RESPONSE OF NUCLEAR CONTAINMENT WALL SUBJECTED TO IMPACT AND THERMAL LOADS

Thesis submitted in partial fulfillment

for the Award of Degree

Doctor of Philosophy

by

ALIM RAWSAN

DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005

Roll No: 16061002

2021

CHAPTER-8

CONCLUSIONS

8.1 GENERAL

The safety of the NPP containment structure against various kind of impact load has been a topic of research. In the present work, an attempt has been made to study the behaviour of nuclear containment wall subjected to different impact load due to aircraft crash and subsequent fire effects. The Concrete Damaged Plasticity (CDP) model has been employed to simulate the behavior concrete while the Johnson-Cook elasto-viscoplastic material model has been used to simulate the behavior of the reinforcement as well as the aircraft. The implicit as well as explicit integration schemes available in ABAQUS finite element code have been employed to carry out the numerical simulation.

Initially, simple PCC, RCC flat pate and cylindrical wall have been analyzed for different aircraft impact. Thereafter, four types of existing NPP structures named Creys-Malville Reactor (CMR), Fessenheim and Bugey Reactor (FBR), Boiling Water Reactor (BWR Mark-III) and Three Mile Island Reactor (TMIR) have been taken into consideration to determine the response of containment wall. The reaction-time curve of Boeing 707-320 aircraft has been determined assuming the rigid and deformable targets with varying curvatures. The aircraft as well as containment wall are numerically modeled to get the most precise results. The response of the containment has been obtained in terms of local and global deformation, stresses induced in the concrete and reinforcement and the corresponding material degradation. The results thus obtained corresponding to the geometric model and the reaction-time curve have been compared and discussed. The fire induced due to aircraft crash has also been considered to study the further degradation of the structural material. The deformed state of the containment after impact analysis has been considered as the initial state for the fire analysis. The coupled impact and thermal analysis have been carried out to identify more accurate global and local behavior of the containment.

8.2 CONCLUDING REMARKS

From the present study the following major and important conclusion may be drawn;

1. When a simple PCC flat plate is under aircraft impact, it is observed that the aircraft Boeing 707-320 has less damaging potential than Phantom F4 fighter jet because the Phantom F4 has more impact velocity with more impact force.

2. BWR Mark-III and TMIR containment walls have been analyzed under impact load of Boeing 707-320, Phantom F4, Airbus A320 and Boeing 767-400 aircrafts. The Boeing 767-400 aircraft caused most significant damage to the concrete leading to the global failure of the containment. On the other hand, Phantom F4 caused local damage and expected to perforate if impacted with high velocity. It is also found that the Boeing 767-400 has more damaging potential and Airbus A320 has low damaging potential among all. The primary reason for this is the Boeing 767-400 with more impact force on larger fuselage area.

3. The four real NPP containment structures (CMR, FBR, BWR Mark-III and TMIR containment) are considered to find out the most damage prone NPP and it is seen that the CMR is more affected NPP containment. It may be due to less thickness of wall compare to the other.

4. The material model has been analyzed considering zero, 290, 620 and varying strain rates. The deformation response is found maximum at zero strain rate whereas in case of 620 and varying strain rate, the deformation is almost same. As the velocity of aircraft impact load is very high, strain rate is an important parameter which must be carefully incorporated to model the material behavior of the containment.

5. BWR Mark-III Nuclear power plant containment wall has been analyzed at seven different location under Boeing 707-320 aircraft impact. It is observed that the most vulnerable location is just above the mid height (24m from foundation) of cylindrical portion of the containment. However, the crown of dome has been found to be the safest location due to more structural stiffness.

6. The curvature and deformability of the target are important parameters affecting the reaction-time response of aircraft. A decrement in the peak reaction force has been noticed with increase in target curvature. The reaction force developed by the deformable target is less in magnitude compare to the rigid target of similar shape and size. The formulating for rection time response curve proposed by Riera 1968 should be modified considering all above parameters.

7. The application of average area scheme underestimated the local deformation of the containment. The deformation response is found almost similar in nature for area trifurcation approach and geometric model approach. However, the geometric modeling of aircraft is very time consuming so the trifurcation approach is better solution scheme.

8. Thickness of NPP wall, % of steel reinforcement in wall, radius of curvature of containment, impact angle of aircraft and velocity of aircraft are the important parameters that affects the deformation response.

9. From heat transfer analysis of TMIR containment wall, the change of temperature gradient is found up to 250 mm depth of the wall and beyond this depth the negligible temperature change is observed.

10. From thermal stress analysis of TMIR containment wall, it is clear that the outer face of containment is always under compression. The thermal stress value increases with time and then decreases gradually due to the variation in the fire intensity of jet fuel curve.

11. Due to combustion of aircraft fuel the maximum temperature of the flame is around 1200^{o}C in open place. After hitting the aircraft on the outer face containment wall, the heat transfer takes place along the thickness of the wall. The maximum temperature of 1062^{o}C was found in concrete near the base of TMIR containment wall and very less temperature (approximately 24 ^{o}C) was observed in inner steel liner because of thicker section.

12. The deformation of the outer face of NPP containment wall is inward direction during impact loading. However, after thermal load analysis, the outward deformation tendency of outer face of containment wall is observed.

8.3 SCOPE OF FUTURE STUDY

The following may be considered as the scope of work for the extension of present study in future;

- The actual impact load characteristic curve may be investigated by performing real time experiments work.
- The effect of impact and fire near the base of NPP containment and its influence.
- The analysis of NPP containment taking effect the sudden blast of fuel container with high velocity impact of aircraft.
- The evaluation of reaction time curve for the new variant of high velocity fighter jet to analysis the effect of impact load.