RAI Volume 2, Chapter 2.1.1.4, Ninth Set, Number 3:

> Provide technical basis for using lumped-mass multi-stick models for CRCF, WHF, and RF buildings for seismic analyses (Tier #1) and design, instead of a more accurate finite-element method (Tier #2) (SAR Table 1.2.2-2).
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> Although BSC (2007ba, Section 7.1.3) states that Tier #2 and Tier # 1 structural analysis results will be compared to demonstrate that the Tier #1 design is adequate, SAR Table 1.2.2-2 indicates that the design of CRCF, WHF, and RF facilities is based only on Tier #1 analysis (IHF analysis is based on a finite element model, but soil-structure interaction effects are not accounted for). Tier # 1 models approximate shear walls as elastic beam-column elements, assume floors and roofs as rigid slabs, and use equivalent linear soil springs to approximate soil-structure-interaction effects. These assumptions may underestimate design forces and moments, and overestimate building performance.

1. RESPONSE

The structural analyses and designs of the important to safety (ITS) surface facilities are developed sequentially. For the Canister Receipt and Closure Facility (CRCF), Wet Handling Facility (WHF), and Receipt Facility (RF), the initial design is developed from seismic analyses that use lumped-mass, multiple-stick models of the structures. The initial design is the basis for the preclosure safety analysis in the SAR. The more detailed final design to be used to support construction is developed from seismic analyses that use finite element models of the structures.

The lumped-mass, multiple-stick models used in the initial seismic analyses of the ITS reinforced concrete facilities (CRCF, RF, and WHF) provide realistic forces and moments that are sufficient for the initial design and its use in the preclosure safety analysis in the SAR.

1.1 CLARIFICATION OF TERMINOLOGY

The terms Tier-1 and Tier-2 are used in several of the supporting structural references. Tier-1 represents the initial structural analysis (e.g., the lumped-mass, multiple-stick seismic analyses) and design described in SAR Section 1.2.2.1. Tier-2 represents the subsequent analysis (e.g., detailed finite element analyses) and design used to finalize details and support construction, as described in SAR Section 1.2.2.1.10.

1.2 INITIAL STRUCTURAL ANALYSIS AND DESIGN

As described in SAR Section 1.2.2.1.6.3.2.3 and illustrated in SAR Figures 1.2.2-14 through 1.2.2-16, lumped-mass, multiple-stick models are used in the analysis of the CRCF, WHF, and RF. In these models, shear walls are represented by beam-stick elements with stiffness properties equivalent to the walls. Roof and floor slabs are modeled to be rigid diaphragms by constraining all points located on a slab using rigid links. The tributary mass to each diaphragm is applied (lumped) at the center of mass of that diaphragm. Soil-structure interaction effects are simulated by frequency-independent soil springs placed at the center of mass of the rigid basemat.

Response spectrum analyses are performed to determine the seismic accelerations and demand forces and moments of the ITS structures using the lumped-mass, multiple-stick models. These analyses provide realistic design forces and moments and a reasonable estimate of building performance considering the following conservatisms:

- Using the CRCF as a representative example of the ITS reinforced concrete structures, the fundamental system frequencies are approximately 8 and 11 Hz in the horizontal and vertical directions, respectively, for the controlling soil case (i.e., the upper bound, 35 ft alluvium case). The peak spectral accelerations for the design basis ground motion occur at frequencies of approximately 9 and 10 Hz in the horizontal and vertical directions, respectively. Thus, initial seismic demands are determined from spectral accelerations that are close to the peak of the ground design response spectra.

- The lumped-mass, multiple-stick models consider the actual wall area for in-plane stiffness of the shear walls, but only a small area for out-of-plane stiffness. This modeling approach results in nearly all of the seismic load in each direction being resisted by in-plane action of the shear walls. In a typical shear wall structure such as the CRCF, some of the lateral load is resisted through out-of-plane action of the cross walls. By not considering this out-of-plane resistance, the in-plane design forces and moments are conservatively increased.

- To account for the effects of diaphragm flexibility and potential amplification of the slabs, the diaphragm accelerations from the initial seismic analysis are increased by a factor of two. The increased accelerations are also conservatively applied to the entire slab. Similarly, the out-of-plane accelerations at the top level of shear walls that span between diaphragms are applied to the entire wall. Out-of-plane bending moments for the shear walls are conservatively calculated considering the wall as a simple beam.

Design calculations are performed for the structural components (e.g., shear walls) using load combinations, code requirements, and other acceptance criteria described in SAR Section 1.2.2.1. The demand-to-capacity ratios of the structural components are limited to approximately 0.6. Expressed differently, the code allowable strength (capacity) is approximately 67% higher than the required demand strength, providing significant margin in the design.

Seismic fragility evaluations are performed to determine the high confidence of low probability of failure capacities and fragility curves of the ITS structures. The fragility curves are then convolved with the seismic hazard curve to determine the probability of unacceptable performance. Using the WHF as the worst-case example, the resulting probability of unacceptable performance is 8.7×10^{-7} per year. Comparing this value to the Category 2 event sequence lower threshold of 2×10^{-6} per year, there is more than a factor of two of margin available in the estimated probability of unacceptable performance.

The initial structural analyses and typical designs of the ITS facilities described in the SAR provide the requisite confidence that the structures will withstand the effects of natural phenomena and external and internal hazards.

1.3 FINAL STRUCTURAL ANALYSIS AND DESIGN

As described in SAR Section 1.2.2.1.10, finite element models are used in the more detailed analysis of the ITS surface facilities to support the design for construction. In the finite element models, shear walls and diaphragms are represented by shell elements that depict membrane and plate bending behavior. Soil-structure interaction effects are represented by three-dimensional elements that model the horizontal soil layers on an elastic half-space.

Time history dynamic analyses are performed on the combined soil-structure model to determine the seismic accelerations. These accelerations are then applied as equivalent static loads to the structural model in combination with nonseismic loads to determine demand forces and moments. Design calculations are performed for the structural components using load combinations, code requirements, and other acceptance criteria described in SAR Section 1.2.2.1. Code capacities are determined using the reinforcement patterns developed in the initial design. In areas of local stress concentration (e.g., out-of-plane crane concentrated loads), or where design demands exceed code capacities based on the initial reinforcement, further analytical and design refinement is performed, and additional capacity is provided, if required (e.g., providing additional reinforcement).

Seismic fragility evaluations are performed to determine the high confidence of low probability of failure capacities. These capacities are compared to those determined in the initial design and, in areas with less capacity, more refined analysis is performed. This ensures that the probabilities of unacceptable performance shown in Table 6.2-1 of *Seismic Event Sequence Quantification and Categorization Analysis* (BSC 2009) are not exceeded.

The final structural analyses and detailed designs of the ITS surface facilities further ensure that these structures will withstand the effects of natural phenomena and external and internal hazards.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2009. *Seismic Event Sequence Quantification and Categorization Analysis*. 000-PSA-MGR0-01100-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20090112.0013.