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Research Article

EVALUATION OF DIFFERENT GEOMETRIC SHAPES OF THE TARGET BUILDINGS IN PWR NUCLEAR POWER PLANT FOR AIRCRAFT IMPACT

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ABSTRACT
Design of the PWR plant's target buildings where safety and security interface with each other is very effective to optimize plant design. One of the important parts of optimized plant design is protection of the target buildings against external events such as aircraft crash. Target buildings are important nuclear building whose resistance against external events plays a major role in safety and security related issues. One of the external events which have become very significant after the September 11, 2001 event is aircraft crash. The target buildings should be designed to avoid or mitigate the effects of an aircraft impact. This paper deals with a numerical assessment of displacements and stresses that arise from the Phantom F4 impact into ten different shapes of target buildings. This paper used explicit finite element analysis (FEA) software (Abaqus 6.12-1) to determine numerically the structural effects of the propagation of dynamic loads due to Phantom F4 impact, on the different geometric shapes of target buildings. The obtained results showed target buildings with inward curved wall and stepped wall are more resistant then other shapes.

***Keywords**: PWR Plant, Target Buildings, Aircraft Crash, Abaqus 6.12-1*

INTRODUCTION

In this paper the main aspects of the aircraft impact on PWR target buildings were investigated. Because of the probability of an accident crash of this type was low, in the past; the requirement for aircraft impact evaluation was not given much attention in the licensing by the regulatory commissions, even if this event was considered in NPP licensing process. One of important works in the area of aircraft impact on containment building was done by Riera. In this study, total reaction versus time relationships expected in case of an accidental impact of large commercial aircrafts against a rigid surface was presented. Maximum response curves for elastic, un damped, one-degree of freedom system arc evaluated and examples of dynamic analyses of representative reinforced or pre stressed concrete structures in nuclear power plants are discussed in some detail (Jorge and Riera, 1986). Another important work in relation to aircraft impact on containment building was done by Abbas *et al.,* (1996). They studied the effect of target yielding by considering an aircraft crash upon the outer containment of an NPP. They investigated in relation to inclined targets also and confidence curves are obtained for aircraft (Abbas *et al.,* 1996). Aircraft crash is considered as design basis event in nuclear power plant (IAEA, 2003). Therefore protection of the target buildings against aircraft crash can improve plant's safety and security aspects simultaneously. Selection of appropriate geometric shape for target buildings is one of optimized means to mitigate the impacts of aircraft crash impact. It can increase protection levels and decrease cost related to the safety and security design due to use the passive features. In this paper, ten conventional geometric shapes of target buildings are modeled and analyzed by finite element analysis (FEA) software (Abaqus 6.12-1) in order to compare their resistance against dynamic load of phantom F4 as aircraft in one contact points. These are included include vertical wall, in-ward and out-ward curved wall, in-ward and out-ward sloped wall, stepped wall, combined stepped wall and in-ward curved wall, combined stepped wall and out-ward curved wall, combined stepped wall and in-ward sloped wall, and combined stepped wall and out-ward sloped wall. Finally these geometric shapes are ranked based on their resistance and appropriate shape for target buildings is provided based on this ranking.

Geometric Shapes of Target Buildings

The target buildings should be designed to withstand the aircraft crash load. Exterior wall of target building is subjected to aircraft crash. Contact point on the exterior wall may affect the stability of the building. Therefore exterior wall design has important influence on protection of target buildings. Shape of the exterior wall can decrease aircraft crash load on the target buildings. Different basic geometric shapes have different capacity to resist against aircraft crash load under the same conditions due to its geometric characteristics. Therefore, this paper modelled ten geometric shapes for exterior wall include vertical wall, in-ward and out-ward curved wall, in-ward and out-ward sloped wall, stepped wall, combined stepped wall and in-ward curved wall, combined stepped wall and out-ward curved wall, combined stepped wall and in-ward sloped wall, and combined stepped wall and out-ward sloped wall. These different geometric shapes are shown in figure 1. Dimensions of target building are same in different geometric shapes in order to create equal conditions. Dimensions are included length 124.5m, width 96 m and height 30 m and thickness 1.2 m. Theses dimensions are shown in figure 2.

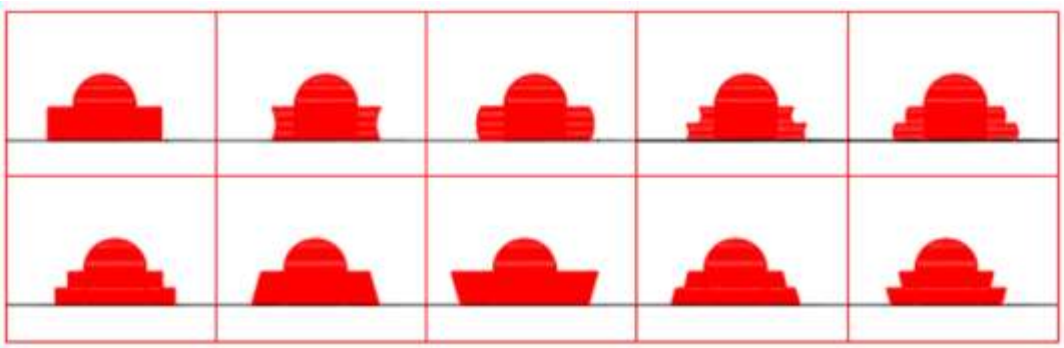

Figure 1: Ten geometric shapes of target buildings

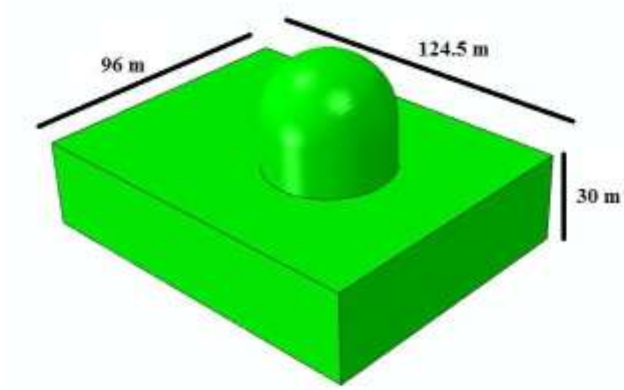

Figure 2: Dimensions of target buildings

Aircraft Impact

The McDonnell Douglas F-4 Phantom II is one of famous fighter-bomber. F-4 Phantom is shown in Figure 3. The Phantom F4 jet aircraft maximum takeoff weighs 28,030 kg and strikes the target building at cruise velocity which is taken as 940 km/h (Fighter Aircraft Directory, 2014). The specifications of the aircraft are shown in table 1. Using Finite Element method, the ten different geometric shapes are analyzed against such impact and time histories of the displacements and stresses in concrete are obtained at vulnerable locations. These data are taken from Abbas *et al.*, (1996). The maximum displacement (m) and Von Mises stress (Pa) are obtained at impact location.

Table 1: Characteristics of phantom f4 (Fighter Aircraft Directory, 2014)

Dimensions	Length:	19.20 meter
	Wingspan:	11.7 meter
	Height:	5 meter
Weights	Empty:	13757 kg
	Maximum Takeoff:	28,030 kg
Performance	Maximum speed	2370 km/h at 12190 m
	Cruise speed	940 km/h

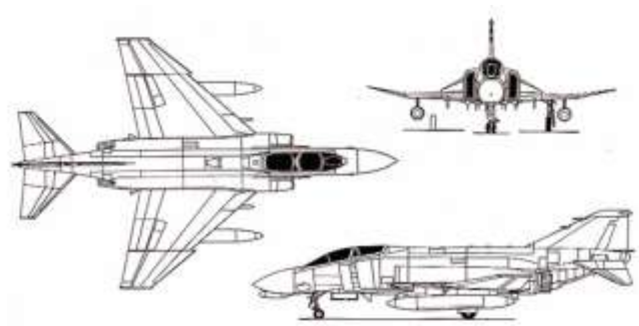

Figure 3: Phantom F4 (Mcchord Air Museum, 2014)

The time period of analysis is 0.04 s. The time step of 0.002 s is employed in the numerical integration which is about 1/20th of the fundamental time period. These ten geometric shapes are impacted by a Phantom F4 aircraft at the location and direction shown in Figure 4. The impact location is middle point on exterior wall. Impact angle is 0°. Based on entire study (Abbas *et al.*, 1996), horizontal impact location was the most critical than the others so the same is considered in the paper (Abbas *et al.*, 1996).

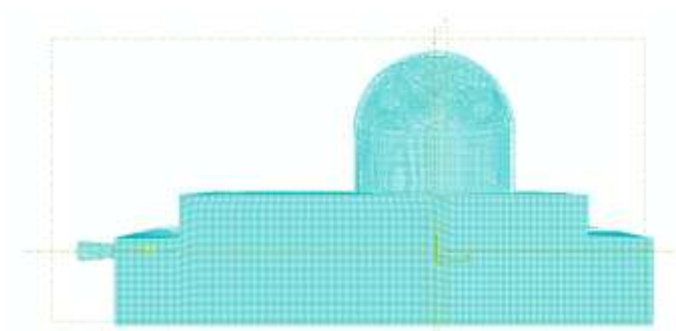

Figure 4: The location and direction of impact points of phantom F4

MATERIALS AND METHODS

In this paper, a computer program, Finite Element Analysis (FEA) software (Abaqus 6.12-1/CEA) is used to model and analyze the reaction of the ten conventional shapes of target building exposed to contact due to phantom F4. The modeling of aircraft crash was implemented using the surface-to-surface contact modeling, which is an empirically based loading model within Abaqus. Abaqus/Explicit the contact model can be used for aircraft crash impact on structural elements. The property of the contact load was specified using the surface to surface contact (Abaqus, 2011). Thus the paper shows the reaction to how different geometric shapes of target buildings will resist contact loading and ranks them based on their resistance. Numerical analysis of the resistance was based on displacement and stress calculations on the contact point. The displacement and stress analysis of the different geometric shapes are computed up to

0.04 seconds, where no further permanent deformation was observed for load. The maximal principal displacements and stresses were evaluated on the contact points. The element type is S4R. Boundary conditions on the bottom surface of the building had to be used in order to keep the model of the target buildings in place during simulations. The bottom surface of the target buildings was fixed in the x z-plane, making it possible for the nodes to move within the x y-plane but not away from it. Mesh size of 0.63m is used based on mesh converge. It chosen based on mesh convergence analysis.

Material Property

The material of the target buildings was assumed to be homogenous consisting only of concrete, thus inhomogeneity's such as reinforcement bars were disregarded. The material properties used for concrete can be seen in table 2. Concrete is assumed to behave as nonlinear elastic material. This paper also disregarded plastic behavior of concrete because it only analyzes behavior of different geometric shapes of target buildings against aircraft crash. Ten different shapes are made of concrete with the same specification as that in journal paper "Identification of Parameters of Concrete Damage Plasticity Constitutive Model" (Jankowiak and Odygowski, 2005).

Table 2: Data for model material characteristics used in modeling (Jankowiak and Odygowski, 2005)

	Material characteristics	
Mass Density	**Young's modulus, E (GPa)**	**Poisson's ratio**
2400 kg/m3	30	0.2

RESULTS AND DISCUSSION

The analysis was carried out for ten geometric shapes under same conditions. The displacement and Von Mises stress after 0.04 s were monitored to compare different geometric shapes of target buildings. The comparison of ten geometric shapes over the entire time period of 0.04s shows maximal displacement in the stepped-outward curved wall and minimal displacement in the inward curved wall. The displacement of different geometric shapes is shown as in figure 5.

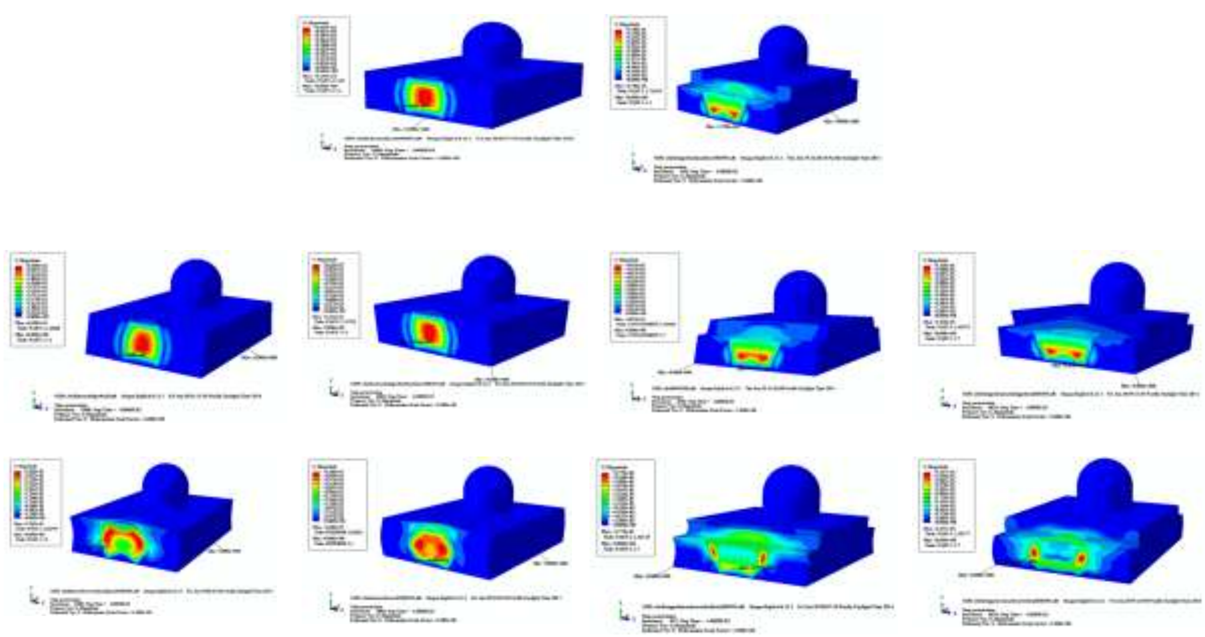

Figure 5: Displacement distributions of ten different target buildings due to aircraft crash

In impact angle 0°, inward curved wall (g) has minimal displacement (0.641265m). Also stepped wall (b) has minimal displacement (0.662379 m) after inward curved wall. Stepped-outward curved wall (j) has maximal displacement (0.712432m). Generally these analyses showed inward curved wall have minimal displacement in compare to others. The displacement- time plots of ten geometric shapes were shown in Figure 6. This analysis showed inward curved shape is more resistant than other shapes.

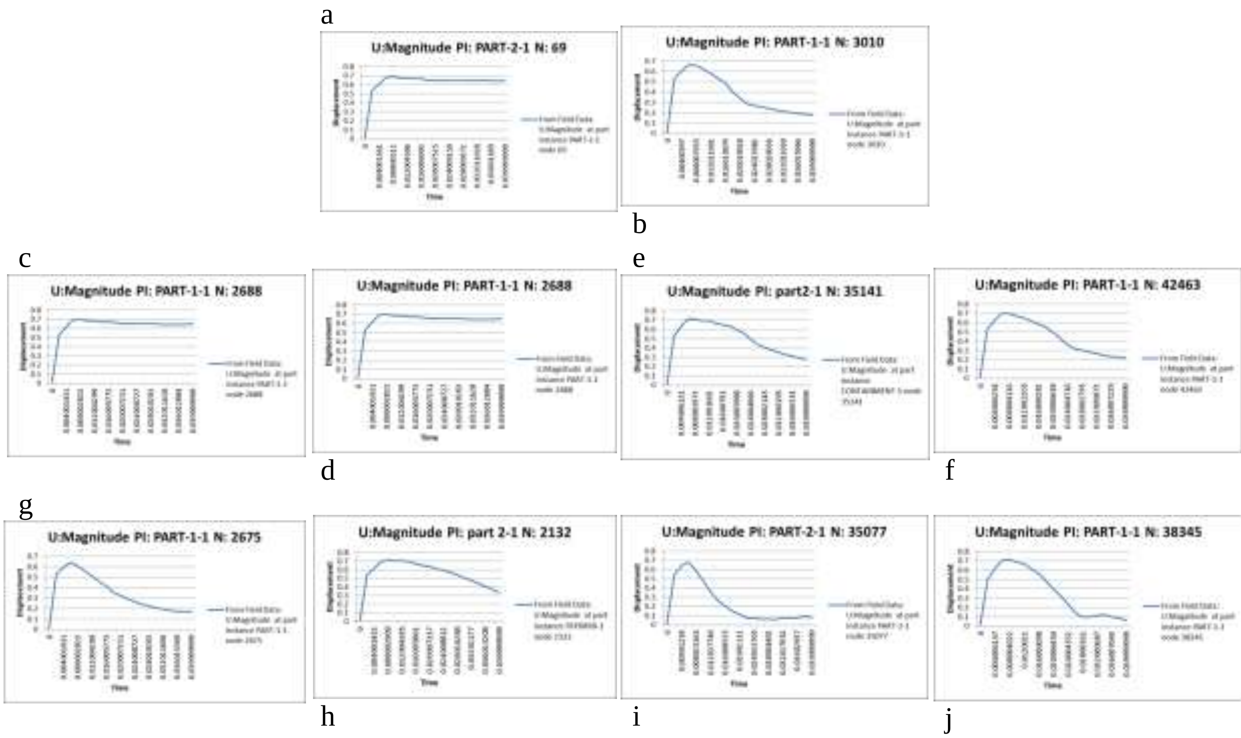

Figure 6: Displacement-time plots for ten different geometric shapes of target buildings due to aircraft crash(a. vertical wall, b. stepped wall, c. inward slopped wall, d. outward slopped wall, e. stepped- inward sloped wall, f. stepped -outward slopped wall, g. inward curved wall, h. outward curved wall, i. stepped- inward curved wall, j. stepped- outward curved wall)

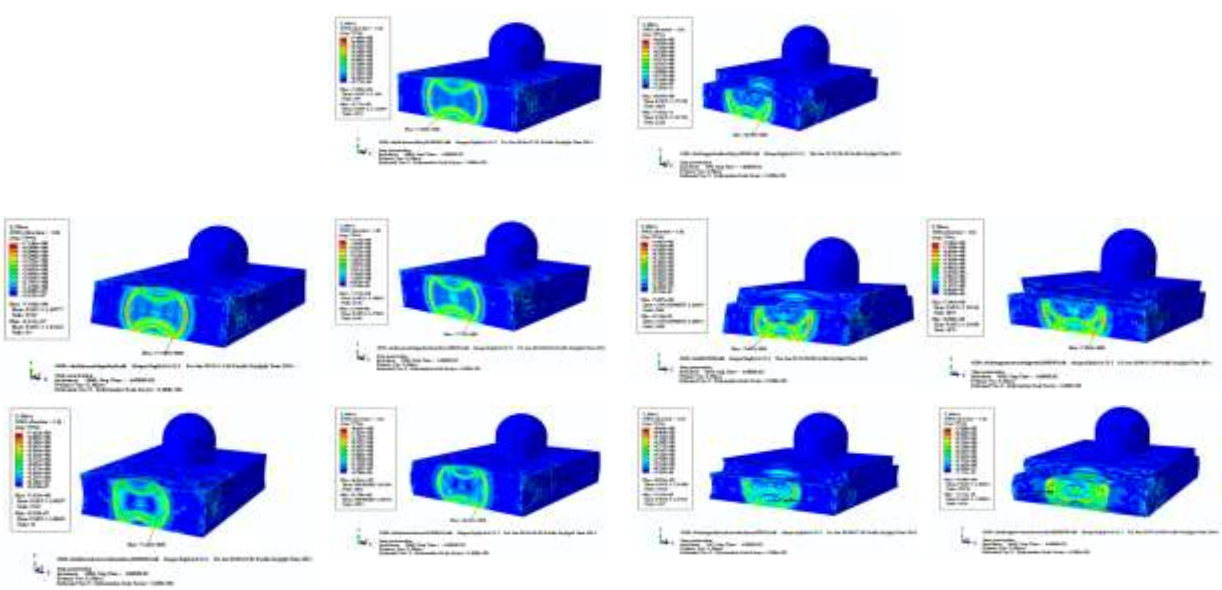

Figure 7: Von Mises stress distributions on target buildings due to aircraft crash

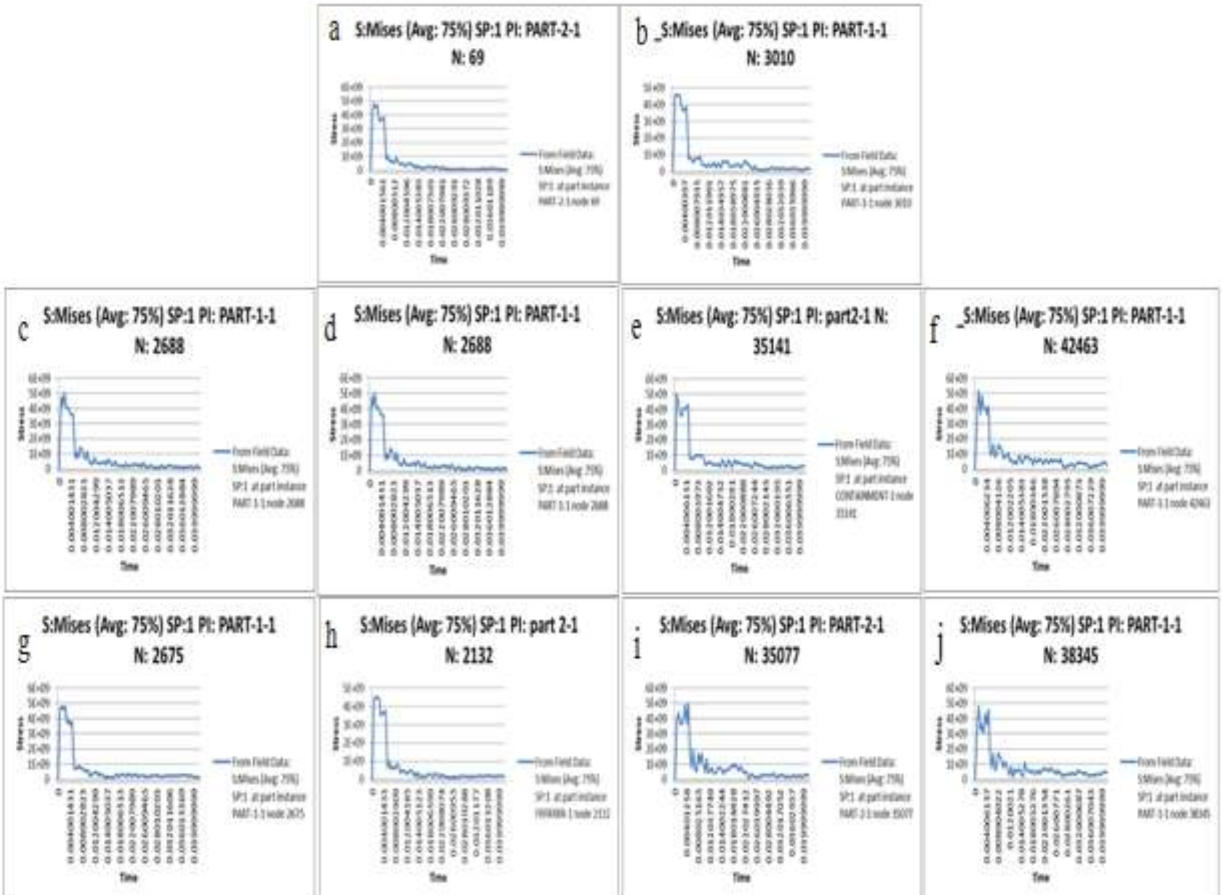

Figure 8: Von Mises stress -time plots for ten different geometric shapes of target buildings due to aircraft crash (a. vertical wall, b. stepped wall, c. inward slopped wall, d. outward slopped wall, e. stepped- inward sloped wall, f. stepped -outward slopped wall, g. inward curved wall, h. outward curved wall, i. stepped- inward curved wall, j. stepped- outward curved wall)

The comparison of ten geometric shapes over the entire time period of 0.04s shows minimal Von Mises stress in the outward curved wall and maximal Von Mises stress in the outward slopped wall.

The Von Mises stress of different geometric shapes is shown as in figure 7.

In impact angle 0°, outward slopped wall (d) has maximal Von Mises stress (5.63e+09 Pa). Outward curved wall (h) has minimal Von Mises stress (4.539e+09 Pa).

Also stepped wall (b) has minimal Von Mises stress (4.53e+09 pa) after outward curved wall (h).

Generally these analyses showed outward curved wall (h) have minimal Von Mises stress in compare to others. The Von Mises stress-time plots of ten geometric shapes were shown in Figure 8.

Results shows, inward curved wall and stepped wall are more resistant than other geometric shapes. Displacement of inward curved wall is smaller than stepped wall but Von Mises stress of stepped wall is smaller than inward curved wall.

Therefore, the stepped shape is considered as the optimum shape in minimizing the aircraft crash impacts on the target buildings.

Table 3: Data for maximal displacement and Von Mises stress of ten different geometric shapes and ranking of them based their resistance against aircraft crash

Item No	Geometric shape	Maximal displacement in contact direction (m)	Maximal displacement magnitude (m)	Maximal Von Mises stress SP1 in contact direction (Pa)	Maximal Von Mises stress SP1 (Pa)	Ranking
1	Vertical wall	0.685957	0.685961	$4.96*10^9$	$4.81*10^7$	5
2	Stepped wall	0.662348	0.662379	$4.52*10^9$	$4.58*10^7$	2
3	Inward sloped wall	0.686911	0.695103	$5.06*10^9$	$5.05*10^7$	6
4	Outward sloped wall	0.673743	0.685164	$5.06*10^9$	$5.63*10^7$	4
5	Inward curved wall	0.641095	0.641265	$4.93*10^9$	$4.83*10^7$	9
6	Outward curved wall	0.712206	0.712244	$4.719*10^9$	$4.539*10^7$	1
7	Stepped-inward slopped wall	0.687141	0.711888	$4.65*10^9$	$5.01*10^7$	8
8	Stepped-outward slopped wall	0.684926	0.701162	$4.84*10^9$	$5.19*10^7$	7
9	Stepped-inward curved wall	0.647758	0.675986	$5.27*10^9$	$5.01*10^7$	3
10	Stepped-outward curved wall	0.705105	0.712432	$4.73*10^9$	$4.82*10^7$	10

The results are shown in table 3.

Conclusion

In this study preliminary nonlinear analyses, simulating the horizontal impacts of phantom F4 on different target building shapes, were performed in order to determine the resistance of different geometric shapes. The ten different geometric shapes of target buildings were chosen as the target and dynamic load of phantom F4 impact was chosen as the impacting load for the study. Calculations were performed utilizing the Abaqus program applying the standard finite element method. The aim of the calculations was to compare the behavior of these different shapes against aircraft crash impact and select the appropriate shape for target buildings. The obtained results highlighted that the aircraft crash impact acting on the exterior wall of target buildings varies with impact angle, with the maximum at the impact angle 90°. This study shows stepped wall is strengthened against aircraft crash in comparison with others, because its displacement and Von Mises stress are smaller than others.

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