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How Structural Engineers Find Errors in Analysis and Design Results. Practice Periodical on Structural Design and Construction

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Abstract: Errors in structural analysis and design are inevitable, but finding them early in the design process saves time and money. Knowledge of the broad causes of errors and how experienced engineers identify the presence of errors can inform training for structural engineers thus empowering them to find their own errors early in the design process. Therefore, this study presents 145 pieces of information about errors in structural analysis and design compiled from structured interviews with 35 structural engineers. The strategies used to find errors have been classified into eight categories: Comparison, Rule of Thumb, Information Check, Visualization, Extreme Value, Previous Experience, Field, and Other. Evaluation of the information shows that responsibility for quality control should not be held only with reviewers but should also be shared with the engineers creating the designs. Also, quality control training should be heavily influenced by the Comparison strategies. Overall, the specific examples of errors and the problems they cause could be helpful in developing in-house training and updating quality control procedures.

Author keywords: Analysis; Design; Errors; Mistakes; Quality Control.

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Motivation

Today's competition in the marketplace and complexity of structural designs necessitate the use of computers for structural analysis and design. With the introduction of computers, however, came the ability to make errors faster than ever before (Huston 2007, Weingardt 2013, Ruby 2020). For the purposes of this paper, "error" is defined as any act or omission by the engineer that would cause the design to not perform as intended. Errors in structural engineering are inevitable. The key is when the errors are found. Stecklein *et al*. (2004), studied the cost of finding errors at different stages of a project's life cycle. They were studying the development of hardware-software systems for NASA-type projects. Consistent with researchers in other fields, they found an exponential growth of cost of errors as a project proceeds through development. Their study showed that the cost of finding an error during operations, the structural engineering equivalent of finding it in the field, resulted in more than a 50× increase in cost to fix the error compared with finding the error during design.

The cost of finding structural engineering design errors in the field is also significant. Peansupap and Ly (2015) studied 11 building projects in Cambodia in order to determine the impact of design errors. They asked a civil engineer on each project to evaluate the likely impact of 122 different errors on the cost and schedule for the project. The errors on the list had all been observed previously by the engineers. For six of the projects, the likely impact would be "severe" where severe was defined as resulting in design revision, additional cost, but not a delay in the construction process. Lopez and Love (2012) obtained estimates of construction costs incurred due to design errors for 139 projects in Australia. The mean total cost of fixing the error was 14.3% of the original project price considering both direct and indirect costs.

Fast-tracking projects, starting construction before the design is complete, is becoming common. In 2002 Knecht reported that fast-track construction accounted for up to 40% of building projects at that time. Indications are that the percentage has increased since then. The faster time to construction means errors must be found earlier in the design process to avoid being found in the field. Also, in the typical building design process the structural engineer is making design decisions well in advance of the other design professionals (e.g., mechanical, electrical, plumbing); therefore, errors in the structural design must be found early to avoid a ripple effect of changes.

Finding errors in structural engineering designs as early as possible in the project life cycle will result in the smallest financial and time impact on the project. How structural engineers find those errors has not been well documented though. Authors have shared their personal recommendations (e.g., Ioannides *et al*. 2000, Willard and Quinn 2010a-d), but there has not been a broad study of the errors made, the problems caused by those errors, or the skills used to identify that there is an error. Knowledge of the broad causes of errors and how experienced engineers identify the presence of errors can inform training for structural engineers thus empowering them to find their own errors early in the design process.

Interview Process

To discover how structural engineers identify the presence of an error, interviews were conducted with building designers with a broad range of experiences. In total, 35 engineers from 9 different firms were interviewed during the second half of 2004. The participating firms were located in seven different states: New York, Pennsylvania, Indiana, Illinois, Texas, California, and Hawaii. The specific offices of those firms ranged in size from 1 to 55 structural engineers. Five of the engineers were female. The experience level of the engineers ranged from 1 to 55 years, with a median of 8 years. All but six of the engineers had their P.E. license at the time of the interviews. The highest degrees of the engineers were the following: 8 Bachelors, 26 Masters, and 1 Doctorate.

Several approaches were used to elicit information from the engineers in the interviews: the critical incident technique, question-and-answer, and a case study. The critical incident technique uses prompts to help subjects recall past events in detail. The following two prompts were used to elicit experiences from the engineers:

> "Think of the *most recent* time you discovered something unreasonable in the results of analysis or design."

> "Think of the *most alarming* discovery you have made of something unreasonable in the results of analysis or design."

Detailed information on how to implement the critical incident technique is provided in other resources (Flanagan 1954; Hanson and Brophy 2012). In the question-and-answer part of the interview, the engineers were asked "What are common errors you have seen?" Follow-on questions often included probes such as "How do you check for those errors?" Four of the firms also participated in a case study. They were given the floor plans for a small building and asked to perform preliminary design. The engineer who was assigned the case study spent between 10 and 40 hours on the design. In the interview, the case study was used as a catalyst for discussion about how the engineer evaluated the reasonableness of results.

It is important to note that the interviews were not structured to gather statistics on errors, so it would be inappropriate to conclude that the distribution of types of errors or how they are found reflects the distribution in day-to-day practice. The interviews were structured, however, to gather as many examples as possible of errors and how to find them.

Summary of Interview Results

After reviewing the information from the 35 interviews using the three approaches, the various ways practitioners find errors were grouped into eight categories:

Comparison. This category involves comparing calculation results from two or more approaches or situations (e.g., hand calculations versus computer results, results from two different computer programs, results considering different conditions, results from two different engineers).

Rule of Thumb. This category involves use of empirically-based formulas to predict member sizes or properties.

Information Check. These approaches are about review of information and process without using calculations. They include verifying the codes used and steps followed.

Visualization. This refers to visualizing the load path. Typically it involves making cuts and confirming that forces have a continuous path to the foundation.

Extreme Value. In some cases, the solution obtained is ridiculously large or small, thereby making it obviously incorrect.

Previous Experience. These strategies can only be developed through experience. They typically involve recognizing a situation as similar to previous projects.

Field. This is the least preferred strategy. It means that the problem is discovered during or after construction.

Other. This category includes all of the other strategies used to discover a problem.

The three interview approaches revealed 73 specific instances where an error was discovered. Much of the data provides information on the type of error and how it was found. Of the 73 instances, only twice did an engineer remember the error but not how it was discovered. In the question-and-answer part of the interview, the engineers identified 35 additional approaches to finding errors. The engineers were also able to identify 37 common errors even though they did not provide information on how they would find those errors. By comparing these common errors with the specific examples, the author was able to annotate each common error with the category of strategy that would likely allow an engineer to identify the common error. Table 1 tallies the occurrences of each category of tool, and the Appendix contains the detailed results.

The results show that Comparison was the strategy used most broadly to identify errors. Previous Experience was also a commonly used strategy, but those experiences must be developed over time. Comparison, Rule of Thumb, Information Check, Visualization, and Extreme Value are all strategies that can be learned, and they accounted for more than half of the strategies identified by the engineers. The Other category contains mostly procedural checks but also some unique experiences; therefore, the specific examples in this category might be used to inform quality control checklists. There were very few errors that were repeated by different engineers, so the results list a broad range of structural engineering errors. The most commonly mentioned error was “Changes in layout not articulated by architect or not noticed by structural engineer.” That error was identified by three engineers each from a different firm. In follow-up conversations, multiple structural engineers stated that Building Information Modeling (BIM) has not fixed this problem.

For the specific instances recalled in the study, the engineers identified whether they found the error in their own work or in another engineer’s work. Table 2 shows this breakout by category of tool. A significant percentage of errors was found by each; therefore, quality control checks are effectively used by both the engineers doing the work and engineers reviewing other’s work. For the instances reported, Comparison was by far the most often used strategy when finding errors in their own work. Previous Experience was the most often used when finding errors in other’s work. This might be due, at least in part, to the tendency of reviewers to have more experience. The other commonly used strategies to find errors in other engineer’s work were Rule of Thumb, Comparison, and Information Check.

Finding structural engineering errors in the field is the least desirable approach. Reviewing the details of the 13 instances where the error was found in the field and comparing them with the eight categories of tools, potential categories of tools have been assigned that might have caught the errors before construction in the field (Table 3). In two of the instances, the engineer was not certain whether the error was made on the engineering side or the construction side; therefore, no categories were identified for those two instances. For seven of the instances, Information Checks might have caught the error; therefore, some of the errors identified in the study could have been found before construction. For four of the instances, however, the error would most likely have been found only by Previous Experience or Other strategies. Since these strategies are the most dependent on the specific experiences of the engineer reviewing the work, these four errors were the most likely to go undetected until the field. Therefore, enhanced training on quality control strategies might not eliminate errors getting to the field but could reduce them. Table 4 contains additional information on how the errors in the field were detected.

Conclusions

Interviews with 35 practicing structural engineers resulted in 145 pieces of information about errors in structural analysis and design. Over one hundred of those included strategies for how to find the error. From the results of this study, we can draw the following conclusions:

- Responsibility for quality control should not be entirely delegated to reviewers but should be encouraged of the structural engineers performing the work. There are proven strategies for finding errors in one's own work, so it can be done. The earlier errors are found the smaller the cost in time and money, so it should be done.
- The most broadly used category of strategies for finding errors is Comparison; therefore, quality control training for structural engineers should be heavily influenced by Comparison strategies.
- Other than Previous Experience, the most broadly used categories by engineers to find errors in another person's work are Comparison, Rule of Thumb, and Information Check. These can be taught, so there is opportunity train engineers on how to use these strategies to find errors in their own work.

- Previous Experience is the most broadly used category by engineers to find errors in another person's work. One option is to develop that experience slowly over time. However, studying common errors and the problems they cause might help junior engineers develop experience-based error identification skills faster. The broad list contained in the Appendix can be used for such a purpose.
- Some errors currently being found in the field could reasonably be found sooner. Some errors will likely continue to be found in the field, but reducing that number would have significant financial benefits. Reducing the number of errors found in the field would also potentially avoid harm to a firm's reputation.

The increasing use of computers and increasing pace of design mean greater risk of structural engineering errors going undetected until construction in the field. Conversely, finding errors as early as possible significantly reduces the impact in terms of cost and time. Understanding how experienced structural engineers find errors could help inform training and quality control procedures so that more errors are identified by the engineer doing the work, thus earlier in the design process.

Appendix – Additional Information from Interviews

Table 4 presents the information gathered about all 73 instances where the engineer recalled a specific error. The columns include what was not reasonable, "The Problem"; what happened to bring about the problem, "The Error"; how someone knew there was a problem, "The Tool for

Evaluating"; and whether the error was found in the interviewee's work or someone else's work. The category of tool was assigned as part of this study.

Table 5 presents an additional 35 approaches to finding errors, labeled as "The Tool for Evaluating". In most cases, the engineer was able to link that tool to common causes, "The Error", and in some cases the engineer was able to identify a common effect of the error, "The Problem". The category of tool was assigned as part of this study. Although not common, duplicate entries from different engineers are presented to reflect how widespread some evaluation tools are used.

Table 6 presents 37 common errors and the resulting problems. Duplicate entries from different engineers are presented as evidence of how common some errors are.

Data Availability Statement

All data, models, and code generated or used during the study appear in the submitted article.

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Table 1. Summary of results of interviews categorized by the type of tool used to identify the error.

Category of Tool	Identified Incidents	Identified Additional Approaches	Described Common Problems
Comparison	15	19	12
Rule of Thumb	7	0	0
Information Check	6	3	7
Visualization	3	2	0
Extreme Value	3	1	0
Previous Experience	20	5	7
Other	4	4	11
Field	13	1	0
Not Reported	2		
Total	73	35	37

Table 2. Breakout of who's work contained the error for the specific instances identified in the interviews.

Category of Tool	Found in Own Work	Found in Other's Work
Comparison	10	5
Rule of Thumb	1	6
Information Check	1	5
Visualization	1	2
Extreme Value	1	2
Previous Experience	4	16
Other	1	3
Field	9	4
Not Reported	1	1

Table 3. Potential categories of error detection strategies that might have been used to find errors before construction in the field.

What was unreasonable [The Problem]	What happened to bring about the problem [The Error]	Potential Category of Tool
Insufficient information on the drawings	Failed to check the drawings	I or O

Assumptions about structural performance were invalid	Followed standard practice, but that was not applicable in this case	P or O
Applied a design procedure outside its range of applicability	Did not realize that it was outside the range of applicability	I or O
Member underdesigned	Error in labeling beam size on drawing	I or P
Discontinuity of longitudinal reinforcement in a beam	Supporting wall was removed from the plan, but a beam detail was not updated	I or O
Inadequate strength across a construction joint	Did not anticipate that the construction joint would be placed in high stress zone	I or O
Member extended below the ceiling	Chose beam size to continue the adjacent beam’s depth	P or O
Member too small	Did not consider all loading conditions; did not consider deflection performance	I or O
Steel member too short	Unknown	-
Member underdesigned	Failed to recognize P-delta effects	P or O
Software used for a situation not intended	Company began new a construction method but used software for an old construction method	I or O
Excessive deflection of slab	Contractor did not recognize that walls under the slab would be bearing walls	-
Deformation of structure under self-weight interfered with erection	Engineer did not consider this effect in the design or specifications	P or O

Note:

Categories of Tools

I = Information Check (no calculations)

O = Other

P = Previous Experience

Table 4. Specific instances where an error in analysis or design was identified.

What was unreasonable [The Problem]	What happened to bring about the problem [The Error]	How to know there was a problem [Tool for Evaluating]	Category of Tool	Own Work/ Other's Work
Slab underdesigned	Assumed rigid diaphragm in 3D analysis, so did not "see" the magnitude of forces in the slab	Calculated forces in the slab as a check	C	Own
Incorrectly combined most extreme loading location and most extreme loading magnitude, but both cannot happen at the same time	Lack of information provided by the manufacturer	Calculations indicated that a design functioning adequately should have failed in the field	C	Other
Member overdesigned	Error in in-house software	Changing input values had little effect on results, even when checked extreme values	C	Own
Members underdesigned	Understanding of boundary conditions changed	Checked members with revised boundary conditions	C	Own
Members overdesigned		Compared beam sizes from one floor to another in the	C	Other

		same structure at the same location		
Incorrect building response	Incorrectly modeled the idealized structure	Compared the period of vibration to similar structures (previous experience)	C	Own
Incorrect building response	Forgot to include some live loads on mechanical floors in the computer model	Compared the weight of the building with the total axial load calculated by computer	C	Own
Underestimate axial force in beam	Analysis performed in 3D with a rigid diaphragm which slaves the nodes, so no axial forces were produced	Compared with an analysis without a rigid diaphragm	C	Own
Incorrect distribution of moments to members at a rigid connection	Incorrectly modeled the idealized structure	Computer results did not match hand results	C	Own
Incorrect building response	Fixed node at the top of the structure	Deflected shape was not what was expected	C	Own
Spreadsheet used a fixed value even though there was a cell for inputting the value	Limitation of software	Member strength was unchanged when dimensions were changed	C	Own
Members underdesigned	Did not properly determine internal forces accounting for	Redesigned under new code	C	Other

	dynamic effects; failed to scale the results from static analysis			
Members under- or overdesigned	Calculation errors by designer	Two different structural alternatives produced nearly identical member sizes	C	Other
Members under- or overdesigned	Load placed in incorrect location in the computer model	Two similar loading situations produced very different results	C	Other
Member overdesigned	Used design software to design members outside the range anticipated by the software	Unable to design a member to have adequate capacity	C	Own
Insufficient information on the drawings	Failed to check the drawings	Beam was constructed through a stairwell at chest height	F	Own
Assumptions about structural performance were invalid	Followed standard practice, but that was not applicable in this case	Cracks formed in a slab on grade that was post-tensioned to avoid cracks	F	Own
Applied a design procedure outside its range of applicability	Did not realize it was outside the range of applicability	Excessive cracking developed in a concrete member in field	F	Own
Member underdesigned	Error in labeling beam size on drawing	Excessive deflection observed during erection	F	Other

Discontinuity of longitudinal reinforcement in a beam	Supporting wall was removed from the plan, but a beam detail was not updated	Identified in a field inspection during construction	F	Other
Inadequate strength across a construction joint	Did not anticipate that the construction joint would be placed in high stress zone	Identified in a field inspection during construction	F	Own
Member extended below the ceiling	Chose the size to continue adjacent beam depth	Identified after constructed	F	Own
Member too small	Did not consider all loading conditions; did not consider deflection performance	Member behaved poorly in the field; too flexible	F	Own
Steel member too short	Unknown	Member did not fit properly in the field	F	Own
Member underdesigned	Failed to recognize P-delta effects	Member failed during construction	F	Other
Software used for a situation not intended	Company began new a construction method but used software for an old construction method	Member failed during construction	F	Other
Excessive deflection of slab	Contractor did not recognize that walls under the slab would be bearing walls	Observed in field while casting slab	F	Own

Deformation of structure under self-weight interfered with erection	Engineer did not consider this effect in the design or specifications	Pieces did not fit in the field	F	Own
Deflections out of allowable tolerance	Not considered by the manufacturer	Deflections were not indicated on the shop drawings	I	Other
Connection drawn incorrectly	Change not updated on the drawings	Designer identified it while proofing drawings	I	Own
Insufficient details drawn	Failed to recognize that a single detail was being referenced for multiple, different conditions	Identified it while reviewing design drawings for sufficient information	I	Other
Member underdesigned	Failed to factor load	Reviewed the design procedure	I	Other
	Took a wrong coefficient from the code	Second engineer checked the criterion	I	Other
	Failed to recognize that there were rooftop units when calculated loads on roof	Second engineer checked the design criteria with the problem statement	I	Other
Inappropriate loads used for design	Lack of understanding of how to use the pertinent codes		NR	Other
Parking garage slab was too thin	Designed the thickness to provide sufficient		NR	Own

	slope for runoff, but didn't check the required minimum thickness			
Larger column above a smaller column	Used computer to pick most efficient sections	Checked for uniformity of column size at different levels	O	Other
Members underdesigned	Effect of extremely stiff transfer girder was not considered in the lateral response of a concrete rigid frame	Checked for this in a design review	O	Other
Foundation underdesigned	Forgot the self-weight of the structure	Remembered later	O	Own
Snow load used for design was less than the required value	Did not recognize drifting effect	Structural failures in the region motivated a closer look at the loads	O	Other
Member underdesigned	Rushing to get drawings out, failed to revise the final member size	Experience showed that a combined loading member should be governed by axial load, but the section chosen was governed by bending	P	Other
Selection of member sizes was inefficient	Failed to recognize that increasing the stiffness of other members would reduce internal forces in the overloaded member	Recognized that members were out of scale compared with previous experience	P	Other

Member underdesigned	Computer design was based on the assumption of a braced top flange, but was not true in this case	Minimum size for perimeter beams that brace façade panels should have been W14x22 based on previous experience	P	Other
Member not sufficiently stiff for serviceability	Did not check service behavior, only strength	Non-standard detail was identified based on previous experience	P	Other
Beam flange of a composite beam not thick enough to weld studs	Designed by computer for strength	Identified based on previous experience	P	Other
Beam size too small to allow bolted connection to girder	Designed by computer for strength	Identified based on previous experience	P	Other
Beam-column connections were not designed to carry the restraining force to prevent column buckling	Failed to consider the load condition	Identified based on previous experience	P	Other
Concrete member was not detailed in accordance with code requirements	Inexperience	Identified based on previous experience	P	Other
Detail was not appropriate	Copied from previous design without verifying that detail was valid for the current situation	Identified based on previous experience	P	Other
Joist spacing too wide	Flaw in computer design software	Identified based on previous experience	P	Own

Ledger beam underdesigned	Unknown	Identified based on previous experience	P	Other
Member underdesigned	Took results directly from computer program	Identified based on previous experience	P	Other
Member underdesigned	Unknown	Identified based on previous experience	P	Other
Members underdesigned	Error made when determining wind loads	Identified based on previous experience	P	Other
Reinforcement on wrong side of concrete member	Unknown	Identified based on previous experience	P	Other
Required splice was not detailed	Did not recognize that a timber member could not be supplied in the length prescribed	Identified based on previous experience	P	Other
Steel connection was not designed to account for all loads	Failed to consider connection eccentricity	Identified based on previous experience	P	Other
Connection not properly designed	Failed to consider all possible failure modes	Identified based on previous experience of reviewer	P	Own
Foundation underdesigned	Missed some loads from the architect's drawings	Identified based on previous experience of reviewer	P	Own
Steel connection was not designed to minimum code requirements	Inexperience	Identified based on previous experience of reviewer	P	Own
Steel beam overdesigned	Double counted beam self-weight in computer design	Checked reactions at the end of member and compared them to hand calcs; used a	R	Own

		rule of thumb for depth: depth in inches at least 1/2 the span in feet		
Member underdesigned	Unknown	Used a rule of thumb for cantilevered steel beams: depth in inches at least the span in feet	R	Other
Member not sufficiently stiff for serviceability	Designed by computer for strength	Used a rule of thumb for steel beams: depth in inches at least 1/2 the span in feet	R	Other
Member not sufficiently stiff for serviceability	Designed for strength and limited by ceiling height, but not checked for serviceability	Used a rule of thumb for steel beams: depth in inches at least 1/2 the span in feet	R	Other
Member underdesigned	Misinterpreted the units in the design tables	Used a rule of thumb for steel beams: depth in inches at least 1/2 the span in feet	R	Other
Members overdesigned	Designer did not account for composite action	Used a rule of thumb for steel beams: depth in inches at least 1/2 the span in feet	R	Other
Steel beam was too shallow for the span	Computer designed for strength, not serviceability	Used a rule of thumb for steel beams: depth in inches at least 1/2 the span in feet	R	Other
Discontinuity in load path	Engineer initially missed part of the load path	Cut a section of the structure and visualized the load path	V	Own

Structural element was unstable	Did not consider load path for all loading conditions	Visualized the load path	V	Other
Structural system was not stable	Site conditions changed such that a column was no longer viable and was removed, but the structural system was not updated	Visualized the load path	V	Other
Member underdesigned	Error in in-house software	Beam depth was outrageously small	X	Other
Member underdesigned	Input loads were in units different from what the computer software was assuming	Calculated deflection was outrageously large	X	Own
Foundation was too small	Failed to account for overturning moment; just considered gravity loads	Footing that must resist overturning was approximately the size of the supported column	X	Other

Note:

Categories of Tools

C = Comparison (calculation based)

F = Field

I = Information Check (no calculations)

NR = Not Reported

O = Other

P = Previous Experience

R = Rule of Thumb

V = Visualization (of load path)

X = Extreme Value

Table 5. Examples of tools for finding errors in analysis and design results not linked to a specific instance of error detection.

What is unreasonable [The Problem]	What happens to bring about the problem [The Error]	How to know there was a problem [Tool for Evaluating]	Category of Tool
Computer model does not represent the intended behavior	Loading, supports, member properties, and/or connectivity are not what thought	Check that the deflected shape is what expect	C
	Loading in computer model is not what thought	Compare the base shear calculated by hand with the total shear calculated by computer	C
		Compare the base shear of the computer model with the applied load	C
	Accidentally fix a node in the computer model that should not be restrained	Compare the base shear of computer model with the applied load	C
		Compare the base shear of computer model with the applied load	C
		Compare the brace force from computer model with a hand calculated force	C

Incorrect building response	Assigning incorrect mass density in the computer model	Compare the computer calculated period of vibration with the code approximation	C
		Compare the computer calculated period of vibration with the code approximation	C
Members overdesigned	Accidentally setting the deflection limit to a fixed amount for all beams regardless of length	Compare the computer selected beams with hand calculated designs	C
		Compare the computer selected gravity columns with hand calculated designs	C
Members under- or overdesigned	Inappropriate assumptions are made in software program	Compare new software programs to programs that have produced acceptable results	C
	Assumptions of a computer program are not consistent with those made by the designer	Compare the results from two different computer programs	C
Exterior columns are larger than interior columns		Compare the sizes of perimeter columns to interior columns	C
		Compare the total weight of the structure with column reactions in the computer model	C
	Loading in the computer model is not what the designer thought	Compare the weight of the building with the total axial load calculated by the computer	C

Members underdesigned		Drift of the braced frame exceeds its drift limit	C
	Loading, supports, member properties, and/or connectivity in the computer model are not what the designer thought	For dynamic analysis, draw a diagram of force at levels and compare the anticipated behavior with the computer predicted behavior	C
Incorrect building response		For new situations, model the structure in three to four different ways: at least two by hand and one or two numerically	C
Computer model does not represent the intended behavior	Loading in the computer model is not what the designer thought, possibly due to inconsistent units; supports are provided in locations not intended	Reactions do not add up to the load applied to the structure	C
Deformation of the structure under self-weight interferes with erection	Designing for minimum weight without regard to constructability	Pieces do not fit in the field	F
	Loading in the computer model is not what thought	Check the magnitude and location of the applied loads in the computer analysis	I
Insufficient details are drawn	Failing to recognize that a single detail is being referenced for multiple, different conditions	Review the design drawings for sufficient information	I
Support conditions are not consistent with the assumed conditions for analysis	Drawing details are either not provided or will not behave in the manner assumed for analysis	Review the design procedure	I

Beams and connections in a braced frame are not designed for axial force	Computer analysis assumes a rigid diaphragm, so the horizontal component of the brace force transfers through the diaphragm rather than the beam	Check for the specific problem since common	O
Underdesign the foundation below a chevron frame	Designing based on column axial, thus forgetting the contribution from the brace	Check for the specific problem since common	O
Foundations are inadequate for uplift	Failing to consider foundation capacity when designing the structural system	Check structure overturning	O
Excessive cracking of slab	Failing to identify the `effect of different supporting beam deflections on the slab	Review the design procedure	O
Members overdesigned		Compare pounds of structural steel per square foot of structure with average values for the type and size of structure	P
		Member size not is typical for the span and loading conditions based on experience	P
Computer indicates that members are understrength when actually fine	New version of computer software has errors	Previous experience can identify the issue	P
Connection unnecessarily difficult to fabricate or erect	Lack of understanding of fabrication or erection processes	Previous experience can identify the issue	P

Member underdesigned		Relative scale of the column to the beam looks odd based on previous experience	P
Inadequate anchorage of diaphragms to lateral elements	Designer misses part of the load path	Cut a section of structure and visualize the load path	V
Column stops at a level without transferring to other columns		Visualize the load path	V
Members underdesigned	Specifying that the deck runs parallel to the beams	All computer selected filler beams are W8x10	X

Note:

Categories of Tools

C = Comparison (calculation based)

F = Field

I = Information Check (no calculations)

O = Other

P = Previous Experience

V = Visualization (of load path)

X = Extreme Value

Table 6. Examples of common errors, the problem that typically results, and possible categories of tools for identifying the presence of the errors.

What is unreasonable [The Problem]	What happens to bring about the problem [The Error]	Possible Category of Tool
Beams underdesigned	Analysis performed in 3D with rigid diaphragm which slaves the nodes, so no axial forces are produced	C
Incorrect building response	Incorrectly modelling the idealized structure	C
Incorrect building response	Incorrectly orienting members in the numerical simulation	C
Member underdesigned	Analysis is in one set of units, but assuming another when selecting members	C
Member underdesigned	Not recognizing the difference between torsion in plane and torsion out of plane when reviewing computer results	C
Member underdesigned	Forgetting to convert mass to weight when working in metric units	C
Member underdesigned	Using feet instead of inches in a computer model	C
Members under- or overdesigned	Computer program does not perform as intended when buttons used out of order	C
Members under- or overdesigned	Failing to check the validity of computer program default values	C
Members under- or overdesigned	Inputting material density in units different from what the computer software is assuming	C
Members under- or overdesigned	Software being used for a situation for which it is not intended	C

Members under- or overdesigned	Using a computer program in situations for which it is not designed, but the manual does not indicate the limitation	C
Inadequate loads used for design	Lack of understanding of how to use the pertinent codes	I
Incorrect member size	Numbers being transposed during drafting	I
Insufficient information on drawings	Failing to consider what information would be required for fabrication and/or construction	I
Insufficient information on drawings	Failing to consider what information would be required for fabrication and/or construction	I
Members or connections underdesigned	Failing to use the correct code for that jurisdiction	I
Members underdesigned	Failing to recognize all the design criteria (e.g., road adjacent to retaining wall); failing to understand the project as a whole	I
Support conditions not consistent with assumed conditions for analysis	Drawing details are either not provided or will not behave in the manner assumed for analysis	I
Fabricator unable to complete the project from the drawings	Insufficient details drawn due to time constraints	O
Incorrect building response	Failing to incorporate the reduced stiffness of concrete members due to cracking	O
Incorrect dimensions on drawings	Using software incorrectly to calculate a dimension	O

Members underdesigned	Changes in loading are not articulated by the architect or are not noticed by the structural engineer	O
Members underdesigned	Changes in MEP are not noticed or anticipated by the structural engineer	O
Members underdesigned	Failing to consider pertinent earthquake information from the geotechnical report	O
Members underdesigned	Missing some loads from the architect's drawings	O
Reinforcement on wrong side of concrete member	Communication lacking between designer and draftsperson	O
Structural layout does not match architectural and/or mechanical layout	Changes in layout are not articulated by the architect or not noticed by the structural engineer	O
Structural layout does not match architectural and/or mechanical layout	Changes in layout are not articulated by the architect or not noticed by the structural engineer	O
Structural layout does not match architectural layout	Changes in layout are not articulated by the architect or not noticed by the structural engineer	O
Concrete member detailed such that it is not easily constructed	Using design software that only ensures that the design meets code requirements	P
Concrete member detailed such that it is not easily constructed	Using design software to design members outside the range anticipated by the software	P

Connections not properly designed	Connectivity does not match the assumed behavior of the idealized structure used in the analysis	P
Connections or columns not properly designed	Failing to consider connection eccentricity	P
Incorrect column load takedown value	Not accounting for the effect of a cantilevered beam	P
Reinforcement does not have adequate development length	Failing to consider changes in beam depth along the length of a beam	P
Steel connection underdesigned	Failing to consider connection eccentricity	P

Note:

Categories of Tools

C = Comparison (calculation based)

I = Information Check (no calculations)

O = Other

P = Previous Experience