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HEAVY IMPACTS ON BRIDGE RESTRAINT SYSTEMS
- State of the Art -
- Loading Cases and Analysis -
- Advantages of Modern Bridge Restraint Systems -

Dipl.-Ing. Alexander Barnaš, Bmstr. Dipl.-Ing. Thomas Edl

DELTA BLOC EUROPA GmbH, Precast Concrete Barrier Systems
www.deltabloc.com

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Abstract: *Due to some hazardous accidents on bridges in the past when heavy goods vehicles broke through bridge safety barriers causing structural damage on bridge structures, the necessity for a more detailed understanding of the impact procedure was obvious. Therefore some research projects under great efforts of accredited test houses, national road authorities, bridge designers and industry were carried out to show what really happens when a 38 ton truck crashes into a bridge barrier system. Now the industry offers highly sophisticated barrier systems to provide very high containment levels causing less stress for the bridge structure – for bridge designers it is possible to optimize their static load cases and calculations.*

1. INTRODUCTION

Traffic on European roads increased significantly in the last decades and all forecasts show that this trend will continue. At the same time the demand for road safety increased. Slogans like the “forgiving road” for road safety related design requirements were established, and the European Commission initiated an ambitious European Road Action Programme to decrease road fatalities by 50 % until 2010.

The use of safety barriers is an essential contribution to reach this objective as they are one of the most import live saving devices among other road safety systems. Road authorities throughout Europe have realized this direct connection and adopted their national regulations. The containment levels required today according to EN1317-1 [1]and –2 [2] are much higher than those of regularly installed systems on the past.

Especially for bridges this fact has caused considerable problems. As a consequence of the increase of hazardous accidents often higher (H2, H3) or very high containment levels (H4a, H4b) are required for road restraint systems on bridges. Consequently the restraint systems on bridges have been upgraded to these containment levels during bridge-refurbishment. Collisions of Heavy Good Vehicles on such barriers showed that the vehicle could be contained but often the impact-loads caused damage on the bridge cap or even the bridge structure (cantilever slab) itself.

Figure 1: Premium bridge restraint system Delta Bloc 100 AS-R, containment level H4b, Siegtal bridge - Germany

Therefore research projects in Austria (1999-2002) [3] and later on in Germany (2002-2004) investigated the collision loads transferred into the bridge during Heavy Good Vehicle impacts. Test houses, barrier-manufacturers, road authorities and bridge designers cooperated intensively in these projects. Several impact tests with various restraint systems have been carried out. The test configuration made it possible to measure the forces induced into a representative bridge cantilever slab built on the test site during the impact test.
The final outcome of these investigations was incorporated in the respective national specifications. In Austria for instance the guideline RVS 15.47 [4] for road restraint

systems on bridges requires the measurement of forces during the acceptance test and specifies the procedure to determine design loads for each of the various bridge barriers.

Accordingly to the experience of research projects and the requirements of international and national regulations the industry was enabled to develop so called “premium restraint systems” for bridges. They have to be positively tested according to EN 1317 providing high containment levels as well as a small deflection of the barrier on one hand and a soft impact behaviour to protect car passengers on the other hand. The loads for convenient bridge designs have to be declared and the optimal retrofitting on existing bridge structures has to be possible.

The following describes what is important for bridge designers to ensure full effectiveness of such state of the art restraint systems, examples of forces induced into the bridge deck during a vehicle’s impact are given.

2. BEHAVIOUR OF BRIDGE RESTRAINT SYSTEMS

To summarize the conclusions of these studies and to help understanding the sequence of an heavy impact it is appropriate to take a closer look at high containment crash tests according to the EN1317.

Figure 2: H2/TB51 test with 13 ton bus and H4b/TB81 test with 38 ton truck

For a restraint system classification H2 a crash test has to be made with a 16 ton bus at a speed of 80 km/h and an impact angle of 20°. The bus should be guided back to the driving lane within certain geometric borders, without rolling over or breaking through the barrier. For containment level H4b the test is carried out with a 38 ton truck at a speed of 65 km/h and also 20° of impact angle. To find out what loads stress the bridge structure a number of sensors are thereby recording all substantial forces acting upon the bridge deck and the restraint system.

When a vehicle crashes into a barrier several peak loads will occur depending on the impact angle and the type of barrier as well as the type of vehicle. For example a bus hits the barrier with its front and causes the first peak load and then slides with its rear end into the barrier which is the second peak load (Figure 3). An articulated truck causes a quite analogue progression of forces – there are several impacts (1st: front impact, 2nd: rear axle of the tractor, 3rd: end of the trailer).

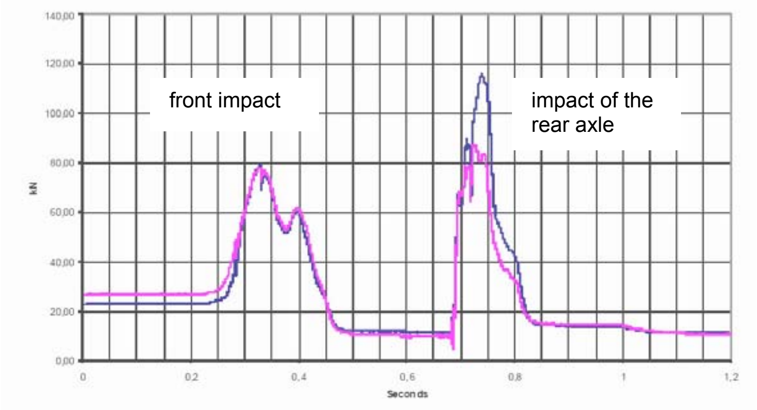


Figure 3: Example: H2/TB51 bus crash - Tension in the anchoring of a restraint system directly in the point of impact [3]

Interpreting the test data the research projects mentioned above came to the following conclusions:

- The forces measured at the crash tests can extremely differ between different barrier types. Some loads are much higher than specified in the EN 1991-2 [4] and some are lower.
- The construction and impact behaviour of the barrier, as well as the barrier´s connection to the bridge have an essential influence on the forces transferred to the bridge structure. Generally: the more rigid a restraint system is designed, the higher are the bridge – loads.
- The characteristic loads cannot be taken directly from the measurements. They have to be derived by interpreting the test data. Especially it has to be judged, if a heavier impact than carried out leads to higher loads than measured. In that case

loads have to be increased accordingly to prevent damage of the bridge structure in any case.

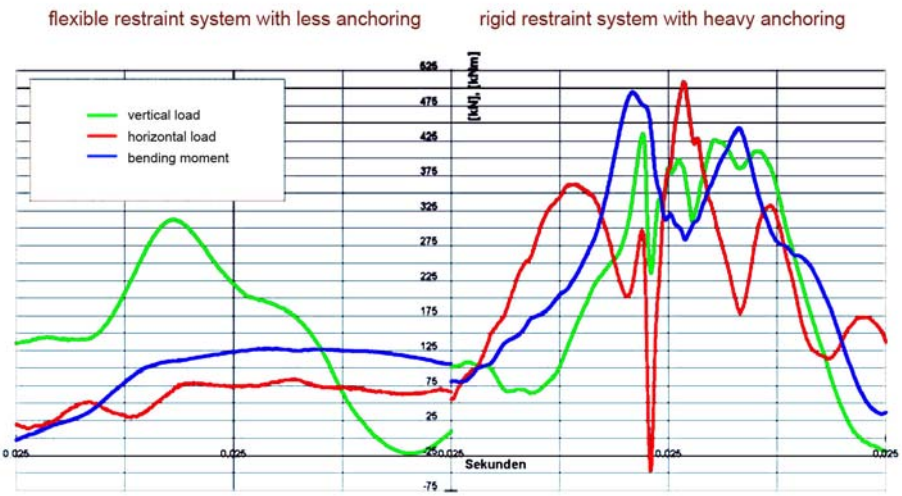


Figure 4: Comparison of stress in a bridge structure between a bridge restraint system at state of the art (left) and a standard system (right) – impact H2/TB51 16 ton bus [reference: Delta Bloc Europe]

- The effect of friction of the vehicles tires and body increases the stress for the bridge structure essentially. Only to consider forces that can be transferred from the restraint system into the bridge deck until failure of the anchoring occurs can be far too less.
- For “real life installation” it is important that the anchoring and installation length of the restraint system are in accordance with the crash test installation; otherwise the occurring loads can deviate.
- A bridge cap and the restraint system itself have distribution effects. There is a delay of some milliseconds until the impact forces reach the bridge structure – the impact is damped down. Therefore the strain rate is not sufficient to increase the material resistance (velocity effect).

3. DESIGN LOADS FOR BRIDGES

3.1 Load case and analysis

When calculating the resistance of the bridge structure against a heavy goods vehicle impact first of all the permanent loads have to be considered. For the specific weight of the construction and the restraint system a partial safety factor of γ_G=1,35 shall be used according to ENV 1991 (a change to γ_G=1,00 in the final version of Eurocode is expected).

For the impact load which is an accidental action the partial safety factor is γ_Q=1,00. The partial safety factors for material resistance are γ_s=1,00 for reinforcement and γ_c=1,30 for concrete. When creating the load case "vehicle impact" a combination with live loads like traffic, wind, etc. as well as other accidental loads is not necessary. Even the weight of the truck has not be considered because it is summarized in the impact loads in [Table 1]. All structural parts of the bridge have to be verified with this loads (bridge cap, cantilever slab, connection of the bridge cap to cantilever slab, …).

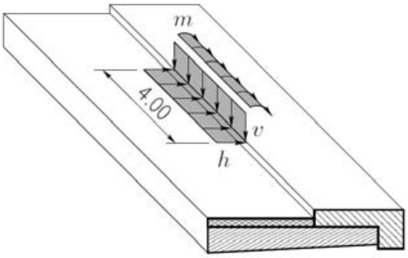


Figure 5: Characteristic impact loads according to Austrian regulation RVS 15.47 [3]

When the containment level is upgraded for an existing bridge the linear static analysis might bring up that the structure is not sufficient to withstand the higher impact loads. A Non-linear analysis with appropriate modelling of the restraint system and all the boundary conditions could help in this case. Investigations of real life accidents have proofed that linear static analysis often underestimates the real load bearing capacity of a bridge structure.

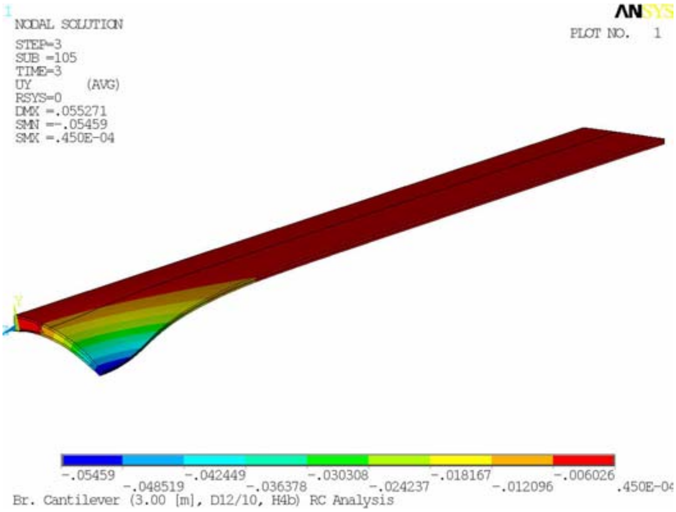
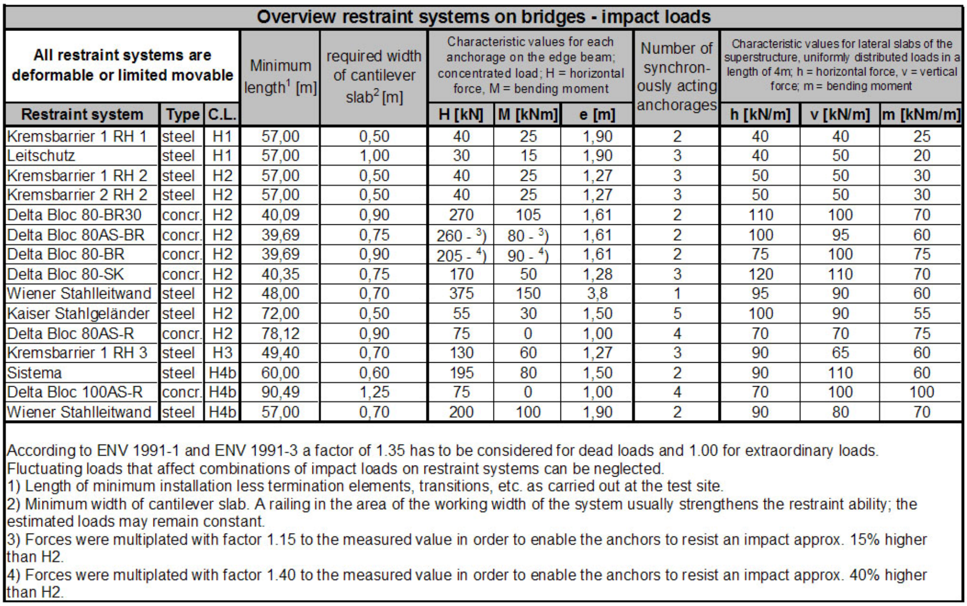


Figure 6: Non -linear analysis of a cantilever slab

3.2 Design loads of different restraint systems

Several research studies brought up that the construction and type of barrier are essential for the way the impact forces are emerged into the bridge structure. Therefore it is important for bridge designers to use the accurate restraint system for the specific application. Industry is providing several types of systems for different containment levels, bridge constructions and impact behaviour.



Overview restraint systems on bridges - impact loads

All restraint systems are deformable or limited movable			Minimum length[1] [m]	required width of cantilever slab[2] [m]	Characteristic values for each anchorage on the edge beam; concentrated load; H = horizontal force, M = bending moment			Number of synchron-ously acting anchorages	Characteristic values for lateral slabs of the superstructure, uniformly distributed loads in a length of 4m; h = horizontal force, v = vertical force; m = bending moment		
Restraint system	**Type**	**C.L.**			**H [kN]**	**M [kNm]**	**e [m]**		**h [kN/m]**	**v [kN/m]**	**m [kNm/m]**
Kremsbarrier 1 RH 1	steel	H1	57,00	0,50	40	25	1,90	2	40	40	25
Leitschutz	steel	H1	57,00	1,00	30	15	1,90	3	40	50	20
Kremsbarrier 1 RH 2	steel	H2	57,00	0,50	40	25	1,27	3	50	50	30
Kremsbarrier 2 RH 2	steel	H2	57,00	0,50	40	25	1,27	3	50	50	30
Delta Bloc 80-BR30	concr.	H2	40,09	0,90	270	105	1,61	2	110	100	70
Delta Bloc 80AS-BR	concr.	H2	39,69	0,75	260 - 3)	80 - 3)	1,61	2	100	95	60
Delta Bloc 80-BR	concr.	H2	39,69	0,90	205 - 4)	90 - 4)	1,61	2	75	100	75
Delta Bloc 80-SK	concr.	H2	40,35	0,75	170	50	1,28	3	120	110	70
Wiener Stahlleitwand	steel	H2	48,00	0,70	375	150	3,8	1	95	90	60
Kaiser Stahlgeländer	steel	H2	72,00	0,50	55	30	1,50	5	100	90	55
Delta Bloc 80AS-R	concr.	H2	78,12	0,90	75	0	1,00	4	70	70	75
Kremsbarrier 1 RH 3	steel	H3	49,40	0,70	130	60	1,27	3	90	65	60
Sistema	steel	H4b	60,00	0,60	195	80	1,50	2	90	110	60
Delta Bloc 100AS-R	concr.	H4b	90,49	1,25	75	0	1,00	4	70	100	100
Wiener Stahlleitwand	steel	H4b	57,00	0,70	200	100	1,90	2	90	80	70

According to ENV 1991-1 and ENV 1991-3 a factor of 1.35 has to be considered for dead loads and 1.00 for extraordinary loads.
Fluctuating loads that affect combinations of impact loads on restraint systems can be neglected.
1) Length of minimum installation less termination elements, transitions, etc. as carried out at the test site.
2) Minimum width of cantilever slab. A railing in the area of the working width of the system usually strengthens the restraint ability; the estimated loads may remain constant.
3) Forces were multiplated with factor 1.15 to the measured value in order to enable the anchors to resist an impact approx. 15% higher than H2.
4) Forces were multiplated with factor 1.40 to the measured value in order to enable the anchors to resist an impact approx. 40% higher than H2.

Table 1: Characteristic impact loads according to Austrian RVS 15.47 [3]

4. ADVANTAGES OF PREMIU BRIDGE RESTRAINT SYSTEMS

Premium bridge restraint systems have to fulfil several requirements (obligatory for tested systems):

- The impact of small cars has to be “soft” to protect car passengers of heavy injuries due to fast deceleration.
- The barrier system has to prevent the breakthrough of heavy vehicles adequate to the classified containment level.
- Vehicles should be redirected onto the carriage way after the impact.
- A roll over of vehicles should be avoided.
- The impact forces should be damped by the restraint system.

- The anchoring of the restraint system should cause as less stress for the bridge deck as possible.
- The deflection of the restraint system should be small.
- After an impact a fast and easy exchange of the damaged restraint system should be possible.

5. CONCLUSIONS AND OUTLOOK

Research projects and modern developments of industry brought up that it is possible to provide high containment levels for bridges at acceptable loads on the bridge structure. Nowadays bridge designers are able to choose from various kinds of "premium restraint systems" complying with national requirements for bridge design and the European standards for restraint systems.

Designing bridge structures by using the failure loads of barrier anchors is not state of the art. For having a load case that comes close to reality also the impact loads mentioned in some national standards are not sufficient for calculating impacts on safety barriers. Now it is possible to operate with forces measured in crash tests. Numerical simulations on this basis brought up that premium restraint systems decrease the impact load on bridges to such an amount that an upgrading of the containment level on existing bridges is also possible.

REFERENCES

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