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FORTUM PARTICIPATION IN IRIS PHASEIII BENCHMARK: SIMULATION OF AIRCRAFT CRASH VIBRATION EFFECTS AND COMPARISON WITH TEST RESULTS

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Abstract

This paper describes the Fortum participation in the third phase of the IRIS benchmark that has been proposed since the beginning of the program (IRIS-2008 and IRIS-2010). The calculation of the floor response spectra due to the vibration of an aircraft impact is in need since the malevolent acts of the 9/11/2001. International feedback in earthquake engineering has provided a way to benchmark the seismic motion propagation into the structure. In the scope of vibration due to aircraft crash there is no such feedback, therefore experimental research is needed. In the framework of this project the vibration response characteristics of the test specimen representing the basic properties of the reactor building structures is set up for the round robin simulation analyses. All participants will receive a set of monitoring results of the tests, namely, displacements, velocities, accelerations and the damping characteristics that will be shared at the end of the round-robin calculations for validating the simulation results. It is necessary to quantify how the induced motion is propagating in structure in terms of magnitude and frequency content through experimental feedback. The appropriate quantification of the induced response spectra is a key element of the qualification of equipment for aircraft impact. There exist a lot of methodologies to evaluate the induced motion spectra. These methodologies have not been properly been validated by experiments. The IRIS PhaseIII experiments will provide data to carry out round-robin simulations to assess the methodologies.

INTRODUCTION

The analysis methods for impact phenomena are based on various techniques: finite element method (FEM) , empirical formulas, based on the results of conducted tests, analytical methods based on mathematical and mechanical theories of structures. All these methods must be proved to confirm that they give results consistent with reality. The users must follow proper procedures and to obtain the correct training and education. The research in the field of impact phenomena is a continuous process, and IRIS Phase III is one item in this sequence.

BASIC IDEAS AT THE ROOT OF IRIS BENCHMARKS

The benchmarks must be based on tests, dedicated to the understanding of the physical phenomena. The tests must not look like real projects, because the aircraft crash impact is a sensitive topic. It is difficult to obtain wide international cooperation, if researched items are related to real buildings and situations. The test structures cannot be scale models, because of the complexity of the physical phenomena under investigation. It is impossible to encompass by limited number of test situations all the possible diversity in the real structures of actual buildings. They aim of the IRIS Phase III research program is to confirm or improve the reliability of the safety demonstrations, by 1) quantification of the uncertainties and 2) by pointing out the good practices.

MAIN TRENDS AND LESSONS LEARNED FROM PREVIOUS IRIS BENCHMARKS

The variety of cases proposed for simulations and the large number of participants are factors that explain the interest and the success of IRIS Phase I and IRIS Phase II benchmarks. In the IRIS Phase II benchmark from the year 2010 until the year 2012 a significant improvement in simulations capabilities of the participants was observed if compared to the IRIS Phase I benchmark concluded in the 2008. The IRIS Phase III benchmark to be conducted during the years 2014 and 2015 will be dedicated to induced vibrations. In the following Table 1 the participant organizations and their corresponding research teams the took part in IRIS Phase I and IRIS Phase II projects are enumerated.

No.	TEAM NAME	ORGANIZATION	COUNTRY
1	AERB	Atomic Energy Regulatory Board	India
2	ANATECH	Anatech	USA
3	BARC	Bahba Atomic Research Centre	India
6	CANDU	CANDU Energy	Canada
7	CEA	Commissariat à l'énergie atomique et aux énergies alternatives	France
8	CNSC Team I	Canadian Nuclear Safety Commission	Canada
9	CNSC Team II	Vector Analysis Group	Canada
10	EDF	Électricité de France	France
11	ENSI	Swiss Federal Nuclear Safety Inspectorate	Switzerland
12	F4E-IDOM	Fusion for Energy - IDOM	International
13	Fortum	Fortum	Germany
14	GRS	German Reactor Safety Authority	Germany
15	IRSN Team I	Institut de radioprotection et de sûreté nucléaire	France
16	IRSN Team II	Institut de radioprotection et de sûreté nucléaire	France
17	IRSN Team III	Institut de radioprotection et de sûreté nucléaire	France
18	IRSN Team IV	Institut de radioprotection et de sûreté nucléaire	France
19	JNES	Japan Nuclear Energy Safety Organization	Japan
20	KINS	Korean Institute of Nuclear Safety	South Korea
21	NRC-SNL	United States Nuclear Regulatory Commission / Sandia National Laboratories	USA
22	NRI	Nuclear Research Institute Res Energoprojekt Praha	Czech Republic
24	Swissnuclear	Swissnuclear	Switzerland
25	UJF	University Joseph Fourier - Grenoble	France
26	VTT Team I	VTT Technical Research Centre of Finland	Finland
27	VTT Team II	VTT Technical Research Centre of Finland	Finland
28	VTT Team III	VTT Technical Research Centre of Finland	Finland
29	Woelfel	Woelfel Group	Germany

Table 1 The participant organizations and their corresponding research teams the took part in IRIS Phase I and IRIS Phase II projects.

The conclusions of results of IRIS Phase I and IRIS Phase II projects are as follows: 1) more data on experimental and epistemic uncertainties is available; 2) it was concluded that the scattering on natural phenomena as measured through experiments is much smaller than the uncertainties associated to predictions made with numerical models; 3) the uncertainties on loading prediction are reasonable and smaller than the ones on structure response prediction; 4) A model that is well adapted to one particular problem type will not automatically give satisfactory results for another type of problem; 5) the use of complex finite element methods should be accompanied by simplified analyses; 6)The main factor for a reliable and safe prediction is the experience and level of expertise of the engineers that make or evaluate that prediction. The next phase IRIS Phase III of benchmarking will be focused on induced vibrations. In the origin of IRIS Phase III benchmark were the following goals: 1) to achieve accurate and reliable modeling of the propagation of the vibration inside reinforced concrete structures in case of soft missile impact; 2) to compare simulation results with experimental results in case of soft missile impact. The following important issues must be addressed during the IRIS Phase III project: 1. The complexity of the vibration signal; 2. The boundary conditions of the structure need to be simple, and if possible, absorbing. The milestones of the IRIS Phase III project are presented in the following Table 2:

Action	Beginning	End
To design the mock-up and define the projectiles and test series conditions including the intended instrumentation	10/03/14	23/08/14
To review through a workshop the expected tests conditions	During TINCE 2014	
To call for participations	15/09/14	01/10/14
To share the input data with the participants	01/10/14	02/12/14
To carry out the tests	First quarter of 2015	
To update the input data following the tests series (if necessary)	At the end of the tests	
To collect the data of the participants	From March to August 2015	
To hold a workshop in order to share the participants results	October 2015	
To set up the recommendations based on IRIS 3 feedback	End of 2015	

Table 2 The milestones of the IRIS Phase III project.

MOCK-UP PROPOSAL FOR IRIS PHASE III AND CONDUCTED PRE-PROJECT TESTS AND SIMULATIONS

The mock-proposal for pre-project tests and simulation looks in cross-section and front views as follows:

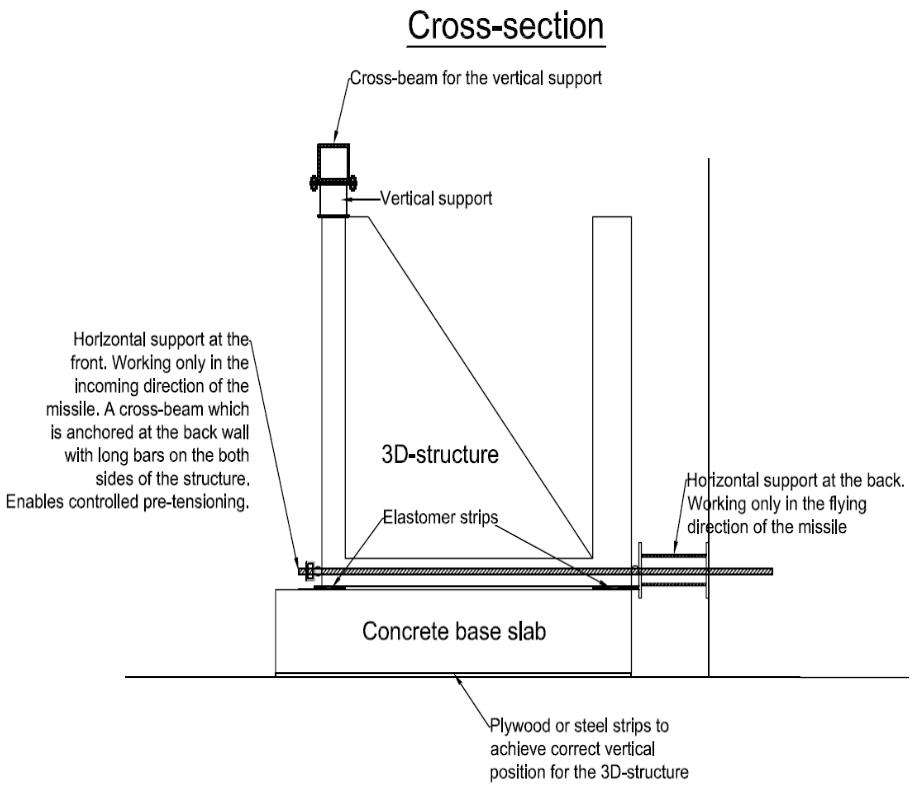

Figure 1 The Cross-section view of the pre-project test specimen

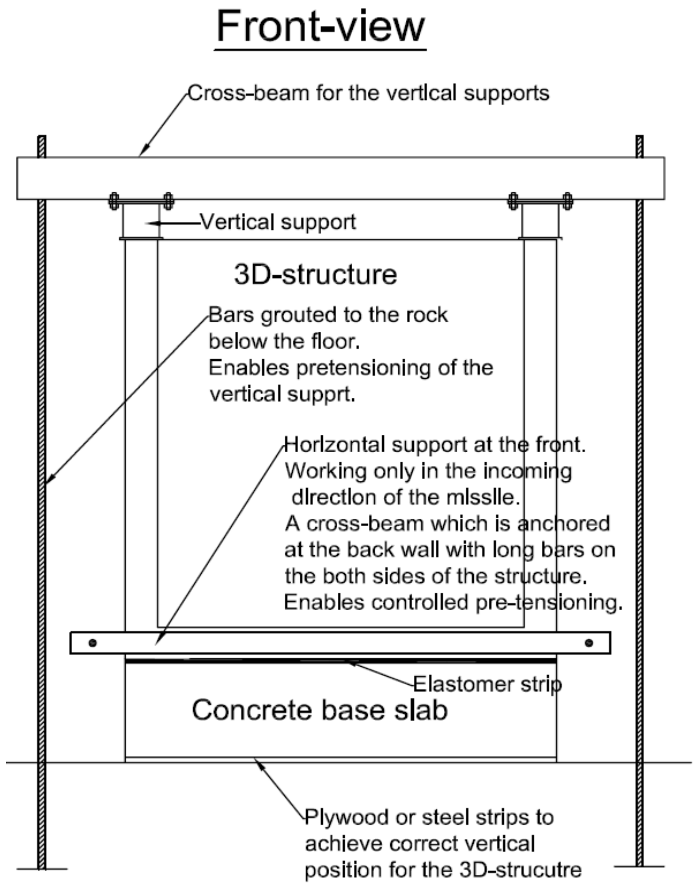

Figure 2 The Front- view of the pre-project test specimen

The properties of the pre-project mock-up are as follows: the mock-up is 3D shell structure consisting of two walls and one floor. The dimensions of the front wall are two meters times two meters times 15 centimetres and the dimensions of the back wall are two meters times two meters times 25 centimetres and the walls are connected by the floor with dimensions of two meters times two meters times 15 centimetres. In addition to the front wall and back wall there are two triangular side that support the front wall. Their thickness is also 15 centimetres. The soft missile impact is directed in the middle of the front wall. The used soft missile for the impact has been presented in the Figure 3:

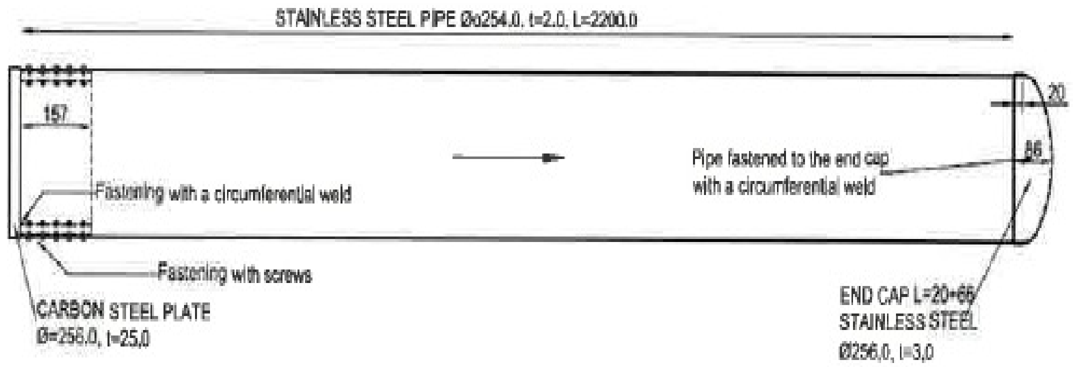

Figure 3 The soft missile for IRIS Phase III pre-project test series. The properties of the missile are as follows: Soft empty stainless steel missile, material steel grade EN1.4332, inside diameter 254 mm, pipe wall thickness 2mm, total 2311 mm, mass 50 kilograms, impact velocity 115 m/s.

The so - called V1 series of tests with the mock-up of figures 1 and 2 have carried out in the State Technical Research Centre in the autumn of the year 2014. Three tests with 115 m/s target velocity have been carried out. First test executed for the target specimen. Two consequent test were carried out for the already damaged target specimen from the previous tests. The front wall middle and the rear wall top displacements in the first test were about 10 mm. The maximum displacements did not change significantly between three repeated tests. Before V1 series so-called V0 series tests have carried out with little bit different test specimen set - up as in the V1 series. In the following the numerical simulation results of the V0 tests are given. In Figure 4 the simulation model for V0 test set up is presented.

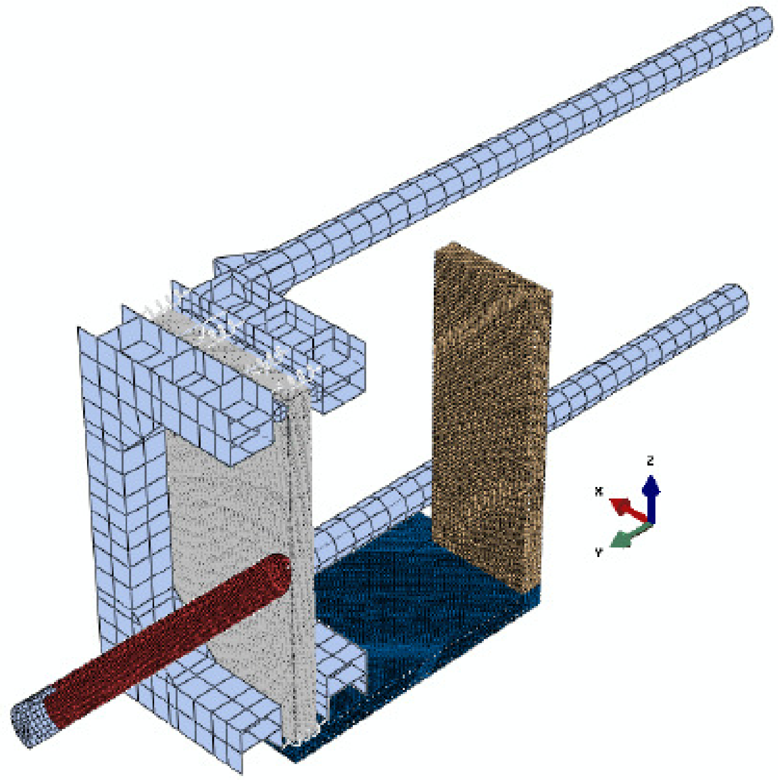

Figure 4 One half finite element simulation model of V0 series test specimen

The numerical simulation analysis was carried out by Abaqus/Explicit 6.12. The number of nodes was 454 000 and the number of elements 393 000. The missile was modelled by elastic-plastic material model, the steel frame by linear elastic material model and the reinforced concrete specimen by linear elastic model for floor and back wall and by elastic-plastic material model for the front wall with ductile damage plasticity. elements of front wall convert to SPH - particles when absolute maximum principal logarithmic strain equals to 0.7. The impact velocity of the missile given in Figure 3 was 110 m/s V0 - series tests. The simulated displacement time history results for the back wall bottom and for the back wall middle are given in Figure 5.

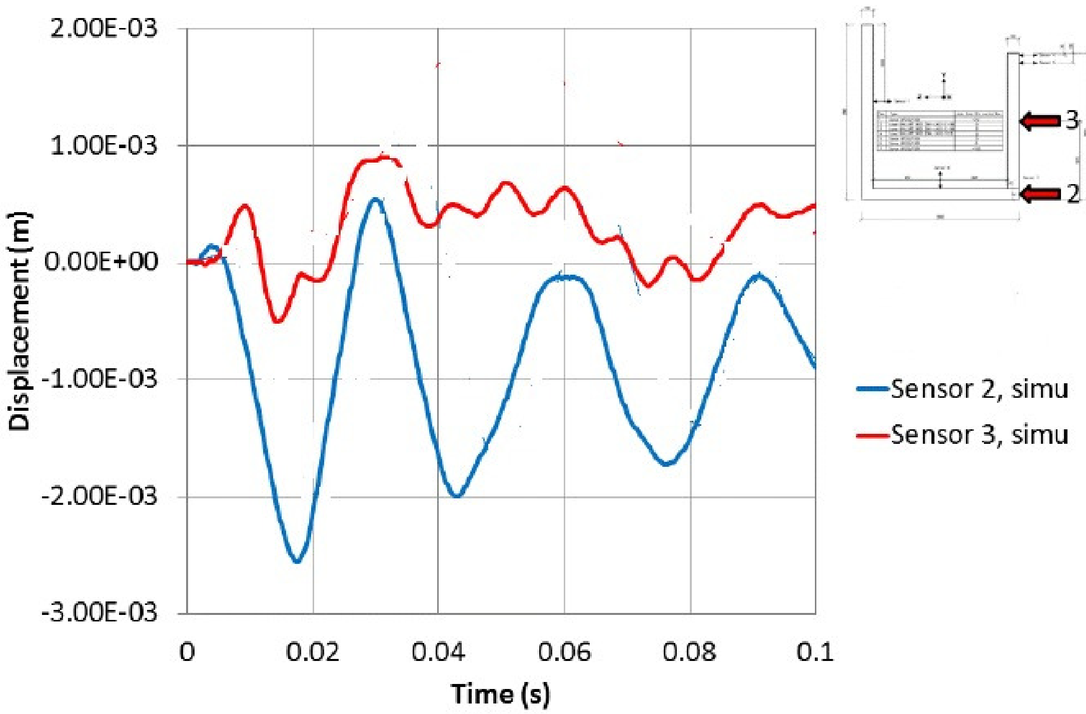

Figure 5 The simulated displacement time history results for the back wall bottom and for the back wall middle for V0 - series target specimen.

CONCLUSION

The numerical simulation gives reasonably accurate results for point 2 in the Figure 5, for point 3 the accuracy of simulation results is much worse. As for acceleration results the simulation accuracy at this stage of the project is not satisfactory.

REFERENCES

[1] IRIS Phase III Project, Scientific Committee Meeting #1 materials, February 2014. (private communication).

[2] ABAQUS/EXPLICIT 6.12, Users manual, Simulia Inc., 2014.