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Reliability of double-wall containment against the impact of hard projectiles

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HIGHLIGHTS

- The reliability of double-wall containment against impact of projectiles was studied.
- Probabilistic procedure based on Monte Carlo simulation technique was used.
- Sensitivity studies were carried out to obtain the results of practical interest.
- Reliability is correlated with the ballistic limit of the outer RC wall.

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ABSTRACT

Effectiveness of single or double-wall containment structures against a possible strike of projectiles, missiles or airplanes is well researched. However, how the uncertainties involved in the various design parameters influence the reliability of the containment is not very well known. In a double-wall containment structure, as name implies, there are two walls – an outer thick reinforced concrete (RC) wall and an inner thin steel shell/wall. In the present study, a simple probabilistic procedure based on Monte Carlo simulation technique is presented to study the reliability of double-wall containment structures against the impact of external hard projectiles on outer RC wall for varying impact velocities. In order to illustrate the proposed methodology, an idealized double-wall containment structure and a hard projectile were chosen. The probability of failure and the reliability indices of the selected double-wall containment structure were obtained for different striking velocities of the projectile and safety of the containment was correlated with the ballistic limit of the outer RC wall. The results of the study show that the double-wall containment is "safe enough" against the impact of the selected projectile if the projectile nominal velocity is less than 65% of the containment outer wall's nominal ballistic limit (V_{BL}). Results also show that under the given uncertainties, if the nominal impact velocity is less than 65% of the nominal ballistic limit of the outer RC wall (i.e. $0.65V_{BL}$), failure probability of the containment is almost zero. However, when impact velocity is more than $0.90V_{BL}$, failure probability of the double-wall containment is quite high. It was also observed that a little change in the impact velocity over $0.90V_{BL}$ may cause a phenomenal change in the containment reliability due to substantial change in the residual kinetic energy of the projectile. A number of sensitivity studies have also been carried out to obtain the results of practical interest.

1. Introduction

A number of single and double-wall containment structures are in existence all over the world. In single-wall containment (Abbas et al., 1996; Siddiqui et al., 2003), a single reinforced concrete (RC) or prestressed wall surrounds the process equipment and machines and provides protection to them against the effects of the outer/external environmental forces or the release of radiations to the environment. In a double-wall containment structure, as name implies, there are two walls – an outer relatively thick RC wall and an inner steel wall. The outer RC wall of the containment (Fig. 1) gives the external protection to the inner steel wall (which may house the reactor, steam generators and other vital plant equipments) against the effects of the outer environment and impacts of external missiles, projectiles and even aircrafts. The purpose of the inner steel wall/shell is to prevent the emissions in the event of a process failure.

Despite the existence of a large number of containment structures, there are only a few containment structures whose detailed

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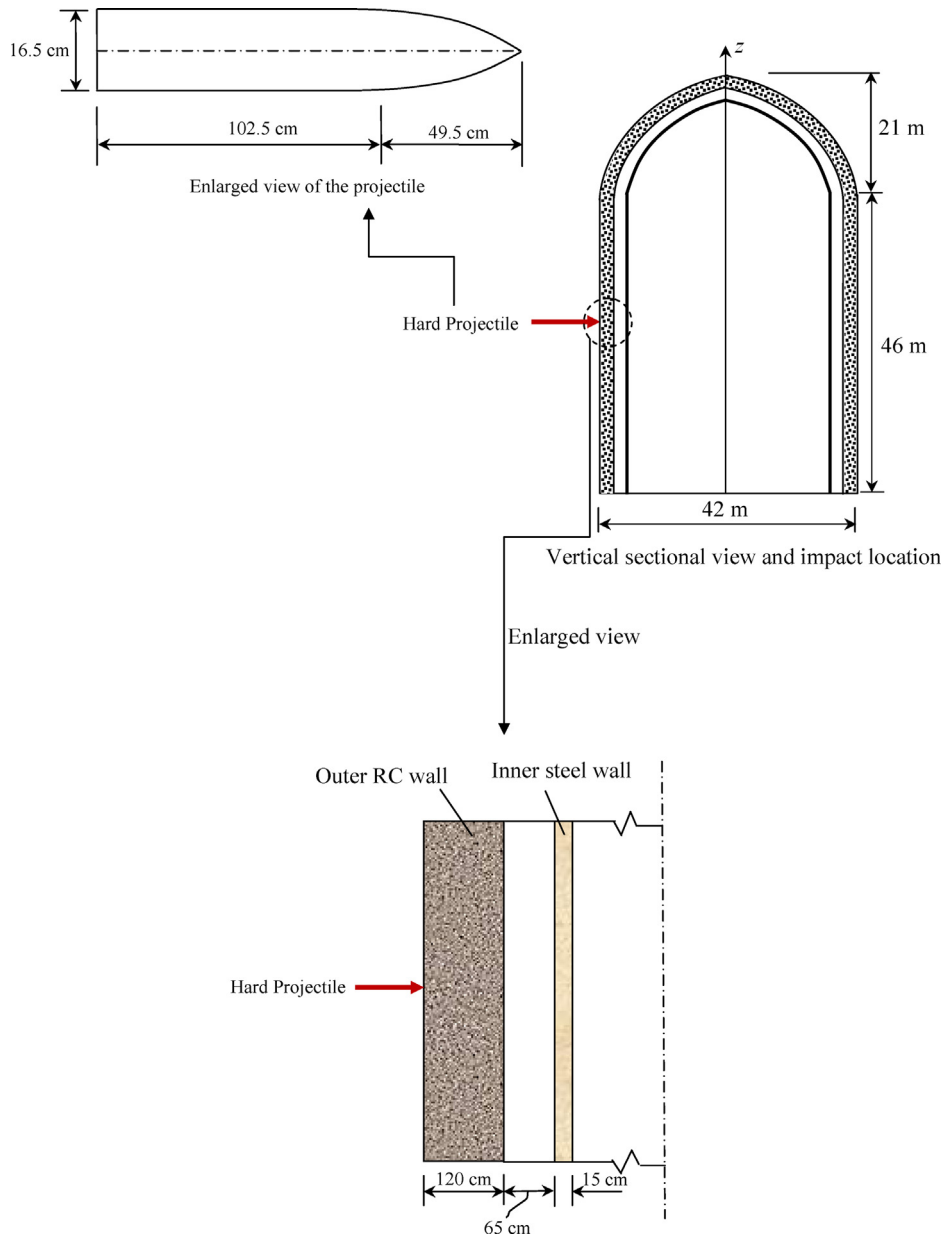

Fig. 1. Schematic details of outer concrete and inner steel walls of uniform thickness.

quantitative safety assessments were carried out against the impact of high velocity missiles, projectiles or even commercial planes. Such quantitative safety and reliability assessments are necessary in order to incorporate uncertainties involved in various design parameters related to the target (containment) and the impacting objects. Neglecting these uncertainties or considering them just in terms of qualitative safety factors may sometimes lead to a structure with substantially high probability of failure. As the consequences of containment structures failure are far severe than even the collapse of a 100 storey commercial building, it is very much necessary to propose a simple methodology for the reliability assessment of such containment structures against the impact of projectiles, missiles, etc. To propose a simple methodology for the reliability assessment of a double-wall containment structure against the impact of high velocity non-deforming projectiles is the subject of the current investigation. In the past, some limited works are reported on the reliability analysis of structures subjected to impact loads of projectiles, missiles and aircrafts on concrete structures. Choudhury et al. (2002) presented a methodology for the reliability analysis of a buried concrete target against normal missile impact. The expressions for the depth of penetration in the buried target were derived. These equations were then employed for the reliability estimation. Design points, important for the probabilistic design, were located on the failure surface. Sensitivity analysis was carried out to study the influence of various random variables on target safety. Some parametric studies were included to obtain the results of field interest.

Siddiqui et al. (2003) presented a methodology for detailed reliability analysis of nuclear containment without metallic liners against aircraft crash. For this purpose, a nonlinear limit state function was derived using the violation of tolerable crack width as a failure criterion. The derived limit state requires the response of containment that was obtained from a detailed dynamic analysis of nuclear containment under the impact of a large size Boeing jet aircraft. Using this response in conjunction with limit state function, the reliabilities and probabilities of failures were obtained at