LS-OPT Parameters Identification on Concrete Sample Tests for an Impact Simulation on Concrete Slab

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1 Introduction

The dynamic behavior of Concrete is one of the most common and difficult problem of simulation in Nuclear, Defense and Civil fields. In most cases, the data available for modeling problems is much reduced; engineers are obliged to predict the behavior with non sufficient information. Due to this lack of experimental sample based input parameters, the result of simulation becomes “engineer dependent”, leading to much different results than people doing the same modeling problem. In previous paper ([5], [6]) presented during last LS-DYNA Conferences, we showed that a probabilistic approach for concrete modeling can be used to reduce these differences due to the modeling choices. But one of the main conclusions of these papers was that all these modeling techniques never replace experimental concrete sample tests to obtain the right material behavior before simulation.

This paper is based on a work realized for an international OECD benchmark initiated by IRSN and CNSC. The main goal of IRIS_2012 Benchmark was to evaluate the ability of simulation to reproduce experimental tests of impacts on concrete slabs. Contrary to the earlier benchmark (IRIS_2010), experimental results of concrete sample tests was this time available in order to calibrate numerical constitutive laws before simulations on real tests. This paper, as the rest of our previous papers about IRIS_2010, will present the use of LSTC products capabilities in this kind of approach.

In a first time, a complete LS-DYNA concrete model based on compressive strength will be created using automatic parameters generation capabilities of LS-DYNA. Then this model will be compared to experimental sample results of several cylindrical sample tests (simple compression and confined compressions at several confinement pressures). After sensitivity analysis to identify which parameters of the concrete model can be used to fit experimental results, LS-OPT parameters identification will be performed simultaneously on all cases.

Based on the VTT Punching test simulation of IRIS_2012, we will compare the results between simulation with parameters automatically generated, simulation with fitted parameters and experiment. This comparison will be focused on missile velocity after impact and slab concrete damage.

We precise that all the calculations presented here are performed with LS-DYNA solver, coupled with LS-OPT software for the probabilistic part of the studies (DoE studies, Monte Carlo Analysis, Robustness and Optimizations).

2 Fitting of Concrete Sample Tests

The concrete sample tests used for this study were realized in 2011 by 3S-R Laboratory of Grenoble University. They have been performed on cylindrical samples (7 cm diameter and 14 cm length) using a high pressure testing machine named „Giga“. The following figure shows the experimental sample test.

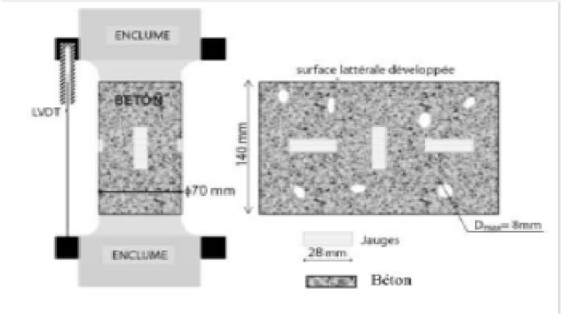

Fig. 1: Experimental sample test

For IRIS_2012 Benchmark, five curves of stress versus strain were given corresponding to:

- A simple compression test,
- Four compression tests with confinement at 15.5 MPa, 26 MPa, 47 MPa and 100 MPa.

LS-DYNA finite elements models have been created for each test case.

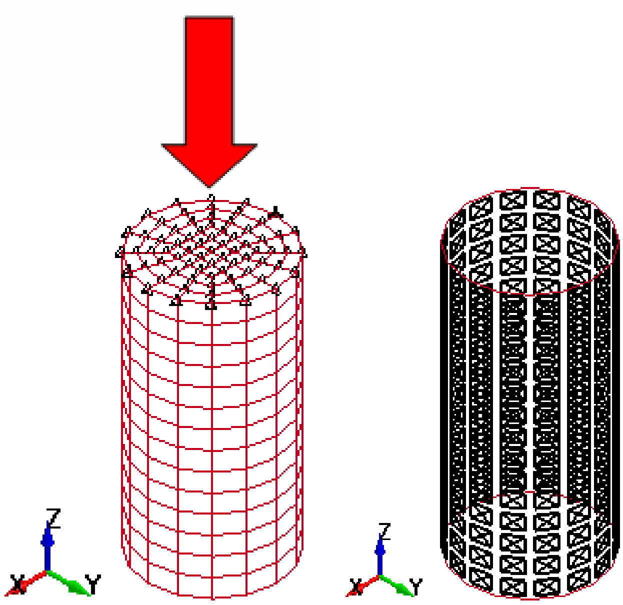

Fig. 2: LS-DYNA model for samples

LS-DYNA® software has several advanced constitutive models developed to simulate concrete material behavior, the most usual ones are currently *MAT_PSEUDO_TENSOR (*MAT_16), *MAT_CONCRETE_DAMAGE_Release3 (*MAT_72r3), *MAT_WINFRITH_CONCRETE (*MAT_84) and *MAT_CSCM (*MAT_159). Most of them have automatic generation capability of concrete law parameters. Indeed, LS-DYNA is able to provide, starting from a first set of physical parameters (unconfined compressive strength Fc, unconfined tension strength Ft,…) a second set of parameters by internally fitting experimental reference results.

Starting from the Fc, we chose to use *MAT_72r3 material law with automatic parameter generation as a starting point to simulate sample tests. Then parameters previously generated will be optimized to better fit experimental results.

In a first time, a simulation has been performed using automatic parameter generation using Fc = 70 MPa. The results obtained have been compared to the experimental ones. On the following figure, there is the comparison between simulation and experiment for simple compression test. We can see that *MAT_72r3 automatic parameter generation gives acceptable results, excepted for a small numerical problem at high strain.

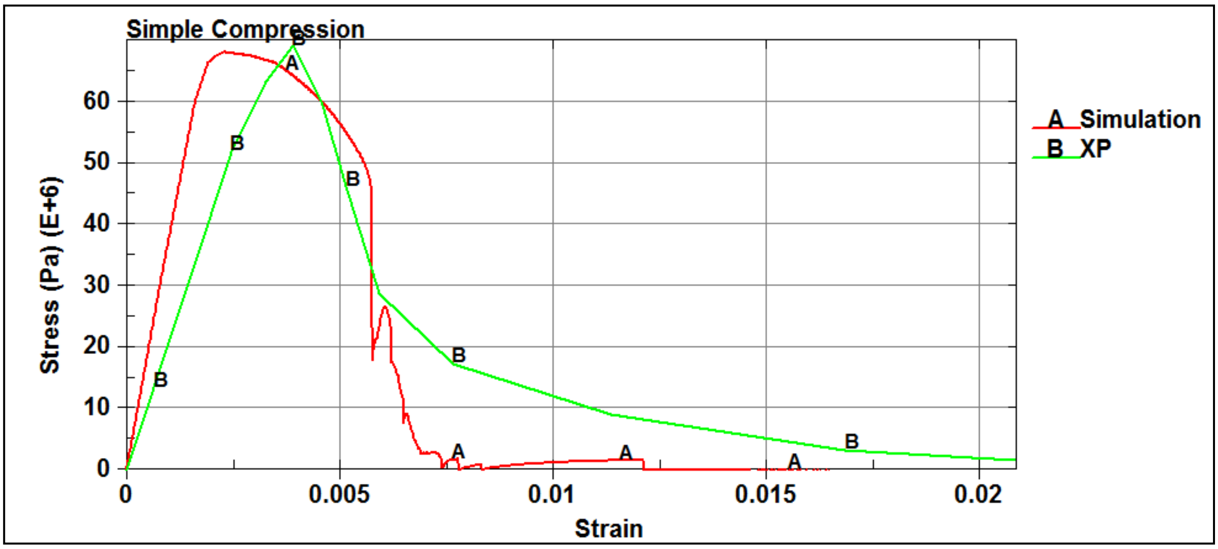

Fig. 3: Comparison between simulation and experiment for simple compression test

Regarding to this result, some options are identified to optimize the behavior of this material. In fact, the Young modulus of the curve and the softening are not optimized for this test.

Starting from this first set of parameters, a lot of tests and calculations have been performed with direct LS-DYNA simulation and LS-OPT sensitivity analysis in order to identify which parameters can be used in optimization to fit the experimental result. On the following figure, there is an example of LS-OPT sensitivity analysis performed.

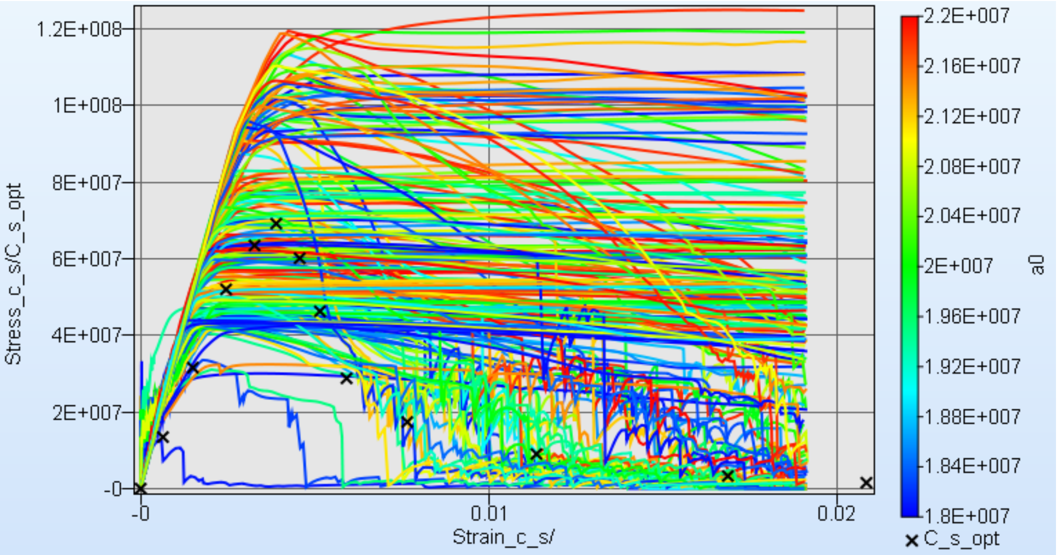

Fig. 4: Example of LS-OPT sensitivity analysis

After this sensitivity part, an optimization with LS-OPT has been performed on identified parameters. The following picture shows the result of this optimization.

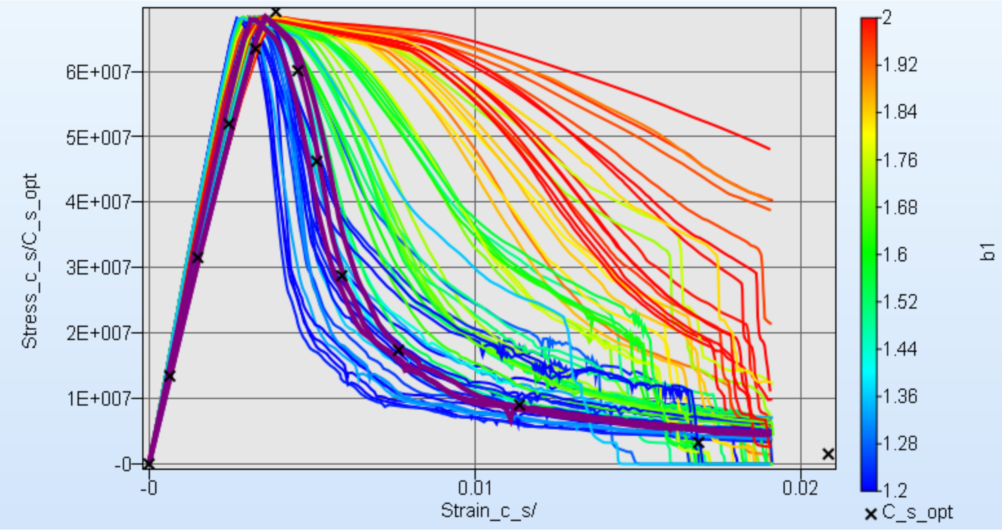

Fig. 5: Results of LS-OPT Optimization

After this optimization phase, we can show the difference between simulation and experiment for automatic parameter generation and after optimization. On the following curves, “A” curve represents the fitted parameters, “B” curve represents the automatic generation and “C” curve represents the experiment.

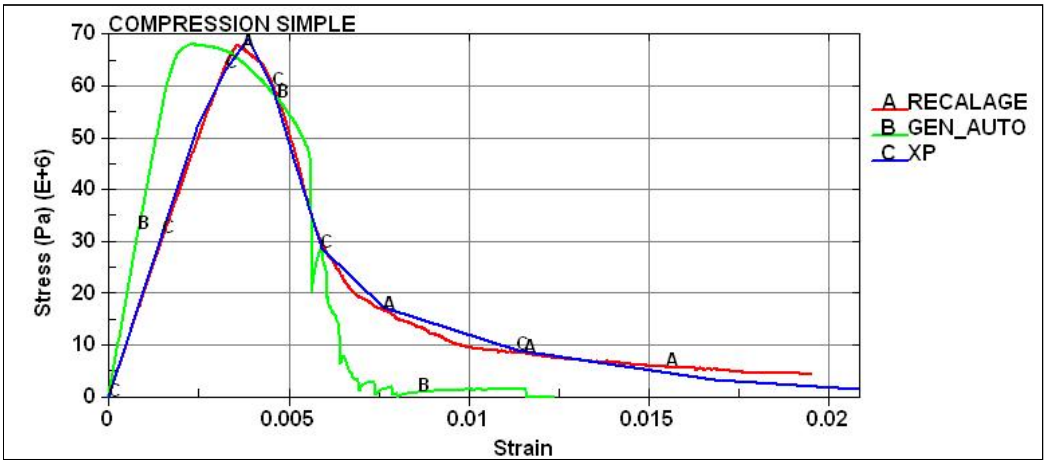

Fig. 6: Results for simple compression test

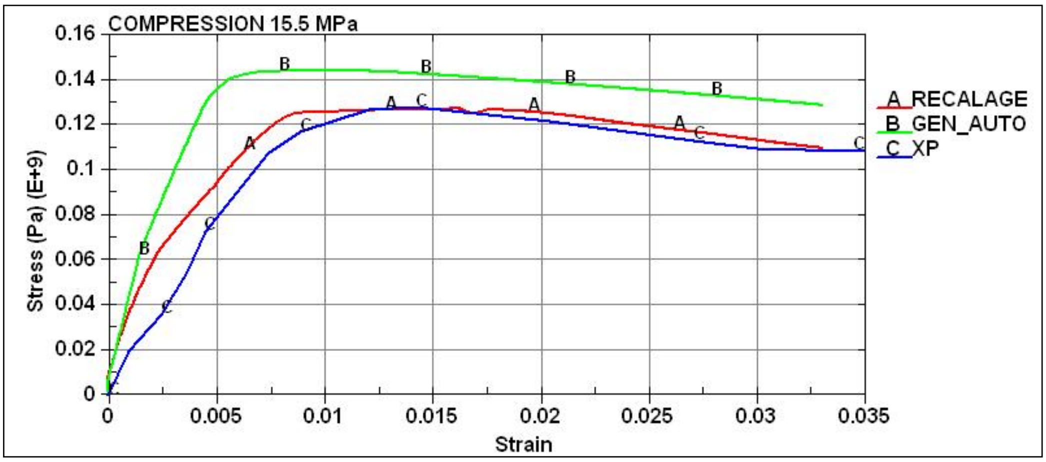

Fig. 7: Results for compression test with 15.5 MPa confinement

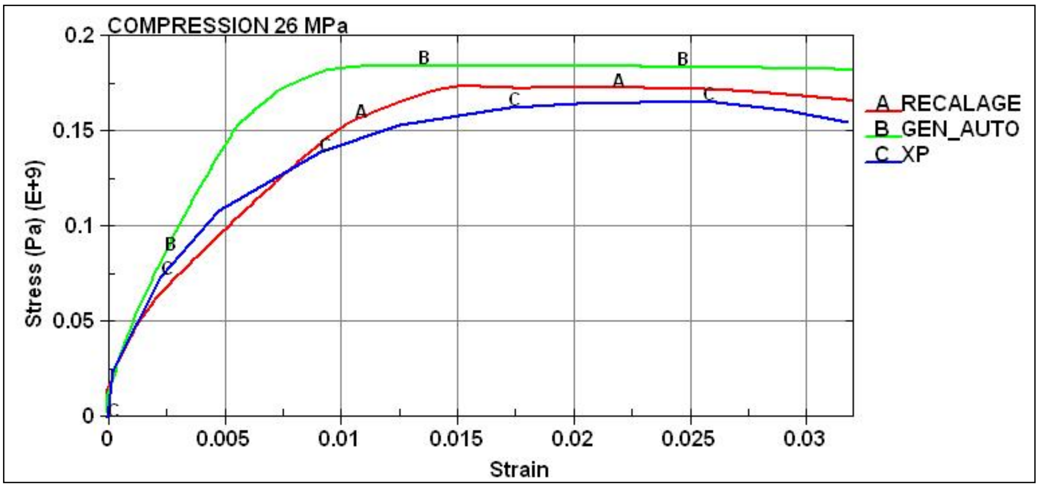

Fig. 8: Results for compression test with 26 MPa confinement

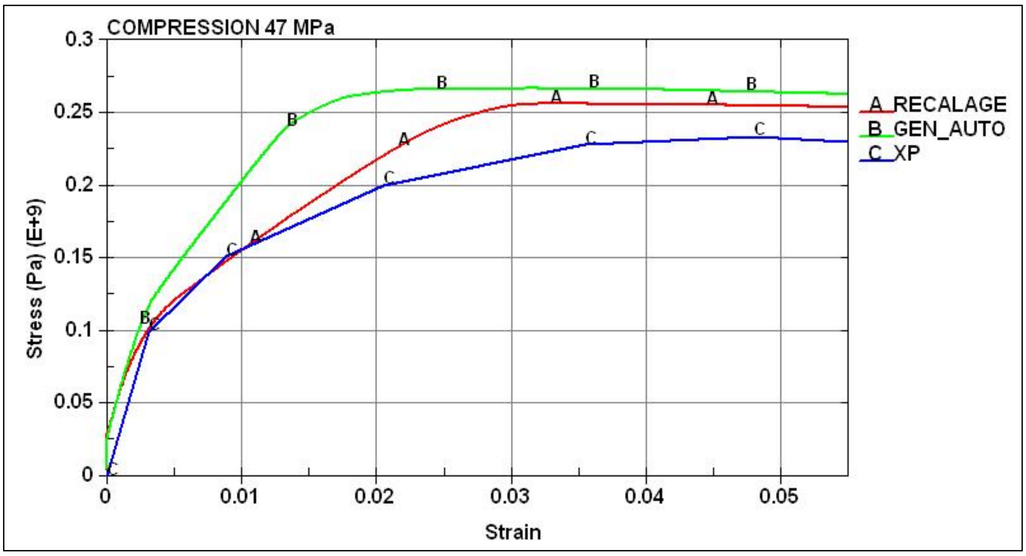

Fig. 9: Results for compression test with 47 MPa confinement

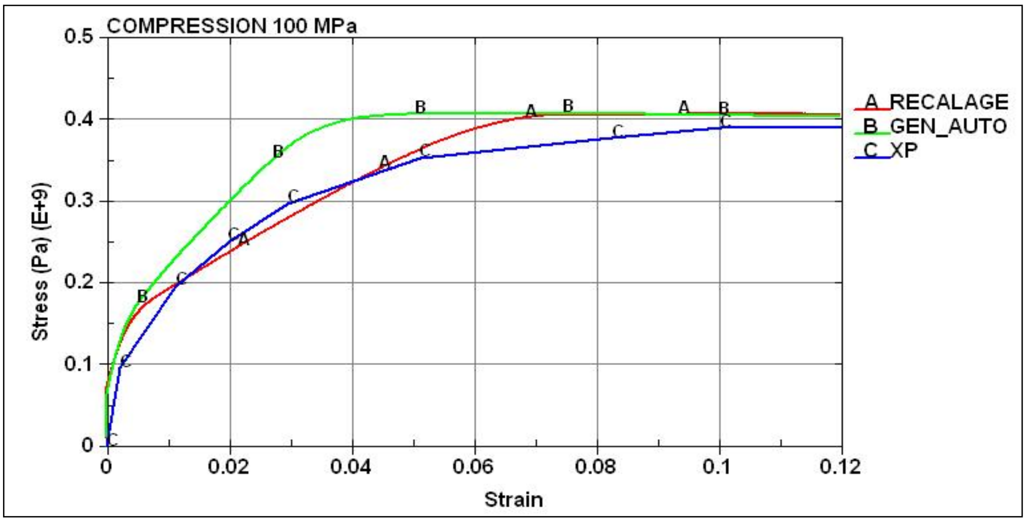

Fig. 10: Results for compression test with 100 MPa confinement

3 Results on VTT Punching Test

All the results presented before show that the fitting approach has improved the results on sample tests. It is now interesting to see the effect of this parameters fitting on a real test case of IRIS Benchmark: VTT Punching test.

The VTT Punching test is composed on two parts:

- A missile with a steel dome and a concrete cylinder with a steel skin, with a total mass (about 50 kg). This missile impacts the slab at 135 m/s.
- A concrete slab of 200 x 200 x 25 cm hold by a UPN Steel part, reinforced by a square mesh of longitudinal rebars on each side of the slab.

This test is modeled by a 3D half model; the goal is to use one symmetry plane to limit the number of elements without forcing a distortion mode.

Concrete is modeled by under integrated constant stress solid element (one integration point per volume). Reinforcement is modeled by Hugues-Liu with cross section integration beam elements. The ratio between slab and missile element size guarantees a good behavior during the contact.

The UPN Steel part, surrounding the concrete slab, is explicitly modeled by Belystchko fully integrated shell element and is merged into the concrete part.

The missile for the VTT Punching test is explicitly modeled. Light-weight concrete and steel dome are modeled using under integrated constant stress solid elements (one integration point per volume). Steel pipe and steel plate are modeled with Belytschko fully integrated shell elements merged with the concrete solid.

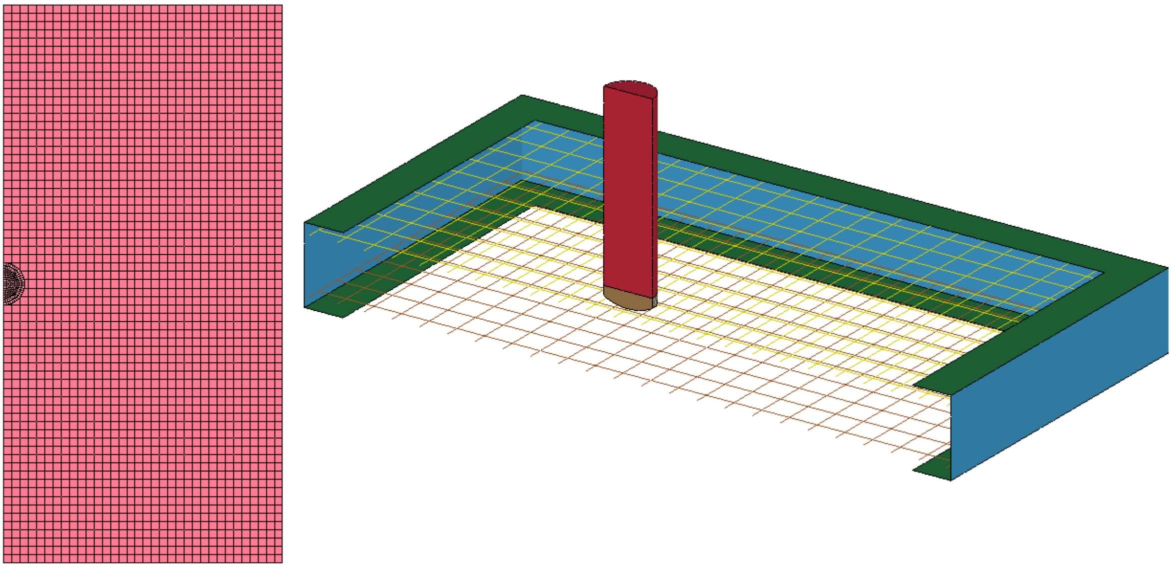

Fig. 11: View of VTT Punching LS-DYNA model

The constitutive law of steel elements is a *MAT_PIECEWISE_LINEAR_PLASTICITY able to model the behavior of steel with a complex plasticity curve and to include strain rate effects. Engineer values are changed into true values up to striction and then interpolated using a swift law. Without stress-strain curves for different strain rates, a simple way to take into account strain rate effects is to add a Cowper-Symonds law.

Rebars are not merged to the concrete elements; the interaction is modeled by a coupling method based on a constrained approach. Junctions between two longitudinal rebars are merged.

Two types of contact are used to model the interaction between missile and slab:

- *CONTACT_ERODING_SINGLE_SURFACE deals with the contact between missile and solid concrete and the auto contact of the missile on itself. This contact is based on penalty method with a segment based option for contact detection (instead of node based) to avoid penetration.

- *CONTACT_ERODING_NODES_TO_SURFACE deals with a possible contact between reinforcement nodes and missile segments (if erosion leads to such a possibility).

Using firstly the automatic generation of parameters, and secondly the optimized ones, we can compare the results with experiment for final missile velocity after penetration and concrete slab damage.

The residual missile velocity in the simulation can be compared to the corresponding experimental value. The following table shows a comparison of these values. We can see that the automatic generation of simulation parameters underestimates the residual velocity. However, with the optimized parameters, the results show a residual speed exactly in the experimental range.

Experimental speed range	**Automatic generation parameters**	**Optimized parameters**
35-40 m/s	**23.2 m/s**	**36.2 m/s**

Fig. 12: Table of speed comparison

We can also compare the concrete damage of the reinforced concrete slab for the two calculations. In the following figure, we can see that comparison with a fringe of concrete damage (internal variable law of *MAT_72r3) for both simulations.

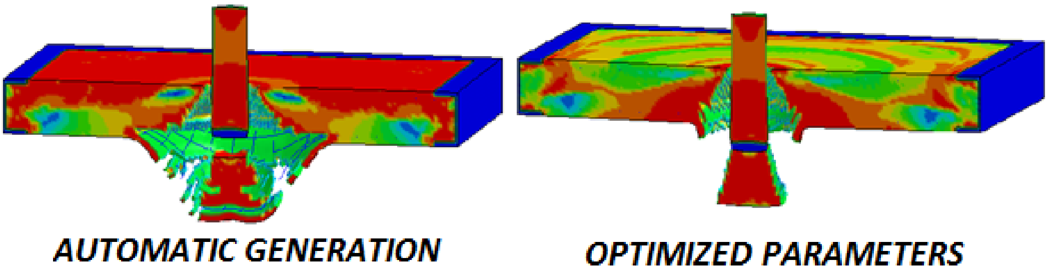

Fig. 13: Concrete damage comparison

In the previous figure, we can see that the slab damage with automatic generation is too important on the front of the slab. Indeed, the upper half of the slab is totally damaged, which is not consistent with the experimental results. For the optimized parameters calculation, we notice a more physical damage, with a damage cone located in the impact area and damages near boundary conditions, which is more consistent with the observation of cracks of the experimental results (see following figures).

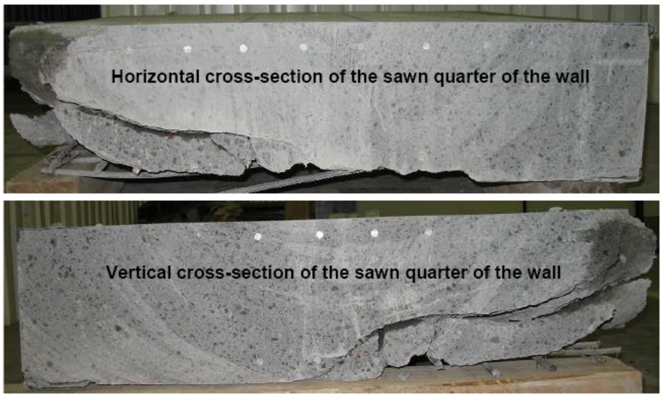

Fig. 14: Experimental slab damages

4 Conclusion

In a first time, a fitting approach on sample compression tests has been performed to optimize the concrete material law using *MAT_72r3 automatic parameter generation capabilities and experimental results. We showed that with LS-OPT DoE studies, sensitivity analysis and optimizations, it is possible to fit experimental stress/strain curves.

Based on the VTT Punching test simulation of IRIS_2012, we have also compared the results between simulation with parameters automatically generated, simulation with fitted parameters and experiment on a real test case. This comparison showed an improvement of quality results for the missile velocity after impact and slab concrete damage.

5 Summary

This paper is based on a work realized for an international OECD benchmark initiated by IRSN and CNSC. The main goal of IRIS_2012 Benchmark was to evaluate the ability of simulation to reproduce experimental tests of impacts on concrete slabs. Contrary to the earlier benchmark (IRIS_2010), experimental results of concrete sample tests was this time available in order to calibrate numerical constitutive laws before simulations on real tests. This paper, along with the two corresponding papers related to IRIS_2010 ([5], [6]), present the use of LSTC products capabilities in this kind of approach.

For the first phase of IRIS benchmark (IRIS_2010), the data available for modeling was reduced to minimum. As a consequence; engineers were forced to predict the behavior with non sufficient information and consequently to rely mainly on the parameters generated automatically by concrete material law and / or to determine relatively arbitrary missing parameters or their variation from the values generated automatically. As a consequence, the result of simulation becomes greatly “engineer dependent”, leading to much different results than people doing the same modeling problem. In previous paper ([5], [6]) presented during last LS-DYNA Conferences, we demonstrate that a probabilistic approach for concrete modeling can be used to reduce these differences due to the modeling choices or at least to assess the dispersion of results based on possible variation of input parameters. Yet, one of the main conclusions of these papers was that all these modeling techniques would never replace experimental concrete sample tests to obtain a proper material behavior.

The second phase of IRIS benchmark (IRIS_2012), for which sufficient experimental data were available, allowed us to supplement the previous papers highlighting the joint capabilities of LS-DYNA and LS-OPT for predictively assess the consequences of an impact on a slab reinforced concrete. In a preliminary phase, from data automatically generated by the constitutive law, a massive use of LS-OPT has enabled an extremely precise calibration of material parameters to fit with great accuracy the experimental data. Simply based on these recalibrated parameters, the results for the impact on the concrete slab were very much improved. The exit velocity of the projectile, initially undervalued, has been heavily modified and is found in the range observed during the tests. Meanwhile, the deformation and damage modes observed in the tests are predicted in a much more realistic manner.

This paper, and previous one presented by DynaS+ related to the IRIS benchmark, highlights the interest to minimize the uncertainties of a joint and widespread use of LS-OPT software along with LS-DYNA for this kind of applications.

6 References

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[3] LS-DYNA Keyword Users’ Manual and Theory Manual – LSTC.

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[5] Van Dorsselaer N., Lapoujade V., Nahas G. , Tarallo F., Rambach J.M. : “Impact Simulations on Concrete Slabs: LS-OPT® fitting approach” - 8th European LS-DYNA Users Conference, May 2011, Strasbourg, France