Plastic barrier for industrial applications

Characterization under impact loading using testing and Ls-Dyna®

C. Goubel[a], E. Di Pasquale[b], J. Pascual[c]

a: Laboratoire INRETS Equipements de la Route (LIER SA) - Lyon Saint Exupéry Aéroport, France

b: Simulation et Technologie (Sim Tech), 37, rue des acacias – 75017 Paris, France

c: BOPLAN bvba Muielstraat 12 – 8560 Wevelgem (Moorsele), Belgium

1 Introduction

Safety structures are needed in industrial areas to protect people, machines or goods from forklift circulation.
Steel roadside safety barriers are often chosen but the accuracy of these structures designed to restraint a light vehicle under a low angle but at high speed is not obvious. After several (even soft) impacts or contacts, this kind of devices suffers of a poor aspect and some parts have to be changed quite frequently.
Plastic barriers developed by BOPLAN present the interest of elastic behaviour which allows to reduce significantly the number of repairs or maintenance operations on the one hand.
One the other hand, the use of plastic structures is not a common choice and without any normative context concerning these products, commercial efforts are required to demonstrate the effectiveness of the structures.
In order to help in the selection of the barrier type and in order to have scientific arguments, a meaningful collaboration combining testing, numerical simulation and mathematical models was set-up with the final aim to obtain a user friendly interface for structure selection as a function of conditions of use (Mass of forklift, customer regulation speed, etc...).

2 Real crash testing

The real test session had two main purposes: first of all to bring an indisputable proof of the effectiveness of the structures under impact loading conditions as close as current usage and, secondly, to serve as a basis for numerical model validation.

2.1 Test protocol

Fig. 1: Test set-up (left) and impact point designation (right)

A total of 20 forklift (2.3 tonnes) impacts were conducted with several impact points, impact angle and impact speed on four different barriers.

Test zone was covered by two high speed cameras (which were used for dynamic deflexion measurement) and deceleration were recorded on the forklift and severity was assessed by the mean of ASI (Acceleration Severity Index) criteria with following formula 1 and 2:

$$ASI = \max\left(\sqrt{\left(\frac{\bar{a}_x(t)}{12}\right)^2 + \left(\frac{\bar{a}_y(t)}{9}\right)^2 + \left(\frac{\bar{a}_z(t)}{10}\right)^2}\right) \quad (1)$$

With

$$\bar{a}_{x,y,z} = \frac{1}{\delta}\int_t^{t+\delta} a_{x,y,z}\,dt \quad (2)$$

2.2 Test results

Test ID	Device	Angle	Speed	Impact point	Dynamic Deflection	ASI
12083 01	DTB-H	18.6°	7.4 km/h	P3	1.5 cm	0.10
12083 02	DTB-H	16.5°	12.7 km/h	M3	3.0 cm	0.11
12083 03	DTB-H	90.6°	5.8 km/h	M2	9.0 cm	0.17
12083 04	DTB-H	95.5°	9.4 km/h	P2	14.5 cm	0.36
12083 05	DTB-H	89.9°	12.1 km/h	P2	19.5 cm	0.43
12083 06	DTB-H	94.2°	10.7 km/h	P3	17.0 cm	0.40
12083 07	TB300	24.7°	4.4 km/h	P0	3.5 cm	0.12
12083 08	TB300	27.2°	8.5 km/h	M0	6.0 cm	0.13
12083 09	TB300	31.1°	12.1 km/h	P1	20.5 cm	0.18
12083 10	TB300	90.7°	4.3 km/h	M2	5.0 cm	0.08
12083 11	TB300	90.1°	8.3 km/h	M2	13.5 cm	0.21
12083 12	TB300	88.3°	12.3 km/h	M2	35.5 cm	0.21
12083 13	TB460	22.3°	8.7 km/h	M1	7.0 cm	0.08
12083 14	TB460	21.7°	11.4 km/h	M1	11.0 cm	0.21
12083 15	TB460	89.7°	9.9 km/h	M2	31.5 cm	0.18
12083 16	TB460	90.4°	13.0 km/h	M2	65.5 cm	0.17
12083 17	DTB-L	22.3°	8.1 km/h	P1	3.0 cm	0.13
12083 18	DTB-L	21.5°	15.1 km/h	P1	9.5 cm	0.10
12083 19	DTB-L	90.0°	9.1 km/h	M2	19.5 cm	0.20
12083 20	DTB-L	89.8°	15.7 km/h	M2	39.0 cm	0.40

Table 1: Test results

2.3 Experimental conclusions

The twenty tests conducted have allowed to illustrate the good behaviour of four devices under a wide range of impact loading conditions which constitute a consistent database for numerical model validation.

3 Numerical simulation

3.1 Devices numerical models

Devices models were built starting from the CAD. All the components are explicitly modelled including anchorages and other coupling bolts. The Fig. 2 illustrates the four devices tested and simulated.

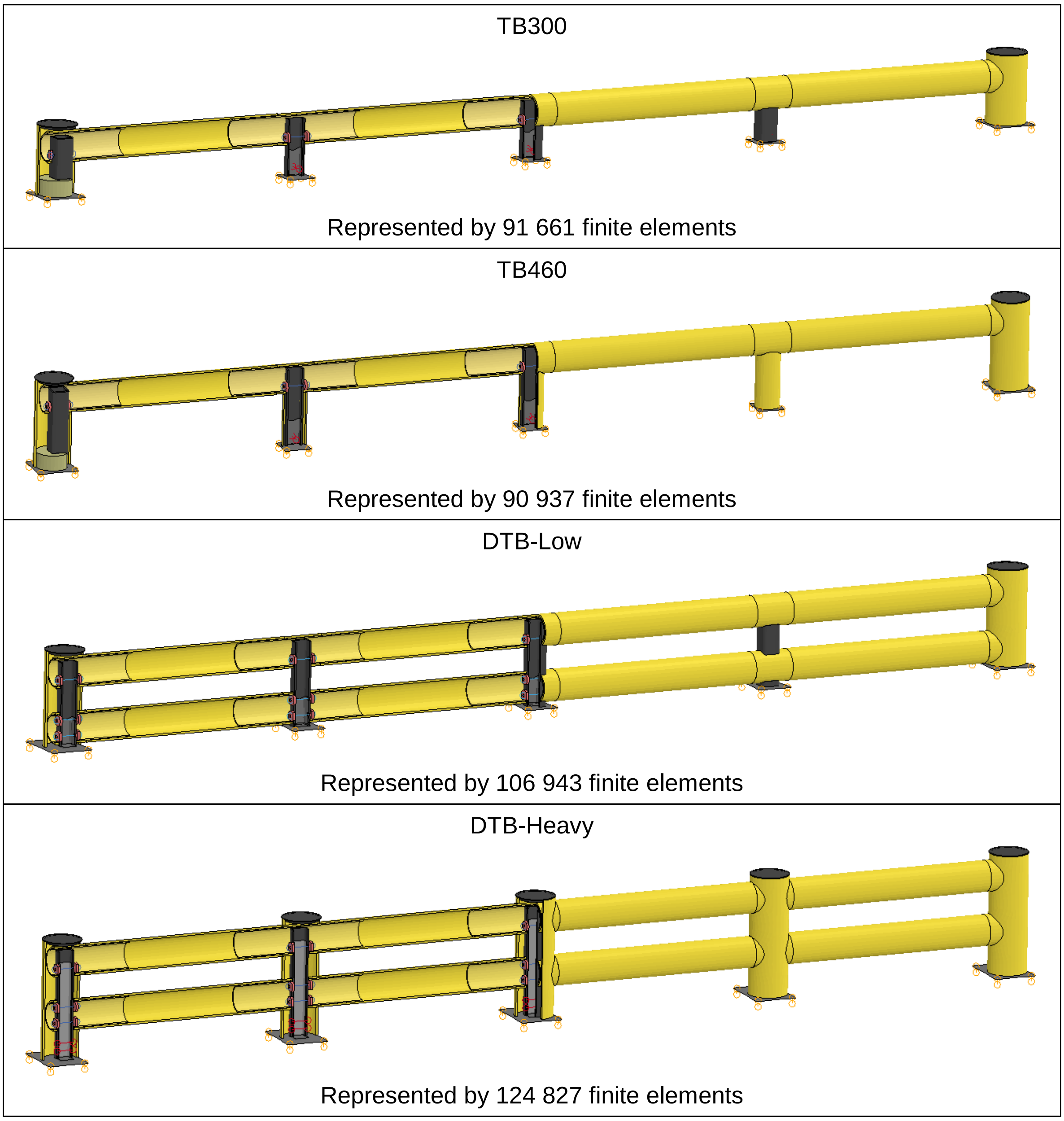

Fig. 2: Barrier numerical models

3.2 Forklift model

A numerical model of the forklift used during the test was realized by the mean of 16 147 finite elements (mainly rigid). Spinning wheels and steering system are represented by the mean of kinematical joints.

Fig. 3: Forklift numerical model

3.3 Model correlation

The experimental results were spitted into three main categories:
The low impact speeds which were not simulated because of the poor interest of the phenomenon
Impacts without failure for which the focus is put on the good representation of the deflexion and severity index (Fig. 4)
Impacts with failure (of at least one component) for which the focus is put on the good representation of the failure mode (Fig. 5).

	T = 0 ms	T = 70 ms	T = 460 ms
Configuration 5			
			

Fig. 4: Example of correlation without failure

Configuration 16			

Fig. 5: Example of correlation with partial failure

The purpose of this correlation process was not to tune the model for each configuration but to find out a set of parameters allowing to obtain appropriate results in all selected cases.
Fig. 6 illustrates the accuracy of the results obtained.

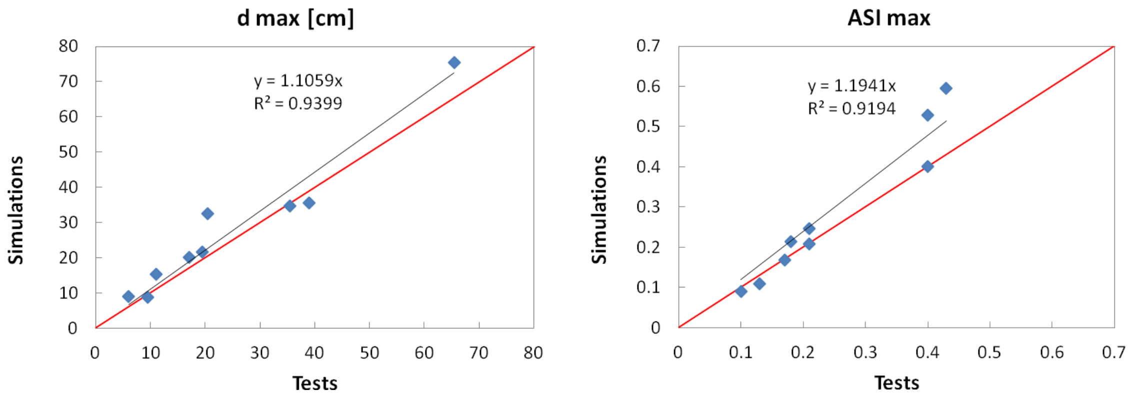

Fig. 6: test/simulation correlation in terms of deflection (left) and ASI (right)

4 Parametric studies

The aim of the parametric studies performed is to characterize the devices in well controlled conditions. The parameters of the DOE are the following:
Impact point: mid-tube and post impacts
Impact speeds from 8 km/h to 30 km/h in order to observe the operating limits. After analysis, additional simulations are performed in order to better define the admissible impact speed.
Impact angle: several impact angles are evaluated leading to a total of 54 impact simulations following the below matrix.

TB300 and TB 400				DTB-Low				DTB Heavy		
Impact angle	**Impact speed**	**Impact point**		**Impact angle**	**Impact speed**	**Impact point**		**Impact angle**	**Impact speed**	**Impact point**
90°	20	M1		*90°*	20	M1		90°	20	M1
90°	20	P2		*90°*	20	P2		90°	20	P2
90°	16	M1		*90°*	16	M1		90°	16	M1
90°	16	P2		*90°*	16	P2		90°	16	P2
90°	12	M1		*90°*	12	M1		90°	12	M1
90°	12	P2		*90°*	12	P2		90°	12	P2
90°	8	M1		*90°*	8	M1		90°	8	M1
90°	8	P2		*90°*	8	P2		90°	8	P2
90°	10	M1		*90°*	30	M1		90°	30	M1
90°	14	M1		*90°*	30	P2		90°	30	P2
90°	12.5	P2						20°	30	M1
45°	12	M1						20°	30	P2
45°	12	P2						45°	30	M1
								45°	30	P2
								20°	20	M1
								20°	20	P2
								45°	20	M1
								45°	20	P2

Table 2: Parametric studies DOE

For each configuration time histories of impactor speed and contact force between impactor and device are output.

5 Analytical model – User interface

The user interface illustrated in Fig. 7 is divided in three main parts detailed in the next paragraphs.

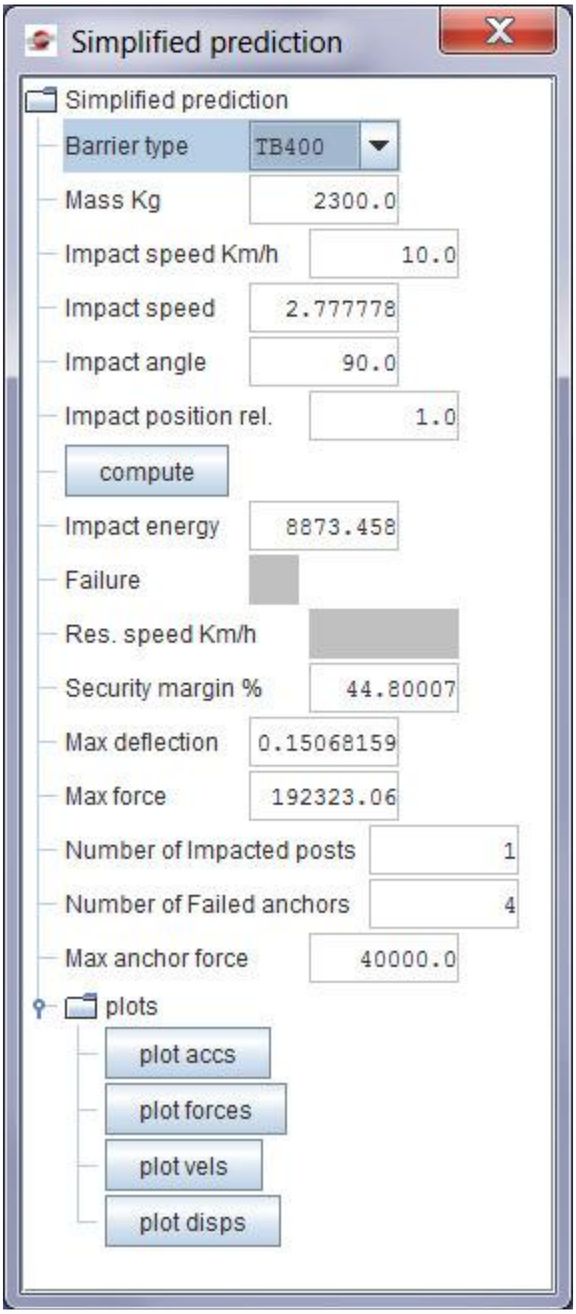

Fig. 7: User interface

5.1 Input data

A semi-analytical algorithm, tuned on the DOE carried out, has been implemented. This algorithm evaluate the restraining force offered by each device as a function of impact parameters:

- Barrier type: Result from DOE integrated in a test database
- Mass Kg: mass of the forklift
- Impact speed
- Impact angle
- Impact relative location (0.5 for mid impact and 1.0 for post impact)

5.2 Results

First of all, the algorithm computes the impact energy and a Boolean “Failure” which is set to true when the barrier is predicted to fail.

If this Boolean is true (barrier failure) the residual speed of the impactor after barrier failure is evaluated.

If failure is false, the following results are computed:

- Security margin in % (with respect to barrier failure)
- Maximum defection in meter, perpendicular to traffic direction
- Maximum restraining force offered by the barrier
- Number of impacted posts.
- Evaluation of maximum forces in the anchorages and number of failed anchors (if any).

5.3 plot section

This section provides time histories for restraining forces of the device, acceleration, velocities and displacement of the forklift.

Fig. 8 highlights the good agreement between the analytical model and the results of the simulations in terms of maximum deflection prediction.

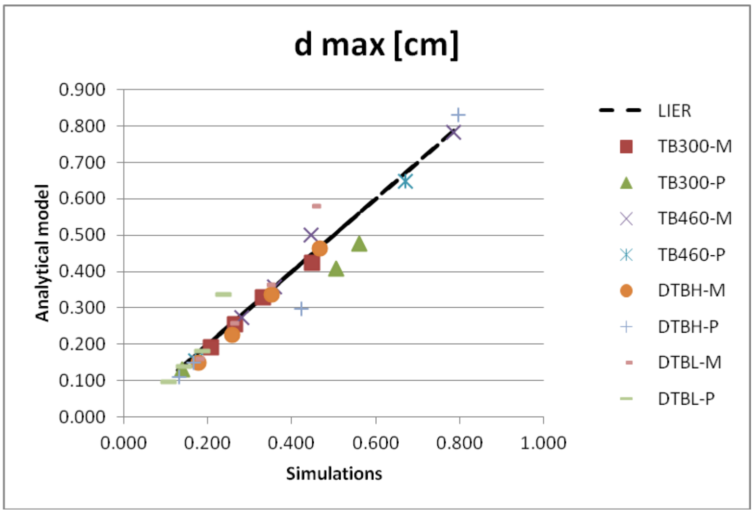

Fig. 8: Correlation analytical model/simulations

6 Summary

The presented study combines testing, finite element simulations and analytical models. Real tests were performed and serve as validation of FE models. Validated numerical models were used to perform parametric studies in well controlled conditions of impact which facilitate the obtention of accurate analytical model.

Finally, the analytical models of four different barriers were integrated in a user interface which allows to predict with good accuracy the expected behaviour of one barrier under specific impact conditions.