The development of standards for road restraint systems

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Abstract. The article discusses requirements for road restraint systems, gives recommendations for their classification, formulates the requirements for layout of cameras for recording tests, proposes a method for determining the values of the dynamic deflection and the working width of the road barriers. This work proposes a classification of road barriers; gives the estimates of the influence of tolerances in weight and collision speed of a vehicle in the field tests of road barriers on the values of dynamic deflection and the working width; introduces the concept of category for the dynamic deflection and working width of a barrier; supplements the testing methods for different types of road barriers.

1. Introduction
As the construction of public highways intensifies and the speed limit and traffic intensity increase, the road safety problem also becomes increasingly more important. The greatest number of road traffic accidents (RTA) with serious consequences are related to vehicles crossing to a wrong lane or leaving the carriageway. The most effective means of improving road safety is by installing road restraint systems. However, most of the currently available national standards were developed on the basis of studies carried out in 2005-2012. The emergency of the novel tools, i.e., virtual testing [1,2,3], made possible studying the mechanics of the barriers in more detail and formulate clearer and unambiguous requirements for road barriers. Therefore, it is necessary to revise and update all existing regulatory documents and standards.

2. Materials and main results
All requirements for road barriers can be divided into the following main categories: classification, technical requirements, testing methods, application rules. The rules for the use of road barriers are given in the updated GOST R 52289-2019 “Automobile roads for general use. Technical Facilities for Traffic Management. Rules of application of traffic signs, markings, traffic lights, guardrails and delineators”.

The draft of updated GOST 33127 "Automobile roads of general use. Road restraint systems. Classification" [5] specifies categories of road barriers according to their functional purpose, groups and subgroups according to the functional purpose of road retaining lateral barriers. By the principle of operation, road retaining lateral barriers are subdivided into types: rail-type; parapet; cable; combined, and other types of structures.
GOST 33127-2014 divides lateral restraint barriers into the following subclasses: non-deformable and deformable. Studies have shown that the classification of lateral restraint barriers into non-deformable and deformable was established back in the 1970’s, when such fences as “curved beam” (figure 1) or rail-type barriers with a reinforced concrete post (figure 2) were used [6]. These constructions of road barriers are outdated and do not meet the restraint requirements of modern metal rail-type barriers (figure 3). Thus, the currently used types of lateral restraint barriers can be either deformable (rail, cable, combined) or non-deformable (parapet). Based on the above, the draft GOST 33127 lacks the classification of lateral restraint barriers into subclasses.

Particular attention was paid to the classification of road frontal barriers, installed in places of traffic flow separation. Studies have shown the need to classify road frontal barriers by types: parallel (with parallel lateral edges in the top-view), non-parallel (in the form of the asymmetrical trapezoid in the top-view) and symmetric (in the form of a symmetric trapezoid in the top-view) (figure 4). This classification will allow the installation of road frontal barriers with the required configuration, contributing to their adequate perception by drivers in specific road conditions.

![Figure 1. Curved beam barrier](image1)
![Figure 2. Barrier fence with a reinforced concrete post](image2)
![Figure 3. Modern road rail-type barrier design](image3)

**Figure 4.** Frontal barrier types: (a) parallel, (b) non-parallel, (c) symmetric

Figure 5 shows the general recommended classification scheme for road barriers.
Draft GOST 33128 "Automobile roads of general use. Road restraint systems. Technical requirements" [7] gives the following main consumer characteristics of road lateral barriers: restraint capacity, dynamic deflection, and the working width of the barrier. These parameters are determined by full-scale field tests, where a vehicle with a maximum weight and a given speed collides with a road barrier (figure 6) [7].

Figure 5. Classification chart of road barriers

![Classification chart of road barriers](image)

Figure 6. Road lateral barrier testing scheme

![Road lateral barrier testing scheme](image)

However, full-scale tests of the same structure of the barrier gave different values of the dynamic deflection and the working width of the barrier. To determine the reason for the obtained variations, the analysis of the field-testing method was done [7]. The analysis has shown that the test results differed because of the tolerances in the mass of the testing vehicle, ranging from 0.4 to 0.7 t, depending on the total mass of the testing vehicle (from 12.0 to 22.0 t), with a collision speed tolerance of ± 5 % [8]. Impact energy value for restraint capacity U4, determined according to GOST 33129-2014 [8] are given in Table 1.

Table 1. Impact energy values as a function of weight tolerances and vehicle collision speed tolerances

| Restraint capacity | Required impact energy, kJ | Total mass of the bus, t | Collision angle, ° | Collision speed, km/h | Actual impact energy |
|--------------------|-----------------------------|--------------------------|-------------------|-----------------------|---------------------|
| U4                 | 300                         | 15.5                     | 20                | 68.01                 | 323.51              |
| U4                 | 300                         | 15.0                     | 20                | 67.0                  | 303.88              |
| U4                 | 300                         | 14.5                     | 20                | 65.99                 | 285.01              |

The analysis has shown that the difference in the values of the actual impact energy reaches up to 10%. In order to determine the effect of tolerances of maximal mass and collision speed on the values of dynamic deflection and working width of the barrier, the side barriers were virtually tested using the LS-DYNA software package. The model was validated by comparing the results of virtual testing with the results of field tests carried out at Federal State Unitary Enterprise "NAMI", State Research Centre
of Motorized Vehicles, Spare Parts and Accessories (figure 7). The reliability of the model for consumer characteristics of the barrier exceeded 90%.

Figure 7. Comparison of virtual and field tests

After a validated model was obtained, the values of the mass of the bus, the speed of the bus collision, and the impact place were varied for the analysis. The results of virtual testing are given in Table 2.

### Table 2. Virtual testing results for lateral rail-type road barrier

| Parameters of the barrier | Test No. | Impact between the posts | Impact on the post |
|--------------------------|----------|--------------------------|------------------|
|                          | 1        | 2                        | 3                | 4                |
|                          | 1        | 2                        | 3                | 4                |
| Vehicle weight, t        | 15       | 15.5                     | 14.5             | 13               |
| Collision speed, km/h    | 67       | 68                       | 66               | 70               |
| Impact energy, kJ        | 304      | 324                      | 285              | 288              |
| Dynamic deflection, m    | 0.99     | 1.06                     | 0.93             | 0.85             |
| Working width, m         | 1.34     | 1.51                     | 1.48             | 1.42             |
| Injury severity index    | 0.15     | 0.15                     | 0.15             | 0.21             |
| Number of deformed posts, pcs. | 7 | 8                       | 6                | 8                |
| Number of deformed beams, pcs. | 5 | 6                        | 4                | 6                |
| Lane exit angle, deg     | 5        | 8                        | 7                | 7                |
| Tilt angle, deg          | 11       | 18                       | 11               | 25               |
The studies have shown that the values of the dynamic deflection and the working width of the barrier can differ by up to 0.2 m. These characteristics of the barrier are also influenced by the impact section aimed at the barrier.

The obtained results were verified by analyzing more than 50 full-scale field test reports and about 170 virtual test reports. The analysis has shown that the field tests are carried out under different weather conditions, and therefore it was decided to study the effect of the tire-road surface traction coefficient ($\phi$) on the dynamic deflection of the barrier and the heading angle of the testing vehicle. Figure 8 gives an example of the influence of the tire-road surface traction coefficient on the deflection of a cable barrier with a restraint capacity of U4 (300 kJ) obtained in virtual testing.

![Figure 8. The influence of the tire-road surface traction coefficient on the deflection of a cable barrier with post pitch 2.0 m](image)

The test results show that the tire-road surface traction coefficient significantly affects both the deflection of the barrier and the trajectory of the vehicle during the collision. Therefore, the tire-road surface traction coefficient shall be regulated in the standards for road barriers testing.

The analysis of the protocols of full-scale field tests also revealed that many of them do not contain values of the dynamic barrier deflection and only present the residual deflection values. The dynamic deflection of the barrier shall be determined based on video recording of the testing vehicle collision with the tested road barrier. It should be noted that the accuracy of its measurement largely depends on the competence of the testing laboratory, as well as the correct placement of video cameras. The dynamic deflection of a road barrier is one of the main characteristics of the barrier and under no circumstances can it be considered equal to the residual deflection (except for parapet barriers). Studies carried out at MiPK LLC have shown that the difference in the value of the dynamic deflection of the rail-type barrier with the residual deflection is about 20% (figure 9), and for cable barriers the difference exceeds 100% (figure 8) [9].

![Figure 9. Dynamic deflection changes of the rail-type barrier during collision](image)
Thus, to date, a methodological framework for solving the following tasks has been formed:

1) Develop a method for determining the dynamic deflection and the working width of the barrier that minimized the difference in the test results of the same barrier structure;
2) Introduce requirements for the location of the impact point of the vehicle on the road barrier.
3) Introduce requirements for the tire-road surface traction coefficient

Solving these tasks requires in first place increasing the accuracy of measurement of the dynamic deflection of the barrier. For this, it is suggested to record the collision of the testing vehicle with the road barrier using high-speed video cameras. The location of the cameras is shown in figure 10.

![Figure 10. Recommended location of high-speed video cameras during full-scale tests of lateral barriers](image)

A, B, C - high-speed video cameras; 1 - tested lateral restraint barrier; 2 - movement direction of the test vehicle; 3 - impact point

**Figure 10.** Recommended location of high-speed video cameras during full-scale tests of lateral barriers

High-speed video cameras A should be located at the beginning and end of the barrier. High-speed video camera B is installed above the impact point and perpendicular to the horizontal surface of the test site. It should record the top view of the impact point, covering the area 6.0 m before and 6.0 m after the impact point. High-speed video camera C should be installed above the barrier at an angle to the horizontal surface of the test site and record the impact (collision) of the test vehicle on the road barrier.

To account for the difference in impact energy due to the tolerances in the mass of the vehicle and the speed of the collision, introducing an impact energy coefficient (K) is recommended; the coefficient is determined by dividing the design impact energy \( E_D \) by the actual impact energy \( E_A \):

\[
K = \frac{E_D}{E_A}
\]

It is recommended to determine the final value of the dynamic deflection of the barrier (normalized dynamic deflection, \( D_n \)), given in the design documentation, as the product of the dynamic deflection \( D_M \) measured in field tests and the impact energy coefficient:

\[
D_n = D_M \times K
\]

A normalized working width of the barrier can be determined in a similar manner. However, even in this case, the distortion of the video records can lead to measurement error in the range of 0.1 to 0.2 m. Therefore, it is recommended to introduce a category of dynamic deflection and the working width of the barrier, determined by the Tables 2 and 3. It should be noted that a similar approach is implemented in the European standard EN 1317-2 [10].
Table 3. Dynamic barrier deflection categories

| Dynamic barrier deflection category | Normalized dynamic barrier deflection, $D_N$ |
|------------------------------------|---------------------------------------------|
| D1                                 | $D_N \leq 0.4$                              |
| D2                                 | $0.4 < D_N \leq 0.7$                        |
| D3                                 | $0.7 < D_N \leq 1.0$                        |
| D4                                 | $1.0 < D_N \leq 1.2$                        |
| D5                                 | $1.2 < D_N \leq 1.5$                        |
| D6                                 | $1.5 < D_N \leq 1.8$                        |
| D7                                 | $1.8 < D_N \leq 2.1$                        |
| D8                                 | $2.1 < D_N \leq 2.5$                        |
| D9                                 | $2.5 < D_N \leq 3.0$                        |
| D10                                | $D_N > 3.0$                                 |

Table 4. Barrier working width categories

| Barrier working width category | Normalized working width of the barrier, $R_N$ |
|--------------------------------|---------------------------------------------|
| D1                             | $D_N \leq 0.4$                              |
| D2                             | $0.4 < D_N \leq 0.7$                        |
| D3                             | $0.7 < D_N \leq 1.0$                        |
| D4                             | $1.0 < D_N \leq 1.2$                        |
| D5                             | $1.2 < D_N \leq 1.5$                        |
| D6                             | $1.5 < D_N \leq 1.8$                        |
| D7                             | $1.8 < D_N \leq 2.1$                        |
| D8                             | $2.1 < D_N \leq 2.5$                        |
| D9                             | $2.5 < D_N \leq 3.0$                        |
| D10                            | $D_N > 3.0$                                 |

To solve the 2nd task, additional virtual tests were performed. The results of the study allowed identifying the most critical cases of a vehicle - barrier collision [9]. Thus, in field tests, the impact of a vehicle should be tested:

a) In the middle of the block for parapet barriers;
b) In the middle between adjacent posts for rail-type barriers;
c) At a distance not exceeding 1/2 of the distance between adjacent posts, but no more than 0.75 m for cable barrier posts; if there is an interlacing of cables in the structure of the cable barrier with respect to the post, the barrier should be installed in a manner that during testing the lower cable on the first post from the point of impact of the testing vehicle was located on the outside of the barrier (Figure 11).

L is the total length of the cable barrier; S is the pitch of the posts; X is the distance from the barrier post to the point of impact of the vehicle on the cable barrier

Figure 11. Cable barrier test scheme

The tire-road surface traction coefficient at the test section must be at least 0.3 [11]; this value shall be measured immediately before testing and indicated in the full-scale test report.
The data obtained in the research generally allow making alterations and addenda to the drafts of GOST 33128 and GOST 33129.
3. Conclusions
Based on the results of the research, this work proposes a classification of road barriers; gives the estimates of the influence of tolerances in weight and collision speed of a vehicle in the field tests of road barriers on the values of dynamic deflection and the working width; introduces the concept of category for the dynamic deflection and working width of a barrier; supplements the testing methods for different types of road barriers. This information is suitable for updating GOST 33127, GOST 33128, and GOST 33129.

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