with orignal design. It's necessary to make a reconciliation for the final situation. The method used for the reconciliation may not the same as used in the orignal design.
In figure 2, the new response spectra considered incoherence effect(including wave passage) could be enveloped by orignal design response spectra. And the exceeding situation was much better than coherence analysis. Except for the response of some special frequencies that were close to the design response spectra, most responses were much lower than design response spectra. And those peaks amplitude were allowed to be reduced by 15% when there were broadened (ASCE4-98 section 3.4.2.3). So consider the wave incoherence effect(including wave passage), the margin in the design response spectras are at least 1.15.
The incoherece analysis can be used for further seismic safety and seismic margin evaluation of Chashma project. From incoherence analysis, most in structure response will be envoloped by orignal design response spectra, and it's not necessary to make additional evaluation in continuation project C3/C4 for some equipments which located in the excceding areas (response can not be enveloped by DRS(Design Response Spectra)).

6. Conclusions

According to the primary incoherence research, due to the complexity of Nuclear Island, generation of floor response spectra should use 3D model. Random analysis should be performed when incoherence effect need to be consider. The incoherence graph and table cannot be used for quantitative analysis directly, but they can be used for qualitative evaluation.
Incoherence analysis can be used as a supplement of traditional coherence analysis in future nuclear projects. Considering of the wave incoherence effect will reduce the unnecessary conservative in the seismic analysis of nuclear project. It will benefit the further seismic probabilistic safety analysis and seismic margin evaluation.

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ANALYSIS OF A LARGE WIDE-BODY COMMERCIAL PLANE IMPACT ON CAP1400 SHIELD BUILDING

Shujian Cheng[1], Xiaowen Wang[2], Honghui Ge[3], Zufeng Xia[4]

Abstract:

CAP1400 is a new type nuclear plant designed by SNERDI. As a 3rd generation nuclear plant, it should survive after a large commercial plane crash on its shield building. A large wide-body commercial plane is chosen as the impact aircraft and these phenomenons will be modeled by LS-DYNA. This paper will demonstrate the results of these impact simulations and how to check the rationality of these analyses.

1. Introduction

This paper mainly about the research of a large commercial plane impact on the shield building of CAP1400 nuclear power plant. A finite element model of a large wide body commercial plane(LWBCP) which can envelop the target load curve together with the shield building(SB) model are built. And the middle of cylindrical wall, the airinlet zone and the conical roof of the SB are chosen as the impact targets. By analysis the phenomenon during the impacts, the anti-impact capacity of CAP1400 is proved.

Modeling methods by LS-DYNA are benchmarked against the experiments by Tsubota H（1999）as prophase work. Details of benchmark works are not mentioned in this paper.

2. Finite element model of structure

2.1 Modeling of structure

Based on the result of nuclear safety screening, the shield building is chosen as the target and need to build its finite element model. The model of CAP1400 steel-plate composite concrete (SC) shield building is as shown in Fig.1, and it is precisely according to the construction drawing.

Concrete is modeled by Solid elements. Steel plates and steel beams are modeled by Shell elements. Rebar, studs and tie bars are modeled by Beam elements. Some parts of the model is fine meshed as shown in Fig.1 to get balance between accuracy and efficiency.

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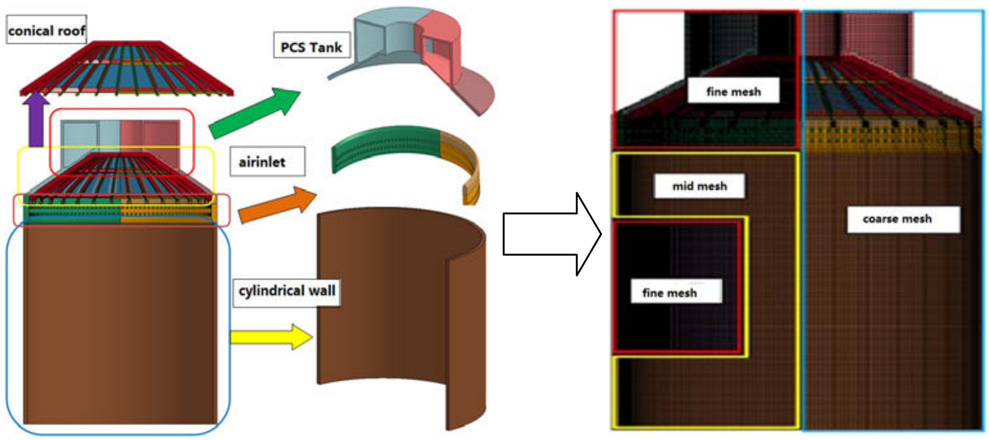

Figure 1. Finite element model and mesh zones of shield building

2.2 Connection, constraint and boundary conditions

Concrete elements with same mesh size are connected by co-nodes. Fine meshed zone, mid meshed zone and coarse meshed zone are connected to each other by LS-DYNA contact "contact_tied" on their contact surfaces.Steel beams and steel plate elements are mainly connected by co-nodes. And shell elements of steel components also are connected to concrete elements by co-nodes. Studs and tie bars are connected to concrete elements by co-nodes, and it's good for their working compatibility.

Rebar elements are connected to each other by co-nodes, and are connected to concrete by LS-DYNA constraint "constrained lagrange in solid" ,which not only can couple the rebar elements' nodes and the concrete elements' nodes, but also can simulate the sliding between concrete and rebar. But most importantly, this constraint is much simpler than the co-nodes connection method.

The bottom of the cylindrical wall (both concrete and steel plate elements) is considered to be completely fixed.

Because the SB model has 2.6 million elements and the analysis cases are symmetric, for calculation efficiency, the 1/2 model with 1.3 million elements is used and the symmetric plane is X-Z (Z is the vertical direction). In this paper, all whole model pictures are generated by LS-DYNA post processing.

2.3 Material and the constitutive model

Q345 (fy=345MPa) is used for steel plate and steel beams. HRB400 (fy=400MPa) is used for reinforcement, studs and tie bars.

Steel material is simulated by " Mat_Piecewise_Linear_Plastic"mat model （LSTC，2007）. In high speed impact, the strength and stiffness of material will be higher because of the high strain rate, and this phenomenon is taken into account.

Concrete material is simulated by "Winfrith"mat model（LSTC，2007）. Winfrith mat model is a smeared crack, smeared rebar model, and is implement in the 8-node

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single integration point continuum element. The crack of Winfrith is an important index of safety for concrete structures. But it can not simulate element erosion, unless "mat_add_erosion" is added to it.

C55(6000psi) concrete is used for shield building. Because of the flying ash added to concrete, the strength of concrete will continue growing in long term. In real construction, the strength of concrete will be a little higher than the testing value. According to NEI07-13（NEI，2011）and ACI 349（ACI 2006）, long term strength growing, testing margin should be taken into account to modify the concrete mat model. The strength and stiffness of material will be higher because of the high strain rate, and this phenomenon is taken into account.

2.4 Finite element model of plane

A large wide body commercial plane (LWBCP) with the weight of 204t and velocity of 156m/s is chosen as the impacting aircraft. The finite element model of the plane is shown in Fig.2. "Mat_ Piecewise_ Linear_ Plastic" mat model is used to simulate aluminum alloy.

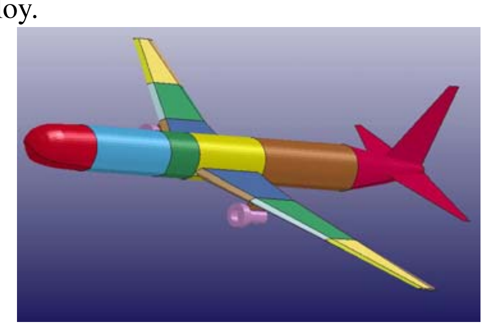

Figure 2. FE model of aero plane

The finite element model is tested by impacting a rigid wall. As shown in Fig.3, the test load curve can match and envelop the target load curve. So this plane FE model is suitable for impacting analysis.

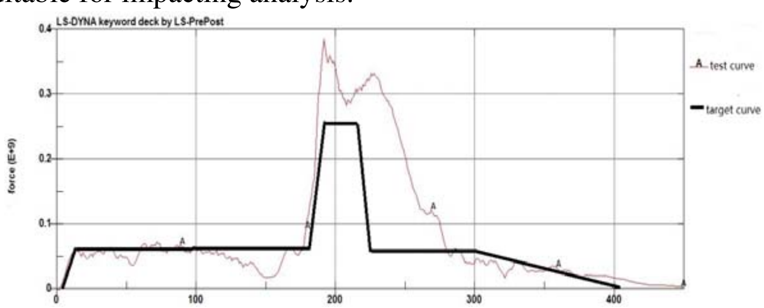

Figure 3. The test load curve VS the target load curve

2.5 Dimension

In this paper, the fundamental units are as follow: mass-g, length-mm, time-ms. Based on the fundamental units, other units are as follow: force-N, pressure-MPa, energy-0.001J. If any fig don't indicate the units, the above units are suitable.

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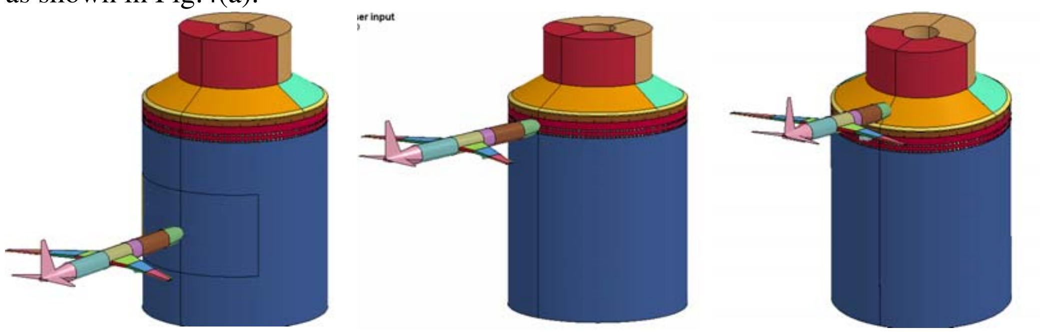
3. Impacting analysis

3.1 Impact on the cylindrical wall

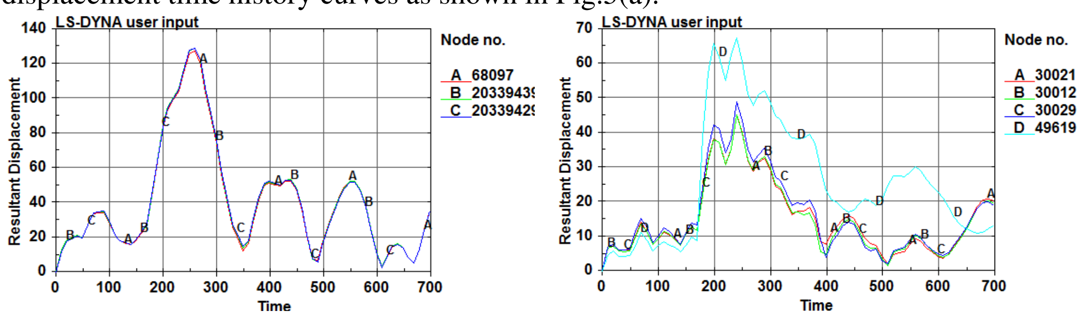
The cylindrical wall will perform with a bending mode in the impact process, so the worst situation will occur on the middle of the cylindrical wall. The height of the CAP1400 shield building cylindrical wall is 50m and the thickness is 1.1m, so the middle of the cylindrical wall (25m above ground) is chosen as the impacting target as shown in Fig.4(a).



(a)on the cylindrical wall (b)on the airinlet zone (c)on the roof

Figure 4. Impact on different positions of the shield building

Check the deformation animation and find that at the time of 250ms the structural deformation reaches its peak value of 130mm. Find the nodes of maximal deformation both of inner side and out side at 250ms, and get their resultant displacement time history curves as shown in Fig.5(a).



(a)impact on the cylindrical wall (b)impact on the airinlet zone

Figure 5. The displacement time history curves of the maximum nodes

Via Fig.5(a), the deformation of inner side is almost the same as out side. At 250ms, the deformation reaches its peak of 130mm. Then, because the impacting load goes down, the structure rebounds. From the shock shape, the residual deformation is about 30mm. The peak deformation of SB is 130mm and is much smaller than the gap between the SB and the steel containment vessel which is 1.3m. So, the steel containment vessel is not touched.

In the impact process, a small part of the out steel plate is damaged, as shown in Fig.6.

The cylindrical wall is a SC structure. Only little part of out steel plate is eroded, and only little part of inner steel plate reaches plastic phase, so the concrete is

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protected well. The concrete is well constrained and the allowable volume strain can be much higher than common reinforcement concrete, so the anti-impacting capacity is obviously enhanced. In the impacting process, no concrete element is deleted.

Mat84 (Winfrith concrete) can calculate the cracking of concrete. As shown in Fig.7, aircraft impacting on the cylindrical wall will cause a lot of surface cracks and some inner cracks. In general, the inner cracks are few, and the penetration cracks also are few. Because the inner steel plate hasn't been damaged, even if the concrete peel off because of the cracks, it will not affect the steel containment vessel.

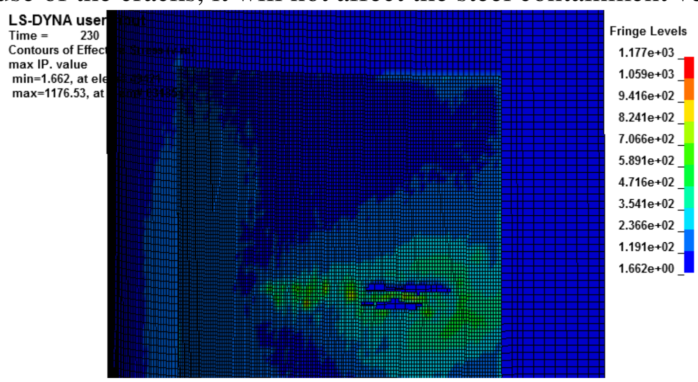

Figure 6. The contour of effect stress (v-m) of the out side steel plate

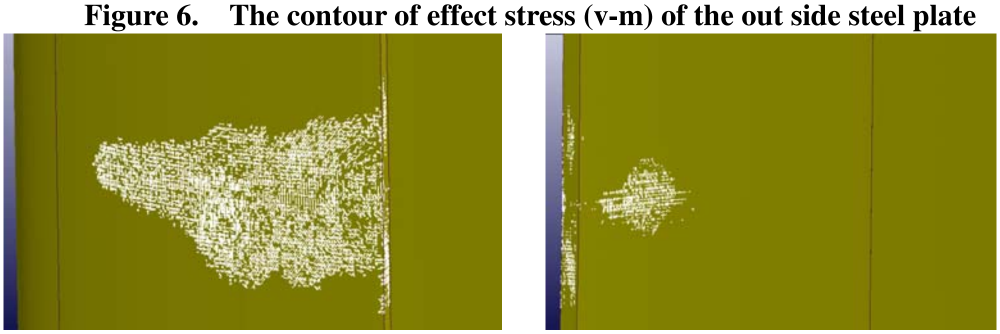

Figure 7. The cracks at the maximum displacement time point

3.2 Impact on the airinlet zone

The airinlet zone is a cylindrical wall with the thickness of 1.5m and tow row of airinlet tubes. In FE model, the round tube section is simplified to rectangle section to avoid radical element meshing. The impacting position is in the middle of the two tube rows.

Check the deformation animation and find that at the time of 250ms the structural deformation reaches its peak value of 67mm. Find the nodes of maximal deformation at 250ms both of inner side and out side, and get their resultant displacement time history curves as Fig.5(b).（49619 is out side node，others are inner side nodes.)

Via Fig.5(b), the deformation of inner side is 50mm and is 17mm smaller than that of out side, so it can be concluded that local deformation occurred at the max deformation node of out side. At 250ms, the deformation reaches its peak of 50mm. Then, because the impacting load goes down, the structure rebounds. At 400ms, the

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impacting is almost ended, but the structure is still vibrating in big range. From the shock shape, the residual deformation is about 10mm.

The peak deformation of SB is 50mm and is much smaller than the gap between the SB and the steel containment vessel. So, the steel containment vessel is not touched.

In the impact progress, a small part of the out steel plate is damaged, as shown in Fig.8.

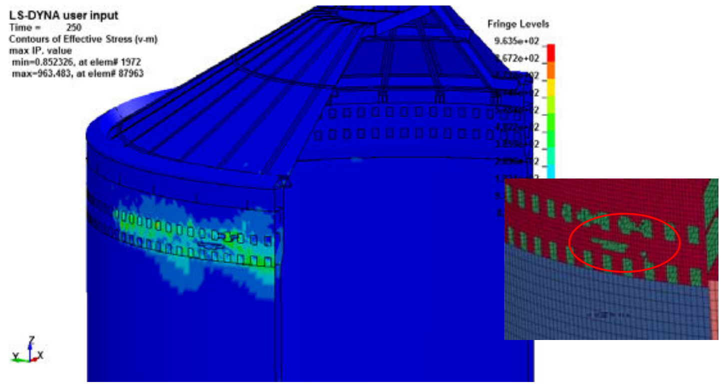

Figure 8. The contour of effect stress of steel plate and deleted elements

The shield building is a SC structure. Only little part of out steel plate is eroded, and only little part of inner steel plate reaches plastic phase, so concrete is protected well. In the impacting process, no concrete element is deleted.

As shown in Fig.9, aircraft impacting on the air inlet zone will cause a lot of surface cracks and some inner cracks. In general, the inner cracks are few, and the penetration cracks also are few. Because the inner steel plate hasn't been damaged, even if the concrete peel off because of the cracks, it will not affect the steel containment vessel.

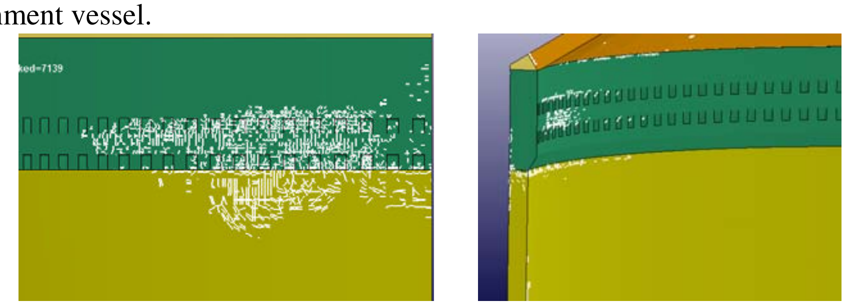

Figure 9. the cracks of the air inlet zone at the maximum displacement time point

3.3 Impact on the conical roof

The roof includes a conical roof with the gradient of 35°and a PCS tank which contains 3700t water. Usually, a large commercial plane can only impact a structure within the angle of ±10° at a high speed, so the angle of -10°is chosen as the impacting angle as shown in Fig.4(c). The PCS tank is excluded by nuclear safety

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screening, so the conical roof is chosen as the impact target. The conical roof is supported by inner steel plate and steel beams, so the position in the middle of conical roof and between two steel beams is chosen as the impact position.

Check the deformation animation and find that at the time of 210ms the structural deformation reaches its peak value of 28mm. Find the nodes of maximal deformation at 210ms both of inner side and out side , and get their resultant displacement time history curves as Fig.3-10.（1074547 is out side node，784267 is inner side node)

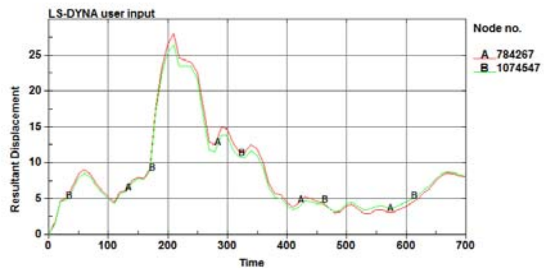
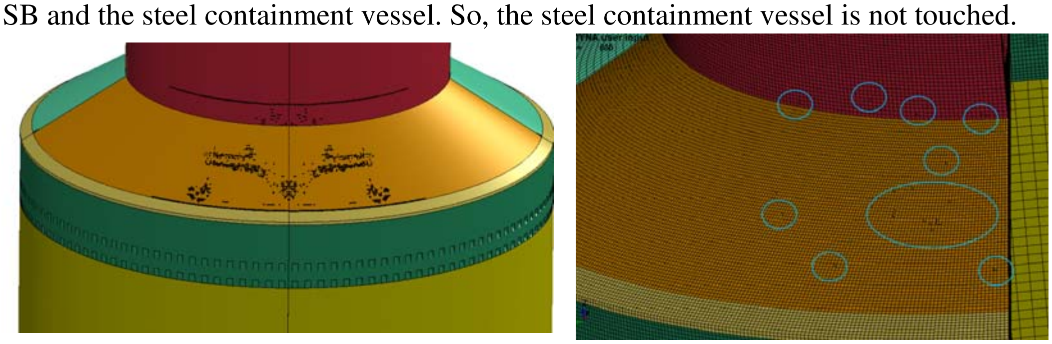


Figure 10. The displacement time history curves of the maximum nodes

Via Fig.10, the deformation of inner side is almost the same as out side. At 210ms, the deformation reaches its peak of 28mm. Then, because the sliding of the aircraft, the structure rebounds. From the shock shape, the residual deformation is about 5mm. The peak deformation of SB is much smaller than the gap between the SB and the steel containment vessel. So, the steel containment vessel is not touched.



（a） out side cracks of 210ms （b）element deletion of 500ms

Figure 11. The cracks and deleted elements of the roof

The conical roof is a seimi-SC structure, and only the inner side is protected by steel plate. The concrete's allowable volume strain is conservatively set to be a little higher than RC concrete but much less than SC concrete.

As shown in Fig. 11(a) and (b), aircraft impacting on the conical roof will cause a lot of surface cracks but almost no inner cracks. Because the inner steel plate hasn't been damaged, even if the concrete peel off because of the cracks, it will not affect the steel containment vessel.

In the impacting process, some concrete elements are eroded and deleted. At the time of 500ms when the impacting is almost ended, deleted elements are shown in Fig.3-11(c). The erosion depth is 157mm（one mesh layer）.

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4. Rationality demonstration

Fig.2 shows the energy time history curves of the case of impacting on the conical roof. The total energy keeps balance in the whole impacting process, and is generally the same as the initial kinetic energy. The sum of internal energy, kinetic energy, hourglass energy, sliding energy and external works is equal to the total energy at all the time. There is no abnormal phenomenon such as negative sliding energy which usually indicates abnormal elements penetration. It suggests that the analysis is rational to a certain extent.

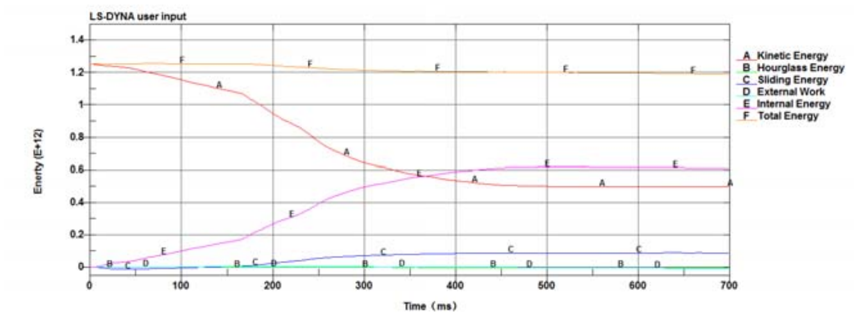

Figure 12. energy time history curves of the system

5. Conclusion

This paper assesses an aircraft impact on CAP1400 Shield Building's cylindrical wall, airinlet zone and conical roof. The results show that:

1. The shield building is still integrative after impact. In the 3 impacting cases, the deformation is 130m, 50mm and 28mm respectively.

2. When impact on the cylindrical wall or the airinlet zone, a small part of the out steel plate is damaged, but no concrete element or inner steel plate element is deleted. The concrete particles caused by cracks wouldn't affect the steel containment which is protected by the shield building.

3. When impact on the conical roof, a layer (about 157mm) of elements are deleted, but no inner steel plate element is deleted. The concrete particles caused by cracks wouldn't affect the steel containment.

So it can be proved that CAP1400 can continue to provide adequate protection for the public health and safety after a LWBCP impact affair.

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