Design and analysis of the Mark I Full Scale Test Facility

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INTRODUCTION.

The Mark I Full Scale Test Facility (FSTF) was designed and constructed by Santa Fe Braun (formerly C F Braun) under contract to the General Electric Company (GE). GE served as the Project Manager on the behalf of the 16 utilities who owned and operated Mark I BWR Nuclear Power plants. The FSTF was designed to simulate both saturated water and saturated steam breaks. The test facility consisted of a full-scale section of a GE Mark I wetwell and the peripheral equipment required to provide complete simulation of the hydrodynamic and structural response of the wetwell to a Loss of Coolant Accident (LOCA).

The FSTF wetwell is a 22.5 degree segment with the exact dimensions of a Mark I Nuclear plant constructed in the United States and has a volume of 12,000 cubic feet. The two major supporting pieces of equipment were the steam vessel, a flash boiler capable of operating at reactor conditions (550 degrees F and 1,050 psia) and the drywell, a vertical pressure vessel with a volume equal to 1/16 of the drywell volume, 6,900 cubic feet, of the operating Mark I.

During the simulation of either a saturated water or saturated steam break, fluids flow from the steam vessel through a blowdown line to the drywell and then from the drywell through vent lines to the wetwell. A LOCA simulation is initiated by rupturing discs located in the blowdown line. The flow rate is controlled by a critical flow nozzle located in the blowdown line. During the LOCA test, some 256 data points were recorded at a rate of up to 1,000 times a second.

SYSTEM DESCRIPTIONS.

The configuration of the FSTF wetwell consisted of the 22.5 degree segment with a 4'-3" extension on either side. This provided the attennuating distance necessary to eliminate any local discontinuity stresses in the wetwell that are caused by the flat head end closures. Inside each extension was a sealed and reinforced cylinder that extended back to the mitered junction of the wetwell and extensions. This arrangement allowed the 22.5 degree wetwell section to completely simulate the effects of a blowdown. Figure 1 shows the construction details of the wetwell arrangement.

Fourteen hinged pipe struts connected the 4'-3" extension on either side of the 22.5 degree wetwell to the concrete abutment structure on each side. The hinged struts allowed both radial and axial displacements of the wetwell to be properly simulated.

The concrete abutments were multi-cell box-like structures with a flat vertical face to which the pipe struts were joined. The entire system consisting of the wetwell, extensions, pipe struts, and concrete abutments was supported on a 5 ft thick rigid mat foundation poured directly on lean concrete covered bedrock.

The FSTF configuration described above had to be designed and have both a static and dynamic response equal to that of one of GE's Mark I Nuclear plants in operation. To obtain this correlation, numerous configurations of the wetwell, abutments, foundation, and underlying rock were completely analyzed to determine the applicable stiffnesses and masses of the respective structural components.

A schematic view of the wetwell system is represented in Figure 2. A complete wetwell (360 degrees) as well as the FSTF wetwell of 22.5 degrees were modeled and their frequencies compared. The analyses accounted for the water contained in the wetwell using Westergard's method of hydrodynamic mass (no sloshing).

DYNAMIC ANALYSIS OF WETWELL.

A Spring-Mass model was first developed to define, size, and develop paramatric evaluations for various wetwell configurations. After the various configurations were evaluated, a complete 3-dimensional static and dynamic finite element analyses were performed on the FSTF configuration as well as the complete wetwell of the operating GE Mark I nuclear power plant. The mode shapes and the frequencies (Figures 3, 4, 5) as well as the time history behavior of the FSTF wetwell were compared to those of the complete wetwell. FSTF wetwell parameters were further refined to obtain a very close level of correlation with the behavior of the complete wetwell system.

DYNAMIC ANALYSES AND EVALUATIONS OF ABUTMENT CONFIGURATIONS.

In developing the required abutment configuration, numerous structural configurations were designed with static and dynamic analyses being performed. In each configuration, the stiffness and associated mass properties were varied in an attempt to develop an abutment system that when coupled to the FSTF wetwell, the entire configuration would yield a wetwell static and dynamic responses identical to those of the complete wetwell in operation. Figure 6 depicts some of the configurations considered in this process.

During this phase of the FSTF design it became apparent that since the foundations were being founded on bedrock covered with lean concrete, the influence of soil-structure interaction was negligible, and it would not need to be considered in the final FSTF system analyses.

FSTF SYSTEM ANALYSES.

In this series of static and dynamic analyses, the 3-dimensional FSTF wetwell model was joined to the 3-dimensional model of the concrete abutments and mat foundation.

Table I shows the comparison of natural frequencies between the complete wetwell and those of the FSTF wetwell system. The frequencies listed are grouped into local ovalling modes, overall wetwell modes, and wetwell bouncing modes. A review of Table I shows that the dynamic response of the two systems is in close correlation as desired. Although the results of some of the local ovalling modes were not in as close a correlation as the other modes, these modes were not of interest in the study and nor do they affect the results of the FSTF tests that were performed.

CONSTRUCTION.

The project was constructed on a site owned by Wyle Laboratories at Norco, California, U.S.A. The site is underlain with bedrock at a shallow depth. After excavating for the foundations and removing the loose material present, a lean concrete cover was poured to fill the surface fractures and to level the site. During the construction of the large mat foundation and abutments, 4" diameter pipes were embedded in the structures to permit the placement of explosive charges. This was done to permit easier demolition of the structures after the testing program was completed. All vessels were shop-fabricated, shipped to the site, for placement and final erection.

The entire project, engineering, procurement, and construction was completed and ready for testing in eight months.

FSTF TESTING PROGRAM AND RESULTS.

Numerous dynamic analyses of the various test conditions were performed on the FSTF wetwell system to predict results prior to actual testing. Results of these analyses were within 3% of tested results at the FSTF facility. This testing program demonstrated that the structural behavior and response of the Mark I wetwell under LOCA conditions met all US NRC requirements.

As a result of constructing this facility and the performance of these LOCA testing conditions, millions of dollars of potential Mark I modifications on existing plants were found not to be necessary.

TABLE I COMPARISON OF NATURAL FREQUENCIES BETWEEN THE COMPLETE WETWELL AND THE FSTF WELL SYSTEM

COMPLETE WETWELL (Hz)	FSTF WETWELL (Hz)	REMARKS
2.54	3.35	Local ovalling modes
3.03	4.79	
3.46	5.99	
4.18	6.45	
15.11	15.04	Overall wetwell modes
16.95	17.10	
17.43	18.46	
17.95	18.90	
27.07	27.31	Bouncing modes
27.20	28.05	
27.85	28.72	

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of Steve Dorsey and Iman Phillips in the preparation of the numerous figures required for this paper. The figures were prepared using Braun's 3-D CADD PDS system.

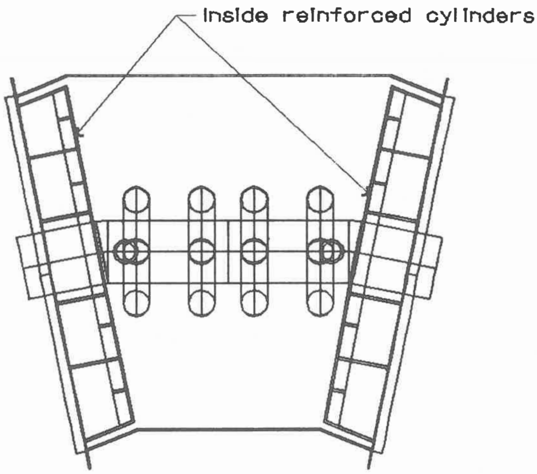

Figure 1. Wetwell arrangement

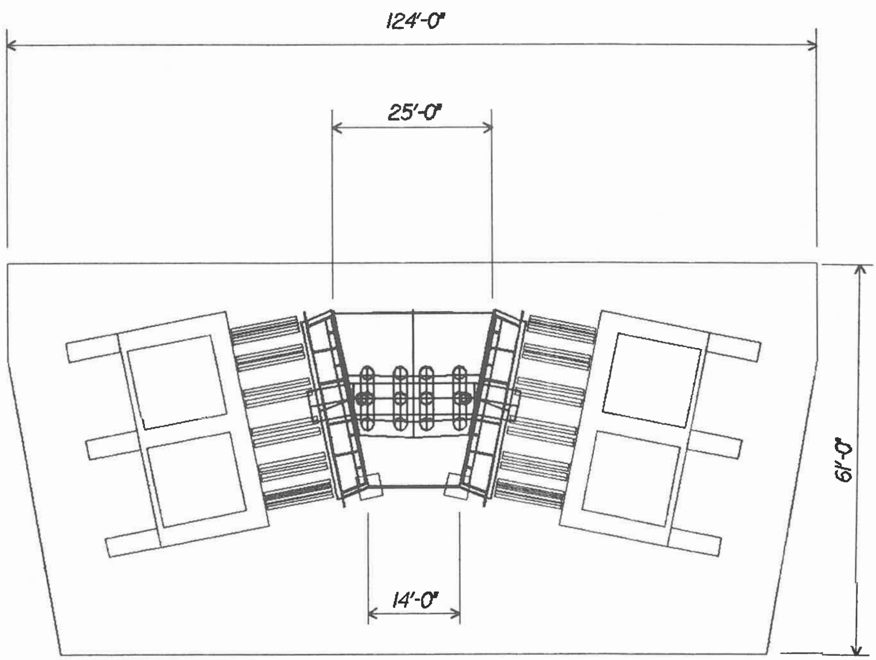

Figure 2. Wetwell - Abutment system arrangement

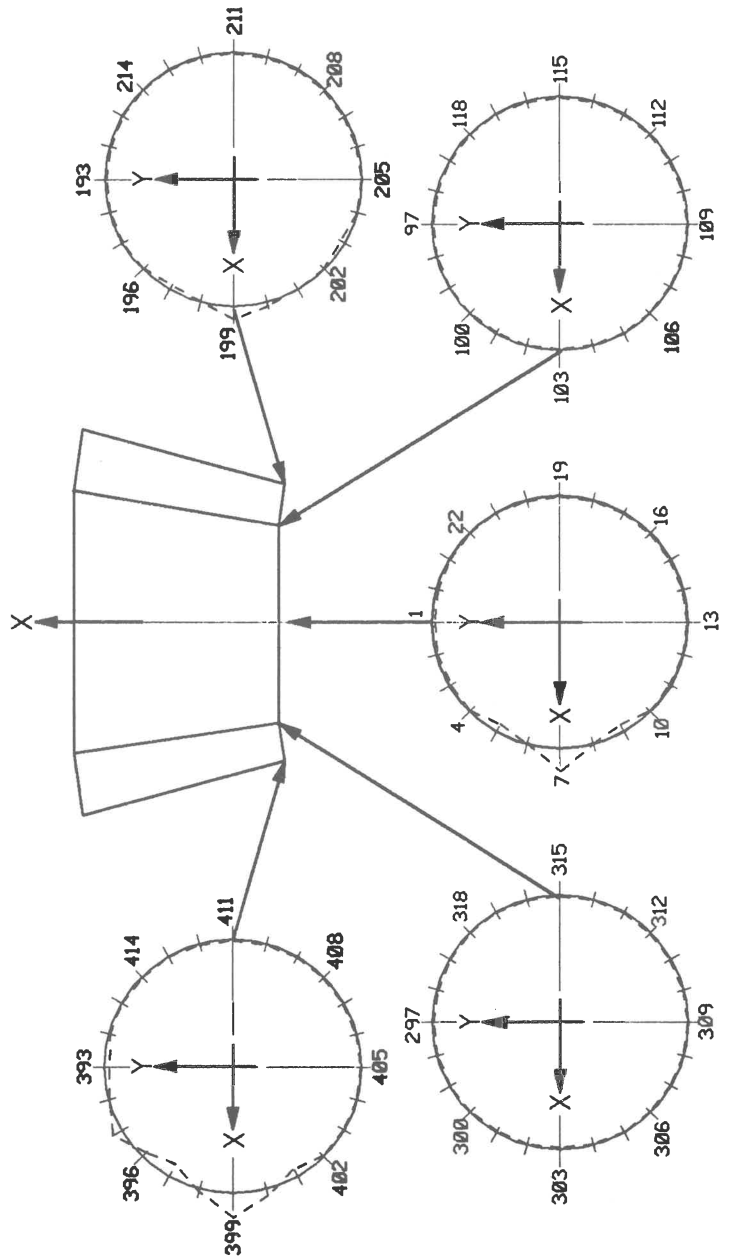

Figure 3 FULL TORUS MODE 3
3.465 Hz SYMMETRIC MODE

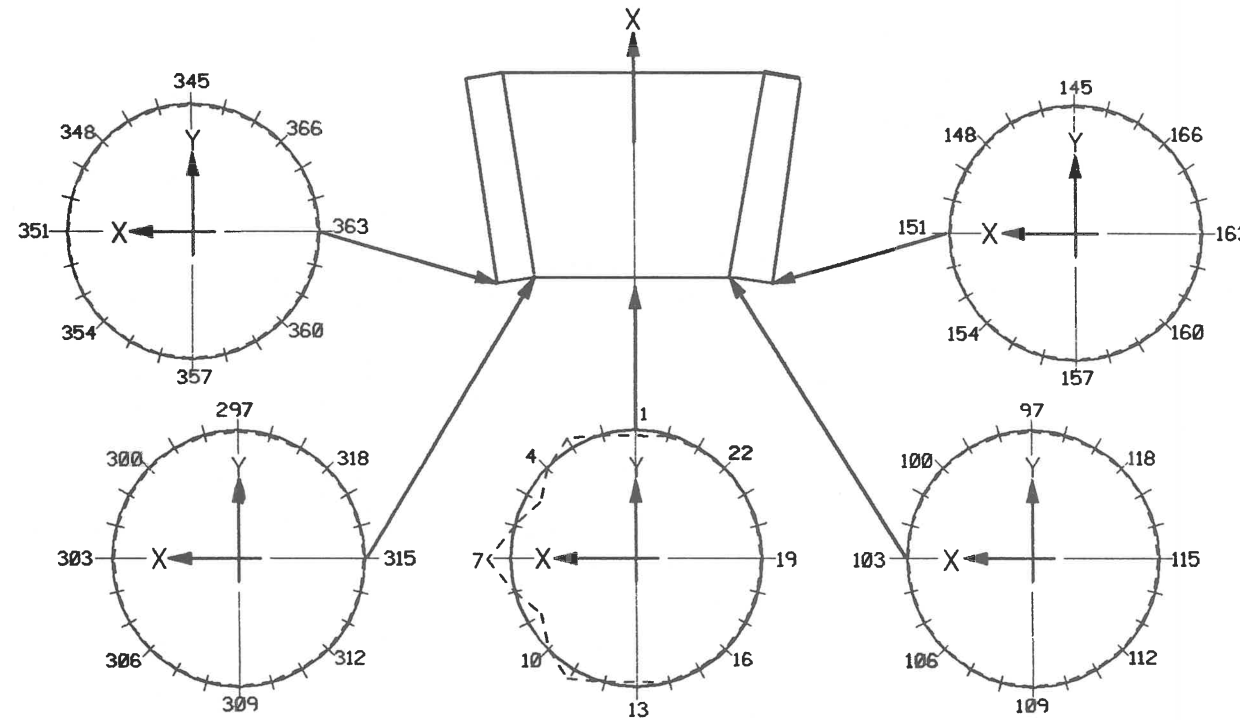

Figure 4 TESTCELL MODE I

3.347 Hz SYMMETRIC MODE

(THIS MODE SHAPE CORRESPONDING TO MODE 3 OF THE FULL TORUS MODEL)

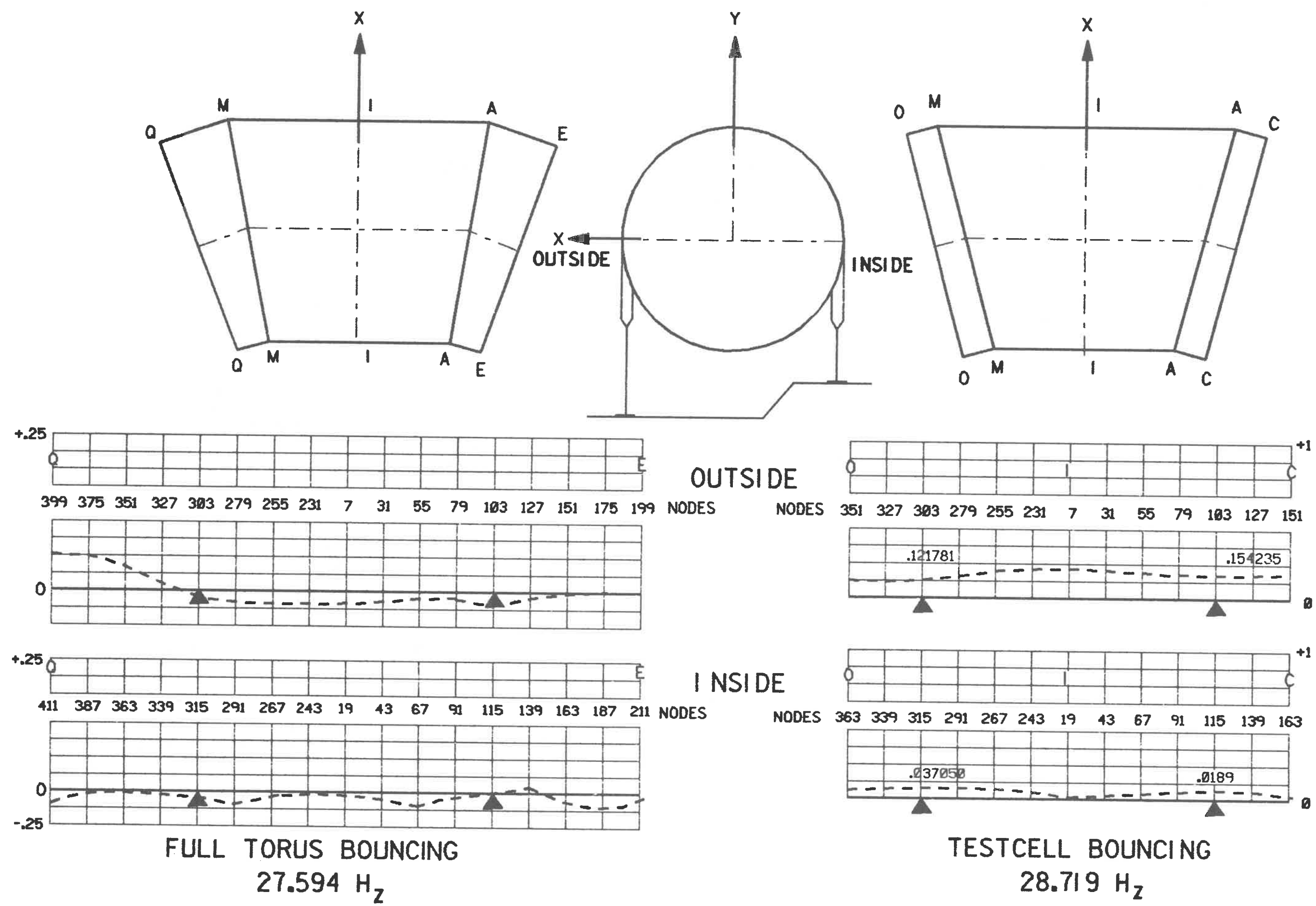

Figure 5. Comparison of Full Torus vs. Testcell Bouncing Mode

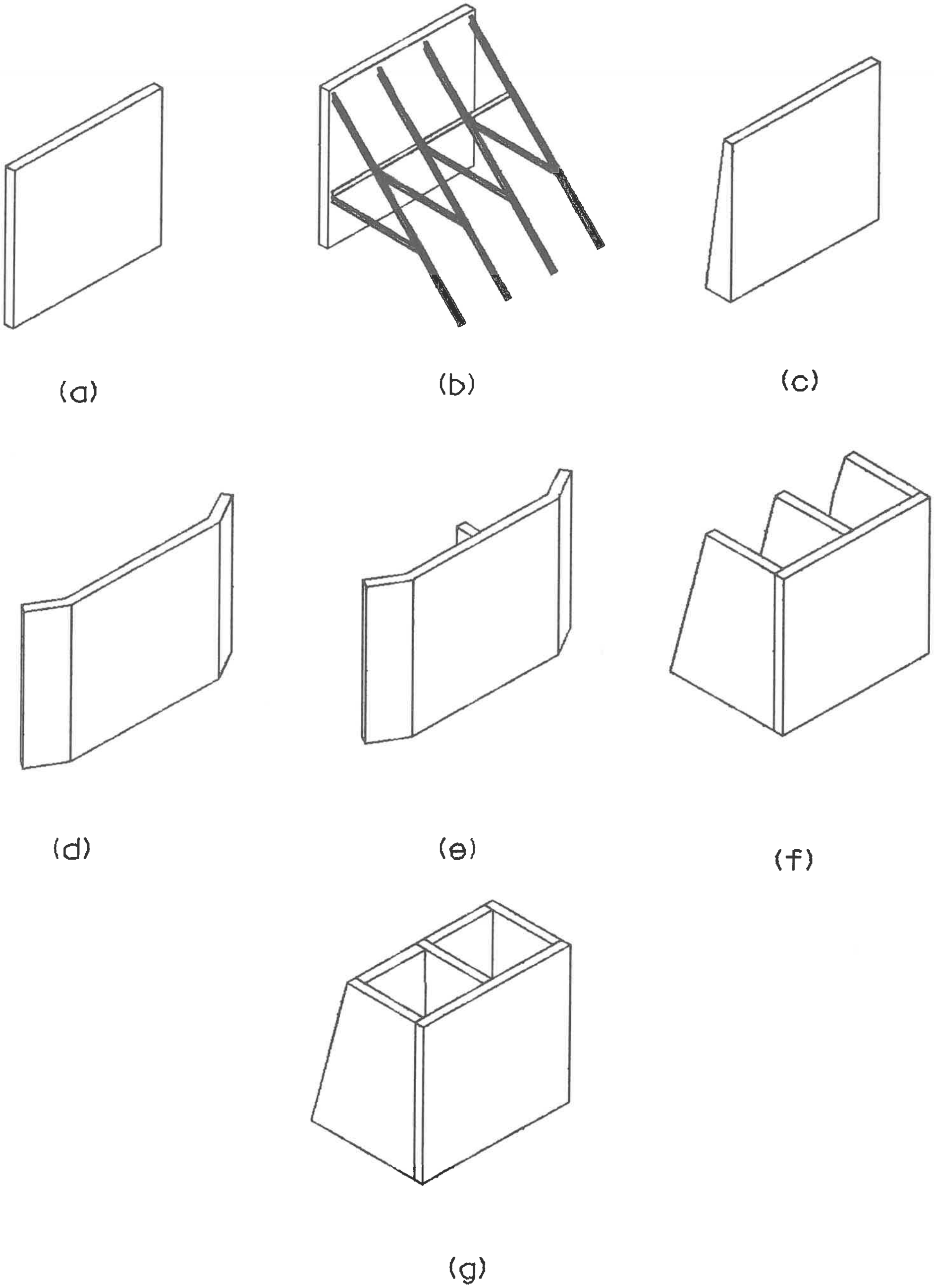

Figure 6. Various Abutment Configurations Analyzed