New aesthetical bridge parapet solutions for existing structures with low transmitted forces

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ABSTRACT

Belgium has one of Europe's densest highway networks. Belgium has many bridges, most were built between 1970 and 1990 before the emergence of European Standard for Vehicle Restraint Systems. The bridges now require rehabilitation, including upgrading the vehicle restraint systems (crash barriers) to current standards. Belgium's problem in 2014 was, that the use of the then current approved safety barriers systems would mean, that the bridge decks would need expansive reinforcement work to support these structures. DESAMI started work in 2015 on an alternative design.

To refine the engineering ideas, in 2016 numerical modelling was used to develop and evolve the engineering concepts. The solution that was found halved the transmitted horizontal loads to the bridge deck. A crash testing program was developed to verify the numerical modelling and engineering.

The resultant range of bridge parapets, DESAMI and their technical collaborators refer to as "DOLRE".

The financial, engineering and safety benefits arising from this DOLRE family of parapet designs can now be realised in Australia.

1 INTRODUCTION

The standards for vehicle restraint systems have repeatedly been revised and upgraded in the last 20-30 years. This was necessary due to increased traffic volumes, coupled with an increased range of vehicles in the traffic mix. Examples of the changes in Standards are the revisions of European standard and the evolution of the US NCHRP350 standard to MASH09 then to MASH16. The current European and North American standards have significantly upgraded the required safety barrier capacity. In the Australian context the Australian Standard AS/NZS3845 "Roads safety Barrier Systems" refers to the MASH standard. These standards will continue to evolve as the vehicle fleet is constantly changing.

Increases in Standards have rendered a lot of existing roadside safety assets obsolete or redundant. This can cost a lot of time, material and money in modernisation to current code requirements. This especially is the case for bridges and bridge decks. However, there is often a lot of utility to be realised in existing bridge decks, provided compatible vehicle restraint systems can be identified.

If the existing bridge decks are to be utilised, then it is obvious that the loads transmitted to the bridge deck, by any vehicle restraint system being impacted, need to be restricted. The restriction of the load that can be transferred to the bridge deck presents the engineering predicament: of increased containment capacity without increased load transfer.

Commonly the practice in Europe was to reinforce the bridge structure (for example, through the use of carbon fibre plates). However, reinforcing bridge decks is an expensive solution to counteract the required increased capacity for complying safety barriers. Certainly, the Belgian government was looking for alternative solutions that both utilized the residual capacity in the bridge structure and provide appropriate safety barriers to the current standards.

2 NEW BRIDGE PARAPET DEVELOPMENT

2.1 Initial development and refinement

The idea of an alternative solution of developing a vehicle restraint system that does not transfer heavy loads to the bridge deck was investigated by Belgian company DESAMI and collaborators in 2015/16. A solution to this engineering predicament, of increased containment capacity without increased load transfer, was resolved and numerical modelling was used for the verification of this solution. The resultant structure was a unique steel post and rail configuration.

2.2 Crash testing and verification

Whilst there was great confidence in the engineering and numerical modelling the standard requires full scale crash testing. Desami's aim was to develop parapets to the European bridge barrier classification of N2, H2, and H4b. These different barriers were developed as bridges have different capacity requirements, and hence a range of parapets are required for usability and efficiency purposes.

The first bridge barrier classification targeted was the N2 classification resulting in the barrier product referred to as the Dolre N2. The EN1317 N2 standard involves the TB32 test and the TB11 test as summarised in Table 1.

Once the N2 barrier was successfully tested the post spacing was reconfigured to be the H2 barrier and the design and testing process repeated. Subsequently, in 2018, a H4b barrier was designed and tested. Sample sequential images from the simulation out-put and the crash test photographs for the H2 fence can be seen below. However, there are similar images available for all the barrier tests.

Table 1: Parapet performances according to EN1317 criteria

	DOLRE LOW STRESS PARAPET			
Containment level (EU)	**N2**	**H2**	**H2 (LNA)***	**H4b**
Containment level (AUS)	**TL2**	**TL4**	**TL4**	**TL5**
Working width	W3	W4	W3	W6
Vehicle intrusion	VI 3	VI 3	VI 3	VI 9
ASI	B	B	B	B

(LNA)* refers to an additional feature of Dolre barriers mounted on a special concrete edge beam. This work is still in progress and not further reported on is this paper.

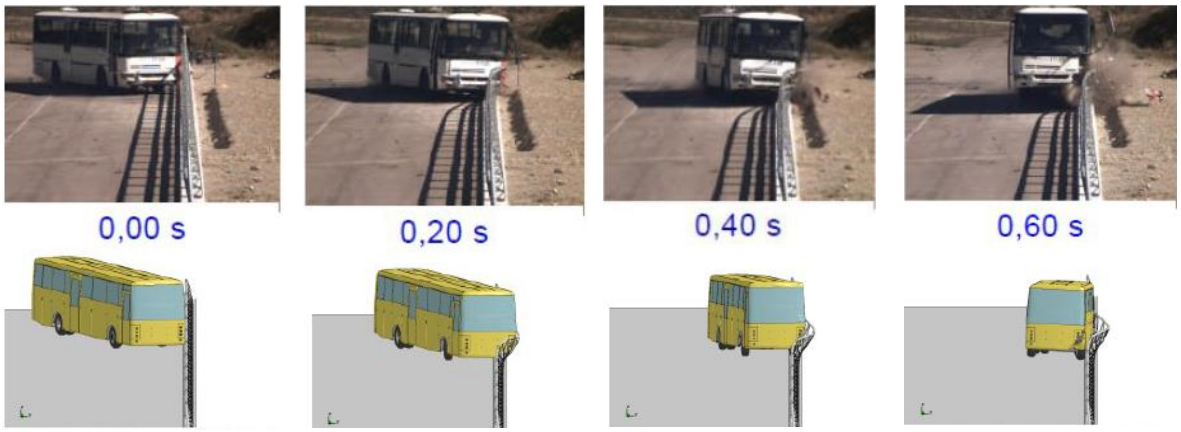
Table 2: Allowable limits in accordance to EN1317 criteria

WW Levels	Working Widths (m)	Vehicle Intrusion Levels	Intrusion (m)	Impact Severity Level	Index Values
W1	W ≤ 0.6	VI 1	VI ≤ 0.6	A	1.0 and THIV < 33kph
W2	W ≤ 0.8	VI 2	VI ≤ 0.8	B	1.4 and THIV < 33kph
W3	W ≤ 1.0	VI 3	VI ≤ 1.0	C	1.9 and THIV < 33kph
W4	W ≤ 1.3	VI 4	VI ≤ 1.3		
W5	W ≤ 1.7	VI 5	VI ≤ 1.7		
W6	W ≤ 2.1	VI 6	VI ≤ 2.1		
W7	W ≤ 2.5	VI 7	VI ≤ 2.5		
W8	W ≤ 3.5	VI 8	VI ≤ 3.5		
		VI 9	VI > 3.5		

Figure 1 – DOLRE low stress parapet respectively N2, H2 and H4b

Figure 2 – Crash tests DOLRE (respectively N2, H2 and H4b)

Figure 3 – Comparison between crash test and numerical simulation (DOLRE H241 – TB51 according EN1317)



These finite element simulations are developed by Global Design Technologies (GDTech) using advanced LSDYNA models in accordance with European Technical Report TR16303 of January 2012. The focus of Technical Report TR16303 is on establishing accuracy, credibility and confidence in the results of crash test simulations to roadside safety devices through the definition of procedures for verification and validation in roadside safety application. The results are provided in model validation reports made by GDTech. The simulations for all the verification crash tests were validated in accordance to the TR16303 procedures.

From there, accessories, transitions and special parts (including pedestrian barrier attachments), were developed, and verification of these was completed through the computer simulation models that had already been validated from the previous full scale testing

Using the same models, the product can be simulated with transitions to other safety barriers, and assess the limits of use in other unique scenarios – for example, across expansion joints, on curves.

It is worth noting, according to the French and Belgian regulations, depending on differences in the performances and the geometry between the two barriers, simulations of the transitions are acceptable in place of crash testing.

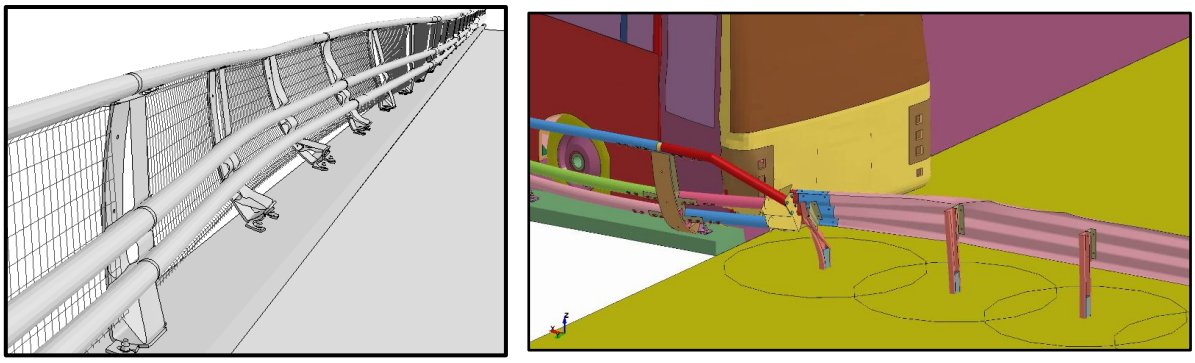


Figure 4 – Numerical simulation for the pedestrian protection and transitions

3.0 MASH performance verification using simulation

The Australian Bridge Standard AS5100-2017 requires bridge barriers to tested to the MASH standard requirements. The standard has three classifications:

- Performance level “Low” corresponding to MASH Test Levels TL2
- Performance level “Regular” corresponding to MASH Test Levels TL4
- Performance level “Medium” corresponding to MASH Test Levels TL5

As can be seen in **Figure 1 – Energy levels for EN 1317 and MASH**and Table 3 the impact severities for the MASH test level are comparable to those in the test levels. It is worth noting that in all cases applicable that the impact severity level is slightly more that MASH impact severity levels.

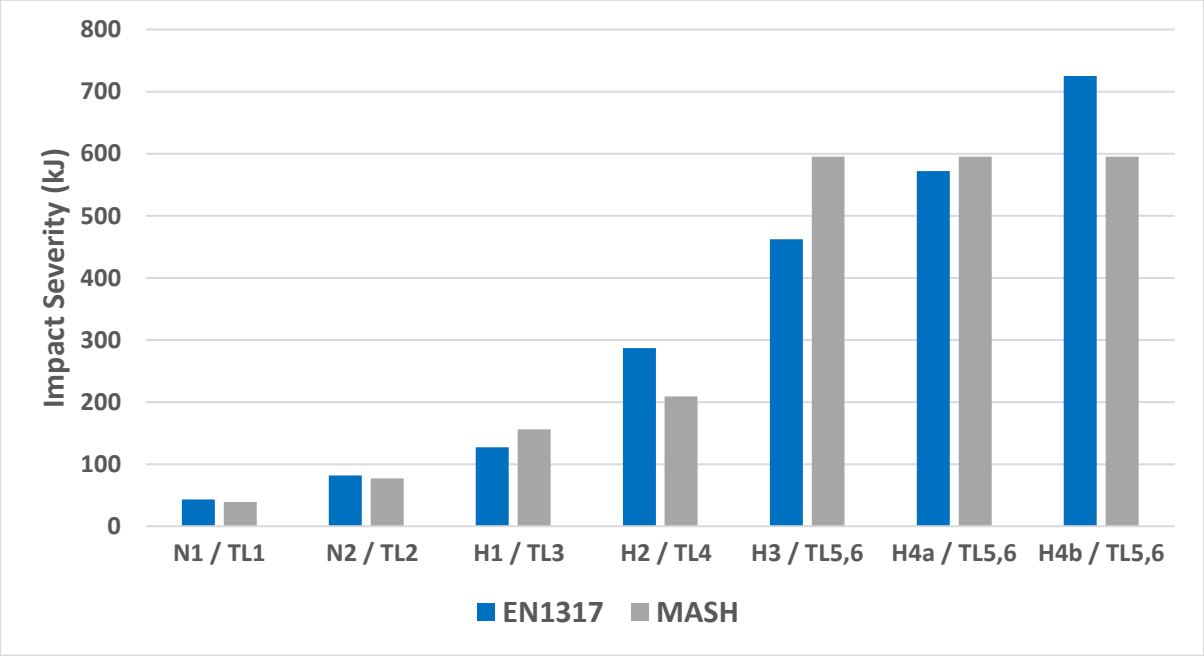


Figure 1 – Energy levels for EN 1317 and MASH

Table 3: Tests level according to EN 1317 and MASH

En 1317	Test	Weight (kg)	Speed (km/h)	Angle	IS (kJ)
N2	TB32 TB11	1500 900	110 100	20° 20°	81.9 40.6
H2	TB51 TB11	13000 900	70 100	20° 20°	288 40.6
H4b	TB81 TB11	38000 900	65 100	20° 20°	725 40.6

MASH	Test	Weight (kg)	Speed (km/h)	Angle	IS (kJ)
TL2	2270P 1100C	2270 1100	70 70	25° 25°	76.6 37.1
TL4	10000S 2270P 1100C	10000 2270 1100	90 100 100	15° 25° 25°	209 156 75.8
TL5	36000V 2270P 1100C	36000 2270 1100	80 100 100	15° 25° 25°	595 156 75.8

IS = impact severity

It is also a relevant observation that the masses and speeds in the relevant test levels, encompass those existing in the relevant MASH test levels. Hence when simulating the MASH crash tests, we are interpolating known results, rather than extrapolating beyond the bounds of the physical full scale crash testing.

3.1 Results of MASH simulations

The results of simulation according to MASH for DOLRE low stress parapet are given in Table 3. At the time of preparing this paper some results are unknown, as simulations work is still in progress. However, the simulations for TL5 and TL2 are completed.

Table 4: MASH results

Test level	TL5			TL4			TL2	
	1100C	2270P	36000V	1100C	2270P	10000S	1100C	2270P
DD	0.3	0.5	1.3	0.4	In progress	0.9	0.4	0.6
WW	0.5 (W1)	0.6 (W1)	1.5 (W5)	0.5 (W1)		1.0 (W3)	0.5 (W1)	0.7 (W2)
VI	/	/	1.8 (VI6)	/		1.7 (VI5)	/	0.6 (VI1)
ASI	1.18 (B)	1.13 (B)	/	1.32 (B)		/	0.86 (A)	/
Remarks	✓	✓	✓	✓		✓	✓	✓

DD = dynamic deflection, WW = working width, VI = vehicle intrusion

Figure 2 – Simulation of TL5 according to MASH (respectively 36000V, 2270P and 1100C)

3.2 DOLRE POST LOAD TRANSFER TO BRIDGE DECK

Table 5 refers to Table 12.2.2 of AS 5100 Part 2, demonstrating the low transverse loads with respect to the Australian Standards requirements.

Table 5 DOLRE transmitted loads expressed as percentage of AS5100-2017 Ultimate Loads

AS 1500-2017 Barrier Performance Level	MASH Test Level	DOLRE nomenclature	AS 5100-2017 Ultimate transverse outward load	DOLRE max transverse load	DOLRE load as % of ultimate load
"Low"	TL2	DOLRE MASH TL2	150 kN	43 kN	28%
"Regular"	TL4	DOLRE MASH TL4	300 kN	43 kN	15%
"Medium"	TL5	DOLRE MASH TL5	600 kN	83 kN	15%

4.0 CASE STUDIES: LOAD TRANSMITTED TO BRIDGES AND REAL APPLICATIONS FOR BRIDGES IN BELGIUM

When determining the suitability of a vehicle restraint system for a specific bridge deck, the process is:

- Calculate maximum loading that the barrier can transmit to the support structure (bridge deck)
- Determine the load capacity of the particular bridge deck
- Compare the results to determine the suitability

As the maximum loading that the barrier can transmit to the support structure is a property of the barrier itself, and is independent of the bridge deck, this calculation is completed regardless of the bridge deck of concern.

4.1 Calculation of transmitted forces

According to EN1317, the maximum transmissible forces transmitted to the structure from the barrier can be found either by a calculation method or by push-out test.

For the calculation method, the M/V diagram is calculated along the strong axis of the post section without taking into account instability phenomena. The values obtained depend on geometry (plastic section modulus, shear area …) of the post and the steel grade. The maximal resistance of the section is defined by EN 1993-1-1 standards.

- $M_u = W_{pl} * f_u$, with W_{pl} the plastic section modulus and f_u the ultimate strength
- $V_u = \frac{A_v * f_u}{\sqrt{3}}$, with A_v the shear area

The diagram is drawn as follows:

- If $V \leq \frac{V_u}{2}$ then $M = M_u$
- If $V > \frac{V_u}{2}$ then $M = f_y * \left(1 - \left(\frac{2V}{V_u} - 1\right)^2\right)$, with f_y the yield strength

The area of the curve to take account in the diagram is defined by M/V = 0.25 and M/V = maximal height. No impact is possible outside this range. This method is useful for simple sections. Because of its geometry, the DOLRE needs another method to define the maximal transmissible forces.

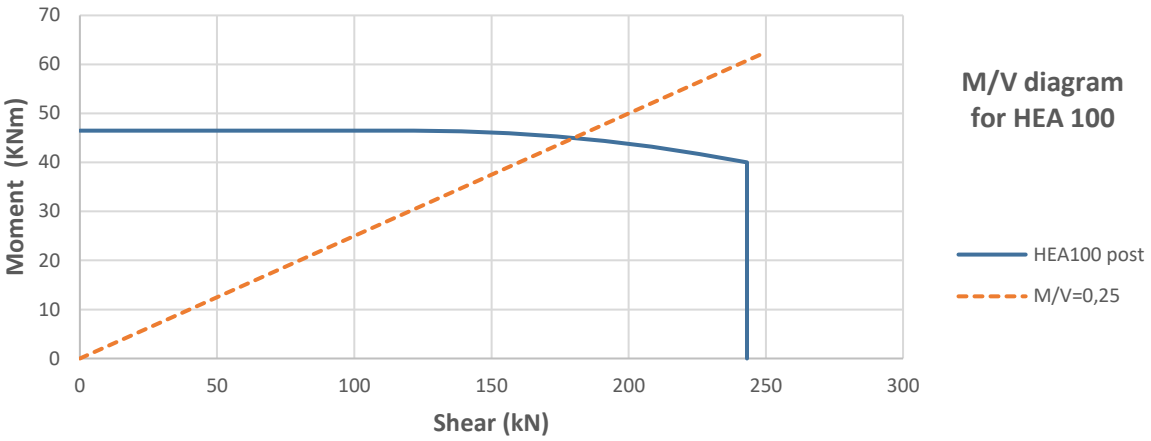


Figure 3 - Example of M/V diagram for the European HEA 100 guardrail post

For the push-out test, forces are determined from a test at 0.25 m and a test at maximal height. Maximal forces transmitted by the post can be determined with a push test at 0.25 m. The tests were made by the university of Louvain-La-Neuve in Belgium. The values need to be multiplied by a safety factor and standard deviation.

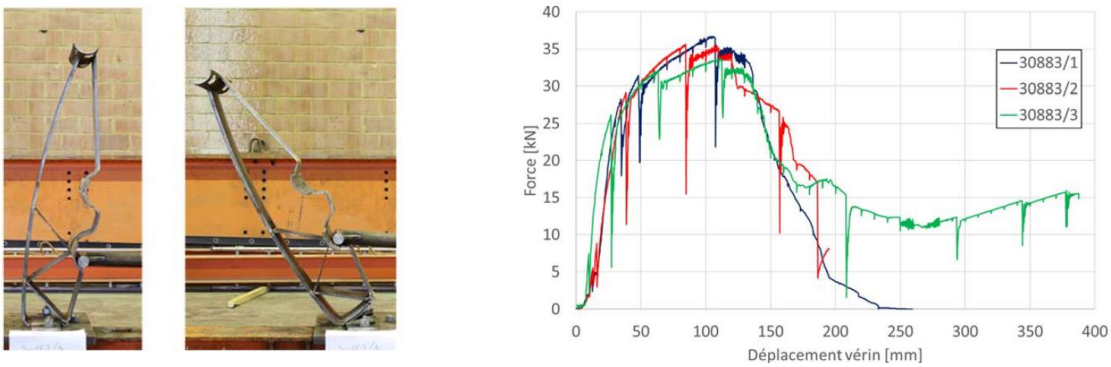


Figure 4 – Push-out test with DOLRE H2/N2 post

4.2 Case study 1: Bridge on highway E19 near to Nivelles (Belgium)

This bridge was built in the early 1970s. The concrete structure is 180mm thick with a road pavement of 90mm on the driving surface and 250mm thick on the edge. The kerb is raised by 120mm. The reinforcement is composed by 5 rods Ø10 mm per meter on the bottom, on the top and on the top of the kerb. The grade of steel rods is TP4 (f_y= 400 MPa). The required new containment level is H4b.

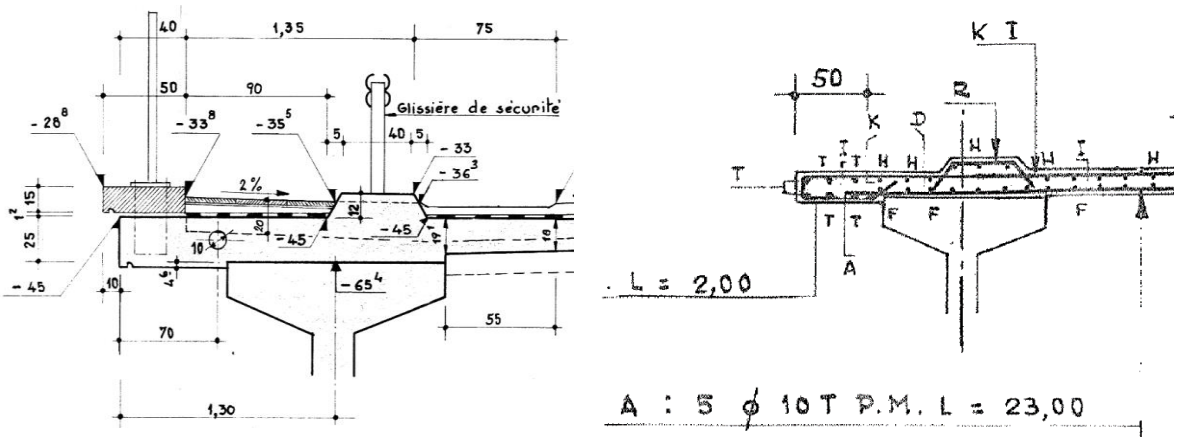


Figure 5 – Reinforcement of the bridge

The constraints were calculated for a traditional parapet (BPL 70 – H4b W4). Its shear and moment values are respectively V = 180 kN and M = 45 kNm. The resultant constraint reaches more than 600 MPa which is 50% greater than the limit.

In comparison, the shear and moment values for DOLRE H464 (H4b W6) are V = 100kN and M = 25 kNm[1] and the maximum constraint to the structure is 360 MPa. Which is allowed following the reinforcement. The comparison between the two bridge parapets is shown on Figure 10. The peak of constraint is reached after the curb.

The low forces transmitted to the bridges with DOLRE parapets allow the system to be placed on existing bridges without any reinforcement of the structure. The transmitted forces with DOLRE parapets are more than 50% less than other existing parapets which are tested according to EN 1317 standards.

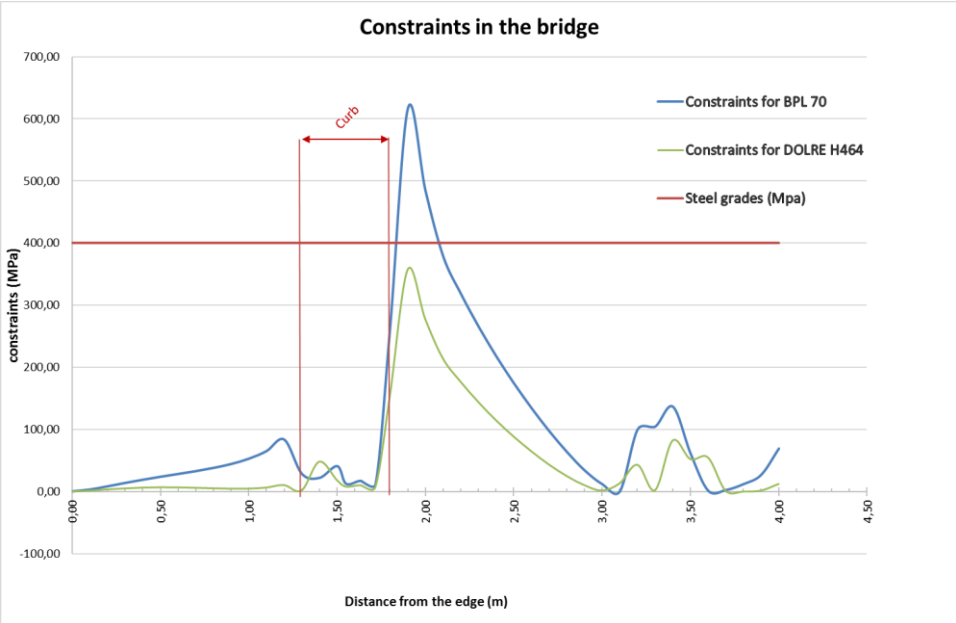


Figure 6 – Constraints in the bridge for BPL 70 and DOLRE H464

5 CONCLUSION

It is highly probably that DOLRE parapet will be a valuable parapet for rehabilitation work on suitable bridges. If nothing else the DOLRE design is in accordance with the Australian Standard AS5100-2017 Part 2 p47 requirement that *"in order to minimize damage to bridge decks and for safety considerations, bridge Barriers shall be designed as progressive strength systems in which barriers and their connections fail prior to the failure of the supporting elements"*

The key advantage of the DOLRE parapet systems in bridge rehabilitation work are:

- Maximises working width of deck
- Minimises loads transferred to the existing deck
- Speed of installation / restoration / maintenance and repair
- Parapet selection to match bridge capacity

[1] These values are for Belgian rules (according to BENOR). The nominal values are multiplied by a safety factor of 1.2.

The key advantage of the DOLRE parapet systems for use on flood prone bridges appears to be:

- Rapid removal
- Easy and fast installation (after flood waters drop)
- Removal of barriers reduces debris surcharge on bridge during floods

The key advantage of the DOLRE parapet systems for new bridge work appears to be:

- May reduce the overall cost of construction
- Aesthetics

The sustainable competitive advantages of DOLRE parapets are

- Simplicity in design
- Low impact deceleration forces (refer TB11 900kg vehicle impact)
- Ensures that low forces transferred to the bridge structure (a key feature to save money when a bridge is being rehabilitated or upgraded). DESAMI transfers only 20% of the maximum force per post to the bridge deck. In Europe the guardrail post transfers 20-30 tons per post but the DESAMI post transfers only 4 tons per post.
- Value for money when upgrading existing bridge.
- Faster to erect / remove because uses half the number of connections (DESAMI uses only 2 connections per posts.

3 REFERENCES

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4 AUTHORS BIOGRAPHIES

David De Saedeleer is an engineer, *CEO* of *DESAMI* (founded in 2012), with over 15 years' experience in the road safety devices. He is a member of the standardization committee for EN 1317 and of Consultative Council COPRO which defines the rules of aggregation of road restraint systems in Belgium.

Clément Everaert is an *engineer* in DESAMI, who studied in the UMONS Faculty of Engineering, Belgium. He's working on the development and production of the DOLRE for DESAMI since 2017.

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