EVALUATION OF ARCHING THEORY IN UNREINFORCED MASONRY WALLS IN NUCLEAR POWER PLANTS

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June 1983

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INTRODUCTION

In response to IE Bulletin 80-11, a total of 16 nuclear power plants have indicated that the arching action technique has been employed to qualify some unreinforced masonry walls. Based on the review of submittals provided by the licensees and published literature, Franklin Research Center (FRC) staff and FRC consultants have concluded that the available data in the literature do not give enough insight for understanding the mechanics and performance of unreinforced masonry walls under cyclic, fully reversed dynamic loading. As a result, a meeting with representatives of the affected plants was held at the NRC on November 3, 1982 so that the NRC, FRC staff, and FRC consultants could explain why the applicability of arching theory to masonry walls in nuclear power plants is questionable [1]. In a subsequent meeting on January 20, 1983, consultants of utility companies presented their rebuttals [2] and requested that they should be treated on a plant-by-plant basis. In accordance with their requests, the NRC staff has started the process of evaluating each plant on an individual basis. In this process, the NRC, FRC staff, and consultants have initiated visits to various nuclear plants to examine the field conditions of unreinforced masonry walls in the plants and to gain first-hand knowledge on how the arching theory is applied to actual walls. Key calculations have been reviewed with regard to the arching theory.

EVALUATION OF ARCHING THEORY

Test of unreinforced concrete masonry walls were recently conducted by Agbabian Associates, S. B. Barnes and Associates, and Kariotis and Associates [3] (this joint venture work is designated as ABK). Based on the visit to Oconee Nuclear Station, the results of the ABK tests, and all relevant information submitted by the licensees including the rebuttals given by the licensees in the January 20, 1983 meeting, the NRC, FRC staff, and consultants have made the following evaluations:

1. The design methodology used at various nuclear plants was developed by McDowell et al. [4] in 1956 for solid brick walls under static monotonic loading. No test data are available to check the adequacy of hollow block masonry under cyclic, fully reversed dynamic loading.

2. The only dynamic test data for arched masonry walls are the URS tests [5] for blast loading. This type of loading is not a true representation of earthquake loading because it is not fully reversed and has a decayed nature. Under very short-duration blast loading, masonry walls, which have much lower natural frequencies, would not fully respond to the applied load. In addition, only two walls were tested under cyclic blast loading at URS for arched masonry walls.

3. Extrapolation of test data from solid masonry to hollow block masonry is questionable. Recent test data [6] of eccentrically loaded masonry assemblages showed that the failure mechanism, strain distribution, and overall behavior of hollow masonry are quite different from those of solid or grouted masonry.

4. Hollow block masonry walls are more susceptible to premature web-shear failure or crushing compression failure. Precluding these types of failure is neccesary for the development of the arching mechanism. No data are available at the present time to determine the safety factors against these brittle failures under seismic loading.

5. Recent ABK dymanic tests [3] showed that unreinforced block masonry walls did fail (collapse) under earthquake loads with ground acceleration (effective peak acceleration) of about 0.3g to 0.4g, which is typical for nuclear plants. Also, some walls experienced local crushing at the base before failure by instability, which emphasizes the possibility of premature compression failure of arched walls. It must be noted, however, that the ABK test walls were not restrained at top to develop arching. The effect of boundary conditions could be significant and cannot be evaluated without further testing.

6. Unreinforced block masonry walls are extremely brittle, and flexural failure occurs without warning. The sensitivity of unreinforced masonry to crack development due to temperature and shrinkage is evident. Also, the inherent strength variability indicates the necessity of different safety indexes in ultimate failure analysis.

7. Masonry walls in nuclear plants usually have openings and attachments. Their effects on wall stability under seismic loading are unknown and cannot be rationally evaluated without testing.

8. No test data are available for gapped arching block walls under cyclic loading. In some cases, restrainers are provided around the gap to prevent gross sliding; this repair measure does not necessarily change the wall behavior from gapped arch to rigid arch.

CONCLUSION

A review and evaluation of the available information on the applicability of arching theory to unreinforced masonry walls in nuclear power plants has been presented. NRC, FRC staff, and consultants are firmly convinced that their original position expressed to the licensees in the November 3, 1983 meeting is still valid. It is evident that test data are needed to quantitatively determine the effects of different wall geometries, material properties, and boundary conditions on unreinforced block masonry walls' resistance to earthquake loading. It is recommended that a confirmatory testing program be performed to investigate the applicability of arching theory to unreinforced block masonry walls in nuclear power plants.

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March-April 1983