Simulation of an Impact Test with a Deformable Missile on a Concrete Wall

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1 ABSTRACT

Reinforced concrete structures are used to protect vital parts and equipment of nuclear power plants. In areas with dense air traffic the external containment buildings have been traditionally designed to resist accidental impact loads. Recent events have shown that also a civil aircraft can be used as weapon for intentional sabotage, emphasizing the need to consider more carefully impact load determination when assessing and designing protective structures of nuclear power plants. In the frame of the reactor safety research program of the German Federal Ministry of Economics and Technology GRS has started to validate the commercial software for fast nonlinear dynamics AUTODYN with respect to its capability to simulate the impact of various missiles on different target structures. For the validation of models to determine the mechanical load assumptions and the consequences, small and large scale tests on the fragmentation of deformable missiles impacting on solid targets are performed at different facilities.

The paper summarizes a study using complex AUTODYN simulations as well as simplified Riera estimations of a test with a thin-walled aluminium missile impacting on a reinforced concrete wall. The test was conducted by Technical Research Centre of Finland VTT.

In a first step a comparison of experimental data and analysis results concerning load time history and missile failure behaviour is performed. The Riera results for the selected impact test show strong sensitivity on the assumptions concerning the crushing force, especially the strain rate dependence is very pronounced. The AUTODYN results for the missile behaviour are satisfactory. The work on simulation of the target response is in progress.

2 INTRODUCTION

With respect to the changed range of external hazards since September 11th, 2001 the consequences of a directed attack with a large civil aircraft on a nuclear power plant has to be evaluated.

Therefore small and large scale tests are conducted at different facilities to explore the response of reinforced concrete walls to impact of deformable or rigid missiles. One objective of such tests is to provide data which can be used for the validation of numerical tools by means of their capability to simulate the measured results in order to improve their reliability in 1:1 calculations. The Technical Research Centre of Finland VTT constructed an impact test facility (Lastunen et al. (2007)) which enables the launching of arbitrary shaped missiles to different target structures, for instance reinforced concrete walls. As scientific-technical expert and research organisation, GRS is one of the international partners in VTT's IMPACT project.

Two different failure mechanisms of reinforced concrete walls due to missile impact are basically distinguished. The wall may fail either by flexural bending or by formation of a punching cone. Missiles are roughly classified into the two categories of deformable missiles and more or less rigid missiles.

The present study discusses the capabilities of the GRS structural dynamics analysis methods based on AUTODYN (2008) as well as the simplified Riera model (1968) to simulate measured data of one VTT test. This test was designed to generate flexural behaviour of a reinforced concrete wall due to an impact of a deformable aluminium missile.

3 EXPERIMENTAL BACKGROUND

This section provides basic information about an impact test carried out by VTT which is the base for the numerical work. It is part of a test series of tests with similar conditions. The major purpose of this test series is to generate and study flexural behaviour of reinforced concrete walls with or without shear reinforcement in order to deliver data for validation and further development of structure dynamics analysis tools for the quantitative simulation of impact phenomena including missile as well target behaviour. Hence the construction makes use of simple geometry and boundary conditions. In particular there is no similarity between the experimental setup and any nuclear facility. Further information is given elsewhere e. g. Lastunen et al. (2007) and Hyvärinen et al. (2007).

3.1 Description of the missile in VTT test 673

The missile used in the test is made of hollow aluminium pipes with an outer diameter of 250 mm, wall thickness 5 mm and length 1800 mm (see Figure 1). In order to crush a sufficient length of the aluminium pipe and achieve the desired load time history a rear pipe made of steel is utilised. About half of the total mass is concentrated in this steel rear of the missile. Furthermore steel rails needed for the acceleration process are attached at two positions. The overall mass is about 50 kg while the measured impact velocity is 127 ms^{-1}.

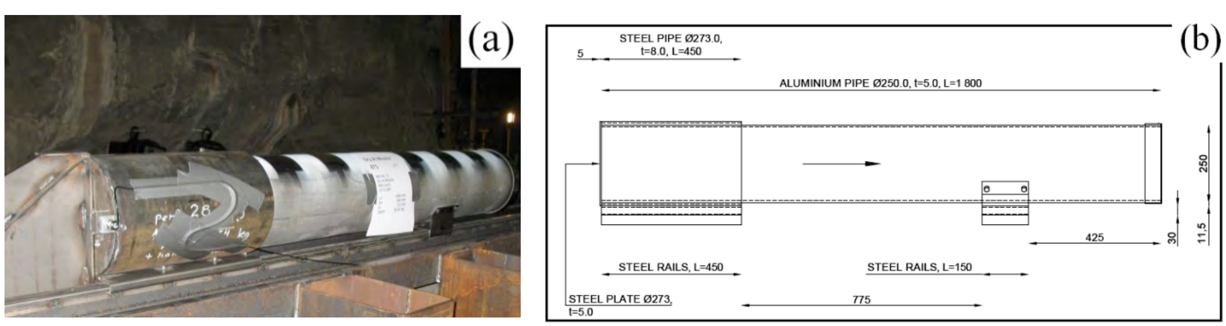

Figure 1. Photograph of aluminium missile with steel rear (a) and related engineering drawing (b) (pictures provided by VTT).

3.2 Description of the target in VTT test 673

The basic outer dimensions and boundary conditions of the reinforced concrete wall are 2000 mm simply supported in vertical direction, 2300 mm in horizontal direction being unsupported while the wall thickness is 150 mm. The supporting frame is firmed up against a rock face by steel pipes (see Fig. 2a).

Bending reinforcement near both surfaces is done by a 50 mm x 50 mm grid of bars with a diameter of 8 mm covered by 15 mm of concrete. Near the wall edges front and back face of the bending reinforcement are bonded by bending over the reinforcement bars and giving them an overlap with the reinforcement bars of the accordant face. Furthermore shear reinforcement is contained in form of closed shaped stirrups of 6 mm diameter. Fig 2b shows the reinforcement before casting.

Several quantities are measured during the test. Of primary interest are the time histories of deflections of the wall, forces recorded in the supporting steel pipes and strains of reinforcement bars due to impact. Therefore displacement transducers are attached at the back side of the wall and strain gauges glued to the reinforcement.

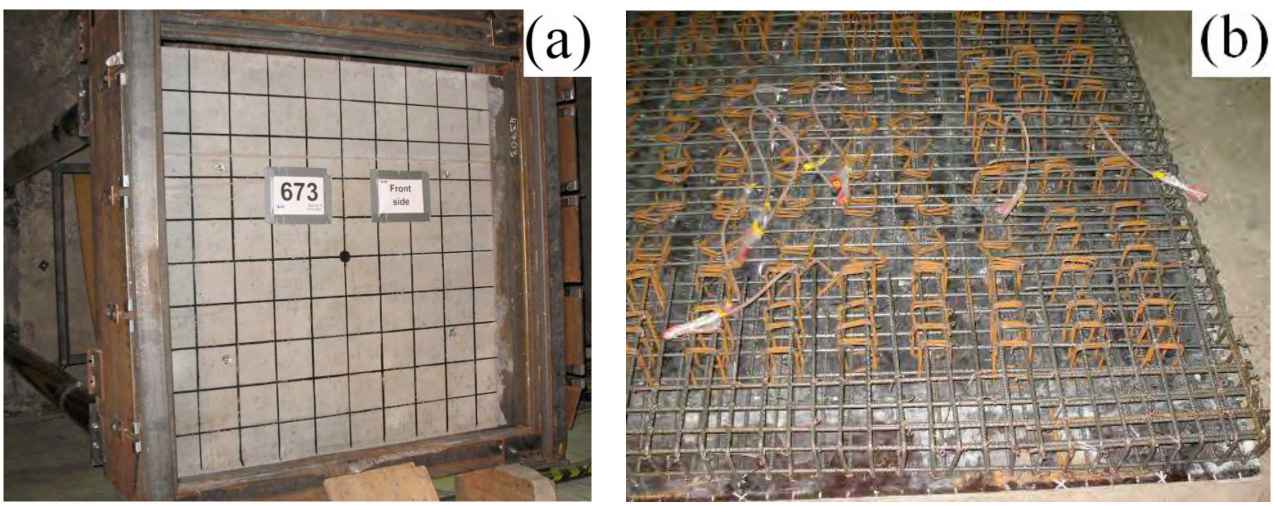

Figure 2. Concrete wall with supporting frame (a) and bending as well as shear reinforcement before casting (b) (pictures provided by VTT).

4 DESCRIPTION OF NUMERICAL MODEL SETUP

4.1 Material modelling

4.1.1 Metals

A proper treatment of impact phenomena also requires material strength models which take into account the effect of strain rate dependent hardening. This effect is included in the Johnson-Cook strength model (Johnson et al. (1983)) in the form of eqn. (1) which is applied in the simulations presented to the missile part as well as to the reinforcement bars of the target. The term in the first bracket marks a well known parabolic hardening relationship while the dynamic increase factor (DIF) in the second bracket introduces strain rate hardening.

=tress. Both models are used in the framework of the current activities. The input parameters used in the calculations presented in this paper are listed in Table 1.

Table 1. Material data applied for parts filled with a Johnson-Cook material strength model (see eqn. 1).

Quantity	Symbol	Unit	Rebars	Aluminium
Bulk modulus	*K*	GPa	175	58,3
Shear modulus	*G*	GPa	80,8	26,9
Static yield stress	*A*	MPa	535	217
Hardening constant	*B*	MPa	1275	596
Strain rate constant	*C*	-	0,014	0,001
Hardening exponent	*n*	-	1,0	0,551

4.1.2 Concrete

In the present study the RHT (Riedel, Hiermaier and Thoma) concrete strength and failure model developed and implemented in AUTODYN (see Riedel (2000)) is applied to the concrete parts. This sophisticated concrete material model is designed to cover a wide range of hydrostatic pressures and strain rates. It includes the effect of increasing concrete strength at higher hydrostatic pressures. A failure model interpolates within the principal stress space between the yielding surface of the undamaged concrete and a residual pressure dependent compressive strength surface of the totally destroyed concrete. Furthermore the RHT model makes use of dynamic increase factors (DIF) for strain rate dependent strength parameters of the material given by eqn. (3a) and (3b) according to Bischoff et al. (1988).