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SIMPLIFIED LIMIT STATES SEISMIC DESIGN PHILOSOPHY FOR CONCRETE STRUCTURES

A Tribute to the Memory of J. Ferry Borges

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ABSTRACT

The writer had the great good fortune, and considerable pleasure, to spend a year in 1968/69 as a post doctoral fellow at the Laboratorio Nacional de Engenharia Civil in Lisbon. At that time J. Ferry Borges was the head of the Structures group at LNEC, and it was a result of his personal decision that my application was approved. I came to LNEC with no real background in Earthquake Engineering, and spent the year attempting to get up to speed in the general areas of structural dynamics and earthquake engineering, while simultaneously trying to hide my ignorance. I do not think that Ferry Borges was fooled, but he was tolerant, and patient, and I ended up learning a great deal, to the extent that my future professional activities were to be completely dominated by a fascination for the seismic response of structures.

While at LNEC, I attended an internal course given by Ferry Borges on Structural Safety in Earthquake Engineering. This was a brave attempt to marry Reliability Theory and Ductile Seismic Response to form a consistent-risk design approach. It was inevitably rather theoretical and philosophical in nature, and the mechanics of translating it into a viable and practical design procedure were not clear. Thirty years later, the goal of uniform risk seismic design has still not been achieved. Though the concept of uniform risk has been well developed for development of design spectra, it has not been established that structural response to such spectra will result in uniform risk of damage or collapse, since the concept of design to an acceleration spectrum is basically flawed. Duration effects are not addressed, and the assumption of relevance of the 5% elastic spectrum to ductile inelastic response is at best controversial. This is clear in codified procedures to estimate displacements from the elastic response values. In the U.S.A., design displacements are taken to be considerable less than those predicted by the equal displacement approach, while in many European and Latin American countries the equal-energy approach is adopted. The result can be a difference by a factor of as much as three in predicted displacement. Since it is reasonable to relate displacement and damage potential, it is clear that we have little idea of the actual structural risk implied by our seismic design processes.

This paper outlines a design procedure that attempts to reduce the uncertainty associated with current seismic design, based on limit states design. Currently, where attempted, limit states design normally involves checking that for a given action (i.e., a given level off seismic attack) the specified limit state is not exceeded. This does not result in uniform risk. The approach taken in the paper is to design a structure such that the specified limit state is achieved, with as much precision as is possible given the uncertainties of seismic input, under the specified level of seismic attack. The basis for this is a strain-based design procedure. It is feasible to define conditions representing a given limit state (i.e., serviceability, or damage control) in terms of maximum permitted strains in reinforcement and concrete. These in turn, can be related

to structural deformations in the form of section curvatures, and ultimately, story drifts or displacements. A design procedure starting from a displacement response spectra set for different levels of equivalent viscous damping is then used in conjunction with a "substitute structure" analysis, based on effective stiffness and damping at maximum response to determine the required strength and initial stiffness of the initial elastic structure. The current design approach, which is based on acceleration spectra and initial stiffness is thus inverted, with strength and stiffness becoming the end product, rather than the initial assumptions, of the design process.

The paper presents the steps necessary to perform this design procedure and presents results to justify its validity. It is contended that though the procedure is simple and comparatively straightforward, it provides a basis for approaching the uniform risk ideals espoused by J. Ferry Borges.