Validating the Results of Structural Engineering Software

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The previous Quality Assurance Corner article discussed the limitations of structural engineering software. This article discusses methods for validating the results of structural engineering computer analysis using simple manual calculations.

Engineers use computers because they can perform repetitive analysis and design calculations thousands of times faster than if performed manually with a calculator and pencil. Obviously, if the wrong data is entered into the computer, the results will be incorrect. The purpose of validating a computer generated design with manual computations is to verify that data was entered into the program correctly, and that the software is employing rational and valid methodologies for design and analysis.

The goal of performing manual calculations to verify computer generated design is not necessarily to match the precise design provided by the computer analysis, but rather to get an answer that is comfortably close to the design provided by the program. As a general rule, if quick manual computations are within approximately10 percent of the results provided by the software, it is reasonable to assume that the computer analysis and design is correct. However, if manual computations differ from computer results by more than 20 percent, then there is a high likelihood that an error was made somewhere. Errors in computer-generated designs are usually the result of incorrect input, incorrect understanding of program default settings or lack of understanding as to how the software works.

The first thing an engineer should do when reviewing a computerized design is to step back, look at the big picture and ask, "Does this make sense?" Although this might seem so obvious as to not warrant stating, it's something that often does not happen. The engineer verifying if a computerized design "makes sense" obviously has to be an engineer with some level of experience. No structural engineering firm should ever allow a computer generated design produced by a junior level, inexperienced engineer to leave the office without a review by a senior level engineer.

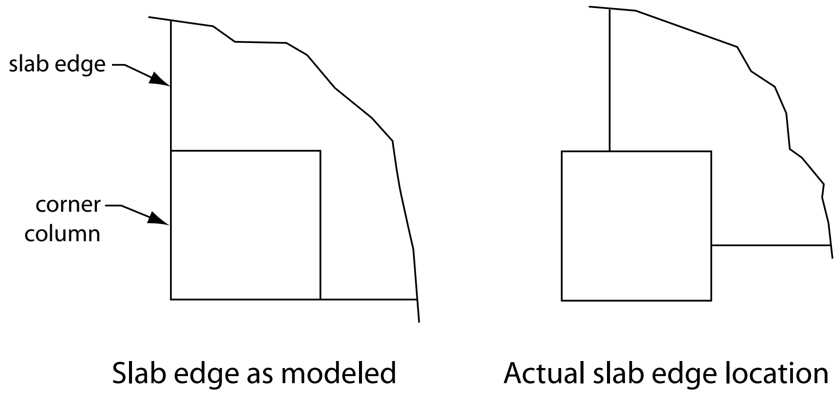

Figure 1: Illustration of discrepancy between slab edge as modeled and actual slab edge location.

Validating Design of Gravity Load Framing

The strategy for validating the design of floor framing plans is to manually design one typical slab, beam, girder, column and foundation. If the manual design for these members closely matches the computer-generated design, then there is a high likelihood that the computer input, analysis and results for the other gravity framing members are correct. Manual design calculations should also be performed to review the design of critical members such as transfer girders. If the manual calculations do not closely match the computer output, then the model should be investigated for errors.

Printing reactions on structural steel floor framing plans can be extremely beneficial for verifying that the correct design loads were used. Manually computed reactions for typical beams and girders should closely match the computer generated values. Printing the reactions on steel framed floor plans allows the engineer to see the flow of the load through the structure. Mistakes that are commonly made when using a computer program to design gravity framing include not counting or double counting the structure self-weight (a software default setting) and not using or improperly using live load reductions and improperly assigning design loads. The accuracy of computer-generated designs is also highly dependent on the geometry that is defined by the user. *Figure 1* shows a corner column in a concrete flat plate floor. On the left is the slab edge as modeled. On the right is the final required slab edge location. Architectural refinements such as slab edge locations often occur when the structural design is almost complete. In the situation illustrated in *Figure 1*, moving the slab edge in from the faces of the column can result in significant loss of punching shear strength at the slab-to-column connection. Architectural changes such as this must be updated in the structural model to investigate what impact they have on the structure.

Validating Design of the Lateral Force-Resisting System

The multitude of building code-mandated load cases and combinations makes manual review of computer-designed lateral load resisting systems a bit more complex than manual review of gravity load framing systems.

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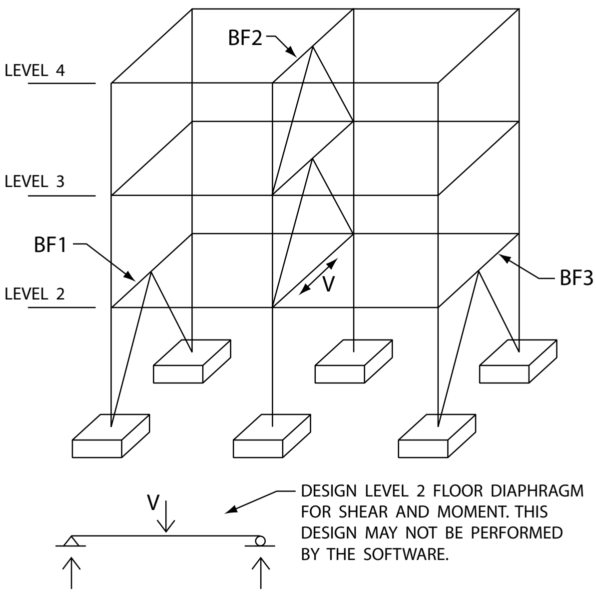

Figure 2: Illustration of a structural member (floor diaphragm) not designed by the software.

While the complexity of precisely analyzing the various wind load cases and seismic load combinations is daunting, there is a way to quickly compute wind and seismic forces on regular shaped building structures to a level of accuracy sufficient for verifying designs produced by computer software.

The following procedures, while not precise enough for design, are generally accurate enough to verify that the computer results are correct for regular shaped buildings of low to moderate height. These procedures will flush out significant errors that might otherwise have slipped by had manual computations not been performed to validate the computer-generated results.

Validating the Magnitude and Distribution of Wind Loads

- Investigate wind loads in each orthogonal direction. (This is the basic wind load case. Investigate other load cases if appropriate for buildings with unusual geometries or framing configurations.)
- Compute wind pressure (windward and leeward) at the base of building and roof.
- Interpolate linearly from ground level to roof.
- Compute the average pressure.
- Compute the total wind load base shear.
- Distribute wind loads to the lateral force-resisting elements in proportion to their tributary area. (Modify distribution where stiffnesses of lateral force-resisting elements vary significantly.)
- Analyze braced frames, moment frames or shear walls using the proportioned wind load.

Validating the Magnitude and Distribution of Seismic Loads

- Investigate seismic loads in each orthogonal direction. (Note: This procedure is appropriate for SDC "A" and "B". For SDC "C" and higher, results from manual computations may be less than computer generated results depending on geometry and framing configuration.)
- Compute the base shear in each direction using the computer calculated building period, T.
- Compare the manually calculated value to the base shear determined by the computer analysis.
- Distribute the load in a triangular load pattern (centroid of loading located two thirds of the building height above the base)
- Distribute loads to the lateral force-resisting elements in proportion to the tributary mass around each element.
- Analyze braced frames, moment frames or shear walls using the proportioned lateral load.

The procedures above will generally be accurate enough for regular shaped buildings of moderate height in areas of low to moderate seismicity within a level of accuracy that will catch significant errors in a computer analysis.

A common mistake with computer design of lateral force-resisting systems is the failure to consider load path issues where lateral loads pass through floor diaphragms from one lateral force-resisting element to another. *Figure 2* illustrates a condition where an out-of-plane offset irregularity in a braced frame transmits lateral loads into the floor diaphragm. While many software programs allow floor slabs to be assigned as diaphragms, not all programs will design the diaphragms. Validation of the computer's results in these situations requires recognition of which structural members may not have been designed by the software.

Conclusion

Validating computer-generated structural design with manual computations is essential and can be accomplished quickly within an acceptable level of accuracy using rudimentary calculations. While those calculations may not be to a level of precision accurate enough for design, they are usually accurate enough to help engineers spot errors in a computer model.▪

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