attempts to express some intent that relates to the real world using an imperfect set of tools – primarily the English language.
2. Party 1 reading and interpreting some *Specification* provision.
3. Party 1 'rewriting' the *Specification* provision to express (using imperfect tools) their interpretation. Any rewriting is likely to change the meaning to some degree. Therefore, unless the *Specification* provision was incorrectly expressed the 'rewrite' will be unlikely to capture the intent.
4. Party 2 reading and interpreting Party 1's interpretation of the *Specification* provision.

There are just too many opportunities for miscommunication to believe that this process can be effective.

71. We primarily express ourselves using words, and words are not well-suited to the task.

There are just too many opportunities for miscommunication to believe that this process can be effective.

“Our language is an imperfect instrument created by ancient and ignorant men. It is an animistic language that invites us to talk about stability and constants, about similarities and normal and kinds, about magical transformations, quick cures, simple problems, and final solutions. Yet the world we try to symbolize with this language is a world of process, change, differences, dimensions, functions, relationships, growths, interactions, developing, learning, coping, complexity. And the mismatch of our ever-changing world and our relatively static language forms is part of our problem.” ~~~ Wendall Johnson

“The limits of language are the limits of my world.” ~~~ Ludwig Wittgenstein

“Definitions are a fetish with some, but defining terms does not always lead to definiteness of ideas.” ~~~ Hardy Cross

“It is really quite impossible to say anything with absolute precision, unless that thing is so abstracted from the real world as to not represent any real thing.” ~~~ Richard Feynman

“But this precise language is not precise in any sense if you deal with real objects of the world, and it is only pedantic and quite confusing to use it unless there are some special subtleties which have to be carefully distinguished.” ~~~ Richard Feynman

72. When words do not suffice, we attempt to communicate mathematically.

"Defining math precisely and non-recursively is a moving target" ~~~ Paul Zorn

"The villain and the hero of math communication is the special language of math". ~~~ Paul Zorn

“In order to translate a sentence from English into French two things are necessary. First, we must understand thoroughly the English sentence. Second, we must be familiar with the forms of expression peculiar to the French language. The situation is very similar when we attempt to express in mathematical symbols a condition proposed in words. First, we must understand thoroughly the condition. Second, we must be familiar with the forms of mathematical expression.” ~~~ George Polyá

“Ordinary language is totally unsuited for expressing what physics really asserts, since the words of everyday life are not sufficiently abstract. Only mathematics and mathematical logic can say as little as the physicist means to say.” ~~~ Bertrand Russell

73. What makes sense to me may not make sense to you.

“I have often noticed that when people come to understand a mathematical proposition in some other way than that of the ordinary demonstration, they promptly say, "Oh, I see. That's how it must be." This is a sign that they explain it to themselves from within their own system.” ~~~ Georg Christoph Lichtenberg

“One of the miseries of life is that everybody names things a little bit wrong, and so it makes a little bit harder to understand things than it would have been if they had been named differently.” ~~~ Richard Feynman

74. Mathematical models are models, and all models are wrong.

“To the pure geometer the radius of curvature is an incidental characteristic - like the grin of the Cheshire cat. To the physicist it is an indispensable characteristic. It would be going too far to say that to the physicist the cat is merely incidental to the grin. Physics is concerned with interrelatedness such as the interrelatedness of cats and grins. In this case the "cat without a grin" and the "grin without a cat" are equally set aside as purely mathematical phantasies.” ~~~ Sir Arthur Eddington

[On the Gaussian curve, remarked to Poincaré:] “Experimentalists think that it is a mathematical theorem while the mathematicians believe it to be an experimental fact.” ~~~ Gabriel Lippman

“A theory has only the alternative of being right or wrong. A model has a third possibility: it may be right, but irrelevant.” ~~~ Manfred Eigen

75. When requesting something from someone pretend you are the other person.

When writing to someone to request information or services, it is first and foremost important to know and to adequately describe what you want.

It is a good idea to also consider the needs and desires of the person you are making the request to. Are there things you can do (with little cost to you) that can make their life better? If there are, then you should do them – especially if minor effort on your end can disproportionately make conditions better for the other individual.

Before sending a request try to reread it from the perspective of the other individual. Are there things that you know, but have not explained, that the other individual cannot possibly know? If there are, then you should explain them - if they are necessary to processing your request.

76. Coupling beams look like they are designed to resist shear, but they can also resist moment.

As defined by the Seismic Provisions a coupling beam is a “structural steel or composite beam connecting adjacent reinforced concrete wall elements so that they act together to resist lateral loads.”

The Seismic Provisions provide equations that can be used to determine the available connection shear strength for the coupling beam. The Seismic Provisions do not provide equations that can be used to determine the available connection FLEXURAL strength for the coupling beam.

Apparently due to the absence of equations that can be used to determine the available connection FLEXURAL strength, it is sometimes (actually it is with some frequency) asserted by engineers that the connection of a coupling beam possesses no flexural strength. In other words, some engineers will assert that a steel beam embedded into concrete possesses no flexural strength.

77. **It should be assumed that doing something untried, monumental, or awe-inspiring will be difficult and not explicitly addressed “in the codes”.**

78. Electrons do not flow through wire like water through pipes.

This statement is obviously not closely related to structural engineering or structural steel.

However, it is not wholly unrelated. Electrons flowing through wire like water through pipes is a model that many of us have been taught that is useful in designing and analyzing circuits.

In my life it has represented two ideas.

1. It reinforces the idea that all models are wrong, but some models are useful - since the model is unquestionably useful in many instances.

2. It reveals how strongly we tend to cling to wrong models that happen to be useful – often even in the face of contrary evidence. Perhaps because I do not interact deeply with electricity, I have tended to believe that the ‘electrons flowing through wire like water through pipes’ model represents actual physical behavior; in other words, I have tended to believe that the model is ‘true’. I found that I continued to believe this, until someone I felt should know asserted it was not true, at which point I found I still tended to cling to the model in an irrational and almost viscerally defensive manner.

How do we know the model is incorrect? Because we can place a cell phone on a charging pad and recharge the phone – even though there are not wires connecting the phone to the pad through which the electrons can flow like water through a pipe. If everyone clung to the wrong but useful model of water flowing through pipes, then the wireless charging pad would be inconceivable. All models are wrong. Useful models sometimes cease to be useful and can in some cases be worse than useless; they can be impedimental.

79. Stiffeners stiffen. Stiffness can be beneficial; it can also be detrimental.

Stiffeners are often used to address strength deficiencies. Less often they are provided to add stiffness. Strength and stiffness are often viewed as beneficial properties and therefore, there can be a tendency to view the addition of stiffeners as universally beneficial. This is sometimes a mistake.

Force is attracted to stiffness. When a stiffener is added, the distribution of stress should be considered relative to the presence of the stiffener. It may not be necessary to explicitly reevaluate (through calculations) the stiffened condition, but it is always a good idea to at least consider the potential effects. It may not make sense (and maty not be safe) to assume uniform distribution of stress at conditions with obviously non-uniform distributions of stiffness.

In addition to adding stiffness where you want to (and expect to) increase stiffness, stiffeners may add stiffness where you do not need or want it. Stiffeners will tend to increase stiffness in both directions orthogonal to the applied stress. In other words, the presence of stiffeners will lead to triaxial restraint and therefore triaxial stress conditions. Triaxial stress conditions can tend to reduce ductility - the ability to redistribute stress without fracture.

The risks associated with concentrating stress in an area of reduced ductility should be obvious but often are overlooked.

80. Residual stresses exist.

Residual stresses exist in all structures.

Residual stresses are introduced when the steel is produced, and very rarely in structural steel buildings are measures taken to reduce these residual stresses.

The distribution and magnitude of residual stresses are changed whenever the steel is modified. The residual stresses change when steel is cut (either mechanically or thermally), bent (hot, cold, or heat-assisted), drilled, or welded.

Since residual stresses always exist, residual stresses are objectively not always detrimental in a manner that needs to be addressed to ensure safety.

81. Residual stresses can sometimes be detrimental and must be addressed.

When addressing stability, the analysis must account for stiffness reductions due to inelasticity, including partial yielding of the cross section that may be accentuated by the presence of residual stresses. Failure to account for the loss of stiffness, not strength, associated with partial yielding accentuated by the presence of residual stresses can lead one to overestimate the buckling strength.

82. Residual stresses can sometimes be beneficial.

Bolts are often tensioned to very high levels during installation (pretensioned to about 70% of the minimum tensile strength of bolts).

Threads in bolts are not an intuitive feature relative to the desired final condition – though they are unquestionably beneficial to the process. The threads – especially at the root – represent significant stress concentrators. In some cases, bolts are further processed in ways that would tend to reduce ductility and the ability to achieve very high pretensions – for example bolts are sometimes hot-dipped galvanized.

If the threads were produced in a manner that resulted in residual tensile stresses at the thread roots, then it would be less certain that the high pretensions required for some applications could be achieved. When threads are rolled (as opposed to cut) residual compressive stresses are introduced that tend to improve fatigue resistance and reduce the likelihood of fracture as the bolt is pretensioned. When threads are cut there is less change in the residual stress. Cut threads can be thought of as having produced no residual stress. There is therefore no beneficial or detrimental effect related to residual stress for cut threads.

There are many factors involved with the proper functioning of bolts and bolted joints. My purpose here is not to indicate rolled threads are better than cut threads. It is to indicate that residual stresses are not universally bad (as engineers sometimes seem to think) and that in some cases residual stresses can be beneficial.

DISCLAIMER: Some of the models described above could be wrong. Every time I think I understand something, I am wrong.

83. A method to design things you do not know how to design.

Structural engineers routinely need to design things that are not directly addressed in design standards or design examples. Here is a process to get to a safe design:

1. Choose a model that you understand and preferably have used before that is like - but ‘worse’ than - the condition you are seeking to design. The chosen model will likely be ‘worse’ in terms of boundary conditions and loading and/or sources of beneficial strength and stiffness that exist will be neglected.

2. Design the worse condition.

3. With the ‘final’ design in-hand, reevaluate the worseness of the condition. In other words, confirm that the condition that had been designed, and shown to be sufficient to the application, is in fact worse than the actual condition.

84. A method to evaluate things you do not know how to design.

Structural engineers routinely need to evaluate things that are not directly addressed in design standards or design examples. Here is a process:

1. Choose a model that you understand and preferably have used before that is like - but 'worse' than - the condition you are seeking to evaluate. The chosen model will likely be 'worse' in terms of boundary conditions and loading and/or sources of beneficial strength and stiffness that exist will be neglected.

3. Evaluate the worse condition.

    a. If the 'worse' condition is sufficient for the demand, then you are done.

    b. If the 'worse' condition is insufficient for the demand, then you will repeat Step 1 making less conservative assumptions regarding the boundary conditions and loading and/or sources of beneficial strength and stiffness that exist but were neglected. As the assumptions become less conservative, it is likely that the calculations will become more complex, and it will become increasingly difficult to justify the assumptions.

4. Repeat the process until:

    a. You develop a model that 'proves' that the existing condition is sufficient

    OR

    b. You conclude that the existing condition is insufficient – often because you either run out of time or you can no longer justify less conservative assumptions.

85. The structural steel construction industry is more than 100-years old.

There is a tremendous amount of information available that is useful in structural steel construction. It is rare to encounter a problem that cannot be solved in a (not necessarily optimal but) reasonable manner.

Many new solutions that are contemplated or proposed in structural steel construction have precedents, though often these precedents have been forgotten or overlooked.

"All these factors have been known to investigators for many years but, surprisingly in the current rush to publish... many present-day writers make no reference to the earlier work in this area, for which there are citations going back to the early nineteenth century... Some of these may be studied profitably before engaging in new projects." ~~~ *Power Recovery from Low Grade Heat by Means of Screw Expanders* by Smith, Stosic, and Kovacevic

86. Other people sometimes know useful things.

I find that some of the most useful information is old and from fields other than structural steel design.

Discussions closer to the origin of a concept tend to treat the concept as more difficult to comprehend and therefore include more steps in the process – aiding understanding. More modern discussions tend to treat concepts as trivial and mere formalities to be addressed before moving on to bigger and better things.

If all one ever does is interact within their own field with folks who have taken the same classes, read the same books, and done the same things, then it greatly reduces the chances that anything new will be learned.

87. Sometimes things other people know are not useful things.

The structural steel construction industry is more than 100-years old. It must be accepted - to some extent – that things are done a certain way because that is the way that works best. ‘Better’ approaches used in other industries may be ill-suited to the rough-and-tumble world of structural steel construction.

88. “It’s the not the destination; it's the journey.” ~~~ Ralph Waldo Emerson

“We have a habit in writing articles published in scientific journals to make the work as finished as possible, to cover all the tracks, to not worry about the blind alleys or to describe how you had the wrong idea first, and so on. So there isn't any place to publish, in a dignified manner, what you actually did in order to get to do the work.” ~~~ Richard Feynman

89. If you want to understand something derive it.

If you want to understand something derive it. Once something is derived, you will find something else you do not understand, so you will derive it… and so on….

“What I cannot create, I do not understand.” ~~~ Richard Feynman

90. No one can know everything.

If you want to understand something derive it. Once something is derived, you will find something else you do not understand, so you will derive it. Then something else will appear that you do not understand… and so on. At some point the answer to the next question is because… Because you run out of time or enthusiasm or other resources.

At this point whatever lies beyond, if you accept it as true, is accepted as true based on faith, not based on reason. You do not understand it, but you believe it.

“Nobody knows more than a tiny fragment of science well enough to judge its validity and value at first hand. For the rest he has to rely on views accepted at second hand on the authority of a community of people accredited as scientists. But this accrediting depends in its turn on a complex organization. For each member of the community can judge at first hand only a small number of his fellow members, and yet eventually each is accredited by all. What happens is that each recognizes as scientists a number of others by whom he is recognized as such in return, and these relations form chains which transmit these mutual recognitions at second hand through the whole community. This is how each member becomes directly or indirectly accredited by all. The system extends into the past. Its members recognize the same set of persons as their masters and derive from this allegiance a common tradition, of which each carries on a particular strand.” ~~~ Michael Polanyi

91. Accepting things on faith is bad but necessary.

No one can know everything. If progress is to be made, if things are to be done, then one cannot start over from the beginning or trace each idea back to its origin.

"Srinivasa Ramanujan was the strangest man in all of mathematics, probably in the entire history of science. He has been compared to a bursting supernova, illuminating the darkest, most profound corners of mathematics, before being tragically struck down by tuberculosis at the age of 33... Working in total isolation from the main currents of his field, he was able to rederive 100 years' worth of Western mathematics on his own. The tragedy of his life is that much of his work was wasted rediscovering known mathematics." ~~~ Michio Kaku

"If I have seen further, it is by standing on the shoulders of giants." ~~~ Isaac Newton

92. Write down the solution before you attempt to solve the problem.

Before solving a structural problem, you should guess at the answer, and preferably write it down so as not to fool yourself later.

If the final worked-out solution conforms to your guess, then this tends towards the conclusion that the solution is correct and makes sense to you, as all solutions applied in practice should.

If the final worked-out solution does not conform to your guess, then this tends towards the conclusion that the solution is incorrect or that your intuition is incorrect (that there is something you do not understand). Examine the worked-out solution and your guess until you understand the reasons for the discrepancies and the solution makes sense to you, as all solutions applied in practice should.

Wheeler's First Moral Principle: "Never make a calculation until you know the answer. Make an estimate before every calculation, try a simple physical argument (symmetry! invariance! conservation!) before every derivation, guess the answer to every paradox and puzzle. Courage: No one else needs to know what the guess is. Therefore make it quickly, by instinct. A right guess reinforces this instinct. A wrong guess brings the refreshment of surprise." ~~~ John Wheeler

93. Tensioning a bolted joint is difficult.

The RCSC Specification contains several methods that can be used to pretension a bolted joint. None of the methods are foolproof, as evidenced by the fact that most methods contain some version of:

“After the snug-tightening operation is performed, the installer shall verify that the direct tension indicator protrusions have not been compressed to a gap that is less than the job inspection gap in half or more of the locations, and if this has occurred, the direct tension indicator shall be removed and replaced.” This recognizes that the force required to pull the plies into firm contact (a snug-tight condition) could flatten the DTI.

“After the snug-tightening operation is performed, the installer shall verify that the splined end has not been severed, and if this has occurred, the bolting assembly shall be removed and replaced.” This recognizes that the force required to pull the plies into firm contact (a snug-tight condition) could break the spline on a TC bolt.

“After the application of the initial torque and when the plies have been brought into firm contact…” This represents two requirements: (1) The initial torque must be applied AND (2) The plies must be brought into firm contact (a snug tight condition).

Other industries use other methods that either rely on better control of the factors (lubrication, environment, etc.) and/or more expensive or onerous hardware or processes.

94. Don’t use slip critical joints.

If everything goes as intended, the variability (the uncertainty) in slip critical connections is quite large. Sometimes everything does not go as intended.

If one must use slip critical connections, then it seems best to eliminate as much uncertainty as possible. A blast cleaned faying surface and turn-of-nut tensioning makes me feel somewhat better.

95. It is difficult to apply load without adding restraint.

I once had a large bookcase that I had to move. I began removing books (reducing the load on the bookcase), but as I did, I found the bookcase became less stable. To keep the bookcase from collapsing, I had to add books. I then had to methodically remove books with one hand as I braced the bookcase with the other.

When the bookcase was disassembled, I discovered that the joints had failed. For years the only thing that had kept the bookcase upright had been the friction between the elements – caused by the weight of the books and the friction between the books themselves, which created a sort of shear wall.

When reviewing physical tests it is important to examine the way the testing apparatus is connected to the element being tested to ensure that what is being reported is the strength of the element and not the strength of elements and the testing apparatus.

96. Decisions are often made to suit the computer - not to suit the engineer or the structure.

James Clerk Maxwell developed the flexibility method for the analysis of statically indeterminate structures. It is a fine method. However, it is not used nearly as often as the stiffness method. The flexibility method requires the structure to be reduced to a statically determinate state by introducing releases, which requires judgement. The stiffness method does not require such judgement and is therefore better suited to a computer.

97. Useful assumptions tend to be self-fulfilling, and assumptions that tend to be self-fulfilling are most useful.

When the stiffness method is used, load will tend to be drawn to the stiffer elements, making the choice of a stiffer (often bigger, stronger) element a good choice.

When the portal method is used, a distribution of force is assumed, which subjects some members to more load than other members. This causes some members to be bigger, stronger, and stiffer than other members, which means that more load will tend to be attracted to these members.

Load paths that are short, direct, and simple tend to be more efficient. Load paths that are long, meandering, and complex tend to be less efficient. If you want to transfer a load provide a short, direct, and simple load path and consider the load in the design along the load path. If you want to not transfer a load (want to provide a release) then provide a long, meandering, and complex potential load path and do not consider the load in the design along the load path.

98. Life's too short to mess with single angles.

Read the Commentary associated with single angles in bending.

There are general cases, special cases, and common cases
There are all cases, this cases, and geometric axis flexure cases
There are cases where all cases means only those cases previously described
To make it easier for the user to do as prescribed

The tips of an angle refer to the free edges of the two legs
Which in most cases if unrestrained will have the same sign, but which begs
The question of what are the signs and where
For the cases that are particularly rare

When bending is applied about one leg of the angle
When the angle is laterally left to dangle
It will laterally as well as in the bending direction deflect
As predicted by the sum of the principal axis flexural effects
But in the equation the geometric axis is what you get
Only with the result increased by twenty-five percent

However, if you want to know how the angle deflects
You must remember to increase by eighty-two percent
That is multiply by 1.56 in one direction and .92 orthogonally
Which produces the right magnitude as if magically

Sometimes (in all cases) Chapter H must be used
But if compression exists do not get confused
For in the latter even with components along the two principal axes
You will get something other than what the facts is

This all seems quite confusing
And has caused my head to be contusing
As I pound it upon the wall
Which is supported by a single angle
Which so precariously does dangle
As I wonder which way to run - when it all falls

99. Determining the maximum force that can be delivered to a system is hard.

From the Commentary to the Seismic Provisions:

"Calculating the maximum connection force by one of these three methods is not a common practice on design projects. In some cases, such an approach could result in smaller connection demands. But, from a conceptual basis, since the character of the ground motions is not known to any great extent, it is unrealistic to expect that such forces can be accurately calculated. All three approaches rely on an assumed distribution of lateral forces that may not match reality (the third approach is probably the best estimate, but also the most calculation intensive). In most cases, providing the connection with a capacity large enough to yield the member is needed because of the large inelastic demands placed on a structure by a major earthquake."

100. It may not make sense to use rectangular HSS in conditions exposed to the environment.

AISC Design Guide 24 states, "…all square and rectangular HSS produced in North America are potentially prone to corner cracking during hot-dip galvanizing because the outside corner radius averages 2t, and the upper limit on outside corner radius for all ASTM A500 HSS is at the minimum bending radius recommended for galvanizing…" I have seen a lot of corner cracks in hot-dip galvanized rectangular HSS.

I have also seen quite a few bulging HSS columns. Inquiries related to bulging HSS usually assert that the column has buckled. I believe that all these incidents can be likely attributed to water entering the HSS and then freezing. In my experience inquirers tend to be quite resistant to this explanation since the HSS have been provided with vent and drain holes. In at least two cases, inquirers have followed-up to report that when the drains were cleared water rushed from the columns.

Though I regularly see rectangular HSS used in exposed conditions, after my experiences with the Steel Solutions Center I personally would be very reluctant to specify them for such applications. They cannot be galvanized without directly 'violating' the guidance in Design Guide 24, and they actually do seem to crack. Even if drains and vents are provided to allow moisture from building up inside the column and causing corrosion, they seem to fill with water. The risks seem to outweigh the perceived benefits (in my opinion).

101. If you get someone 95% of the way to an answer, they will either assume that you have gotten them 100% or will assume the last 5% is unimportant.

It is sometimes better to be brief and obviously incomplete than to give the impression that your words account for all possible conditions.