NRC Notes about AP1000 Shield Building

9/11/09

MAJOR CONCERNS TO THE STAFF (PRELIMINARY REVIEW RESULTS):

1. The staff basic concern that the WH module, which does not have cross ties between steel plates, cannot work well as a unit, especially during earthquakes, is not addressed in the report.

   - No response to the staff concern on "The lack of UNITY" as stated in the staff June 15, 2009 presentation.
   - No technical response to stirrups requirements as stated in the staff June 15, 2009 presentation.
   - WH conclusion of studs' adequacy to bond steel plates to concrete did not address the law of similitude in engineering and the scale effect as stated in the staff June 15, 2009 presentation.

2. WH's "pick and choose" approach of codes requirements and its interpretation of codes requirements remain a major concern to the staff.

   - WH did not address ACI Code's minimum reinforcement requirements intended for the effects of concrete shrinkage, creep, cracking, and thermal.
   - WH eliminated ACI Code's requirements for shear stirrups in the wall module, by citing that its wall is equivalent to a slab and not a beam, is not a sound engineering interpretation, especially under the circumstance that the staff had provided sufficient test data to WH on the Code's requirements.

3. The adequacy of WH design in the area near the junction of the roof and tension ring and the perforated SC wall by air inlets needs to be confirmed by model tests.

   - WH's statement that the tension ring and air inlets design following the intent of ACI 349 and supplemental requirements is insufficient.
   - WH defined the tension ring as the connection between the roof and the air inlets structure, but the exterior plate is actually extended from the top of the roof through the 4'-6" thick air inlets region and down to the 3'-0" SC wall, which makes the tension ring incorrectly defined.
   - WH did not address the complicated load paths from the roof through this region to the SC wall below.
   - WH did not address the behavior of the new SC module functioning as a tension ring, and the behavior of perforated SC modules under loads.
   - WH did not include thermal load in the load combination of dead Load plus seismic for roof, tension ring, and air inlets, which is inadequate because the thermal load is always present during earthquakes.

4. Actual maximum tensile stress in the steel plates under loads is unclear

   - Section 3.6.2.5 states that the calculated principal stresses in the top and bottom plates are about 99% of the allowable stress value.
   - Section 3.4.5.2 states that the vertical tensile force is increased by 24%, as a result of stress redistribution due to concrete cracking.

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- WH did not address whether the increased tensile force of 24% would put the original calculated principal stresses over the allowable stress value.

5. WH did not provide detailed stress analyses near the boundary regions between the SC wall and the RC wall and between other structures connected to the shield building where complex stress conditions arise due to discontinuity, which requires proper elements and fine meshes to capture those complex stresses.

    - WH used one shell element to cover the whole 36" thick wall, which cannot capture the complex stress conditions near the area of discontinuity.

6. Seismic margin was inadequately addressed

    - Section 2.3 states that the shield building has reserved strength that increases its seismic margin from 0.3g, used in the design, to above the review level earthquake (0.5g) without providing convincing reasons.
    - WH states that there is a margin to code allowable, but fails to provide the magnitude of the margin and where the margin comes from.
    - WH states that there are factors of safety within the code allowable, but fails to provide the magnitude of these factors and where these factors come from (note: the load factor for SSE is 1.0).
    - WH states that there is a margin to critical buckling, but fails to provide the magnitude of the margin and where the margin comes from.
    - WH states that there is a margin due to the actual strength to theoretical or code strength, but fails to provide the magnitude of the margin and where the margin comes from.
    - WH states that "A large amount of energy associated with a seismic event will be absorbed and dissipated by inelastic-response that is a function of the structure ductility" without providing evidence. On the contrary, the staff had provided sufficient evidence with test data to WH indicating that concrete members without stirrups failed in a brittle manner.

7. WH proposed testing program for in-plane shear plus tension is inadequate

    - The proposed test apparatus has edge restraints to specimens, which affects the appropriateness of the test results, and that remain to be a concern to the staff.
    - The proposed tests should including cyclic loading to simulate seismic affects.

8. WH has not proposed a method and program for inspecting concrete inside the steel plates right after the concrete is poured and cured and subsequent inspections.

    - Inspection on voids, cracking, and delamination in concrete, after concrete is poured and cured, is required.
    - Maintenance of concrete structures requires periodical inspection on degradation of concrete.

STAFF'S CONCERNS ON THE DESIGN, ANALYSIS, CONSTRUCTION, AND INSPECTION OF THE SHIELD BUILDING
7/14/2009

I. Design method

I.1 SC wall

Design philosophy (criteria) of structures:

The shield building should survive severe earthquakes without collapse, and, therefore, any brittle failure modes, such as shear or torsion (twisting), should be avoided or suppressed.

I.1.1 SC wall without stirrups (shear reinforcement) in the radial (wall thickness) direction

WH proposed to conduct a full scale test, and needs to state what the test would achieve and provide a criterion for what constitutes a successful test.

- Staff believes that the SC wall without stirrups will fail in a brittle mode in shear during severe earthquakes.
- WH consultants indicated that the Bechtel test did not show the brittle failure mode of a "diagonal tension failure" at a shear stress equaled to 1.25 square root of fc', and implied that they believed that the SC wall might have behaved differently from, or better than, the RC wall in shear.
- WH needs to state the purpose of the test and what the test would achieve

I.1.2 Design method for the SC wall subjected to membrane (in-plane or tangential) shear plus membrane forces

WH proposed to conduct tests for wall modules subjected to membrane shear plus membrane forces in both meridional and circumferential directions, and needs to state what the tests would achieve and how to achieve them.

- WH indicated that the SC wall design would comply with JEAG.
- WH needs to ascertain that JEAG is applicable to wall modules of the SC wall subjected to membrane shear plus membrane forces in both meridional and circumferential directions.
- If WH determines that JEAG is applicable to the wall module design, WH's tests should substantiate that the JEAG' design method for the wall module is adequate.
- If WH determines that JEAG is not applicable to the wall module design, WH needs to establish a design method for the wall module based on test data.

I.1.3 Bending moment capacity of the SC wall subjected to out-of-plane bending

WH needs to choose or establish a method for the calculation of the bending moment capacity of its SC wall.

II Analysis method

II.1 WH's analysis for the SC wall did not account for the irregular boundary (support) conditions.

- WH's analysis assumed the entire cylindrical wall of the shield building as a unit, built with the same material, and is fixed to the basemat.
- The shield building wall is actually consisted of two dissimilar components: the RC wall and the SC wall.
- The SC wall is anchored to the RC wall with irregular boundary (support) conditions both in the meridional and circumferential directions, and therefore,
- WH needs to perform an analysis of the SC wall with actual boundary (support) conditions. Such an analysis will reveal the twisting (torsion) effects near the boundary and different vibration mode shapes of, and forces on, the SC wall than that obtained from the assumption made in the first bullet above.
- In additional to pay attention to the actual boundary conditions, WH needs to ascertain that the type of elements and the fineness of meshes that it selects will yield adequate accuracy of forces, bending moments, and twisting moments for the design.

II.2 WH's analysis for the SC wall did not account for the phenomenon of potential stress increase over its linear elastic analysis, due to stress redistribution, resulting from concrete cracking in other regions, as Illustrated below.

- WH's analysis stopped at linear elastic, and does not account for the potential increased stress values due to the non-linear stress redistribution phenomenon.
- WH is required to determine whether its shield building has a possibility of such a stress increase (a code requirement). If not, provide the justification. If yes, WH needs to include the increased stress in the design.

III. Other components of the shield building

WH has not included its design and analysis on the water tank, the ring girder, the air inlets, the connection between the roof and the SC wall, and other critical sections in the report, and is urged to do so

IV. Construction method

WH is urged to include the construction method and sequence for the shield building in the report.

V. Inspection method

WH is urged to include the inspection methods for all components of the shield building in the report. Specifically, the inspection method for concrete, after being poured and cured, between the steel faceplates should be stated.

NRC PRESENTATION

June 15, 2009

1. What the ACI Code does or does not provide.
    - The Code provides a minimum standard for acceptance of design and construction.
    - The Code does not provide detailed specifications, recommended practice, complete design procedures, or design aids.
    - The Code and Commentary cannot replace sound engineering knowledge, experience, and judgment.
2. ACI Committee 334, "Concrete Shell Structures Practice and Commentary" states
    - There is a size effect.
    - An ultimate strength analysis may be used only as a check, and it is not to be used as a sloe criterion.
    - In extreme case the buckling load for a cylindrical shell obtained experimentally is only 10% of that predicted by the small deflection theory.
3. What has the Westinghouse analysis and design advanced to?
    - Obtained element forces from a linear elastic finite element analysis computer code, based on the small deflection theory.
    - Calculated steel reinforcement in vertical and horizontal directions required by element forces from a computer code, based on ACI Code equations, and then replacing them with steel faceplates.
    - Westinghouse's design stopped at the element level, and has not advanced it to the shell structure as a whole.
    - Westinghouse's analysis did not consider concrete cracking during earthquakes, and concrete creep due to the compressive load of water of 8.5 million pounds.
4. Minimum stirrups (shear) size and their maximum spacing for a 36 inch thick 6,000 psi concrete wall.
    - Based on the ACI Code requirements and test data, #6 steel bars with 60 ksi yield stress are required to be spaced at 18 inch vertical and 24 inch horizontal, if out-of-plane shear stress is less than 387 psi, and 12 inch, if shear stress is greater than 387 psi, but the SC wall did not contain these stirrups.
    - Test data indicated that the shield building could fail in a brittle mode in shear.
5. Scalability issue for small models
    - LANL small model shrinkage problems.
    - Shear strength decreases while the depth of members increase.
6. Acceptance criteria for anchorage tests
    - Section 12.14.3.2 of ACI Code: the anchorage shall develop in tension or compression, as required, at least 125% of the yield strength of the reinforcing steel bar.
7. Problems required practical considerations for the design of the shield building
    - Heavy vertical load: 8.5 million pounds of water.
    - Lollipop effect.
    - Cathedral ceiling effect on the wall.
    - Complicated load paths: roof & wall junction.
    - Dissimilar components of wall modules in the same shield building.
    - Unproven SC components of wall modules used for the shield building.
    - Non-linear and irregular anchorages in both meridional and hoop directions.
    - The lack of UNITY.