NONLINEAR SEISMIC SSI APROACH FOR REINFORCED CONCRETE BUILDINGS IN ACCORDANCE WITH ENGINEERING BEST PRACTICES IN US AND JAPAN. PART 1: MODELING

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ABSTRACT
The paper presents an efficient practical nonlinear SSI approach for evaluating the reinforced concrete (RC) shearwall structures behaviour under severe earthquakes based on the best industry practices and regulatory requirements in USA and/or Japan. The nonlinear SSI approach is based on a hybrid complex frequency-time domain approach that uses a local iterative equivalent-linearization procedure for modelling the hysteretic behaviour of the RC walls depending on the strain levels occurring in walls. The hybrid approach is both robust and extremely fast since its convergence is achieved in few reanalysis iterations. The hybrid approach is implemented in the new ACS SASSI Option NON software. For deeply embedded structures, as SMRs, the hybrid approach runtime can be largely reduced, if used in conjunction with the Flexible Volume Substructuring with Reduced-Order Modelling approach included in the new ACS SASSI.

The hybrid nonlinear SSI approach is applicable to both: i) Design Basis Earthquake (DBE) applications for evaluating the RC cracking pattern in structures, and ii) Beyond Design Basis Earthquake (BDBE) applications for evaluating the RC wall post-cracking and yielding behaviour until failure. It should be noted that the nonlinear SSI approach is designed as an industry practice-based tool for affordable, efficient project applications, not as a general FE theory-based tool for research studies. The nonlinear SSI approach bases on the recent ASCE 4-16 and/or JEAC 4601-2015 standard recommendations for the nonlinear RC structure modelling. The nonlinear SSI approach accuracy and robustness was carefully investigated against actual project results, OpenSees specialized RC structure software packages, and experimental wall test data.

The Part 1 presentation provides key details related to the overall nonlinear SSI analysis procedure and RC structure modelling aspects as implemented in ACS SASSI Option NON (Figure 1). The analyst has the choice to use the US or Japan practice guidelines for computing the shear and bending BBCs for each RC wall. The BBC are automatically computed based on the wall cross-sections at each floor, the concrete and reinforcement properties and the percentage reinforcements in horizontal and vertical directions in wall webs and flanges. Automatic section-cuts are executed for each wall at each floor level. The axial forces in walls are computed for under gravity loads, while the shear and bending moments in walls are computed under simultaneous seismic inputs in X, Y and Z directions. The BBC inputs are determined based on either the US or Japan practice requirements (such ASCE 4/43, ACI 318, EPRI in US, and JEAC 4601-2015, AIJ RC in Japan).

The ACS SASSI Option NON hysteretic model library for RC walls include eight hysteretic models that can be selected by the user. Six types of hysteretic models, 3 for the wall shear deformation and 3 for the wall bending deformation are presented and their performances against wall test data are shown. The selected hysteretic models for the study include the Cheng-Mertz shear (CMS) and bending (CMB) models used in US, in several research studies for improving DOE and ASCE standards, and the maximum Point-Oriented shear and Point-Oriented Degrading

Trilinear (PODT) bending models, used in Japan, and recommended by the JEAC 4601-2015. Other two hysteretic models called the Hybrid shear (HYS) model and bending (HYB) model, which are based on rule combination of the CMS/CMB and PO/PODT models are also used, since in several validation studies they fitted best the wall cyclic test data (Figure 2).

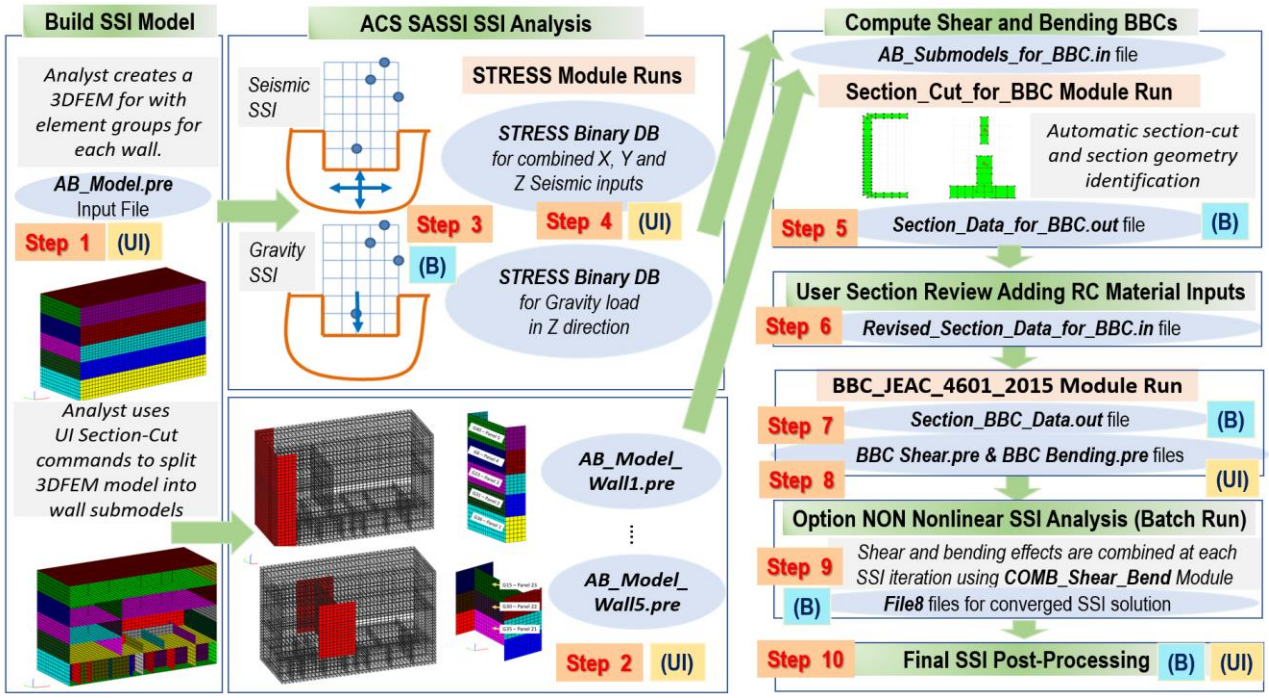

Figure 1. Nonlinear Structure SSI Analysis Flowchart

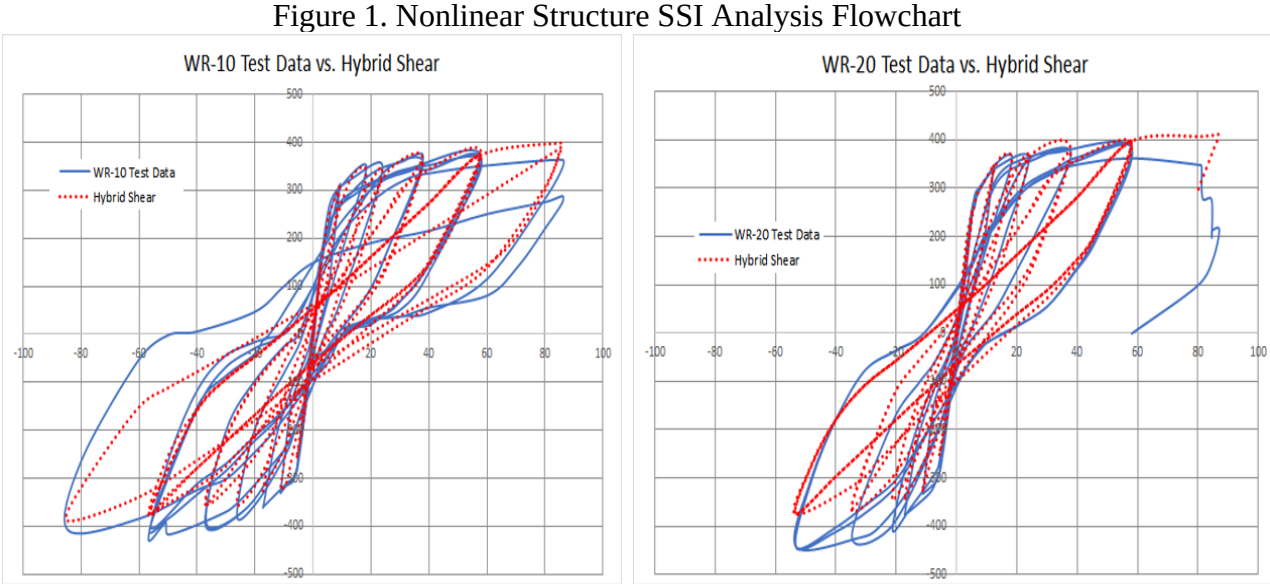

Figure 2. Hybrid Shear (HYS) Model Against WR-10 and WR-20 Wall Test Data.

The Part 1 presentation provides comparisons of the shear and bending BBCs and hysteretic responses computed based different input assumptions and types of models. The SSI result interpretation addresses various influential factors, including the effects of bending on the wall shear capacities, and the discrepancy between the hysteretic damping computed by nonlinear FEA, against the standard recommendations and wall test data.