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Chapter 3

CFD-Based Investigation of Wind-Strokes over Highway Bridge Section

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Additional information is available at the end of the chapter

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Abstract

There is an almost everlasting debate on the possibilities of the investigation tools for their applications in a prospective fashion (while solving the engineering tasks) and – against this fact – on the use of these engineering tools while correcting the existing technology problems. A unique chance to compare these needs of research in traffic intentions (while setting the modern road communications through southern Bosnia and Herzegovina) with the natural occurrences in the atmosphere (such is a strong north wind in this geographic region) offers us the highway section Pocitelj-Zvirovici. Exactly in such cases (and before the actual construction of this highway bridge) "for the sake" of prospective engineering, the CFD mechanism (the "toolkit" for performing the computational fluid dynamics) was applied to engage this atmospheric problem. Both as steady-state explorations (while applying the k-ε turbulence treatment) and as the time-dependent CFD-based mode, we explored the wind-strokes of 10 m/s, 20 m/s, 30 m/s and 40 m/s, expected but certainly unwanted strong gaseous flows over the bridge, detecting in this way the traffic safety edge points. The results coming from the explorations performed by the CFD tool are explained and discussed.

Keywords: Traffic safety, Highway bridge, Wind-stroke, CFD (computational fluid dynamics)

1. Introduction

While establishing the modern road and railway infrastructure that is not only impressive in the construction way but is also needed for accurate and important trafficking, one confronts the reality that is always surrounding such objects: the nature of our planet [1-4]. In spite of evaluations [5-8] and certain suggestions[9], every new object of traffic infrastructure that is exposed to rather strong atmospheric influences is presenting the safety risks and calls for

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exploring in a large-scale fashion. Such investigations, due to the ever-stronger software and hardware tools [10-12], are performed not only through the physical measuring [13] and scaled testing [14] but also more frequently by applying the CFD (computational fluid dynamics)-based approach[12]. The latter research mode [15] did find application in wind exploring [16, 17] and traffic safety [18] which is the research pathway of the work presented in this paper, offering very satisfying results accomplished in its attempts at "prospective engineering" for particular explored cases of fluid phenomena [19].

All of these research attempts that have been brought up into the CFD community do report on good capability of the numerical approaches used in handling the reactive flows in straight, enclosed traffic infrastructure. Besides the slight denivelation of a few percent, the geometry of the arbitrary objects of interest was relatively a simple one.

Therefore, the aim of the study is to explore the (accidental) wind-strokes over such a bridge that, as a segment of to-be-constructed highway, for sure turns up as an element of this modern traffic road communication and hence suggests some countermeasures serving the overall traffic safety.

2. Numerical approach

2.1. Treatment of turbulence: Mathematical model in this study

For turbulence-modelled conservation equations, for mass and momentum, employing a time-averaged k-ε turbulence model (a CFD mode that was applied in this study as well), the governing integro-differential equations must be discretised in space only [20, 21]. These equations, together with the equations of state for an ideal gas, form here a closed set of coupled equations. These are again discretised and solved on a three-dimensional, finite-volume Cartesian mesh. In choosing the numerical method, we [22] rely on the standard of the finite volumes [21, 23, 24]. The spatial discretisation of time-independent equations employs a segregated solution method. The linearised equations result in a system of linear equations for each cell in the computational domain, containing the unknown variable at the cell centre as well as the unknown values in surrounding neighbour cells. This mechanism for a scalar transport equation [22] is also used to discretise the momentum equations; in the same mode for the pressure field (if face mass fluxes were known) and the velocity field will be obtained in same way as well.

In cases where the pressure field and face mass fluxes are not known, FLUENT (the software package applied in this research attempt) uses a co-located scheme, whereby pressure and velocity are both stored at cell centres. A need for interfacial values includes an application of an interpolation scheme to compute pressure and velocity out of cell values. The integration over the arbitrary volume (a cell in a computational domain) can be performed and is discretised through an arbitrary surface of a face.

Executing these numerical steps, the equations can express the state for each other cell in the computational grid. This again will result in a set of algebraic equations with a sparse coefficient matrix. In this way, the segregated solver is handling "the updating" of a single variable

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field, by considering all the cells of the domain at the same time, solving the governing equations sequentially (segregated one from another). Subsequently, the next field of another variable will be solved by again considering the entire cells at the same time. The computational loop for the converged solution had about 5,500 iterations.

3. Procedure of investigation

The estimation of the boundary conditions in this CFD-based investigation was supported by the experience of some previous studies and so were the bridge surrounding space characterised as open (pressure) atmospheric boundaries with minor pressure increase or pressure drop of 2 Pa, respectively. All zones formed around the road bridge an open (pressure) boundary, which was used for initialising the values for the velocity and pressure in the computational domain, while the global temperature was set to 293 K.

The bridge body and bridge road elements as well were presumed to be nonadiabatic in the area where the objects of interest (the investigated bridge crown) are situated. This decision was based on some reality-oriented investigation on modern bridge construction, denoting the thermal conductivity of a reinforced concrete to be λ =2,3 *W*/*mK*.

3.1. The explored object of interest

The cross-section shapes of this highway viaduct are distinguished as those between the major carrier pylons. Further, the bridge crown shapes are mounted onto the "bridge legs" of this traffic steady object. Standing with the angle of ca 3.1 °, the road treks of this bridge have the bow-length of 954 m and their arch radius is 983 m. Going partly over the river bed and partly over the terrain valley, the highway bridge "Pocitelj-Zvirovici" demonstrates its highest section to be 96 m. The wide range between the six major pylons is set to 147 m.

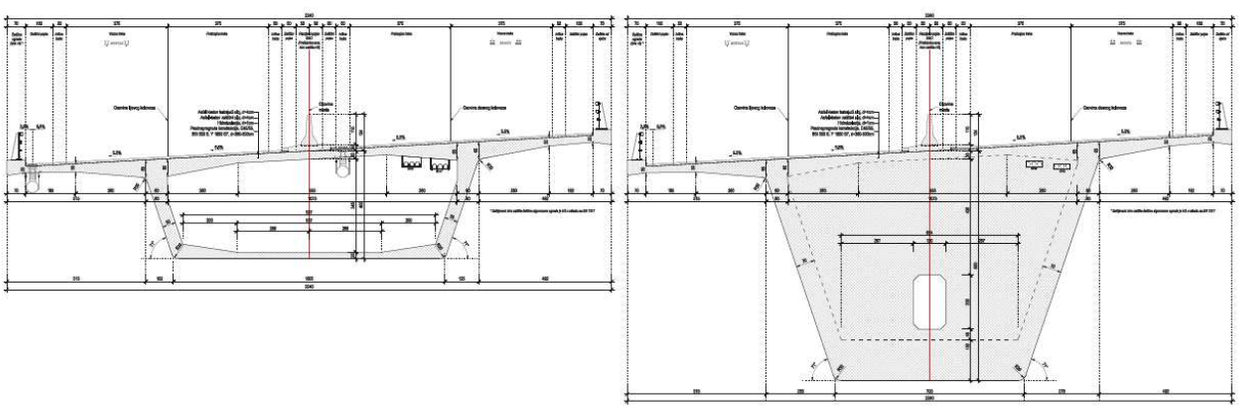


Figure 1. The cross section of the bridge crown in the free air as well as over the pylon

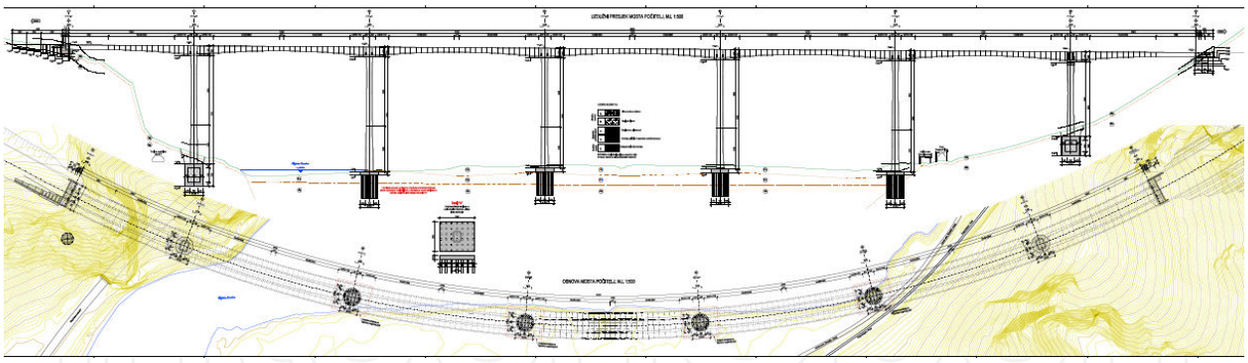


Figure 2. The constructive disposition of the highway bridge "Pocitelj-Zvirovici" in southern BH

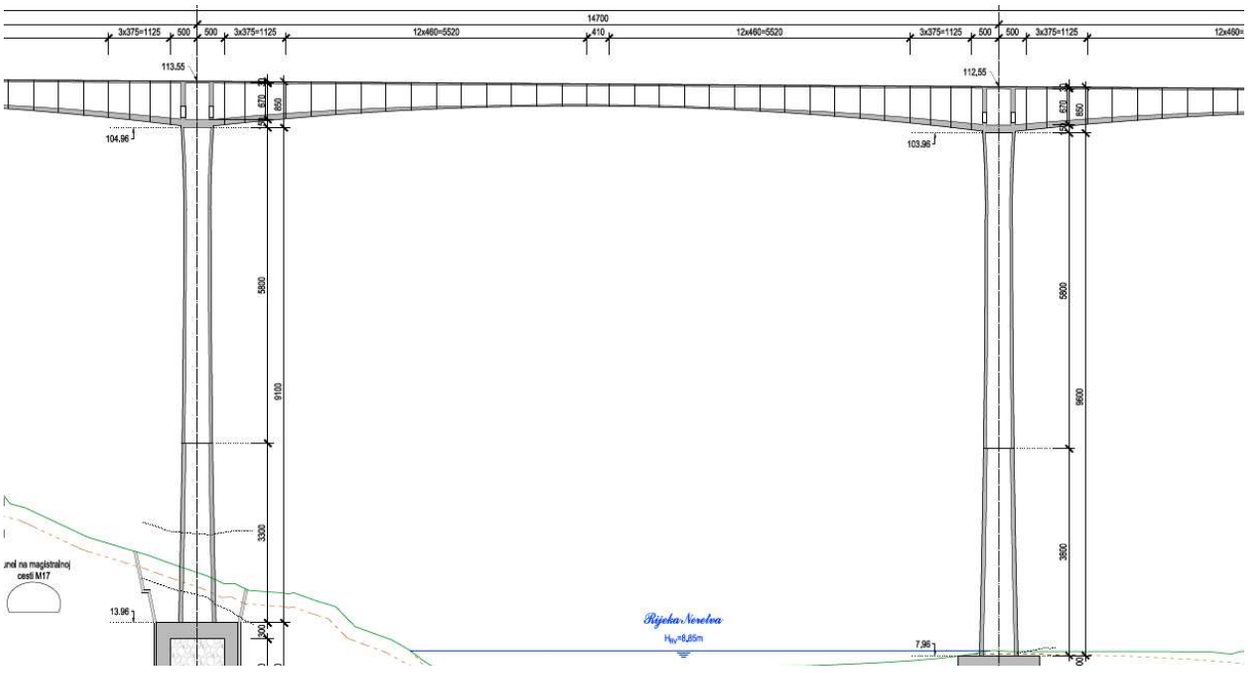


Figure 3. A side view of one of the bridge sections while crossing the river Neretva and following its shore terrain

3.2. Computational domain

The area in which the computation with applied mathematical model approach and additional numerical discretisation was performed is the very volume that a fluid can take without the "walls", where the solid body is the shape of the explored road bridge. Therefore, the computational domain of the section "Pocitelj-Zvirovici" was set to be 30m x 22m x 14,5 m.

3.2.1. The highway bridge "Pocitelj-Zvirovici"

The mesh of this computational domain (Figs. 4 and 5) is characterised through tetrahedral cells and hexahedral prisms of a random structure. In this case, a denser grid was also applied

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in the area around the zones where particular mechanical fluid phenomena are expected, having so more grid points to support the major occurrences.

Such an unstructured mesh (sized here to 350 mm) was installed in such zones of whole computational domain. However, the following parts of the 954-m-long bridge are also meshed with unstructured hexahedral cells in the explained way, having subsequent increased cell size up to 400 mm, 800 mm and 1,200 mm – as the distance from the bridge bottom towards the open space was growing.

The "Pocitelj-Zvirovici" bridge body and the road elements were in the computational domain defined as nonadiabatic walls. The fluid domain is air, with the ambient conditions and no fluid movement, onto which the wind-strokes were expected. The computational fluid sides were designed as opened pressure boundaries.

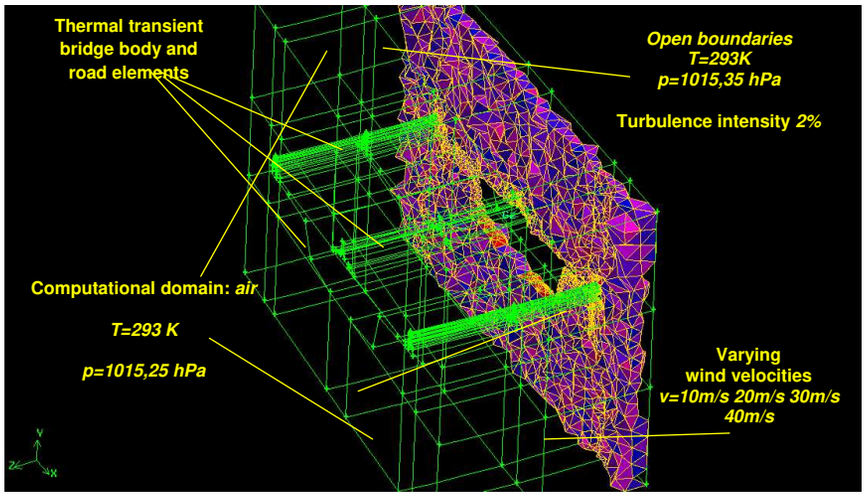


Figure 4. The unstructured hexahedral mesh is applied over the "Pocitelj-Zvirovici" highway bridge – here, at one fourth of its length, around the zone of the fuel pool

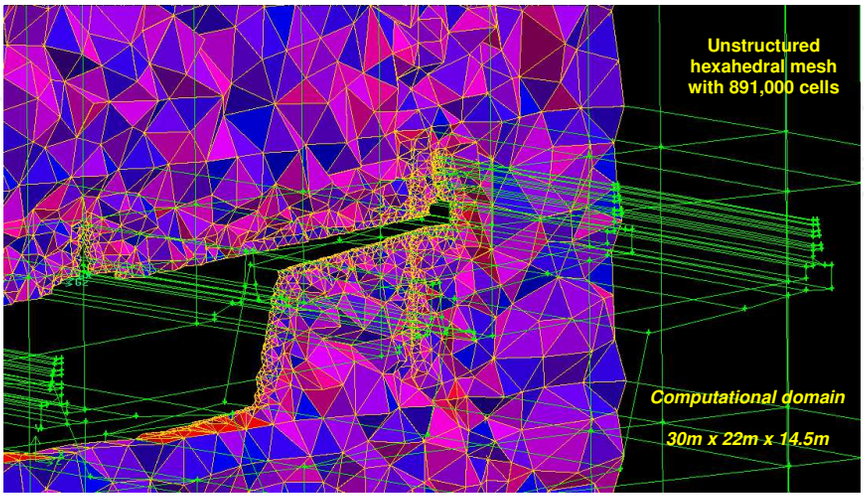


Figure 5. The meshing detail over the "Pocitelj-Zvirovici" highway bridge – here, demonstrating the solution around the road fence

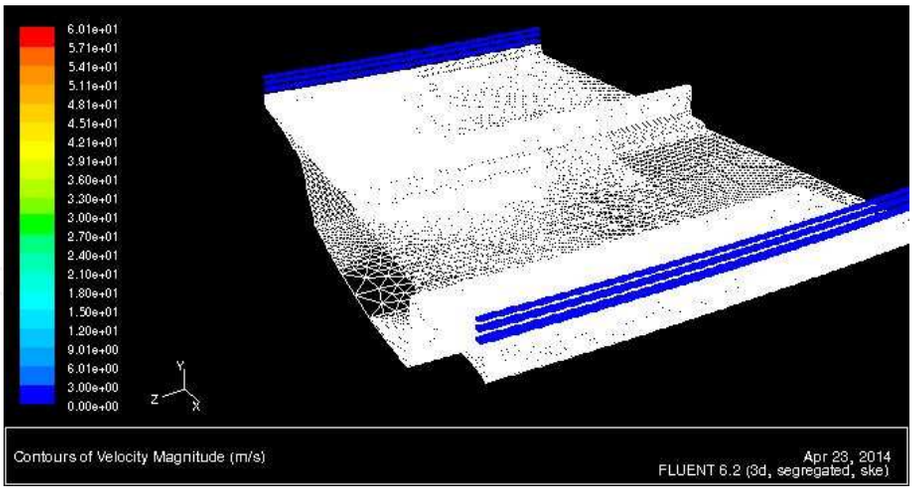


Figure 6. The meshing detail of the Bridge segment "Pocitelj-Zvirovici"

4. Discussion and outlook

Consulting the meteorological survey of the State Weather Service of Bosnia and Herzegovina[25], we performed several investigation scenarios by varying computationally aided, simulative conditions of the unwanted wind-strokes: from both south and north side of the highway bridge "Pocitelj-Zvirovici". Here (Fig. 4), we have chosen the sketch that presents CFD calculation of a (not seldom) 40 m/s stroke, from the more influencing north wind. Taken alone, this result (that was presented by the time-independent Reynolds-averaged Navier-Stokes numerical research) points up the need for a wind flow disturbing panel fences along the roadsides [26].

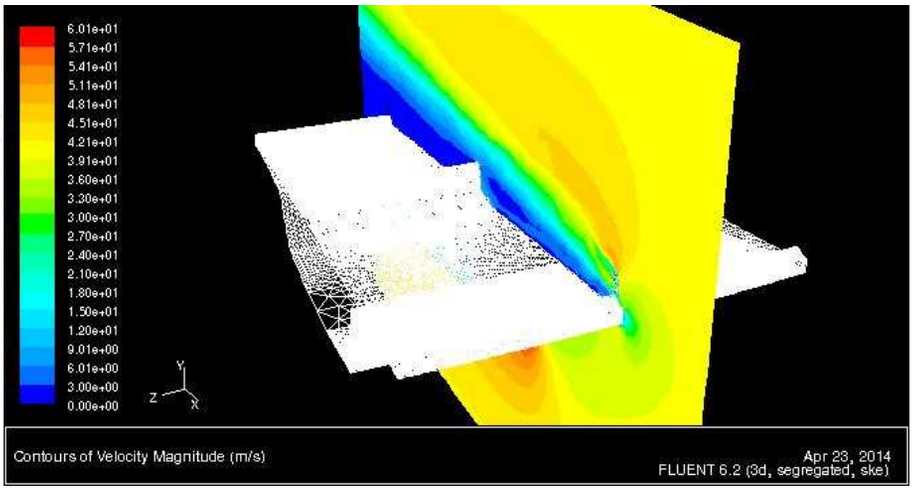


Figure 7. The computationally aided research of the wind-stroke, with the velocity of above 140 km/h: after the "Staupunkt" zones, the air, as every Newtonian fluid [6] that eventually runs around the obstacle and increases its propagation velocity

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Even "weaker", sudden wind occurrences (out of 10 m/s – Fig. 8) that do turn up more frequently in the roses of wind for the geographic region, where this highway viaduct is to be constructed, do present the traffic hazard for the infrastructure element in this road communication. Our investigation performed in CFD mode does correlate with modern studies [27] and does report [28] on the importance [1] of taking into account security and safety.

During this research, we were able to perform the importance of a prospective engineering approach in treating the (gaseous) fluid phenomena in a large-scale mode. In this case, the traffic safety profits out of our findings – where again those results are "pushing" towards further prospective investigations. Exactly CFD-based research obligates to continuing investigation of the mentioned highway bridge, where the whole set of interacting answers and their questions could be satisfied: by applying another turbulence treatment (while using the *LES* model, for instance), by changing the regime of the numerical approach in another time fashion, by discretising the computational domain while using the other basic-cell shapes, and by applying different real-case scenarios based upon the atmospheric data from the statistics of the meteorology services.

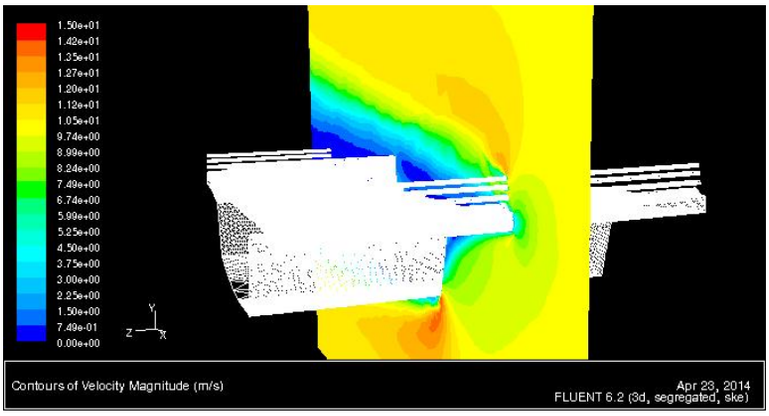


Figure 8. Even the "weaker" wind-stroke of some 36 km/h, after passing its "Staupunkt" zones, increases its velocity propagation and according to the CFD-based observation, reaches the wind fluctuation of above 50 km/h

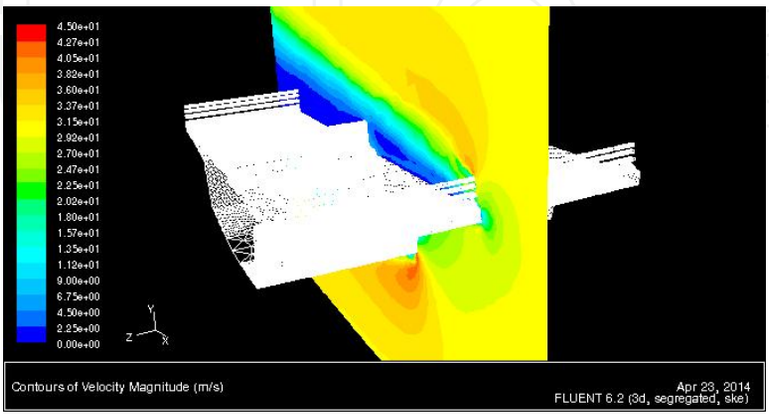


Figure 9. Averaged by its occurrence, the wind-stroke in a range of 70 km/h is due to the climatic changes, one of the frequent and unwanted air blows over the viaduct infrastructure throughout Europe

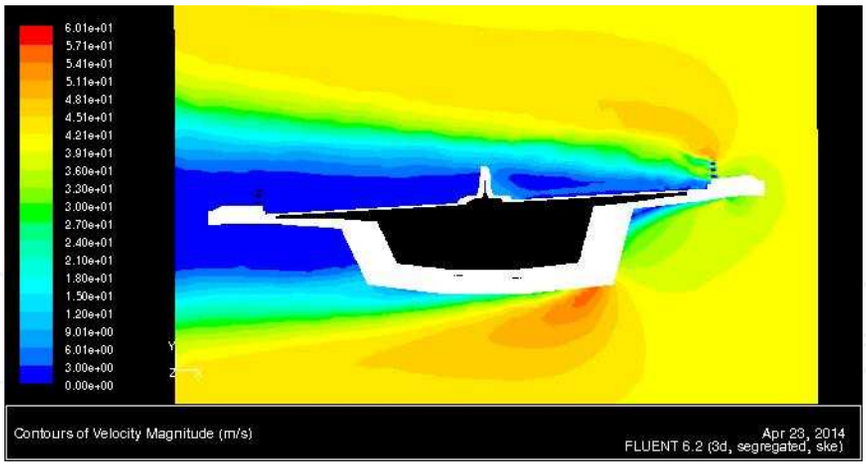


Figure 10. The mentioned dangerous increase of wind velocity after the obstacle in the form of traffic road security fence is visible

The safety issue caused by atmospheric occurrences varies in different parts of Europe (let alone in various parts of the world); what is inviting or even more is it is "provoking" us to further explore on these traffic safety issues. The landscape of the geographic regions where the future (both road and rail) infrastructure is to be constructed and to them belonging particular meteorological circumstances offers a unique perspective for each of these traffic objects. Modern hardware and software [29] developments [30] in the last 20 years [31] endorsed the computational modelling [32] into the modern and very reliable CFD toolkit [29] for scientific engineering and research [33].

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