PDHonline Course G387 (4 PDH)

Tips for Avoiding Design Blunders

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PDH Online | PDH Center

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Course Outline

Throughout the history, there are many engineering and architectural blunders, from the infamous crash of the Tacoma Narrows Bridge in 1940 to the tragic explosion of the Space Shuttle Challenger in 1986. Some of these blunders could have been avoided if the designers were more careful and cautious in their work. This course provides some valuable tips that will help you avoid design blunders in your practice. Whether you are a professional engineer, land surveyor, construction manager, or architect, you will benefit greatly by applying some of the advice contained in this course to your professional practice.

The tips compiled in this course are based on the advice of several contributors and on the personal experience of licensed professionals like you. If you feel that you can contribute additional error prevention tips to this course, please send us your feedback through email (John at PDHOnline.com) or through "Contact Us" on our website. If your feedback is more than 250 words, you will receive two additional PDH through the companion course "Tips for Avoiding Design Blunders – Feedback." Your effort will also be credited within the course content if your tips are incorporated into the next version of the course.

This course includes a multiple-choice quiz at the end, which is designed to enhance your understanding of the course materials.

Learning Objectives

Through this course, you will be able to

1. Become familiar with error prevention techniques;
2. Improve the quality of your design work;
3. Reduce your chances of making errors; and
4. Better protect the health and safety of the general public.

Intended Audience

This course is designed for engineers, architects, contractors, land surveyors, or anyone who wishes to improve the quality of their work and to better serve their professions.

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Tips for Avoiding Design Blunders

John C. Huang, Ph.D., PE

Introduction

Did you know more than 1,500 bridges failed in the U.S. in a 25-year span between 1966 and 2005? That is equivalent to an average of 38 bridge failures each year.

Each bridge failure has its own story. Let's begin with a Highway Accident Report about the collapse of the I-35W Highway Bridge over the Mississippi River (excerpted from the website of the National Transportation Safety Board, NTSB Number HAR-08/03.)

I-35W Highway Bridge before collapse

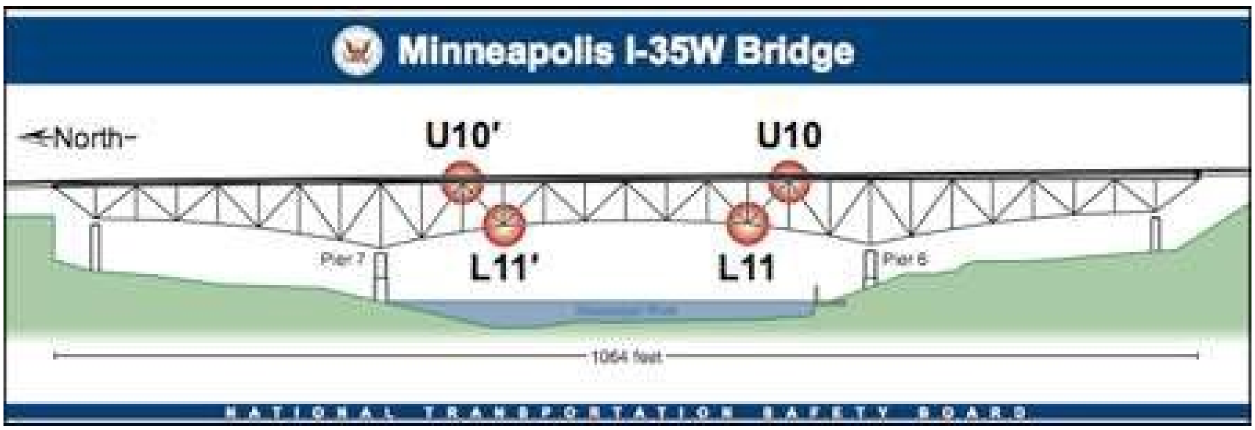
I-35W Highway Bridge after collapse
Photo: NTSB

Collapse of I-35W Highway Bridge
Minneapolis, Minnesota
August 1, 2007

About 6:05 p.m. central daylight time on Wednesday, August 1, 2007, the eight-lane, 1,907-foot-long I-35W highway bridge over the Mississippi River in Minneapolis, Minnesota, experienced a catastrophic failure in the main span of the deck truss. As a result, 1,000 feet of the deck truss collapsed, with about 456 feet of the main span falling 108 feet into the 15-foot-deep river. A total of 111 vehicles were on the portion of the bridge that collapsed. Of these, 17 were recovered from the water. As a result of the bridge collapse, 13 people died, and 145 people were injured.

On the day of the collapse, roadway work was underway on the I-35W bridge, and four of the eight travel lanes (two outside lanes northbound and two inside lanes southbound) were closed to traffic. In the early afternoon, construction equipment and construction aggregates (sand and gravel for making concrete) were delivered and positioned in the two closed inside southbound lanes. The equipment and aggregates, which were being staged for a concrete pour of the southbound lanes that was to begin about 7:00 p.m., were positioned toward the south end of the center section of the deck truss portion of the bridge and were in place by about 2:30 p.m.

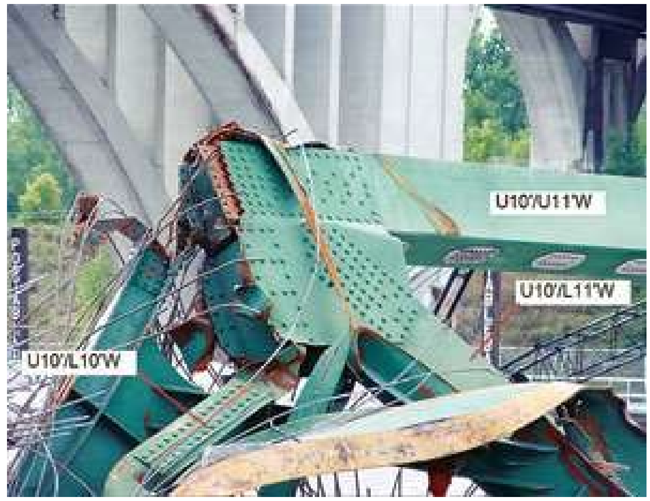
About 6:05 p.m., a motion-activated surveillance video camera at the Lower St. Anthony Falls Lock and Dam, just west of the I-35W bridge, recorded a portion of the collapse sequence. The video showed the bridge center span separating from the rest of the bridge and falling into the river.



Credit: the National Transportation Safety Board

The National Transportation Safety Board determines that the probable cause of the collapse of the I-35W bridge in Minneapolis, Minnesota, was the inadequate load capacity, due to a design error by Sverdrup & Parcel and Associates, Inc., of the gusset plates at the U10 nodes, which failed under a combination of (1) substantial increases in the weight of the bridge, which resulted from previous bridge modifications, and (2) the traffic and concentrated construction loads on the bridge on the day of the collapse. Contributing to the design error was the failure of Sverdrup & Parcel's quality control procedures to ensure that the appropriate main truss gusset plate calculations were performed for the I-35W bridge and the inadequate design review by Federal and State transportation officials. Contributing to the accident was the generally accepted practice among Federal and State transportation officials of giving inadequate attention to gusset plates during inspections for conditions of distortion, such as bowing, and of excluding gusset plates in load rating analyses.

Before determining that the collapse of the I-35W bridge initiated with failure of the gusset plates at the U10 nodes, the Safety Board considered a number of potential explanations. The following factors were considered, but excluded, as being causal to the collapse: corrosion damage in gusset plates at the L11 nodes, fracture of a floor truss, preexisting cracking, temperature effects, and pier movement.



By early 2008, NTSB team knew gusset plates, half as thick as required, were critical factors behind 2007 bridge collapse. Photo: NTSB

The following safety issues were identified in this investigation:

- Insufficient bridge design firm quality control procedures for designing bridges, and insufficient Federal and State procedures for reviewing and approving bridge design plans and calculations.
- Lack of guidance for bridge owners with regard to the placement of construction loads on bridges during repair or maintenance activities.
- Exclusion of gusset plates in bridge load rating guidance.
- Lack of inspection guidance for conditions of gusset plate distortion.
- Inadequate use of technologies for accurately assessing the condition of gusset plates on deck truss bridges.

As a result of this accident investigation, the Safety Board makes recommendations to the Federal Highway Administration and the American Association of State Highway and Transportation Officials. One safety recommendation resulting from this investigation was issued to the Federal Highway Administration in January 2008 (see Appendix.)

Engineering disasters such as the I-35W Bridge Collapse have certainly made our professions more vigilant. Engineering is a precise science. Attention to detail and the highest safety standards must be adhered to at all times to prevent any potential design error and omission.

Tips for Avoiding Design Blunders

Although engineering failure modes vary from one structure to another, these failures are usually caused by one of the following factors:

- human errors
- design flaws
- materials defects
- extreme conditions or environments
- a combination of the above factors

The tips compiled in this course are aimed at helping reduce human errors and design flaws, which are the primary causes of many engineering failures.

In his book *The Civilized Engineer*, Samuel C. Florman summaries various forms of incompetence and their shares for failures attributable to engineering:

Insufficient knowledge	36%
Underestimation of influence	16%
Ignorance, carelessness, negligence	14%
Forgetfulness, error	13%
Relying upon others without sufficient control	9%
Objectively unknown situation	7%
Imprecise definition of responsibilities	1%
Choice of bad quality	1%
Others	3%
	100%

The above statistical data are derived from a study conducted at the Swiss Federal Institute of Technology in Zurich, which analyzed 800 structural failures in which 504 people were killed and 592 people injured. These data indicate that engineers and architects need to be more careful in their work, more thoughtful in proposing solutions, and more aware of new technological development.

The photo on the right shows a 12-story building toppled over in the early morning hours of June 27, 2009. This apartment building was located in the eastern outskirts of Shanghai, China. Here is what happened:

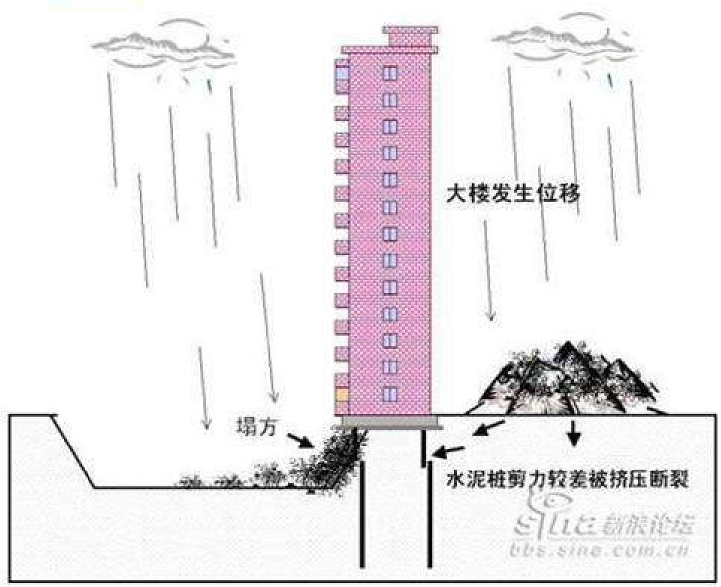
After the building was constructed,

(1) An underground garage was being dug on the south side, to a depth of 4.6 meters.

(2) The excavated dirt was being piled up on the north side, to a height of 10 meters.

(3) The building experienced uneven lateral pressure from south and north.

(4) This resulted in a lateral pressure of 3,000 tones, which was greater than what the foundation piles could tolerate. Thus the building toppled over in the southerly direction.



Photos: www.sina.com.cn

Obviously, improper planning and failure to stabilize the structural foundation had led to the collapse of this residential building – a typical human error. Luckily, the building was not occupied and did not hit other building when collapsed.

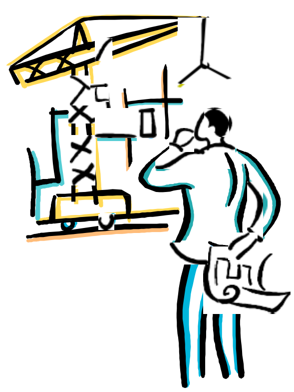
Here are the tips for avoiding design blunders:

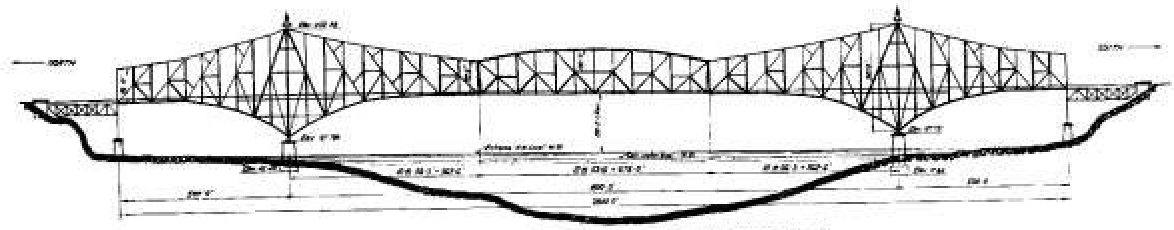
1. Visit Project Site

A simple and indispensable way to avoid any potential design blunder is to visit the project site during the design stage, especially for renovation projects and for projects surrounded by other buildings or utilities. A site visit will also help you visualize your project in 3D space. While on the site, always take plenty of pictures for later review. Oftentimes, your site visit will reveal conflicting information or interfering structures not shown on the preliminary plans.

Once the project is under construction, designers should again periodically visit the site to see if there are any unexpected problems. Such site visits will provide another opportunity to correct any mistakes to avoid costly repair later, and to provide the owner with a greater degree of confidence that the completed work will conform to the contract documents. It is highly recommended that a written checklist be provided to contractors after each site visit so any outstanding issue can be followed up later.

In addition, carefully administered site visits by the architect or engineer will result in a reduced number of disputes and a timely resolution of disputes between owner and designer and between owner and contractor.





GENERAL ELEVATION OF THE DESIGN PROJECTED BY THE PHOENIX BRIDGE COMPANY.

The first Quebec Bridge collapse on August 29, 1907 (during construction) can be partially attributed to the lack of site visits during the construction by the bridge designer.

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The Quebec Bridge was twenty years in the making, from the founding of the Quebec Bridge Company in 1887 to the bridge's collapse in 1907. A cantilever bridge was proposed as the most feasible design to bridge the harsh, icy waters of the St. Lawrence River. A riveted steel truss structure, the Quebec Bridge has an eighteen-hundred-foot main span, exceeding in length by some ninety feet the then-longest cantilever, the Forth Bridge in Scotland. The original design for the bridge called for a span of sixteen hundred feet, but Theodore Cooper, the consulting engineer, recommended changing the design after the contract for construction had been drawn up. Thus, cost projections were modified; resulting design changes led to strain on the lower compression members and the bridge's collapse.

During the three languid years that preceded the project's lurch into progress, Cooper visited the site of the bridge three times. His third visit, in May 1903, when he was sixty-four, would be his last. After that, he would decline requests that he come to Quebec. His health was poor, he said, and his physician had advised him not to travel. From that point on, he would oversee the construction of the world's longest spanning bridge from his office in New York, and the rest becomes the history of the world's worst bridge construction disaster, in which 75 workers were killed and 11 injured.

Unfortunately, the Quebec Bridge suffered the second construction failure nine years later during its reconstruction. This time, 13 lives were lost. The bridge was finally completed in 1917, and stands today.

2. Create Redundancy

The redundancy in the reinforced concrete floor construction prevented the total collapse of the building shown on the left even when one of the supporting columns was completely destroyed during the Great Sichuan Earthquake on May 12, 2008 (China). Many buildings with precast concrete floor planks in the same region fared much worse than this cast-in-place concrete floor.

Photo: www.sina.com.cn

In engineering, redundancy is the duplication of critical components or functions of a system with the intention of increasing reliability of the system, usually in the form of a backup or fail-safe.

Redundancy can be added to all kinds of systems and it can help you prevent disaster down the road. For example, a continuous roof beam over several columns provides some redundancy in a building structure. A suspension bridge's numerous cables as shown below are also a form of redundancy.

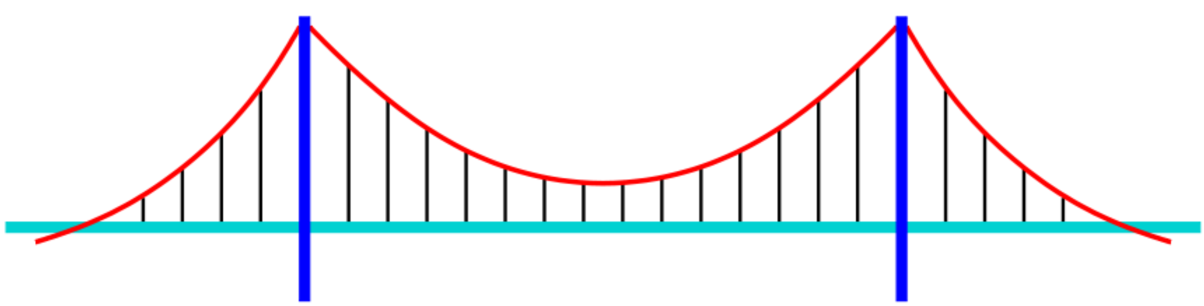


Illustration of a suspension bridge: Wikimedia

Other examples of redundancy in engineering range from back-up controls and power systems in airplanes to extra hard drives and power supplies in computers used in data centers. The Internet itself is a prime example of redundancy, as most of its core transport networks and popular sites have been designed to withstand the failure of individual links or nodes.

In many safety-critical systems, such as hydraulic systems in aircraft, some parts of the control system may be triplicated, which is formally termed triple modular redundancy (TMR). An error in one component may then be out-voted by the other two. In a triply redundant system, the system has three sub components, all three of which must fail before the system fails. Since each one rarely fails, and the sub components are expected to fail independently, the probability of all three failing is calculated to be extraordinarily small; often outweighed by other risk factors, e.g., human errors.

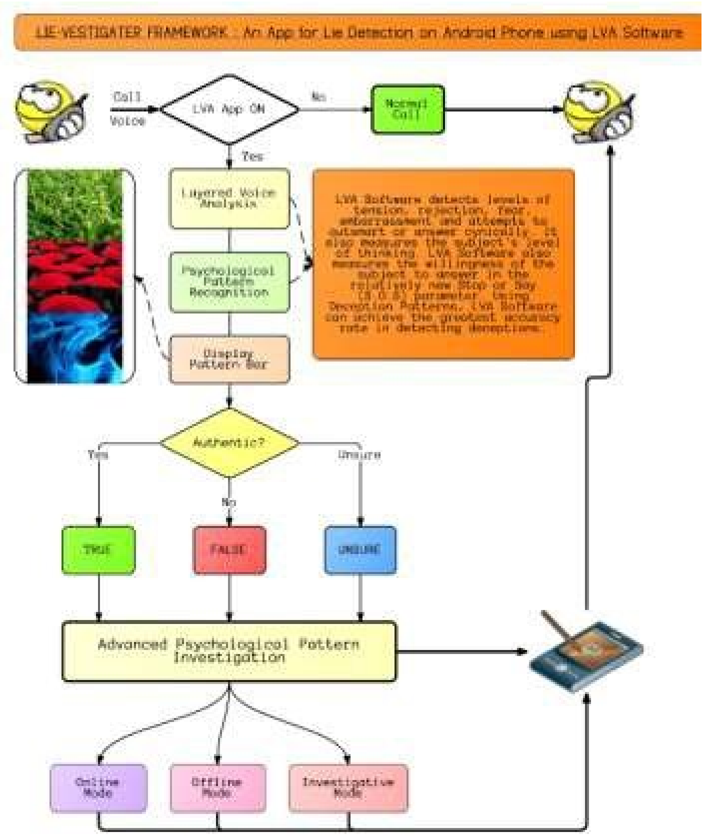
Space Shuttle Challenger's smoke plume after its in-flight breakup, resulting in its destruction and the deaths of all seven crew members. Afterwards, there was a total redesign of the solid rocket boosters, in which three O-rings were incorporated to increase the redundancy and reliability.
Photo: NASA

On 28 January 1986, space shuttle Challenger broke apart, killing its seven crew members just 73 seconds after its launch. The subsequent Rogers Commission found the cause of the accident was the failure of both primary and secondary O-rings on the right solid rocket booster, allowing pressurized gas to reach the outside. This in turn caused the external tank to dump its payload of liquid hydrogen causing a massive explosion. The problems with the O-rings had been known about for nine years but had been ignored, partly because safety was deemed ensured with the presence of the second ring. However, as was later made clear, the second ring was there for unforeseen failure, not a failure that had been considered. Engineers' warnings that low temperatures would exacerbate the problem were also ignored by NASA managers because of pressure to keep to the launch timetable (human errors).

3. Show and Don't Tell

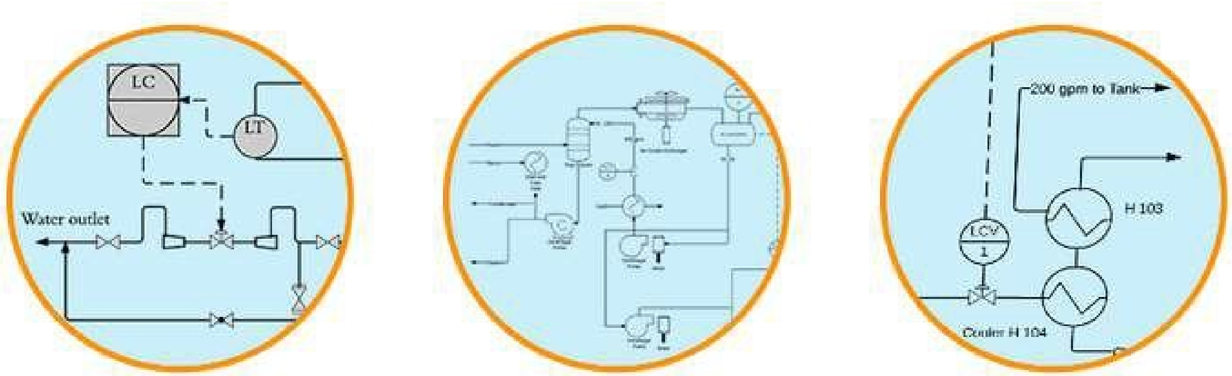
The adage that "a picture is worth a thousand words" is as true a guide to design information dissemination as to other communications. A graphic can communicate best if it is carefully designed and constructed for its purpose. Most often, graphics include writing to draw attention to specific features or to explain individual items. So try to communicate with contractors through sketches and diagrams as much as possible. With the help of a computer, 3D rendering or modelling can also be easily created to facilitate communication.

As a professional, you know that it can be difficult to create expressive flowcharts or diagrams that are both compact and look good. Software tools such as Gliffy and LucidChart make all that easy by transforming the diagramming process into interactive dragging-and-dropping. Multiple users can work simultaneously on the same flowchart, encouraging collaboration. The iPad and Android apps allow you to make diagrams on the go that are ready for a presentation or just sharing with colleagues.

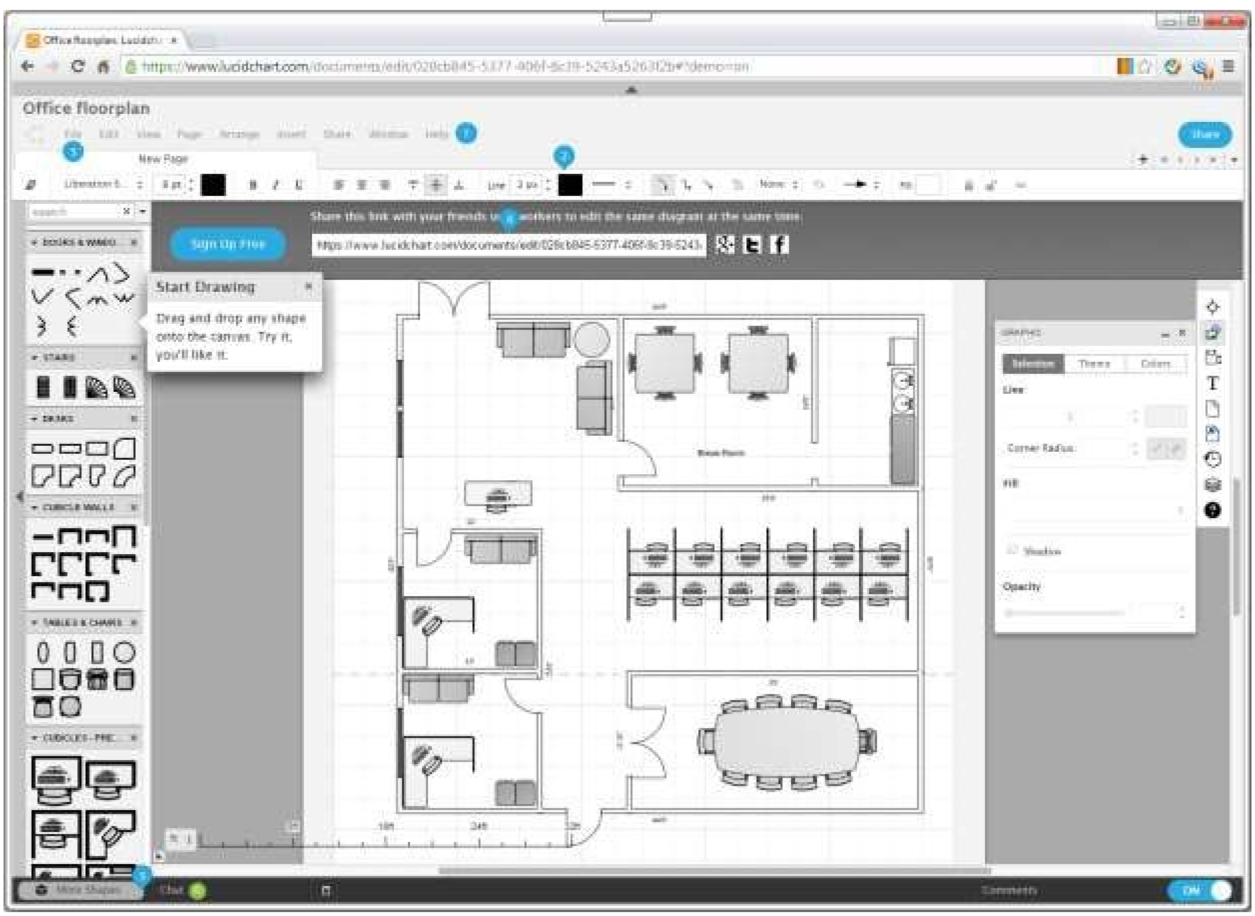


Flowchart Example from LucidChart.com

Besides flowcharts and business diagrams, LucidChart can also be used to generate various engineering applications such data flow diagrams, value stream maps, network diagrams, circuit diagrams, P&ID diagrams and floor plans.



P&ID Diagram Samples: LucidChart.com



Office floor plan created using LucidChart

4. Don't Repeat

A typical project usually involves tens of thousands of items and dimensions. The best way to avoid any conflict is not to repeat the same information on different sheets.

In this CAD age, it is very tempting to label all dimensions on construction drawings since it can be easily done during the design stage. However, all these duplicated information could become a burden during the construction stage when some changes are inevitable. When that happens, it becomes a daunting task to make all the necessary changes throughout the entire set of drawings. If the changes are not completely done, there will be conflicting information on different drawings, which will lead to more confusion during the construction.

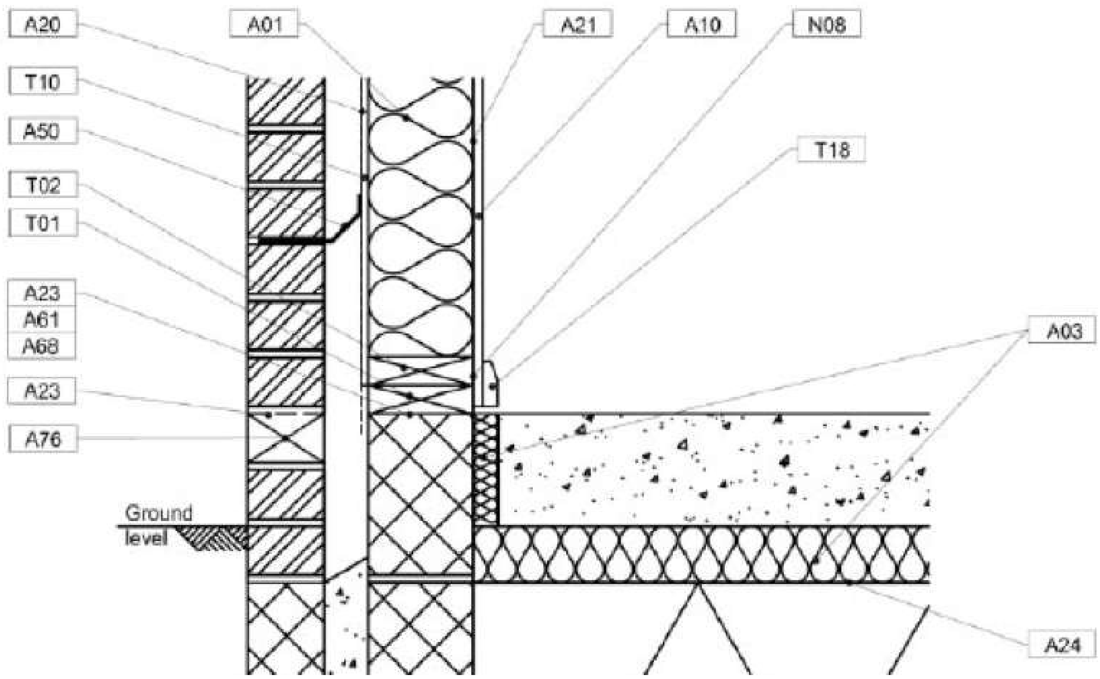
Not repeating the same information will also reduce the liability of design professionals while making it easier for any changes during the construction. However, it may not be very convenient for contractors to find the information easily in a set of plans with hundreds of sheets. One way to ease that problem is to create an alpha-numeric referenced product list that can be located near the beginning of a set of plans and can be easily changed during the construction. Here are a sample referenced product list and its application:

A01 – R-19 FIBERGLASS BATT INSULATION
A10 – 1/2" (MIN) INTERIOR GYPSUM BOARD
A20 – 1/2" (MIN) EXTERIOR GYPSUM BOARD
A23 – 8" CMU GROUTED SOLID
A50 – METAL FLASHING
…
T01 – 2x8 PRESSURE TREATED BOTTOM PLATE
T02 – 2x8 WOOD PLATE
T10 – 2x8 WOOD STUDS 16" O.C.
…

H-EX-01 & F-EX-01 – Mineral Wool

Junction of external wall and foundations: concrete slab floor with insulation below slab, with masonry upstand

Drawings not to scale



Credit: TRADA

5. Check Units

Some of the common mistakes in engineering calculations are due to the incorrect unit conversion or the use of non-consistent units. The unit conversion mistakes are not limited to students or inexperienced interns, it also happens to seasoned engineers or navigators like Christopher Columbus. He miscalculated the circumference of the earth when he used Roman miles instead of nautical miles, which is part of the reason he unexpectedly ended up in the Bahamas on October 12, 1492, and assumed he had hit Asia. Another incident involves an Air Canada plane in 1983, which ran out of fuel in the middle of a flight. The cause? Not one but two mistakes in figuring how much fuel was needed. It was Air Canada's first plane to use metric measurements and not everyone had the hang of it yet. Luckily, no one was killed and only two people received minor injuries. That's amazing considering the flight crew thought they had double the fuel they actually had.

Photo: Wikipedia

In 1999, NASA lost its $125-million Mars Climate Orbiter because spacecraft engineers failed to convert from English to metric measurements when exchanging vital data before the craft was launched.

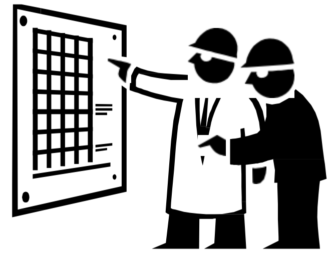
A navigation team at the Jet Propulsion Laboratory used the metric system of millimeters and meters in its calculations, while Lockheed Martin Astronautics in Denver, which designed and built the spacecraft, provided crucial acceleration data in the English system of inches, feet and pounds. As a result, JPL engineers mistook acceleration readings measured in English units of pound-seconds for a metric measure of force called newton-seconds.

Asking someone to check your answer and units or to derive another independent answer could help you prevent this type of embarrassing mistakes.

When using software for engineering analysis and design, it is also very important to use consistent units for all input data.

For large size projects with many team members, it is highly recommended to establish a preferred unit system for the entire project team.

6. Request Peer Review



Peer review is the evaluation of work by one or more people of similar competence to the producers of the work (peers). It constitutes a form of self-regulation by qualified members of a profession within the relevant field. Peer review methods are employed to maintain standards of quality, improve performance, and provide credibility.

An engineering peer review may also be called a technical peer review, a product peer review, a peer inspection. Engineering peer reviews are a well-defined review process for finding and fixing defects, conducted by a team of peers with assigned roles.

When a licensee's technical competence becomes questionable as a result of a board investigation, some state licensing boards for design professionals may require the licensee to go through the peer review process for his/her design work for a certain period of time as a form of disciplinary action. In this case, the peer review process is designed to improve the licensee's competence and to ensure the safety of the public.

7. Use Building Information Modeling Tools

BIM Screenshots | Credit: DPR Construction

Many contemporary structures push the envelope of building design, exploring space and the limits of modern engineering, sometimes through amorphous volumes and organic forms. Given the new level of complexity, we need to use the latest design tools such as Building Information Modeling (BIM).

BIM is a process involving the generation and management of digital representations of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility. It forms a reliable basis for decisions during a building's life-cycle, from earliest conception to demolition.

Individuals, businesses and government agencies use BIM to plan, design, construct, operate and maintain diverse physical infrastructures, from water, wastewater, electricity, gas, and communication utilities to roads, bridges and ports, from houses, apartments, schools and shops to offices, factories, warehouses and prisons, etc.

The David H. Koch Institute for Integrative Cancer Research at the Massachusetts Institute of Technology Photo: The Tech

One of the major benefits of BIM is its ability to allow virtual building and clash detection prior to construction. From the pre-construction phase to the construction phase, everyone – designers, contractors, foremen – can review the model layer by layer and room by room, looking at doors, windows, pipes, even small scale things like conduits. Clash detection reporting generated by BIM enables the building team to make early changes, avoiding later, costly changes during the construction process. BIM also enables early coordination between disciplines and helps reduce time spent in the field. For example, the building team for the David H. Koch Institute for Integrative Cancer Research saved $650,000 by utilizing BIM to identify where beam penetrations needed to be, so that they could be incorporated at the time of steel fabrication.

The use of BIM has increased dramatically over the past few years, not just in architecture and engineering firms, but also industry-wide. ArchiCAD by Graphisoft, Bentley Building by Bentley Systems, and Revit by AutoCAD are some of the common BIM software used in the construction industry.

8. Conduct Pilot Studies

A pilot study, pilot project or pilot experiment is a small scale preliminary study conducted in order to evaluate feasibility, time, cost, adverse events, and effect size in an attempt to predict an appropriate sample size and improve upon design prior to performance of a full-scale project. For example, building designers often rely on mockup tests to see how a wall assembly with windows performs under driving rain.

For any new, untried system, a small-scale pilot study should be conducted whenever possible. In some fields, such as water treatment, such pilot studies are routine. Computer simulation has become very important in this field. Entire river systems can be modeled in great detail using software, and a little experience. Both water quality and quantity can be examined in this way and serious, unwanted consequences avoided.

Sometimes multiple pilot studies are necessary for comparison purposes.

Better known as the "sinking airport," Kansai International Airport was built on an artificial island (reclaimed land). The excessive and continuous soil settlement caused huge cost overruns for the construction and maintenance of this island. A pilot study could have prevented this geotechnical engineering disaster.

The construction of this artificial island started in 1987. Three mountains were excavated to create a 98 ft layer of earth over the sea floor and inside the sea wall. The island had been predicted to sink 19 ft by the most optimistic estimate as the weight of the material used for construction compressed the seabed silts. However, the island had sunk 27 ft during the construction alone – much more than predicted. In 1991, the terminal construction commenced. To compensate for the ongoing sinking of the island, adjustable columns were designed to support the terminal building. They are extended by inserting thick metal plates at their bases.

9. Resolve Conflicts

Given the large number and variety of documents required to administer a construction project today (plans, specifications, shop drawings, etc.), the likelihood of discrepancies arising between these different sources is almost unavoidable.

Many specification writers attempt to resolve these in advance by declaring an order of precedence among the contract documents. Here is a sample of such a specification:

***

Precedence

If there is a conflict between contract documents, the document highest in precedence shall control. The precedence shall be: first, permits from other agencies as may be required by law; second, Special Provisions; third, Plans; fourth, reference specifications…

***

Recently the trend has been away from such specific requirements for one simple reason. We do not know, before they are revealed, what problems will arise. Declaring a specific order presumes we know how best to solve a problem before we know what the problem is.

The following sample specification shows an alternate approach which emphasizes the intent of the design. It has been found to work well on many projects.

***

If a conflict, error, omission, or lack of detailed description is discovered in the contract documents, the Contractor shall immediately notify the Designer and request clarification. The Designer will resolve the conflict and make any corrections or interpretations necessary to fulfill the intent of the plans and specifications.

***

In the event of a legal conflict, a clear understanding of which document is "controlling" is critical in resolving discrepancies. Usually, conflicts between plans and specifications are resolved under the general rule that specifications exhibit control over plans. Therefore, all engineers working on a project should get familiar with the project specifications while developing project plans. The details and description on project plans shall match the language in project specifications.

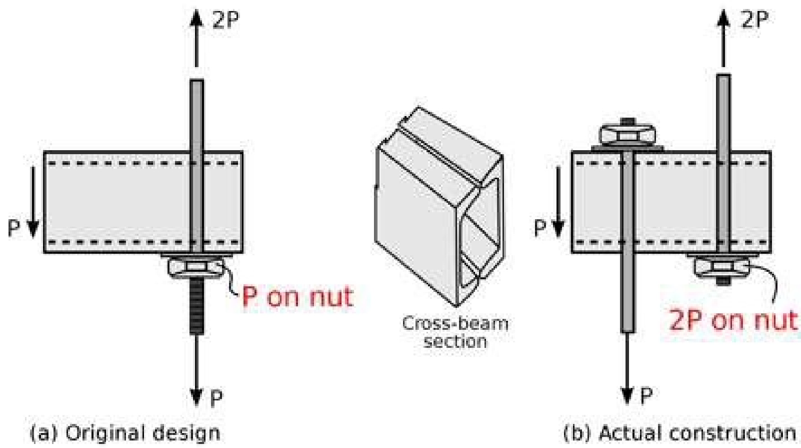


Diagram: Wikimedia. Connection details of a cross beam on the fourth-floor elevated walkway (the Hyatt Regency Crown Center in Kansas City, MO)

The Kansas City Hyatt Regency hotel walkway collapse occurred on Friday, July 17, 1981. Two vertically contiguous walkways collapsed onto a dance competition being held in the hotel's lobby. The falling walkways killed 114 and injured 216 people. It remains the worst single-structure collapse in terms of loss of life due to engineering/management errors in U.S. history.

This tragedy did not occur as a result of innovative design, construction or material use, but rather as a product of several engineering and management errors. It was these fatal errors that resulted in the flawed construction detail to be used in the support system of the walkways of the Hotel Atrium. Various events and disputed communications between G.C.E. engineers and Havens Steel Company resulted in the design change from a single to a double hanger rod box beam connection on the fourth floor walkways. The original design detail of continuous threading of the nut through two stories of the building appeared to be impractical to the contractor and as such he changed the design drawings and replaced the original single hanger rod design with a two rod system (see details above). In the two rod system, one rod goes from the lower to the upper bridge and the other goes from the upper bridge to the roof truss, which resulted in the doubling of the load on the supporting nut/beam.

10. Use Proper Writing Style

Specifications, notes on the plans and other directions to the contractor must be written in a style that demonstrates not only brevity, but also clarity. Since project specifications are directed to the construction Contractor, you do not need to use the term "the Contractor shall." Instead, write in a direct, active voice with simple, concise sentences as much as possible. Use the imperative mood (e.g., Install equipment) except when clarity requires the use of the indicative mood (e.g., equipment must). In addition, use the directive style in the imperative mood to minimize words and to ease interpretation:

- *Spread adhesive with a notched trowel.*
- *Install equipment plumb and level.*
- *Apply two coats of paint to exposed surface.*

Avoid statements like:

- *Adhesive shall be spread with notched trowel.*
- *Equipment shall be installed plumb and level.*
- *Two coats of paint shall be applied to each exposed surface.*

To avoid ambiguity and potential misunderstanding, Unified Facilities Criteria (UFC) 1-300-02 suggests:

- Avoid the use of colloquial terms or jargon. For example, do not use "bulkhead" for wall, "deck" for floor, or “drywall” for gypsum board.
- Eliminate redundant and superfluous wording such as "conforming to," "all," and "type."
- Avoid the use of indefinite items such as "etc.," "any," and "and/or."
- Avoid the use of vague words and phrases or escape clauses such as "as may be required," "as necessary," “securely," "thoroughly," "suitable," "properly," "good working order," "neatly," and "installed in a neat and workmanlike manner.”
- Avoid the use of pronouns "he," "his," "this," "they," "their," "who," "it," and "which." Pronouns should be used sparingly if at all; it is usually better to repeat the noun.
- Capitalize "Contractor," "Contracting Officer," "Government," ”Owner,” and “Contract” in specifications.

Use of abbreviations and acronyms must follow the practices within the discipline involved and be defined at their first use in a section. At the first use, write out the term completely and follow with the abbreviation or acronym in parentheses.

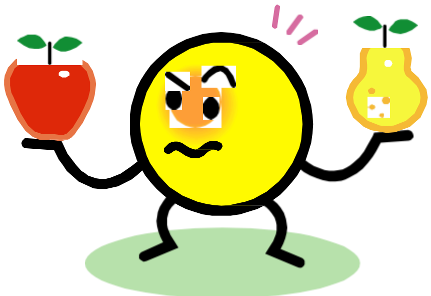
Specifications should speak only to the Contractor, not the subcontractor, supplier or manufacturer. The Contractor cannot be directed through the manufacturer or supplier or vice versa. Stating "the manufacturer must provide," could be interpreted as simply informing the Contractor that a party other than the Contractor is responsible. Here are some additional recommended rules:

- Avoid the use of "shall" and "must;" if use cannot be avoided, use “must” instead of “shall” unless it changes the meaning of the sentence.
- Do not use the word “should” in the specification text for mandatory requirements as “should” implies a recommendation. “Should” may be used in the Notes to indicate desirable procedures that are advisory in nature.
- Do not use the term "furnish" unless only delivery of material to the site is required. Use "provide" to mean "furnish and install."
- Do not use the word "per" but use "in accordance with" instead.

Bhopal memorial for those killed and disabled by the 1984 toxic gas release
Photo: Wikimedia

The Bhopal disaster, also referred to as the Bhopal gas tragedy, was a gas leak incident in India, considered the world's worst industrial disaster. It killed more than 3,700 people and caused significant morbidity and premature death for many thousands more. The leak of over 40 tons of methyl isocyanate gas was caused by a series of mechanical and human errors in the pesticide-producing plant, operated by the Union Carbide Corporation, a U.S.-based multinational. Since the disaster, India has experienced rapid industrialization. Widespread environmental degradation with significant adverse human health consequences continues to occur throughout India.

11. Find the Comparable



Most projects are not unique in all respects. Some similar projects may have been constructed previously in your geographic area. When faced with a new design assignment, you will find it very useful to look around your own or check with other colleagues to see if you can find similar projects. The Internet is certainly another source of abundant information. If there are parallels, use them as models of both what you want to accomplish in your design and what errors you want to avoid. For example, when there is not enough time to do any calculations to determine the proper concrete column size for a five story hospital building during a meeting, you may come up with a preliminary size based on another hospital project with the same number of floors and a similar bay size. In addition, taking advantage of the similar project would significantly reduce the workload as many construction details are applicable to similar projects. All final designs should be tailored to your project, however.

If these similar projects have been built and put into service, see if you can visit them and talk to the people who own and operate them. They will tell you what they like and do not like, which can be invaluable to the next similar project.

12. Follow Natural Laws


Photo: AP

Many of you probably remember this image from your television. As Hurricane Katrina roared ashore in the summer of 2005, the long-ignored warnings about the inadequacy of New Orleans' defenses came shockingly, vividly alive. The flooding of New Orleans that followed was a tragic and appalling disaster. But it was not a natural disaster. Poor project planning, flawed project design, misplaced priorities, and the destruction of the city's natural flood protection – Louisiana's coastal wetlands, were the root causes of the city's ruin. Ultimately 80 percent of New Orleans and large portions of nearby parishes became flooded, and the floodwaters did not recede for weeks. After Katrina, organizations such as American Rivers have called for the adoption of natural flood protection and the abandonment of over-reliance on structural protection as a new approach to flood protection across the country.

This tip is about the natural laws governing the construction industry. Here are just three simple natural laws to keep in mind when you work on your projects:

(a) **Water flows from high ground to low ground.** Therefore, you should avoid locating a building in a low lying area as it will be more susceptible to flooding. For all your projects, you should create exterior grading plans with positive slope to divert water away from the structures.

(b) **All caulks tend to lose their flexibility as they age and will begin to crack over time.** If your design has to rely on caulking to stop water leakage or seepage, you may have to meet your client in the courtroom down the road. Many caulked joints are effective for only a few years. To make your structure waterproof, you need to revise your design until water will not leak or seep through even if caulking fails. Usually, grouted joints are more permanent than caulked joints. Where feasible, use metal flashing to direct water away from the building interior.

(c) **All wood decays or warps in outdoor environments.** So if you have an exposed element in your design, try to use more durable plastic composite materials or corrosion-resistant metal instead of wood. If you must use wood to support exterior structures such as a porch, set the wood column on a pedestal to keep the bottom of the wood free from moisture.

The Ray and Maria Stata Center at MIT defies some natural laws governing construction. Photo: The Tech

When the $300 million Stata Center opened in 2004 at Massachusetts Institute of Technology (MIT), it got a lot of press, especially for its novel appearance featuring tilting towers, many-angled walls and whimsical shapes. However, the building soon suffered persistent leaks, blocked drainage and falling ice. As a result, MIT filed a lawsuit in 2007 against the design and construction teams.

13. Develop a Checklist

Checklists help ensure consistency and completeness in carrying out a task. A basic example is the "to do list." A more advanced checklist would be a schedule, which lays out tasks to be done according to time of day or other factors.

Checklist formats generally have a description of what needs to be checked in the document as various bullet points with a check box next to it. The engineer or designer needs to check out the box with a X or √ after verifying that the requisites of the particular point mentioned in the checklist are fulfilled for the document being checked. A digital checklist could be easily created or modified using MS Word or Excel. There are also apps available to create a checklist on convenient mobile devices.

Some established engineering consulting companies already have standard checklists for most engineering design activities. However, these standard checklists need to be reviewed periodically as part of the overall quality management system of the organization in keeping with the latest changes in engineering design philosophy and client requirements.

The following is an example of a completed partial checklist for utility distribution sheet review:

- ✓ Is the Utility Distribution Diagram plot plan oriented?
- ✓ Are all Utilities shown?
- ✓ Are the branches from the Utility headers in the correct sequence?
- ✓ Are the sizes for all the branches all known and indicated?
- ✓ Is the number of Utility Stations correct?
- ✓ Are the Utility Stations numbered?
- ✓ Are the Utility Stations schematically located correctly?
- ✓ Do the connectors from the Utility Distribution Diagram match the connector on the P&ID?
- ✓ Is there a Line Identification (Line Number, Line Designation or other) for each line?

Course Summary

Through this course, you have learned some error prevention techniques that can be incorporated into your practice. These techniques are aimed at improving the quality of your work, reducing your chances of making errors, and better protecting the health and safety of the general public.

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The tips compiled in this course are based on the advice of several contributors and on the personal experience of licensed professionals like you. If you feel that you can contribute additional error prevention tips to this course, please send us your feedback through email (John at PDHOnline.com) or through "Contact Us" on our website. If your feedback is more than 250 words, you will receive two additional PDH through the companion course "Tips for Avoiding Design Blunders – Feedback." Your effort will also be credited within the course content if your tips are incorporated into the next version of the course.

Appendix: I-35W Bridge Collapse Investigation Outcome

What did we learn from the tragic I-35W Bridge Collapse? The following excerpts from NTSB Highway Accident Report NTSB/HAR-08/03 provide a glimpse of the findings and recommendations by the NTSB.

Conclusions

Findings

1. The initiating event in the collapse of the I-35W bridge was a lateral shifting instability of the upper end of the L9/U10W diagonal member and the subsequent failure of the U10 node gusset plates on the center portion of the deck truss.
2. Because the deck truss portion of the I-35W bridge was non-load-path-redundant, the total collapse of the deck truss was likely once the gusset plates at the U10 nodes failed.
3. The examination of the collapsed structure, the finite element analysis, and the video recording of the collapse showed that the following were neither causal nor contributory to the collapse of the I-35W bridge: corrosion damage found on the gusset plates at the L11 nodes and elsewhere, fracture of a floor truss, preexisting cracking in the bridge deck truss or approach spans, temperature effects, or shifting of the piers.
4. The initial emergency response to the bridge collapse by fire and rescue units was timely and appropriate, and the incident command system was well coordinated.
5. The damage to bridge components that occurred during victim recovery did not, in this case, prevent determination of the collapse sequence.
6. The gusset plates at the U10 nodes, where the collapse initiated, had inadequate capacity for the expected loads on the structure, even in the original as-designed condition.
7. Because the bridge’s main truss gusset plates had been fabricated and installed as the designers specified, the inadequate capacity of the U10 node gusset plates had to have been the result of an error on the part of the bridge design firm.

8. Even though the bridge design firm knew how to correctly calculate the effects of stress in gusset plates, it failed to perform all necessary calculations for the main truss gusset plates of the I-35W bridge, resulting in some of the gusset plates having inadequate capacity, most significantly at the U4 and U4′, U10 and U10′, and L11 and L11′ nodes.
9. Although the U10 gusset plates would have required edge stiffeners according to American Association of State Highway Officials specifications, the addition of stiffeners would not have made the U10 gusset plates adequate or prevented the gusset plates from yielding.
10. The design review process used by the bridge design firm was inadequate in that it did not detect and correct the error in design of the gusset plates at the U4 and U4′, U10 and U10′, and L11 and L11′ nodes before the plans were made final.
11. Neither Federal nor State authorities evaluated the design of the gusset plates for the I-35W bridge in sufficient detail during the design and acceptance process to detect the design errors in the plates, nor was it standard practice for them to do so.
12. Current Federal and State design review procedures are inadequate to detect design errors in bridges.
13. Because current American Association of State Highway and Transportation Officials guidance directs bridge owners to rate their bridges when significant changes occur but not before they place new bridges in service, the load carrying capacity of new bridges may not be verified before they are opened to traffic.
14. Had American Association of State Highway and Transportation Officials guidance included gusset plates in load ratings, there would have been multiple opportunities to detect the inadequate capacity of the U10 gusset plates of the I-35W bridge deck truss.
15. Because bridge owners generally consider gusset plates to be designed more conservatively than the other members of a truss, because the American Association of State Highway and Transportation Officials provides no specific guidance for the inspection of gusset plates, and because commonly used computer programs for load rating analysis do not include gusset plates, bridge owners typically ignore gusset plates when performing load ratings, and the resulting load ratings might not accurately reflect the actual capacity of the structure.
16. The loading conditions that caused the failure of the improperly designed gusset plates at the U10 nodes included substantial increases

in the dead load from bridge modifications and, on the day of the accident, the traffic load and the concentrated loads from the construction materials and equipment; if the gusset plates had been designed in accordance with American Association of State Highway Officials specifications, they would have been able to safely sustain these loads, and the accident would not have occurred.

17. Without clear specifications and guidelines to direct bridge owners regarding the stockpiling of raw materials, they may fail to conduct the appropriate engineering reviews or analyses before permitting raw materials to be stockpiled on a bridge.
18. Although the I-35W bridge had been inspected in accordance with the National Bridge Inspection Standards and more frequently than required by the standards, these inspections would not have been expected to detect design errors.
19. Although the I-35W bridge had been rated under the National Bridge Inspection Standards as *Structurally Deficient* for 16 years before the accident, the conditions responsible for that rating did not cause or contribute to the collapse of the bridge.
20. The bowing of the gusset plates at the U10 and U10′ nodes was symptomatic of the inadequate capacity of the plates and occurred under an undetermined load condition before 1999.
21. Because visual bridge inspections alone, regardless of their frequency, are inadequate to always detect corrosion on gusset plates or to accurately assess the extent or progression of that corrosion, inspectors should employ appropriate nondestructive evaluation technologies when evaluating gusset plates.
22. Distortion such as bowing is a sign of an out-of-design condition that should be identified and subjected to further engineering analysis to ensure that the appropriate level of safety is maintained.
23. Because the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* does not include gusset plates as a separate bridge inspection element, bridge owners may fail to adequately document and track gusset plate conditions that could threaten the safety of the structure.
24. The lack of specific references to gusset plates in the *Bridge Inspector's Reference Manual* and in National Highway Institute bridge inspector training courses could cause State bridge inspectors during routine or fracture-critical bridge inspections to fail to give appropriate attention to distortions, such as bowing, in gusset plates.

Recommendations

As a result of its investigation of the collapse of the I-35W bridge in Minneapolis, Minnesota, the National Transportation Safety Board makes the following safety recommendations:

New Recommendations

To the Federal Highway Administration:

Develop and implement, in conjunction with the American Association of State Highway and Transportation Officials, a bridge design quality assurance/quality control program, to be used by the States and other bridge owners, that includes procedures to detect and correct bridge design errors before the design plans are made final; and, at a minimum, provides a means for verifying that the appropriate design calculations have been performed, that the calculations are accurate, and that the specifications for the load-carrying members are adequate with regard to the expected service loads of the structure. (H-08-17)

Require that bridge owners assess the truss bridges in their inventories to identify locations where visual inspections may not detect gusset plate corrosion and where, therefore, appropriate nondestructive evaluation technologies should be used to assess gusset plate condition. (H-08-18)

Modify the approved bridge inspector training as follows:
(1) update the National Highway Institute training courses to address inspection techniques and conditions specific to gusset plates, emphasizing issues associated with gusset plate distortion as well as the use of nondestructive evaluation at locations where visual inspections may be inadequate to assess and quantify such conditions as section loss due to corrosion; and,
(2) at a minimum, include revisions to reference material, such as the *Bridge Inspector's Reference Manual*, and address any newly developed gusset plate condition ratings in the American Association of State Highway and Transportation Officials commonly recognized (CoRe) structural elements. (H-08-19)

To the American Association of State Highway and Transportation Officials:

Work with the Federal Highway Administration to develop and implement a bridge design quality assurance/quality control program, to be used by the States and other bridge owners, that includes procedures to detect and correct bridge design errors before the design plans are made final; and, at a minimum, provides a means for verifying that the appropriate design calculations have been performed, that the calculations are accurate, and that the specifications for the load-carrying members are adequate with regard to the expected service loads of the structure. (H-08-20)

Revise your *Manual for Bridge Evaluation* to include guidance for conducting load ratings on new bridges before they are placed in service. (H-08-21)

Modify the guidance and procedures in your *Manual for Bridge Evaluation* to include evaluating the capacity of gusset plates as part of the load rating calculations performed for non-load-path-redundant steel truss bridges. (H-08-22)

When the findings of the Federal Highway Administration–American Association of State Highway and Transportation Officials joint study on gusset plates become available, update the *Manual for Bridge Evaluation* accordingly. (H-08-23)

Develop specifications and guidelines for use by bridge owners to ensure that construction loads and stockpiled raw materials placed on a structure during construction or maintenance projects do not overload the structural members or their connections. (H-08-24)

Include gusset plates as a commonly recognized (CoRe) structural element and develop guidance for bridge owners in tracking and responding to potentially damaging conditions in gusset plates, such as corrosion and distortion; and revise the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* to incorporate this new information. (H-08-25)

Previously Issued Recommendation Resulting From This Accident Investigation

As result of its investigation of this accident, the Safety Board issued the following safety recommendation to the Federal Highway Administration on January 15, 2008:

> For all non-load-path-redundant steel truss bridges within the National Bridge Inventory, require that bridge owners conduct load capacity calculations to verify that the stress levels in all structural elements, including gusset plates, remain within applicable requirements whenever planned modifications or operational changes may significantly increase stresses. (H-08-1)