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WIND BARRIERS ON BRIDGES: THE EFFECT OF WALL POROSITY

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1 INTRODUCTION

Wind-induced accidents of road vehicles can result in the loss of lives and property (1, 2). This fact motivated engineers to make efforts on improving the ride comfort and safety of passengers in moving vehicles in regard to wind effects.

Previous studies focused mostly on wind-induced instability of vehicles on roads (3, 4, 5, 6, 7). Some efforts were also made to improve the protection on bridges, as the vehicles on bridges are extremely exposed to strong wind gusts (1). Štrukelj et al. numerically studied the effects of wind barrier geometry on resulting wind forces on vehicles. They also tested a part of barrier prototype in the wind tunnel in terms of thermal and mechanical endurance. While usually very helpful for improving traffic safety, wind barriers have negative influence on aerodynamic characteristics of bridge itself. An attempt to reach the compromise between those two contradictory demands was made by Wang et al. (8) for the purposes of designing the Hangzhou Bay Bridge in China. They suggested an optimal design of wind barrier which does not significantly deteriorate the aerodynamic stability (e.g. flutter, vortex resonance, etc.) of this bridge.

The negative effects of strong winds on traffic experienced also the designers of the Rijeka-Zagreb highway in Croatia, as well as commuters between those two cities, as this highway was often closed for traffic through the past due to safety requirements. Major threat to traffic poses a strong, cold, north-easterly wind Bora, blowing over the Dinaric Alps along the eastern Adriatic coast. Its most prominent feature is strong gustiness. In severe bora cases mean hourly wind speeds exceed 17 m/s (9, 10, 11; 12, 13), while gusts may reach values of up to 69 m/s (14).

The aim of this study is to investigate the possibilities of protecting the vehicles on viaducts in parts of the newly reconstructed Rijeka-Zagreb highway. The effects of wind barrier porosity on a flow field at the viaduct Bukovo and at the viaduct Hreljin are presented in this paper.

2 WIND TUNNEL MODEL

Viaduct Bukovo is located about 20 km from Rijeka downtown in direction of Zagreb. It consists of two bridge decks; the existing one and a new one, which is currently under construction. As the construction of the existing bridge does not allow the placing of the wind barrier due to static reasons, only the protection of a new bridge was investigated. The final goal is to propose a wind barrier design, which would enhance the safety and comfort of passengers , especially in trucks. The wind tunnel tests presented in this paper were preceded by numerical simulations (15). Wind tunnel model of both bridges (Figure 1) was manufactured from wood, exactly matching the prototype in all details at the scale of 1:66, which corresponds to a length of about 30 m in full scale. It is a 2-D section with width to length ratio approximately 3:1. There was no indication of the disturbance introduced by the boundary conditions at the model sides.

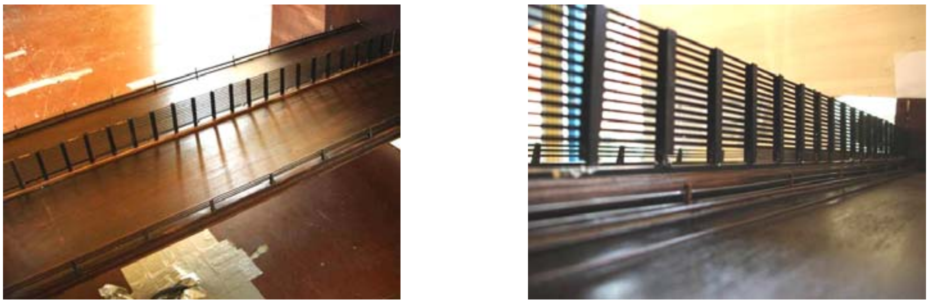


Figure 1. – Wind tunnel model of the viaduct Bukovo

Another viaducts investigated during the same experimental campaign is the one of Hreljin, also part of the new Rijeka-Zagreb highway. As the Bukovo viaduct it is made of two bridge decks: the existing one and a new one, in which wind barriers are in project. Also in this case the wind tunnel model is a 2-D section, manufactured at the scale of 1:66.

3 THE BOUNDARY LAYER WIND TUNNEL TESTS

Experiments were carried out in the Boundary Layer Wind Tunnel of CRIACIV in Prato, Italy. Detailed description of this tunnel can be found in (16). During the tests the flow field on the road plane was measured using the Particle Image Velocimetry (PIV) technique. The measuring domain is shown in Figure 2.

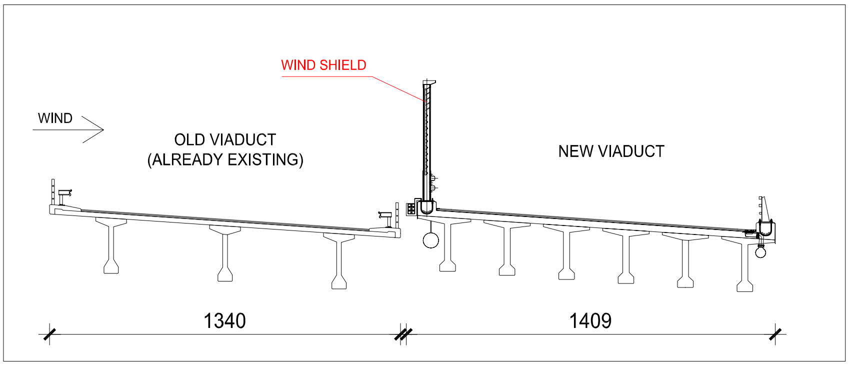


Figure 2. – Bukovo viaduct, made of two bridge decks

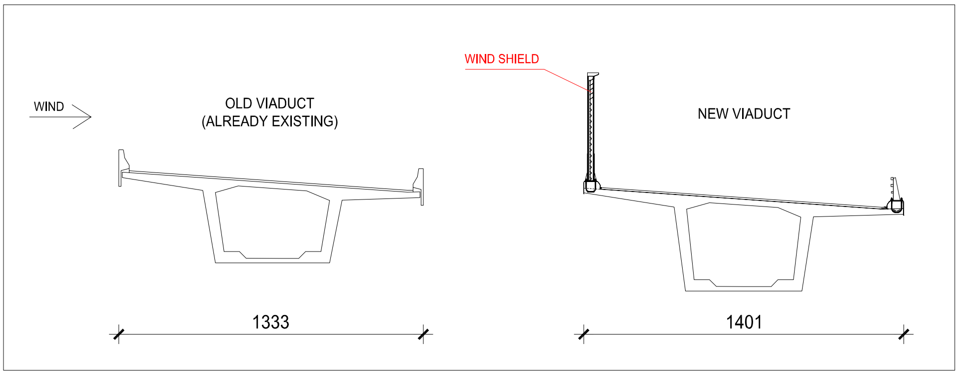


Figure 3. – Hreljin viaduct, made of two bridge decks

The barrier walls were composed of horizontal bars (L profile with side of 10 mm), which were adjusted for two pillars at the distance of 2.5 m. Three different porosities of barriers (30%, 43% and 53%) were investigated (Fig. 4).

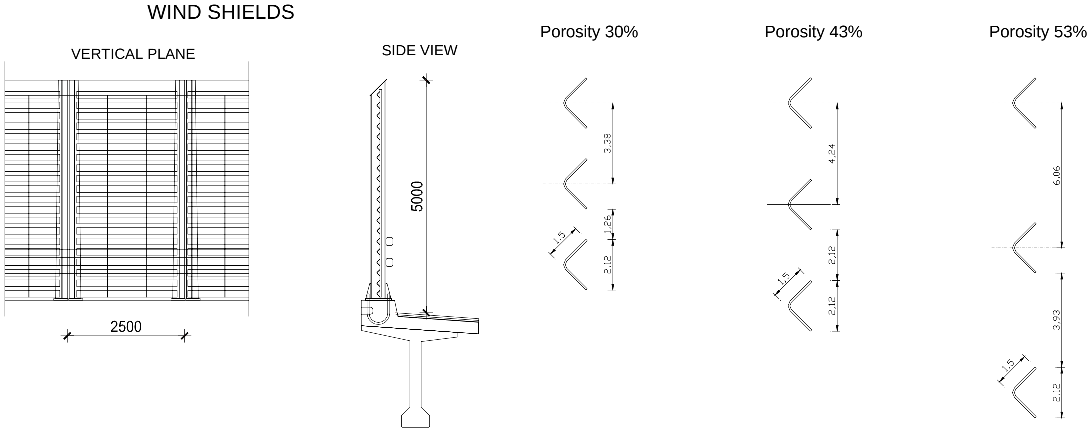


Figure 4. – Wind shields for both Hreljin and Bukovo viaduct. Porosity 30%, 43% and 53%, (quotes in mm, model scale)

In the Bukovo viaduct the total height of the barrier corresponds to a 4 m height in full scale and the orientation of the bar was tested both in the ‘concave’ and ‘convex’ way (Fig. 5).

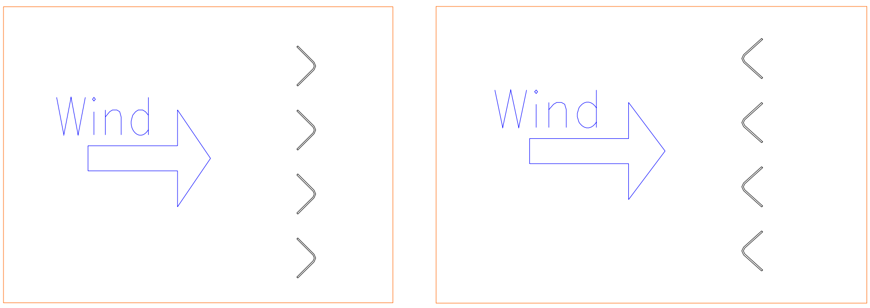


Figure 5. – Orientation of the bars towards wind: concave (left) and convex (right)

The model was exposed to a turbulent oncoming flow. The incoming wind turbulence was generated using a grid positioned at the inlet of the wind tunnel test section. Longitudinal turbulence intensity was 17%, where the variance of velocity fluctuations was normalized with mean freestream velocity in an undisturbed flow.

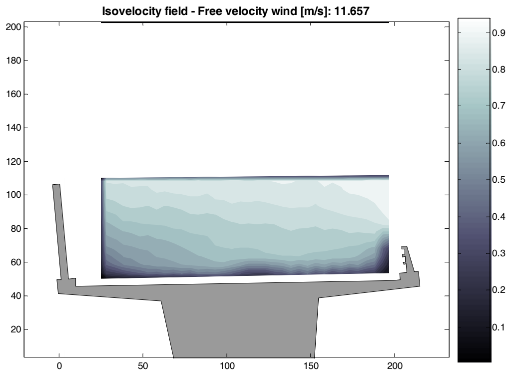
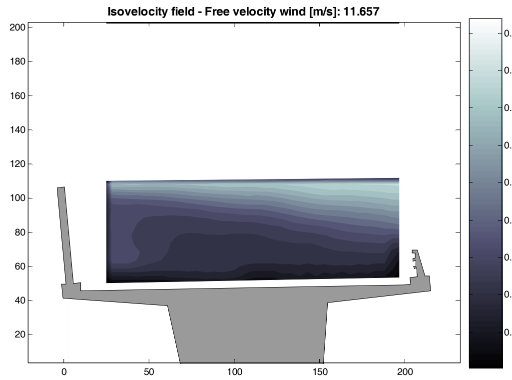
In the Hreljin viaduct the efficiency of the barrier was investigated with three different incoming wind conditions, characterized by turbulence intensity of 0% (<1%), 3.3% and 17%. The effect of the total height of the barrier was also evaluated by varying its value from 4 m to 5 m. In this case the orientation of the barriers was fixed in the convex way.
The incoming wind profile was acquired using a Pitot-Prandtl tube and a hot wire anemometer. The flow field on the bridge deck behind the wind barrier was measured using the PIV system. Approximately 200 instantaneous velocity fields were acquired in each configuration. Tests were performed following standard wind-tunnel modelling procedures (17, 18, 19).
During the experimental campaign 66 configurations have been investigated. In this work only the configurations reported in the following table have been analyzed. As explained in the preceding paragraph each test is characterized by a composed name. Every part of the name indicates a particular configuration.
The composition of the name is:
name of the viaduct _ configuration of the barrier _ angle of incidence of the wind _ level of turbulence _ porosity of the barrier

Part of the name	**Suffix**	**Description**
name of the viaduct	**B**	Bukovo viaduct
	H	Hreljin viaduct
configuration of the barrier	**5mt**	The shield is 5 m high
	4mt	The shield is 4 m high
	0mt	The shield is not present
angle of incidence of the wind	**va10**	The vertical angle is 10° (for Bukovo, horizontal angle is always 0°)
	ha0	The horizontal angle is 0° (for Hreljin, vertical angle is always 8°)
level of turbulence	**turb0**	The turbulence intensity of the wind is <1%
	turb3.3	The turbulence intensity of the wind is 3.3%
	turb17	The turbulence intensity of the wind is 17%
porosity of the barrier	**por30**	The porosity of the barrier is 30% (see tab.1 §2.1.1)
	por43	The porosity of the barrier is 43% (see tab.1 §2.1.1)
	por53	The porosity of the barrier is 53% (see tab.1 §2.1.1)
	No_wall	The barrier is not present
orientation of the bars	**mag or min**	There are some test in Bukovo viaduct in which both the orientation were investigated, at the end of the names of these particular tests there is a suffix respectively: **_mag** when the bars are in this orientation against the wind: → > , **_min** when are in this orientation: → <. Otherwise, when it is not indicated, for Bukovo the orientation of the bars is → >, and for Hreljin is → < (see figure 14 and 15 in §2.1.1) .

Tab. 1 Description of the suffix of the names

4 RESULTS AND DISCUSSION OF THE RESULTS

For each of the analyzed configurations, the maps of isovelocity have been realized. The velocity has been normalized by the free stream velocity of the incoming flow. Due to measuring problems near the solid walls the value of the velocity can not always be considered correct; for this reason an area in which the gotten data can be held reliable has been set. Following the maps of the analyzed configurations are represented.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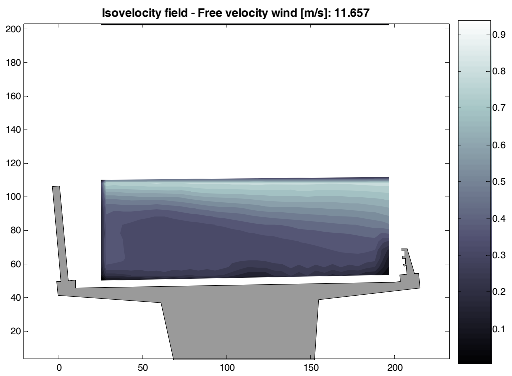
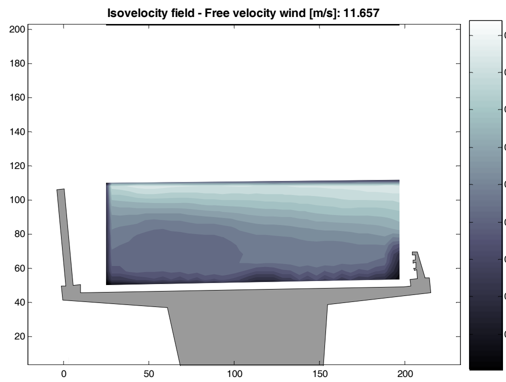
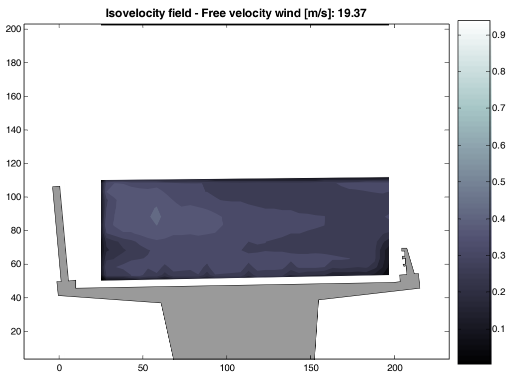
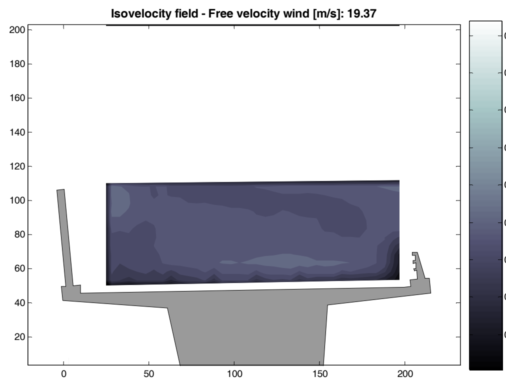
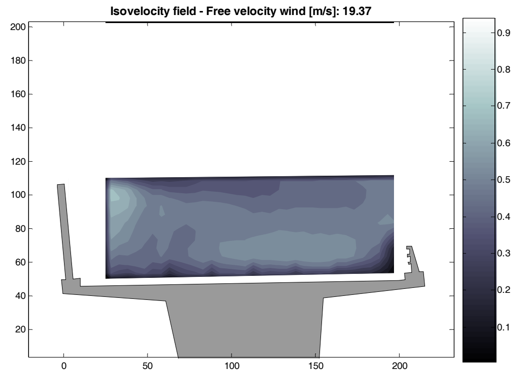
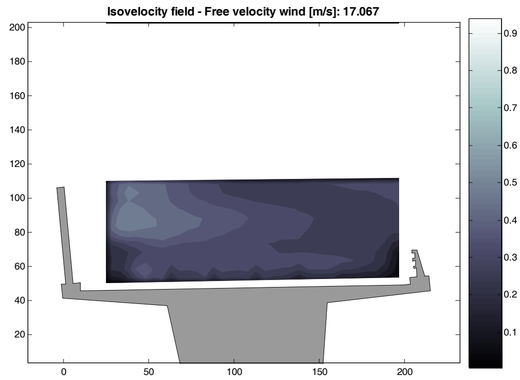
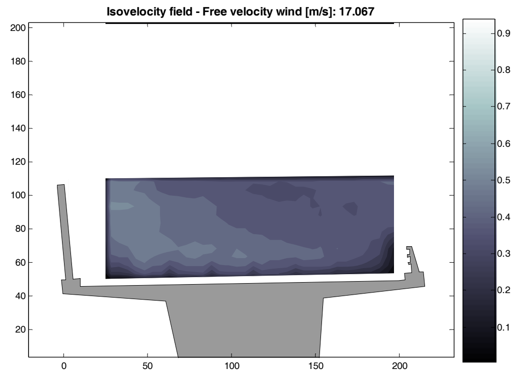
	
c)	d)
	
e)	f)


Isovelocity field - Free velocity wind [m/s]: 19.37

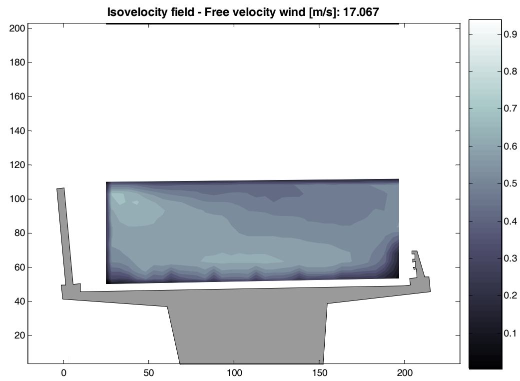
g)


Isovelocity field - Free velocity wind [m/s]: 17.067

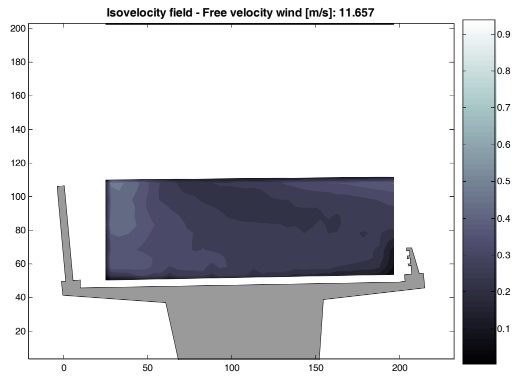
h)


Isovelocity field - Free velocity wind [m/s]: 17.067

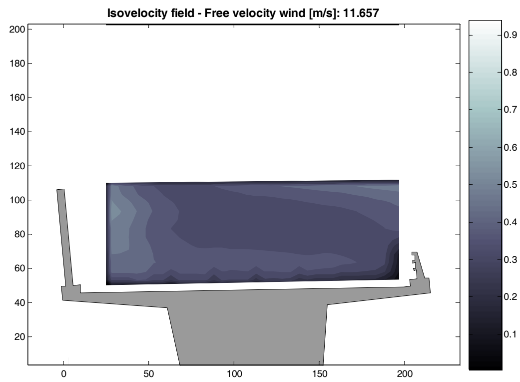
i)


Isovelocity field - Free velocity wind [m/s]: 17.067

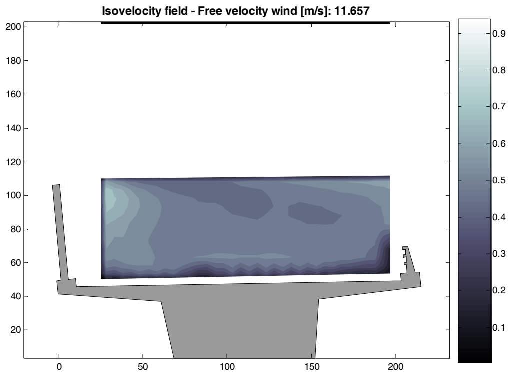
l)


Isovelocity field - Free velocity wind [m/s]: 11.657

m)


Isovelocity field - Free velocity wind [m/s]: 11.657

n)



o)

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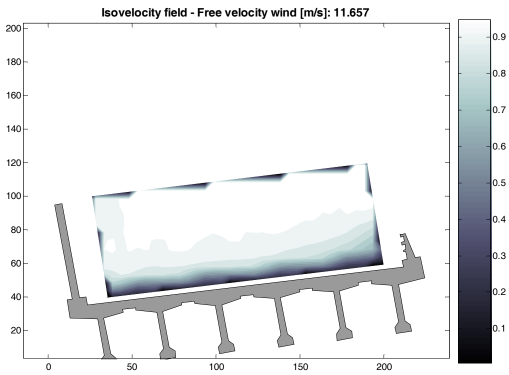
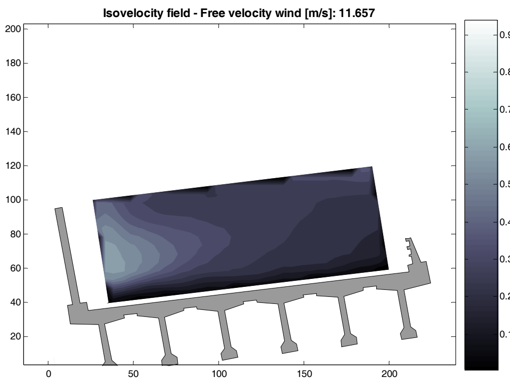
b)=H_4mt_ha0_turb17_por30
c) =H_4mt_ha0_turb17_por43
d)=H_4mt_ha0_turb17_por53
e)=H_5mt_ha0_turb0_po30
f) =H_5mt_ha0_turb0_po43
g)=H_5mt_ha0_turb0_po53
h)=H_5mt_ha0_turb3.3_por30
i)=H_5mt_ha0_turb3.3_por43
l)=H_5mt_ha0_turb3.3_por53
m)=H_5mt_ha0_turb17_po30
n)=H_5mt_ha0_turb17_po43
o)=H_5mt_ha0_turb17_por53

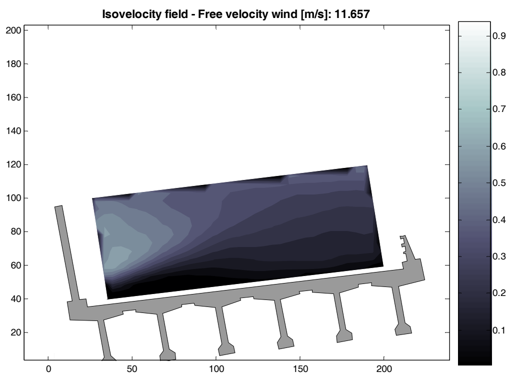
Figure 6. – Mean velocity field for different configurations on Hreljin viaduct



a)



b)



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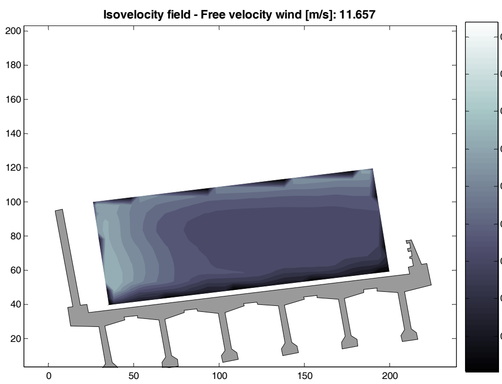

d)

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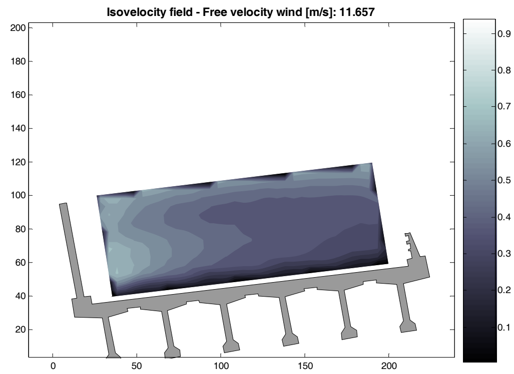
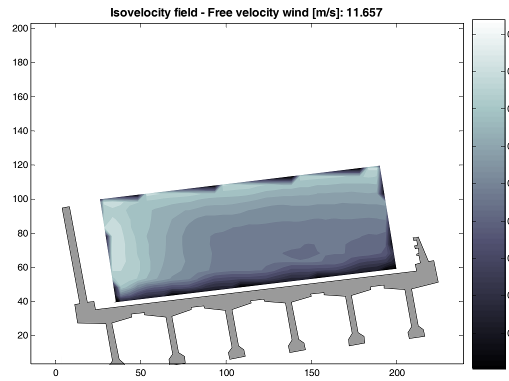
<tr><td>
</td><td>
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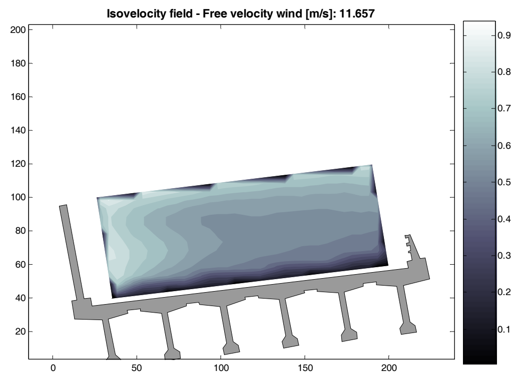
<tr><td>
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c)=B_4mt_va10_turb17_por30_min
d)=B_4mt_va10_turb17_por43_mag
e)=B_4mt_va10_turb17_por43_min
f)=B_4mt_va10_turb17_por53_mag
g)=B_4mt_va10_turb17_por53_min</td></tr>
<tr><td>g)</td><td></td></tr>
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Figure 7. – Mean velocity field for different configurations on Bukovo viaduct

The result in each configuration was obtained by averaging 200 instantaneous velocity fields and normalizing it with mean freestream velocity.

A significant reduction of mean velocity (up to 50%) can be obtained if a wind barrier is placed on the bridge. In all configurations there is a region of higher velocities immediately behind the barrier, which decrease further downwards. The obtained velocity fields illustrate the trend of increasing the velocities in protected region behind the barrier with increasing the barrier porosity.

5 COMFORT CRITERIA

According to literature the shelter efficiency of a wind barrier can be defined by using a local protection factor that permits to classify and compare different configurations of interest. A parameter bounded to the free stream velocity and to the square of the local velocity in the zone to be protected (proportional to the force) is defined as follow:

$$S_u(x,z) = 1 - \frac{\|\boldsymbol{u}(x,z)\|^2}{{u_{ref}}^2} \qquad (1)$$

where Su(x,z) is the local protection factor, u(x,z) is the local velocity in the point of interest and uref is the free stream velocity. A Su < 0 represents a region of accelerated flow while Su > 0 characterizes protected areas. In this definition turbulence is not considered.

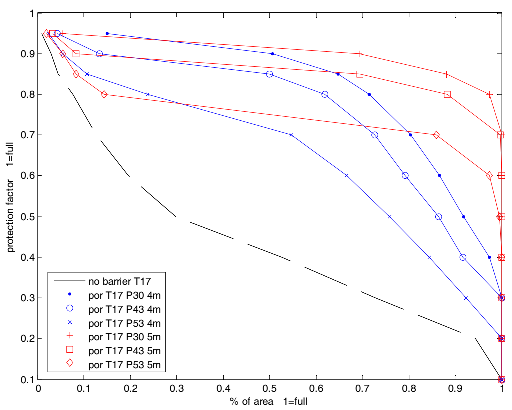
This work aims to associate to each configuration a value that indicates the level of efficiency of the barrier in terms of level of protection and of extension of the protected area.

The area of interest is the one crossed by vehicles, defined as visible in Fig. 6.

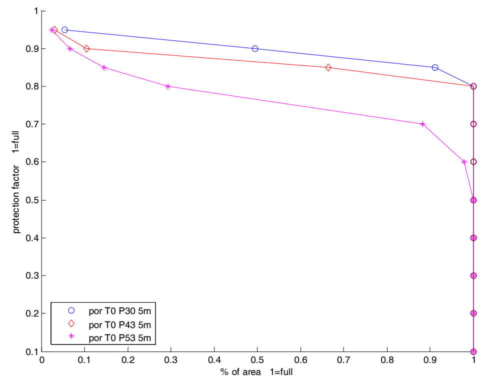
For all the investigated configurations, term Su was calculated (see eq. 1). Then it was calculated the amount of the global area (normalized with respect to the entire area of interest) in which Su was higher with respect to a given threshold; results have then been plotted by reporting in abscissa the values of Su versus the amount of global area (reported as ordinate in following diagrams). In such a representation, a fully shielded configuration would lead to a constant value of 1 with respect to every value of Su.

The obtained diagrams are reported in Fig. 8, showing the performances of the four typology of barriers in the two viaducts.

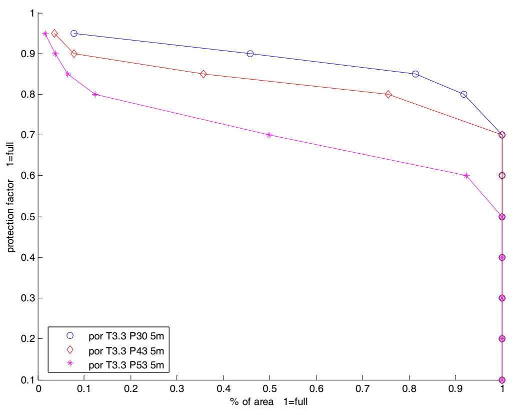
a) Viaduct Hreljin: comparison between 4mt and 5 mt height barrier with porosity factor 30, 43 and 53, compared with the configuration without barrier.



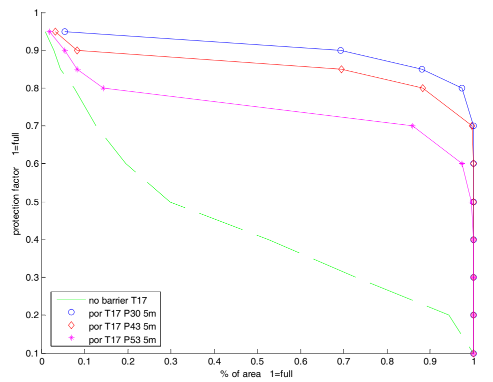
b) Viaduct Hreljin: shelter effect of the 5 mt height barrier with porosity factor 30, 43 and 53, turbulence intensity 0%.



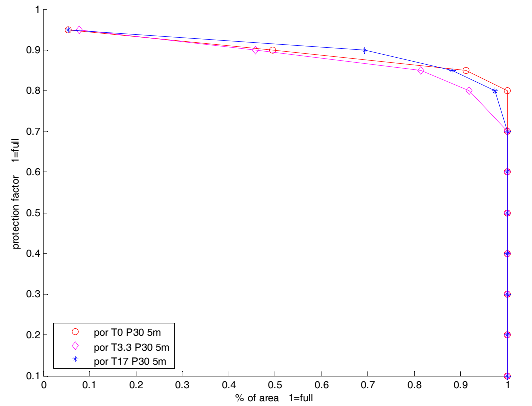
c) Viaduct Hreljin: shelter effect of the 5 mt height barrier with porosity factor 30, 43 and 53, turbulence intensity 3.3%.



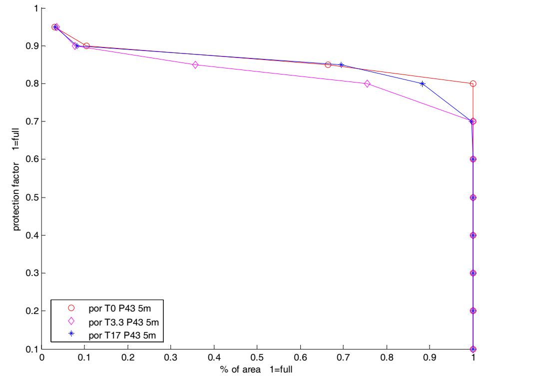
d) Viaduct Hreljin: shelter effect of the 5 mt height barrier with porosity factor 30, 43 and 53, compared with the configuration without barrier, turbulence intensity 17%.



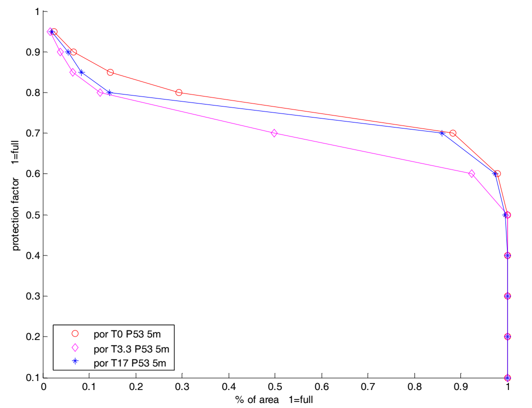
e) Viaduct Hreljin: comparison between shelter effect of the 5 mt height barrier with three turbulence conditions: 0%, 3.3% and 17%. Porosity factor 30.



f) Viaduct Hreljin: comparison between shelter effect of the 5 mt height barrier with three turbulence conditions: 0%, 3.3% and 17%. Porosity



g) Viaduct Hreljin: comparison between shelter effect of the 5 mt height barrier with three turbulence conditions: 0%, 3.3% and 17%. Porosity factor 53.



h) Viaduct Bukovo: comparison between shelter effect of the 4 mt height barrier in the orientation concave and convex with porosity factor 30, 43 and 53.

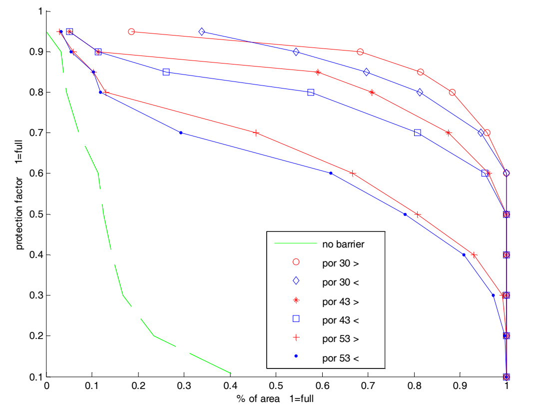


Figure 8. – Comparison between different typology of barriers in the two viaducts.

Fig. 8a to 8g show a comparison between the shelter effect of the barriers in different configurations tested on viaduct Hreljin.

In particular Fig. 8a shows that for a protection factor between 0 and 0.5, the amount of protected area strongly depends on the height of the barrier and secondly depends on the porosity factor; otherwise, for protection factor higher than 0.5 the amount of protected area is less dependent on the height but varies with the porosity of the barrier.

In the figures 8b, 8c and 8d is compared the efficiency of the wind shield for different values of the porosity, in the incoming wind turbulence of 0%, 3.3% and 17% respectively. It is visible as the porosity factor plays a significant role.

There is not a significant dependence of the efficiency of the barrier on the turbulence intensity for all the grades of porosity, however this behaviour is more accentuated in case of low porosity (Fig. 8e, 8f and 8g).

In the last picture, 8h, the effect of the orientation of the barrier towards wind is investigated on Bukovo viaduct. For all the porosity factor the "→ >" configuration has a better efficiency than the "→ <" one, this effect anyway is not much important. Moreover the shelter effect increase with the decrease of the porosity.

6 CONCLUSION

The improvement of the conditions of comfort on the investigated region due to the introduction of the barriers can vary conspicuously, due to the variation of some parameters.

While planning the most efficient and economic way of assembly the barriers designers needs to know the effect of their choices on the behaviour of the flow.

During this experimental campaign several tests have been made in order to see the dependence of the protection factor of the wind shield in the region crossed by vehicles on some geometric parameters of the barrier itself, such as the porosity, the height and the orientation.

Besides the effect of the incoming flux turbulence has been investigated. The effectiveness of the barriers increases weakly to increase some intensity of turbulence.

The present study is to be considered strictly dependent on the specific configurations investigated, anyway the 'trend' of efficiency of the barriers can be useful in a general way.

ACKNOWLEDGMENTS

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