



MODEL UPDATE FOR NUMERICAL SIMULATION OF MISSILE IMPACTS ON REINFORCED CONCRETE PLATES – IRIS 2012 BENCHMARK TEST

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ABSTRACT

This paper describes the procedures and results of the works done by KINS(Korea Institute of Nuclear Safety) as a participant of the IRIS-2012 benchmark project which is the continued project of IRIS-2010 of OECD/NEA IAGE working group. Within the scope of the project, uniaxial and tri-axial concrete tests were performed and the results were supplied by the organizing committee. With these material test data, impact simulations of IRIS-2010 experiments (VTT-IRSN-CNCS Punching P1 and VTT-IRNS Bending B1) were re-performed to improve the accuracy of the simulation results and reduce the computation time.

The initial FE model was updated through numerous parametric studies. Considering the symmetry of the structure, the updated model was constructed for 1/4 of the structure, and the stiffness and mass of the supporting structure was considered. Loading function with loading plate was applied instead of modeling the projectiles for reduction of the computation time. Three concrete models, Concrete damage rel3(#72r3), Winfrith concrete(#84), and CSCM concrete(#159), were used for the impact simulations and the results were compared.

INTRODUCTION

IRIS-2012 benchmark project, following IRIS-2010, was launched for updating the initial model of IRIS-2010 and proposing simplified method using the test data of IRIS-2010 and additionally provided tri-axial concrete test results. Detailed information of IRIS-2010 was presented in the references (Berthaud et al. (2011), Orbovic et al. (2011), Rambach et al. (2011), Tarallo et al. (2011), Vepsa et al. (2011)). KINS, Korea Institute of Nuclear Safety, participated the IRIS-2012 project, and the procedures of model updating and simplifying performed during the project is described in this paper. LS-DYNA is used for the numerical simulation (LSTC, (2007)), and comparative investigation of the three kinds of concrete models, the most frequently adopted concrete models, is included within the procedure (FHWA, (2007)). The major considerations of the simulation works are as follows.

- 1) Model simplification: The symmetric condition of the test specimens is considered, and loading function-time history approach is applied with fictitious loading plate part to reduced computation time.
- 2) Supporting structures: Consideration of the stiffness and mass of the supporting frames and columns of VTT test significantly affected the vibration frequencies of slab deflection.
- 3) Concrete material model: The concrete models most frequently adopted in recent researches, Concrete damage rel3(#72r3), Winfrith concrete(#84), and CSCM concrete(#159), were used for the simulation of uniaxial and tri-axial compression tests, and the simulation of impact tests.

SIMULATION OF THE UNIAXIAL AND TRI-AXIAL CONCRETE TEST

Uniaxial and tri-axial concrete tests were simulated using three concrete material models such as concrete damage rel. 3(#72r3), Winfrith concrete(#84), and CSCM concrete(#159). As shown in the Figure 1, one quarter of the specimen is modeled. Loading is applied to the numerical model using the *BOUNDARY_PRESCRIBED_MOTION command, and confining pressure is applied using the *LOAD_SEGMENT command.

Stress-strain curve is obtained using the applied displacement and the resulted reaction force output. Calculated stress-strain curves of various concrete models and confining pressure are shown in Figure 2 with the test results. As shown in the figure, concrete damage rel.3 model shows the most similar trend with the test results. When the Winfrith concrete model is used, hourglass mode is observed during deformation, thus the results are less reliable than other cases. Since the Winfrith concrete model does not support formulation 2 of solid element (fully integrated S/R solid), finer mesh size is required.



Figure 1. FE model of concrete test specimen

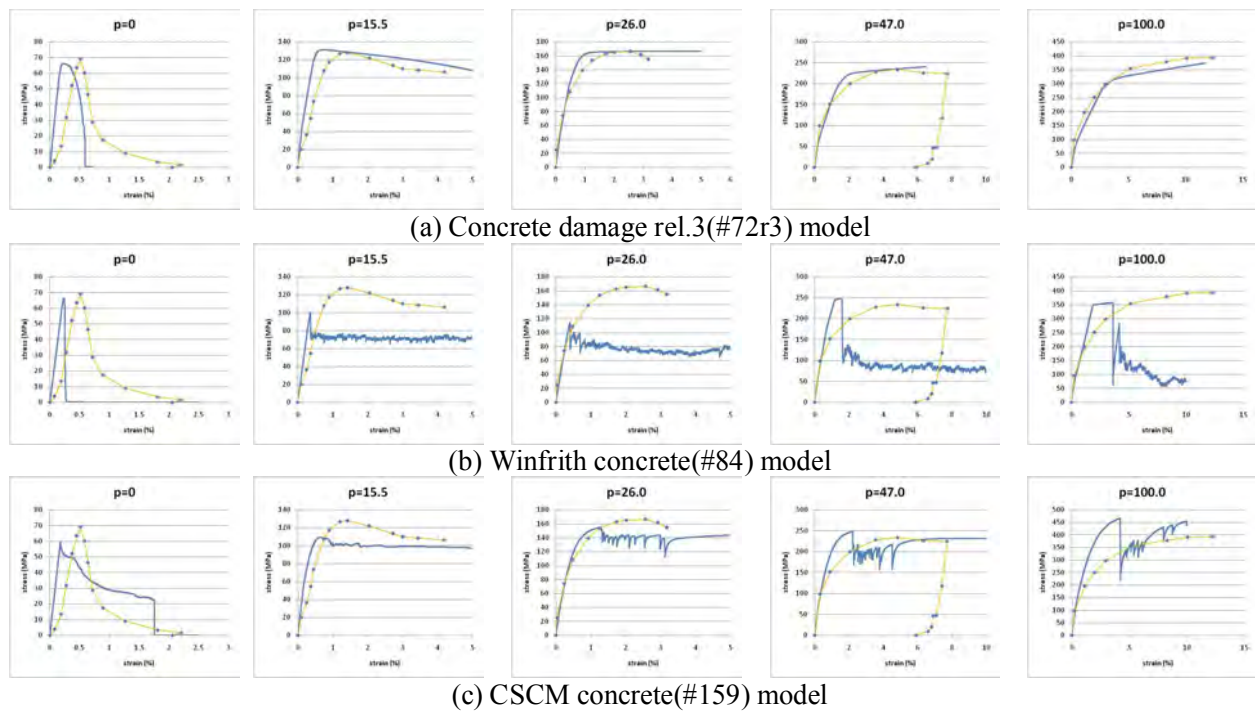


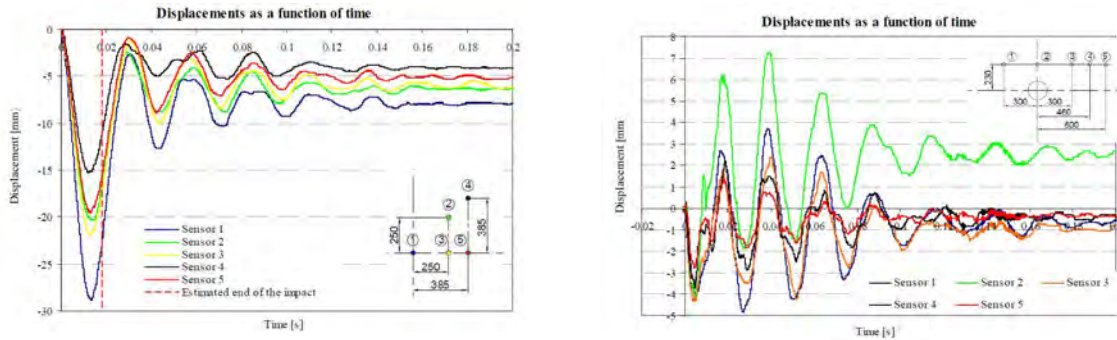
Figure 2. Stress-strain curves of concrete test

NUMERICAL MODEL UPDATE

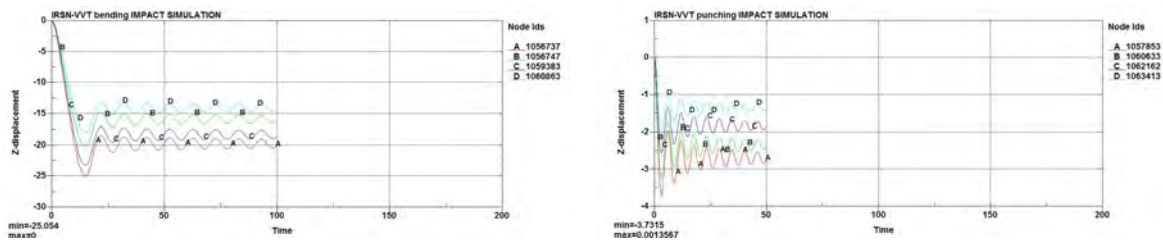
Results of the previous simulation

The calculated displacement responses of previous simulations performed during the IRIS-2010 project are shown with the measured responses in Figure 3 (Kim et al. (2011)). As mentioned in the

benchmark synthesis report authored by IRSN and as shown in the Figure 3, maximum displacement values are similar between the calculated and measured responses. However the differences of residual displacements are relatively larger than those of the maximum displacements. Also, the vibration frequencies of calculated responses are much higher than that of the measured responses. Therefore, the main objective of the continued work was reducing the differences of residual displacement and vibration frequency. Another objective was simplifying the FE model for reducing the computation time.



(a) Measured displacement time history of the test B1 and P1



(b) Calculated displacement time history of the test B1 and P1

Figure 3. Comparison of the displacement response of previous simulations and experiments

Simplification of FE Model

To reduce required computation time, the existing model previously built during IRIS-2010 project was reduced to one quarter of the full model, and symmetric boundary condition is applied. After confirming that the two models, full model and 1/4 model, give reasonably consistent results, loading function with rigid loading frame replacing missile modeling is adopted.

Figure 4(a) and (b) show the shapes of the adopted rigid loading plates. Fictitious rigid loading plate is devised to make the loaded area similar with that of missile modeling approach regardless of the mesh size of the slab model. Also it is possible to load the slab continuously even if the elements under load are eroded with this loading plate approach. In the Figure 4(c) and (d), loading function of bending test and punching test are shown with load history acquired from missile modeling approach.

Calculated slab displacements of three cases such as 1) full modeling with missile model, 2) 1/4 modeling with missile model, and 3) 1/4 modeling with loading function, are comparatively shown in Figure 5. CSCM concrete model is utilized in these analyses. Maximum values of each case are listed in Table 1, and consumed computation time of each case are listed in Table 2. As shown in the Figure 5, Table 1, and Table 2, computation time could be drastically reduced without significant sacrifice of accuracy of the simulation results. Also, similar pattern of damage is observed after the model simplification. The damaged shapes of the slabs after missile impact are compared in Figure 6.

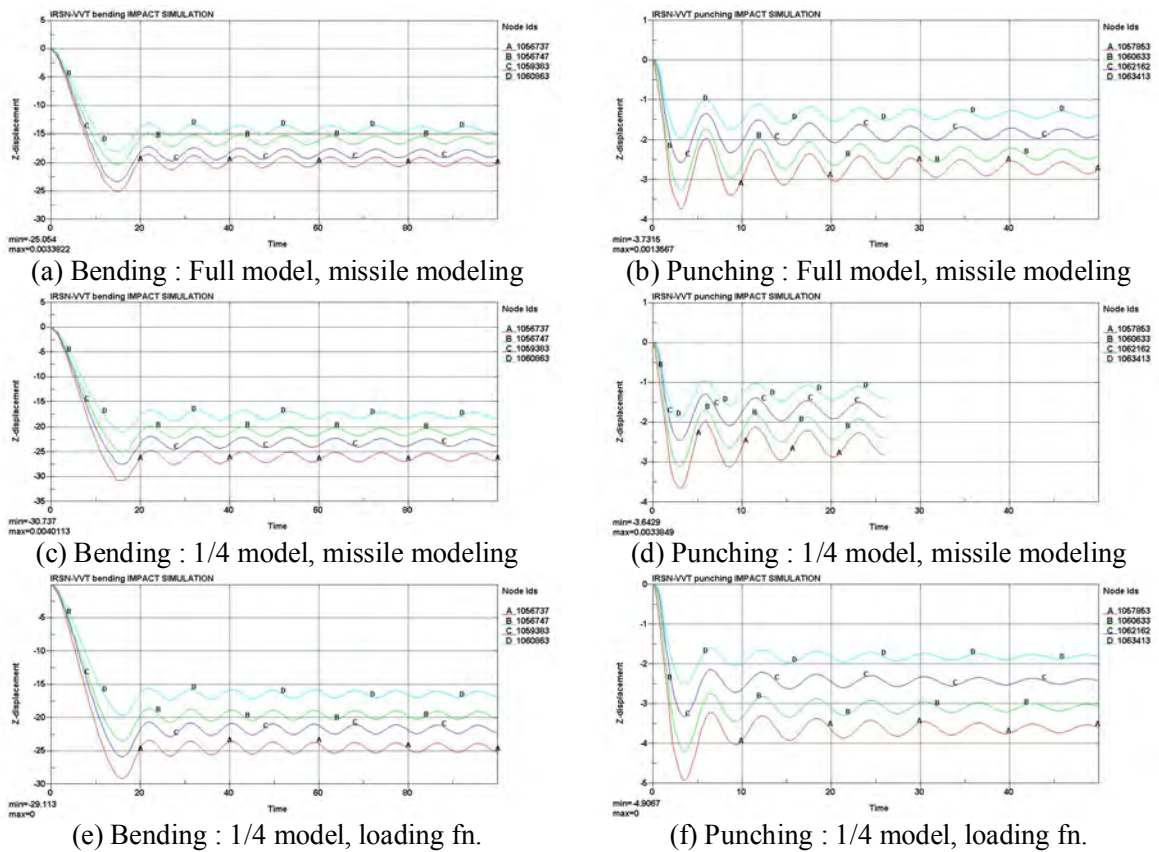
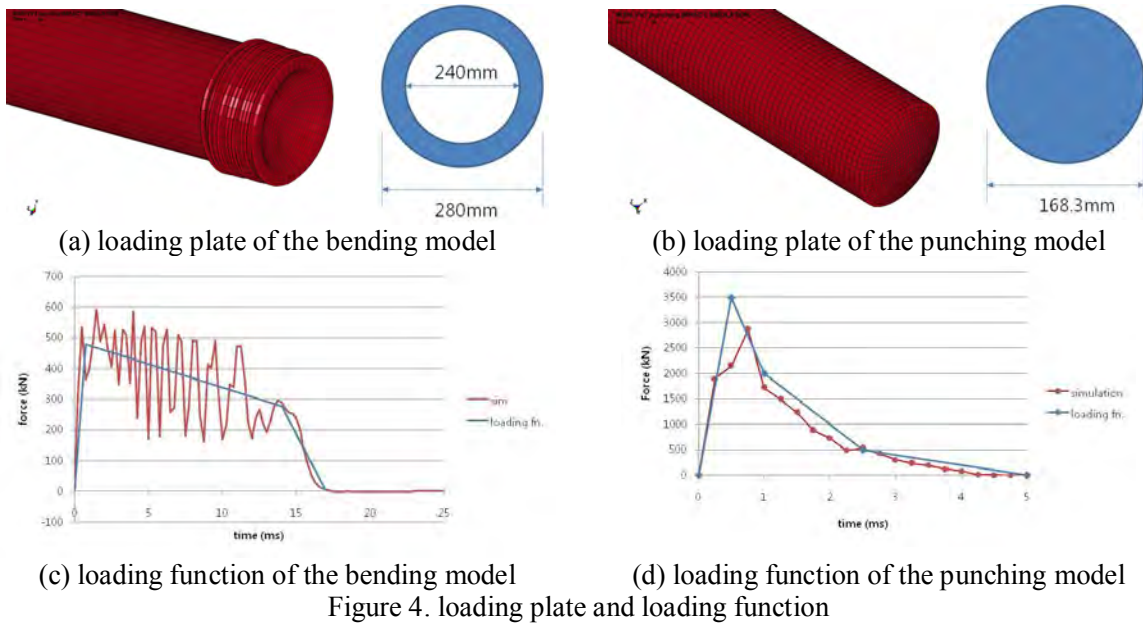


Table 1: Comparison of the maximum displacements (mm)

Case	Full, missile	1/4, missile	1/4, loading fn.	Test
Bending	25.0	30.7	29.3	27.0
Punching	3.7	3.6	4.9	5.2

Table 2. Comparison of the computation time (hrs)

Case	Full, missile	1/4, missile	1/4, loading fn.
Bending	33	14	1
Punching	441	42	3

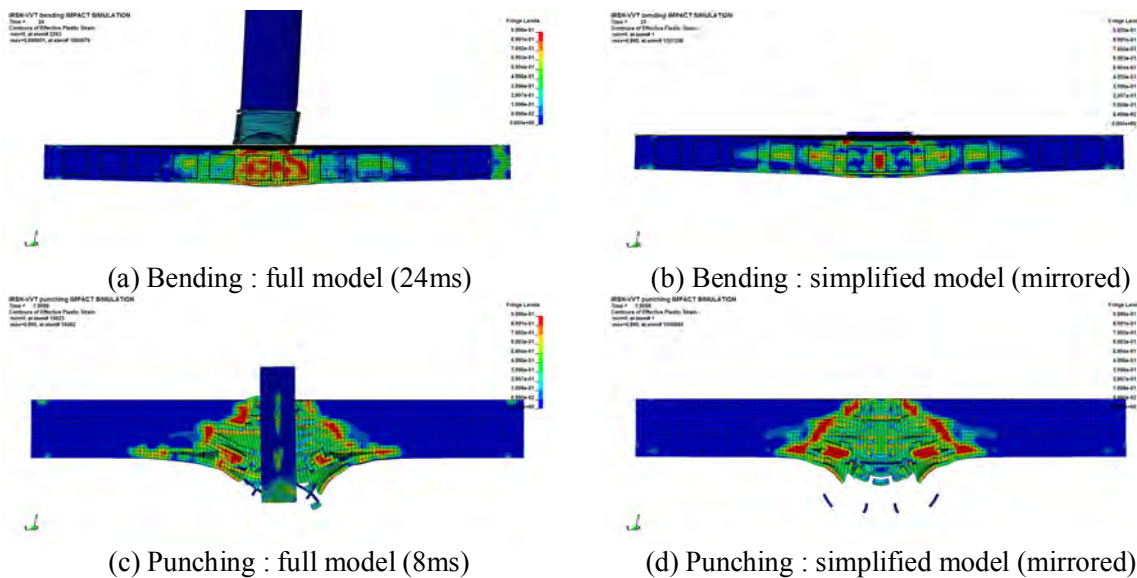


Figure 5. Comparison of the damage pattern

Consideration of the supporting structure

Although the computation time is largely reduced by 1/4 modeling and loading function approach, the vibration frequency is still considerably higher than the experimental results. To match the vibration frequency of the simulation result with that of experimental result, supporting frame and column is considered in the FE model. With this consideration, global vibration of supporting structure mainly caused by the axial deformation of the columns could be included in the impact response of the slab.

FE Model with supporting structure is shown in Figure 7. As shown in the Figure, supporting structure is considered in the simplest way with single beam element and one point mass element. The input value of the point mass is acquired from the document provided from the organizing committee. Since the supporting frame has much higher stiffness than the slab, constraint condition is applied instead of modeling the frames as shown in the Figure 7.

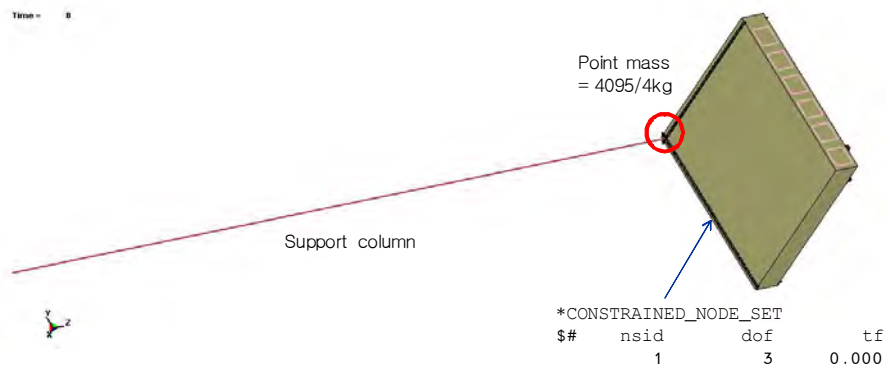
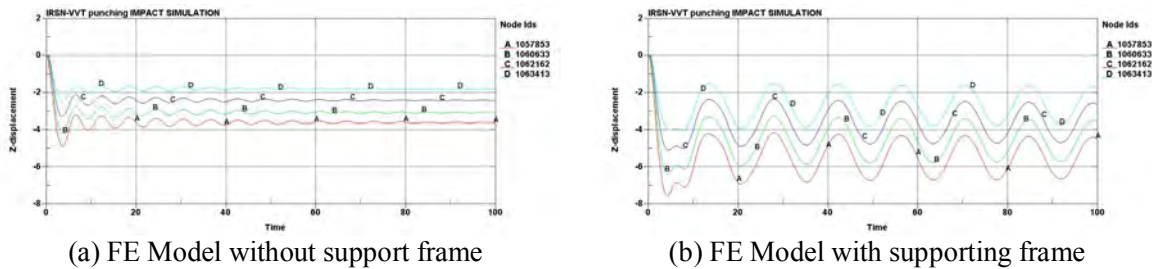


Figure 7. Modeling of the supporting structure



(a) FE Model without support frame

(b) FE Model with supporting frame

Figure 8. Effect of supporting structure modeling (punching test case)

The displacement results of the two models, the model with and without supporting structure, are compared in the Figure 8. Also CSCM concrete model was utilized in these analyses. As expected, major vibration frequency is lowered and closed to the experimental results.

EFFECT OF MATERIAL MODEL OF CONCRETE

1/4 model with loading function and supporting structure is decided as the final model, and the three concrete models previously considered are applied to the model to observe the effect of concrete model. Since the erosion function is included only in the CSCM model, additional *add_erosion command is used for the other two concrete models, concrete damage rel.3 and Winfrith concrete model. The element deletion criterion is set as 0.10 for compressive strain and 0.05 for tensile strain. In case of CSCM concrete, included erosion capability is utilized with the input value of erode parameter 1.4.

Resulting time histories of displacement responses are shown in the Figure 9 and failure shapes are shown in the Figure 10 and 11. As shown in the figures, concrete damage rel.3 model shows excessive damage for bending case, and CSCM concrete model shows larger residual displacement and lower rebound behavior.

Although the effect of element deletion criterion is not clearly identified, Winfrith concrete model shows most similar pattern of displacement response with the measured results so far. However, in view of damage pattern, CSCM concrete model shows the most realistic results.

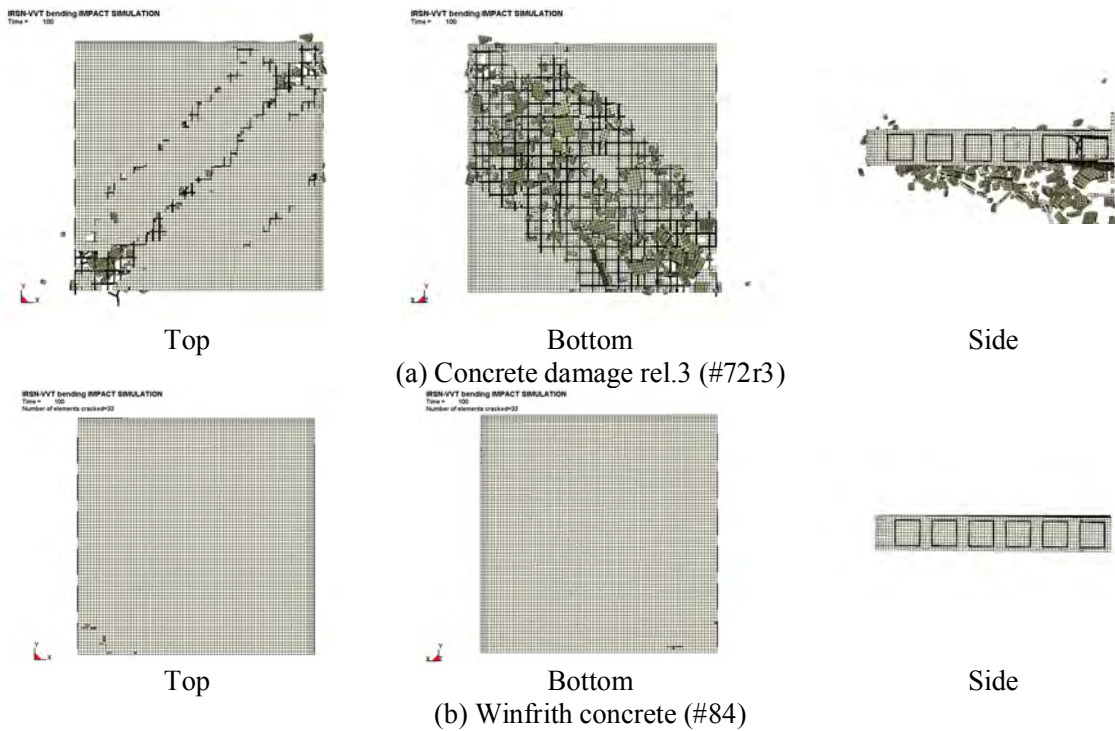
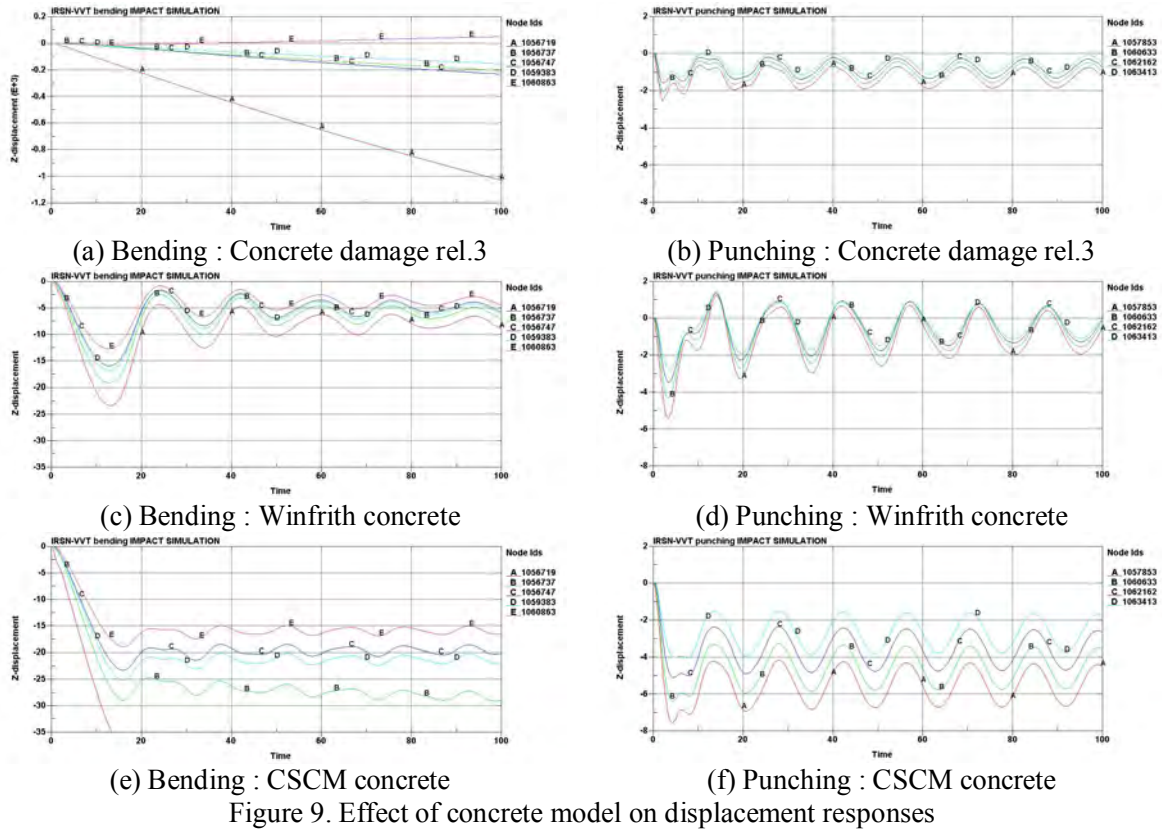
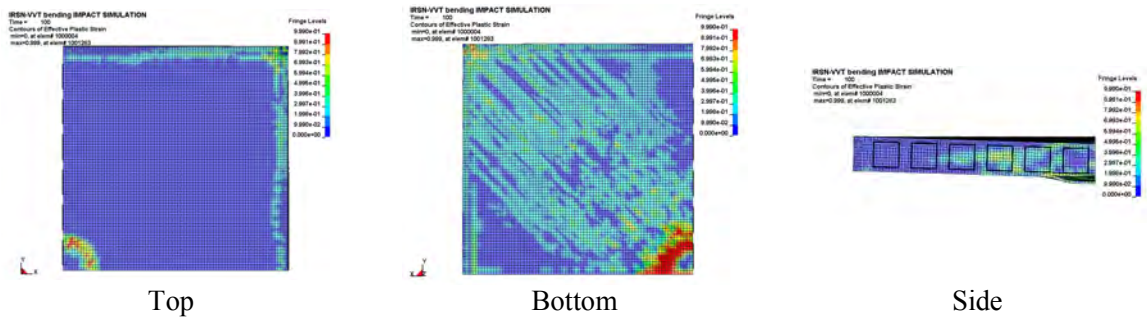


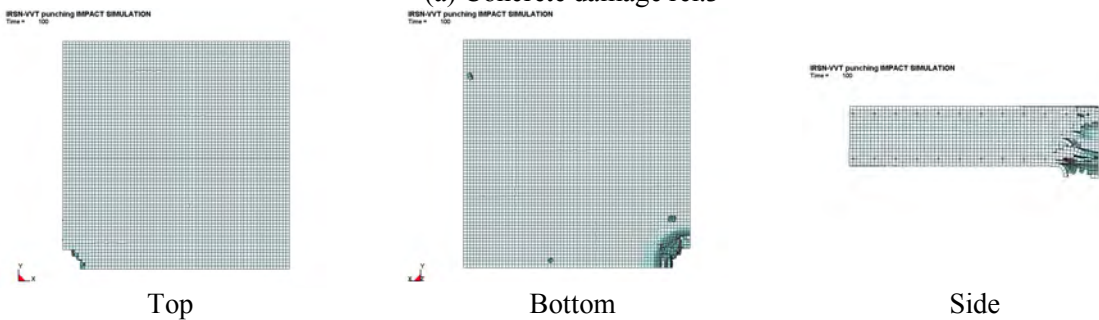
Figure 10. Effect of concrete model on damage pattern (bending test) (continued)



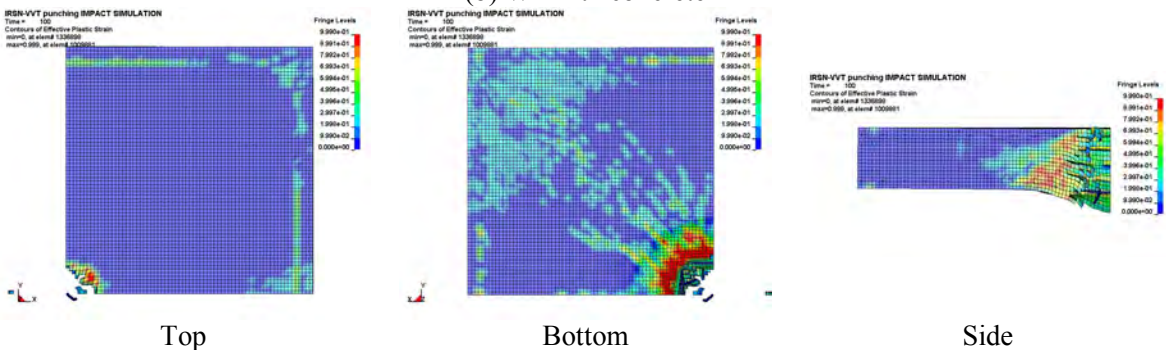
(c) CSCM concrete (#159)
 Figure 10. Effect of concrete model on damage pattern (bending test)



(a) Concrete damage rel.3



(b) Winfrith concrete



(c) CSCM concrete

Figure 11. Effect of concrete model on damage pattern (punching test)

CONCLUSION

Conclusions drawn based on the above mentioned simulations results and lessons learned through the procedure are as follows.

1) Computation time could be reduced considerably without significant sacrifice of accuracy of the simulation results by adopting 1/4 model and loading function with loading plate approach.

2) More realistic vibration frequency of the slab displacement response could be simulated by considering support columns and frame mass. Therefore, it is reasonable to think that the major vibration frequency of the slab response is governed by the vibration of the supporting structure rather than vibration of the slab itself.

3) In case of concrete compressive test simulation, concrete damage rel.3 model showed most similar behavior with the test results, however highly overestimated damage pattern in impact simulation of bending specimen was observed with this concrete model.

4) By using Winfrith concrete model, the most reliable displacement responses were obtained in view of both maximum value and residual value. However, damage extent or scabbing area was relatively underestimated.

5) CSCM concrete model could effectively be utilized for estimating maximum displacement and failure mode such as penetration, perforation, and scabbing. However CSCM model did not give reasonable results of residual displacement, or rebound behavior.

6) For the considering simulation cases, element deletion criterion is presumed to be one of the most important factors that affect the simulation result. Therefore an in-depth study about the element deletion criterion is in progress.

REFERENCES

- Berthaud, Y., Benboudjema, F., Colliat, J.-B., Tarallo, F., Orbovic, N. and Rambach, J.-M. (2011). "IRIS-2010-Part IV: Numerical simulations of flexural VTT-IRSN tests," SMiRT 21, Div-V: Paper ID #197, Nov. 6-11, New Delhi, India
- FHWA. (2007). *User manual for LS-DYNA concrete material model 159*, FHWA-HRT-05-062.
- Kim, S.Y., Lee, J., Chung, C., Kim, S.P., Chung, Y.S., Lee, J., and Jung, R. (2011) "Numerical Simulations of Missile Impacts on Reinforced Concrete Plates - IRIS 2010 Benchmark Test," SMiRT 21, Div-III: Paper ID #253, Nov. 6-11, New Delhi, India
- LSTC (2007) *LS-DYNA keyword user's manual*
- Orbovic, N., Benboudjema, F., Berthaud, Y., Colliat, J.-B., Tarallo, F., and Rambach, J.-M. (2011). "IRIS_2010-Part III: Numerical simulations of MEPPEN II-4 test and VTT-IRSN-CNSC punching tests," SMiRT 21, Div-V: Paper ID #163, Nov. 6-11, New Delhi, India
- Rambach, J.-M., Orbovic, N. and Tarallo, F. (2011). "IRIS_2010-Part I: General overview of the benchmark," SMiRT 21, Div-V: Paper ID #147, Nov. 6-11, New Delhi, India
- Tarallo, F., Rambach, J.-M., and Orbovic, N. (2011). "IRIS_2010-Part V: Lessons learned, recommendations and tracks for future works," SMiRT 21, Div-V: Paper ID #145, Nov. 6-11, New Delhi, India
- Vepsa, A., Saarenheimo, A., Tarallo, F., Rambach, J.-M. and Orbovic, N. (2011). "IRIS_2010-Part II: Experimental data," SMiRT 21, Div-V: Paper ID #520, Nov. 6-11, New Delhi, India