Performance-Based Design White Paper

Title: "General Considerations for the Use of Performance-Based Design Approach on Structures"

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Performance-Based Design (PBD) is a relatively new and powerful approach to structural engineering born from ongoing efforts to resolve the differences between the actual observed performance and the expected performance of structures. Previously observed differences between the actual and expected performances of structures, especially because of earthquakes, has led to advances in the understanding of system and material performance by the research and practicing community that at times go beyond the prescriptive requirements often found in the building codes. With the improvements in the capability of relevant analytical tools and computing technology, structural engineers are increasingly using PBD for new design and for evaluation or retrofit of existing structures to better predict building performance, provide more economical designs, or address when the prescriptive provisions of the building code just do not apply.

With the continued growth in the use of PBD, it is critical to share the successful experiences and lessons learned within the structural engineering community so that this powerful approach will be properly used and better designs and reduced construction costs for structures will continue to be realized. Examples of the successful implementation of PBD are available through technical literature and industry magazines. This document is solely intended to convey common general considerations, risks, and concerns that are typically relevant when PBD is being implemented. This document is not intended to all aspects of PBD including the history, the technical basis, every application, or how to implement PBD.

The term "performance-based design" is also being used by some to describe design or evaluation procedures for applications other than the design or evaluation of a structure's lateral force-resisting system. The general considerations, risks, and concerns shared in this document may be relevant to those other PBD applications when performance targets are defined and the design or evaluation is more directly tied to actual performance and go beyond prescriptive methods including the ones commonly defined in the building code. For example, PBD is being used for fire protection applications. The *CASE Structural Engineers Guide to Fire Protection Guideline – 2008* includes a section regarding fire protection PBD.

PBD is a rational evaluation and design methodology that is intended to provide a desired result in its most advanced applications that are based on an enhanced modeling of a structure.

While linear analysis approaches can be used, PBD often includes non-linear analysis modeling of structural elements as such modeling often maximizes the return from using PBD. By including an enhanced modeling of the structural elements of a building, a structural engineer can gain significant understanding into the actual behavior of the structure being analyzed and better relate that actual performance to the desired performance of the building. With this understanding, a structural engineer can confidently develop conclusions or designs that will achieve the desired performance while potentially minimizing unnecessary conservatism that is often inherent in cover-all-possible-cases prescriptive methods. Unnecessary work in retrofits can be avoided and more efficient new designs can be realized.

The impetus for the development of PBD for lateral force-resisting systems of structures can be in part traced back to the observed discrepancies between expected and actual performance of buildings during earthquakes. Predictions based on prescriptive design methods for the performance of the lateral force-resisting systems of some structures were found to be occasionally inconsistent with the actual structural performance during an earthquake. Typically, the buildings were found to have out-performed predictions based on the prescriptive methods. Starting from ATC-33 in the 1990s to the subsequent SEAOC Vision 2000 project, FEMA 273/274, ATC-40, FEMA 356/357 and the current ASCE-41, a rational formal PBD methodology was developed to improve the correlation between evaluation-based predictions and actual structural performance during seismic events. Further refinement of the seismic PBD is included in ATC-58. Visit www.atcouncil.org/Projects/atc-58-project.html for additional information on ATC-58.

The challenge for implementing PBD can be in the details. Unfortunately, to cover every possible issue or aspect of PBD is beyond the scope of this document and the reader is directed to the various technical resources available for additional info including those available through the National Earthquake Hazards Reduction Program for seismic PBD (http://www.nehrp.gov/library/guidance_pbsd.htm). However, the following important general considerations, risks, and concerns about PBD are shared to help you avoid some common pitfalls:

- **Know your building official**: Does the agency with jurisdiction over your project accept the use of PBD over the prescriptive requirements of the building code? Does the agency accept the design provisions of a PBD standard as an alternative rational design method to the building code's prescriptive requirements? If not, then you will likely have to prepare and have approved design criteria that define how you will implement PBD.

- **Expect a peer review**: When utilizing PBD, it is common to have your work peer reviewed whether the review is triggered by the governing agency (covered by plan check fees, the owner and/or your client), by an owner desiring an independent review (at owner's cost), or for self-assurance (included in your fees or at your own cost). Whether required or not, a fair independent peer review can be used to demonstrate that you have fulfilled your obligation to meet the "Professional Standard of Care" while also providing a measure of reassurance that you are implementing a rational approach.

- **Educate your client**: Convey to your client the motivation behind implementing PBD. Is the goal to better predict structural performance, reduce construction costs, or avoid retrofit work or does PBD provide the only possible analytical approach to accurate predict and justify the structure's performance? It is also important to establish with your client an understanding on the targeted performance for structure. Is the client (or the

governing agency) only concerned about safety or is there some other higher or lower performance goal?

- **Talk schedule and compensation:** Expect to do more work when you implement a PBD approach. The project schedule and your compensation should reflect the added effort to correctly implement PBD. PBD often can save the owner money in construction costs for the structure and minimize related disruption even if it means greater design team compensation.

- **Know the building:** In modeling the structure to correctly reflect the behavior of structural elements, you must understand and accurately represent the actual material and geometric properties of the structure. For existing buildings, material testing and verification of the as-built construction is likely necessary.

So are you ready to try PBD? Before you implement PBD, be aware of the following general risks and concerns:

- **Keep a Rational Approach:** Many buildings can be demonstrated to work via "creative" approaches but not all "creative" approaches are valid. You need to be realistic in your assumptions and have a thorough understanding of the building and the capabilities and limitations of the analytical tools. Internal quality control is extremely important.

- **Know the Limits**: Before applying PBD, know the inherent assumptions and limitations of the specific application being considered. Especially when your evaluation method relies on a new research paper, conclusions from test data, a new theory, etc., there is a real danger that a mistake will be made unless you have done the proper validation.

- **Avoid the Temptation to Over-Promise:** Higher analysis techniques including nonlinear analysis can demonstrate that a building that might not appear adequate using traditional techniques is actually capable of achieving the desired performance. However, do not expect that PBD will justify any and every new or existing building! Be careful not to over-promise.

- **You Do Not Know What You Do Not Know:** If PBD is new to you, you will likely experience a significant learning curve. To help minimize the risk of a negative experience, retain a peer reviewer for your first few projects so you can quickly develop an understanding of when and what level of PBD is appropriate and how to correctly apply the related principles and procedures.

- **Software Programs Have Limitations:** You need to understand the limitations of the programs that you are using. Understanding those limitations can be difficult especially since analysis programs can be extremely complex with proprietary features and limited technical documentation that does not fully detail all aspects of the inner workings of the program. Careful selection of modeling software up front is critical and can save you significant time and effort.

This is just an introduction to some general considerations, risks, and concerns about PBD for you to consider if you are looking to implement PBD on your projects. There is much more to know about the benefits and risks associated with PBD. That being said, if you are able to avoid the pitfalls that are the basis of the general considerations, risks, and concerns mentioned above, you should be well on your way to successfully using PBD on your projects. It is

inevitable that you will also have successes and lessons learned once you implement PBD on a project and when those moments happen, share your experiences with the rest of the structural engineering community. Together, we can continue to improve the use of PBD for the betterment of everyone.