Temporary Road Signage- better sign designs

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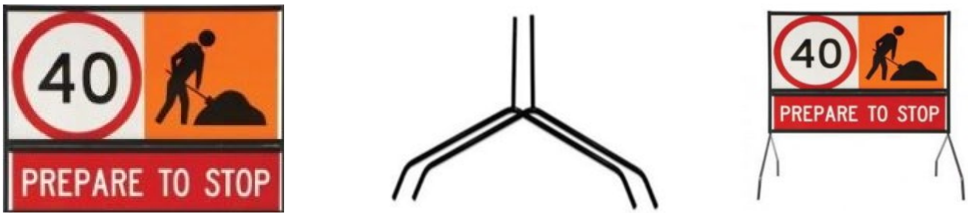
Abstract

The primary concern addressed by this project is the risk of signs toppling due to natural wind flow and vehicle-induced wind gusts, posing potential dangers to pedestrians and passing vehicles. Current road signs feature bipod legs, enabling them to pivot around a vertical axis when accidentally run over, reducing safety risks. However, they remain vulnerable to collapse when subjected to certain loads. The project aims to explore design modifications that can increase the stability threshold. To achieve this, the project involves pinpointing specific requirements, adhering to relevant codes and standards, conducting a literature review to gather design inspiration, and performing mathematical analyses to determine the structures' stability. The final phase includes fabricating the new design and conducting experiments to validate its effectiveness. The project deliverables encompass a comprehensive report covering the literature review, proposed design, mathematical analyses, and fabrication details. The new sign design will be handed over to Main Roads.

1. Introduction

The falling of road signs due to their inability to resist wind (both natural and vehicle induced) can pose a significant safety concern by causing confusion among drivers and increasing the likelihood of accidents. When signs collapse but do not fall entirely to the ground, there is also a risk of passing vehicles running over the partially collapsed sign, incurring damage and potential loss of control. Trailer mounted mobile variable message signs are available, but their implementation in rural areas may not be feasible due to the significant expenses and labour involved in deployment. In rural areas, if temporary road signs are toppled over, there may not be adequate logistical arrangements or workers available to promptly restore them to their original positions.

The figure 1(a), 1(b), and 1(c) shows the existing multimessage substrate, existing bipod legs and the existing overall sign respectively. The model uses sandbags over the bipod legs for additional weight and stability. However, it remains prone to collapse once a certain threshold is reached. When the sign is exposed to conditions that exceed stability limits, such as high winds or other impacts, the legs of the sign are designed to fall parallel to the ground rendering the sign safe but ineffective. Since 2019, Main Roads WA has been actively researching ways to improve the stability of road signs.



(a) (b) (c)

Figure 1 (a) Present substrates (b) Present legs (c) Present sign model

In their previous studies (Kumar et al., 2023), Main Roads conducted mathematical analyses assuming the sign to be rigid, to calculate the drag coefficient of the road sign and the maximum load it can withstand without sliding. To better understand the effect of wind generated by the road trains on these signs, Main Roads employed CFD simulations, assuming the sign to be rigid. Physical stability tests were conducted on rigid and non-rigid signs, to determine the stability of the respective road signs on different surfaces such as smooth concrete, gravel, and asphalt. Wind tunnel experiments were also conducted on rigid and non-rigid signs, until a continuous motion in the signs were observed. It was observed that the rigid sign could resist higher wind velocities for sliding compared to the non-rigid sign during the experiments.

In an effort to make the sign rigid and improve the stability of road signs, they made some simple modifications to the design, such as adding washers to the legs as represented in Figure 2. Field trials were conducted on a modified rigid sign that had washers installed on a highway. These trials indicated that the road sign was most stable when it was positioned more than 1.2 meters away from the edge line of the pavement (Kumar et al., 2023).

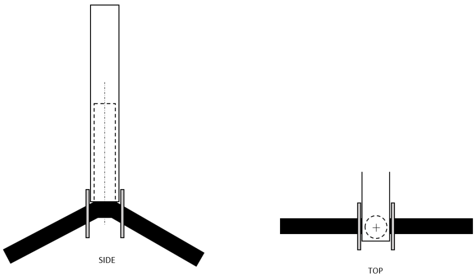


Figure 2 Schematic representations of the modified legs with washers

2. Methodology and Results

2.1 Technical evaluation of the present sign model

The force equations found from the side and top view of the free body diagrams of the sign structure exhibiting yaw mobility, represented by Figure 3(a) and 3(b) respectively are:

$$F.W + \frac{F_p}{2}.h - \frac{m.g.W}{2} = 0 \quad (1)$$

and

$$\frac{F_p}{2}.\frac{W}{2}.\sin \emptyset = \mu_s.F.W.\cos \emptyset \quad (2)$$

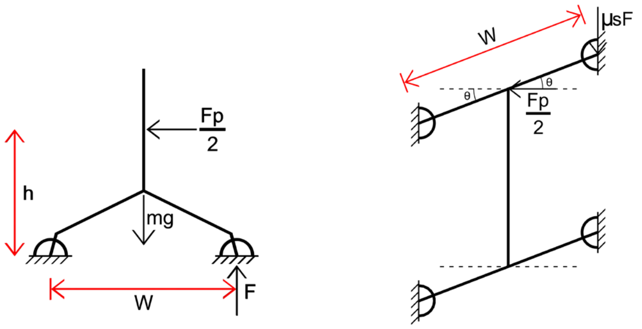
where F, W, F_p, μ_s h, m, g are the sliding force, distance between the 2 pods of each leg, drag force generated by uniform wind profile, coefficient of friction between the leg and surface, mass of the sign and acceleration due to gravity respectively.

Rearranging the Equation (1), $F = \frac{m.g.W - F_p.h}{2W}$ (3)

Substituting the expression for F from Equation (3) and $F_p = \frac{1}{2}\rho A C_d V^2$ in Equation (2), the velocity that the sign structures withstand can be found as:

$$V = \sqrt{\frac{4.\mu_s.m.g.W}{(W.\emptyset + 2.\mu_s.H)(\rho A C_d)}} \tag{4}$$

where V, ρ, A, C_d are limiting velocity of wind perpendicular to the sign, density of air, frontal area of the sign and drag coefficient respectively.



(a) (b)

Figure 3 a) Free body diagram of the sign, Side view (b) Free body diagram of the sign behaving as a non-rigid body, Top view

2.3 Detailed literature review and development of new design

CFDs studies have been conducted on a road sign with perforations of diameter 6 mm and various porosities (0%, 5%, 10%, 20%, and 30%), aspect ratios (1.0, 2.0, 4.0) and clearance ratios (0.2, 0.3, 0.5). The results of the experiments imply that the drag coefficient gets lowered with increasing porosity and clearance ratios, whereas aspect ratio does not have a significant effect on the drag coefficient and displays an inconsistent trend. The drag coefficient reduction effect was found to be 0.88, 0.86, 0.85 and 0.85 times for road signs with a porosity of 5%, 10%, 20% and 30%, respectively (Sung et al., 2022).

The background study also revealed that the proposed design must satisfy the Australian Standards- AS 1743 & AS 1906 (Committee MS-012, Road Signs and Traffic Signals, n.d.), and the Main Roads-specific recommendations in Specifications 601(Main Roads Western Australia, 2023).

Based on the literature and inference from the evaluation of the existing sign, the proposed design was formulated. Design consideration 1 was incorporating a perforated aluminium sheet with holes 3 mm in diameter and pitch of 45 degrees, with 40 % openness, as shown in Figure 4(a). This modification aims to reduce the drag coefficient of the sign, thereby increasing the stability of the structure. Design consideration 2 was increasing the diameter of the bottom portions of the bipod legs, as shown in Figure 4(b), to bring up the weight of the bipod legs from 3.4 kg in the original design to 7kg in the new design. By increasing the weight of the bipod legs, the overall weight of the structure is also increased enhancing stability and resistance to wind loads. The distribution of weight to the base of the legs, contributes to a lower center of gravity, further improving its stability and ability to withstand external forces. Figure 4(c) represents the overall proposed sign incorporating both the design considerations.

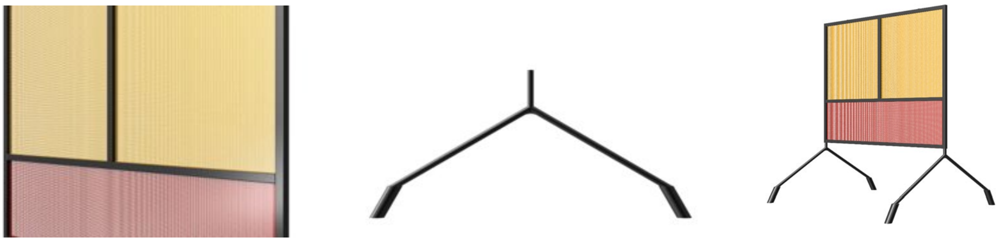

(a) (b) (c)

Figure 4 (a) Proposed substrates model (b) Proposed leg design (c) Proposed sign

The limiting velocities of the wind for the various proposed design considerations, the overall proposed sign and present sign, with orientation changes of 1 to 5 degrees were found using the Equation (4). The following assumptions are used in the calculation: (1) a modified drag coefficient of 0.85 times the original C_d value of 1.38 (Kumar et al., 2023) has been used for C_d of proposed sign based on the observation from Sung et al. (2022). (2) the mean values from the Mihora et al. (2013) spectrum were utilized for μ_s.

Table 1 presents the limiting velocities for the proposed sign with only perforated substrates consideration against the limiting velocities for the present sign. Table 2 presents the limiting velocities for the proposed sign with only alternative leg design consideration against the limiting velocities for the present sign. Table 3 presents the limiting velocities for the proposed sign against the limiting velocities for the present sign.

		Limiting velocity for proposed sign with only perforated substrates consideration (m/s)			**Limiting velocity for present sign(m/s)**		
		Asphalt	Gravel	Concrete	Asphalt	Gravel	Concrete
Orientation change (°)	1	13.293	13.256	13.208	12.240	12.206	12.162
	2	13.217	13.143	13.050	12.169	12.102	12.016
	3	13.141	13.033	12.898	12.100	12.001	11.876
	4	13.067	12.926	12.751	12.031	11.902	11.740
	5	12.994	12.822	12.609	11.964	11.806	11.610

Table 1 Limiting velocities for proposed sign with only perforated substrates consideration against the present sign

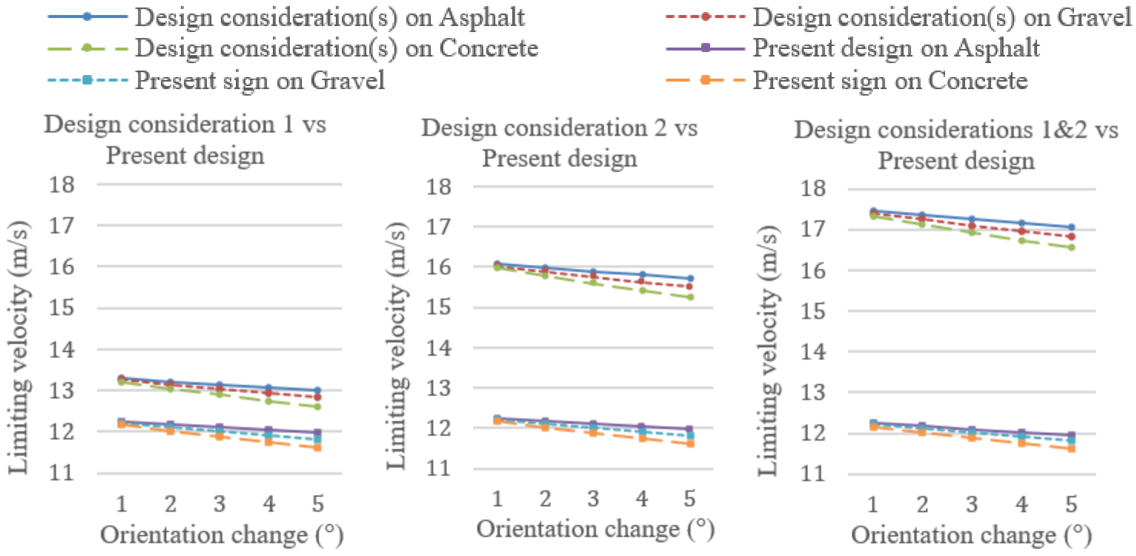
		Limiting velocity for proposed sign with only alternative leg design consideration (m/s)			**Limiting velocity for present sign(m/s)**		
		Asphalt	Gravel	Concrete	Asphalt	Gravel	Concrete
Orientation change (°)	1	16.072	16.027	15.969	12.240	12.206	12.162
	2	15.979	15.891	15.778	12.169	12.102	12.016
	3	15.888	15.758	15.594	12.100	12.001	11.876
	4	15.798	15.628	15.416	12.031	11.902	11.740
	5	15.710	15.502	15.245	11.964	11.806	11.610

Table 2 Limiting velocities for proposed sign with only perforated substrates consideration against the present sign

		Limiting velocity for overall proposed sign (m/s)			Limiting velocity for present sign(m/s)		
		Asphalt	Gravel	Concrete	Asphalt	Gravel	Concrete
Orientation change (°)	1	17.446	17.397	17.334	12.240	12.206	12.162
	2	17.345	17.249	17.127	12.169	12.102	12.016
	3	17.246	17.105	16.927	12.100	12.001	11.876
	4	17.148	16.964	16.734	12.031	11.902	11.740
	5	17.052	16.827	16.547	11.964	11.806	11.610

Table 3 Limiting velocities for overall proposed sign against the present sign

The above comparisons have been represented graphically as Figure 5(a), Figure 5(b) and Figure 5(c) corresponding to Table 1, Table 2, Table 3 respectively.



(a) (b) (c)

Figure 5 (a) Limiting velocities for proposed sign with only perforated substrates consideration against the present sign (b) Limiting velocities for proposed sign with only alternative leg design consideration against the present sign (c) Limiting velocities for overall proposed sign against the present sign

The results obtained from the analysis demonstrate a substantial improvement in the performance of the overall proposed design when compared to the current design. Comparing the limiting velocities of the different design considerations, overall proposed sign and present sign across different orientation changes on diverse surfaces, it is evident that the overall proposed design exhibits higher limiting velocities than the present design, by around 5 m/s on all surfaces, with substantial improvement from the design consideration 2 i.e. the alternative leg arrangement.

2.4 Fabrication and experiments on the proposed sign structure

Wind tunnel test will be carried out prior to the fabrication of the proposed design to validate the reduction in drag coefficient, as claimed in the literature. Post fabrication, the stability tests and on-site tests will be carried out to assess and validate the structural integrity and efficacy of the proposed design. The stability test will involve applying separate push forces at various points on the sign using a digital force gauge to simulate different wind conditions and potential impacts, whereas the on-site test will evaluate the sign structure's performance under real-world conditions, specifically focusing on its ability to withstand the combined wind gust generated by the passing trailer and atmospheric air. The tests will observe whether the sign structure collapses, slides excessively, or shows any signs of instability. The stability and on-site tests will be repeated to validate the findings and ensure consistency in the results.

4. Conclusions and Future Work

By evaluating the limiting velocities of the proposed and existing design across various surfaces, the proposed design involving perforated substrates of 3 mm diameter and 40 % open ratio and an alternative leg design of increased mass with lowered centre of gravity, has been found to withstand higher wind velocities by around 5 m/s on all surfaces, compared to the existing design, thus minimizing collapse hazards and need for frequent replacement. The utilization of the perforated substrates that modifies the drag coefficient to 0.85 times the original value and the increase in overall weight from 11.6 kg to 20 kg, have contributed to the increase in threshold velocities. The proposed design also demonstrates ease of transport and adaptability to various locations. Notably, it eliminates the necessity for sandbags, promoting a more hygienic work environment for laborers. However, the testing phase remains pending completion, awaiting wind tunnel, stability and on-site assessments to evaluate the sign structure's performance and reliability.

5. Acknowledgement

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