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Full scale experiments on vehicle induced transient loads on roadside plates

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ABSTRACT

Every day and innumerably, road vehicles of different types pass flat roadside-placed elements like stable or temporary traffic signs, noise barriers, charge devices, etc. The elements are exposed to a vehicle-specific flow and pressure field, i.e. to transient loads. In order to quantify the involved phenomena, full-scale experiments were performed for six different vehicle types and three sizes of square plates, which were aligned in three different configurations with respect to the vehicle's track. For the measurement of loads effecting the plate, the pressure multi-tapping technique was implemented with high temporal and spatial resolution. The experiments delivered a broad database for the proper quantification of vehicle induced loads on flat elements as a function of vehicle type, vehicle velocity and passing distance to the plate, element size as well as spatial plate alignment with respect to the vehicle.

1. Introduction

Around a moving vehicle, typical pressure zones develop showing first a zone of overpressure at the front of the vehicle followed by a zone of underpressure due to the air flow acceleration especially at the leading edge of the vehicle. These zones, which can also be characterized as a pressure jump, lie close to each other and they are responsible for transient forces acting on objects located next to or above the road. Analogously, pressure jumps are formed at the rear edge of vehicle or at junctions of a vehicle train, although, the forces there are not as strong and stable as the forces induced by the vehicle front. Attention should be paid not only to the force amplitude but also to the time duration of the excitation force, which can provoke resonance effects and material fatigue of the roadside elements.

Vehicle aerodynamics has been investigated in numerous studies in the last decades, see e.g. Sovran et al. (1978), Hucho (1994), and Watkins and Pagliarella (2007), however, the interaction of the vehicle induced flow with static elements near the road has been investigated barely. In literature, only few studies exist on this topic. Cali and Covert (2000) conducted scaled experiments measuring transient loads on overhead highway signs induced by passing of simplified model vehicles. Macciachera and Ruck (2001) performed model investigations in a reduced scale giving detailed pressure measurements near passing vehicles. Full-scale experiments on vehicle induced forces acting on flat plates were carried out by Quinn et al. (2001a, 2001b). In this case, plates of different shape and inclination were tested on a road side, however, without precise acquisition of vehicle type, distance and traveling speed. Sanz-Andrés et al. (2003a, 2003b, 2004) have introduced mathematical models of vehicle-induced transient loads which roughly approximated experimental results in the vehicle front section regarding traffic signs, pedestrians and pedestrian barriers. In comparison to that, more studies exist on train-induced loads e.g. concerning noise barriers and trackside structures at high speed train lines, where frequent passings can lead to dynamic reactions and material fatigue, see e.g. CEN (2005), Friedl et al. (2013), Lee (2009) and Carassale and Brunenghi (2013). Comprehensive reviews including field and numerical studies of high speed trains especially regarding the aerodynamics in tunnels, train passing close to each other and the crosswind exposure can also be found in Schetz (2001) and Raghunathan et al. (2002). Further, crosswind and gust induced effects on vehicles and roadside structures were treated in several studies in model as well as in full scale experiments, see e.g. Dorigatti et al. (2012) and Pulipaka et al. (1998). A field experiment and numerical study on vehicle-induced aerodynamic loads on highway sound barriers were done by Wang et al. (2013a, 2013b) where three vehicle types were considered passing along a barrier.

Unfortunately, no data of systematic investigations of vehicle induced forces can be found for the road traffic applications

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respecting all, the element size, vehicle type, element distance and element alignment with respect to vehicle's track. Therefore, the present full scale experiments were carried out with six vehicle types to ensure a good representation of typical traffic situations. The experiments were performed on a closed track under good weather conditions, i.e. as calm as possible, no rain and controlled low wind conditions. The results given in this paper refer to square plates of three different sizes located next to or above the road. The overall aim of the full scale measurement campaign was to establish a comprehensive database allowing a proper assessment and design of roadside elements based on extreme peak loads and temporal load characteristics.

2. Experimental set-up

Typical parameters characterizing vehicle types are given in Table 1. A passenger car was also included to allow a comparison to the larger vehicles. The shape of all goods vehicles used in the experiments were of box-type, since highest aerodynamic forces were expected from them.

The experiment layout is sketched in Fig. 1. The vehicle motion speed of U is counter the x-axis direction, so the steady flow is aligned with the x-axis of the vehicle reference frame (x,y,z), where X denotes the distance to the front of vehicle in the x-direction, Y denotes the absolute distance to the side of vehicle in the y-direction, and Z denotes the distance to the ground in the vertical z-direction. The bounding box of the vehicle (excepting side mirrors) has a length L, a width B, and a height H. Three square plates of the edge size of $a_1 = 0.50$ m (small-sized plate), $a_2 = 1.00$ m (medium-sized plate) and $a_3 = 1.50$ m (large-sized plate) were used for the testing. Plates were adjusted relatively to the vehicle in three different configurations as shown in Fig. 1. In case of configuration A, the plate was aligned parallel to the vehicle side wall and the positive acting force ($F > 0$) was assigned to the direction away from the vehicle. In case of configuration B, the test plate was aligned normal to the driving direction so that the positive acting force was assigned to the driving direction. In the case of configuration C, the test plate was aligned normal to the driving direction and positioned above the roof of the vehicle and the positive acting force was assigned to the driving direction. Further, plates were positioned in several heights Z above the ground and the vehicle. In the case of configuration C, the distance between vehicle roof and the lowest edge of the plate is denoted by Z', and the distance between the vertical axes of plate and vehicle is denoted by Y'.

In total, hundreds of test runs were performed for different test positions. A test position is defined as a combination of one particular configuration, vehicle type and vertical level Z of the test plate. At each test position, typically, $N = 15$ to 25 test runs were carried out. For each run, the variable vehicle velocity U and the variable distance Y between the plate and the vehicle were captured automatically using a laser light beam trigger and a distance measuring technique.

Table 1
Fleet of testing vehicles – classification and main parameters.

Vehicle type	Total width B [m]	Total height H [m]	Total length L [m]	Characteris-tics	**Illustration** (DIN 70010)
Passenger car (saloon)	1.75	1.45	4.5–4.8	combined lim./ estate	
Van (commercial vehicle)	2.0	2.7	5.4 or 6.8	combined short/long	
Truck (goods vehicle)	2.5	3.4	7.8	rigid box body	
Truck with trailer (road train)	2.6	4.0 (3.55)	16.6	canvas cover, trailer lower	
Trailer-truck (articulated vehicle)	2.6	4.0	16.6–18.6	canvas cover	
Tour-bus (long distance coach)	2.55	3.7	12.95	3-axle, roof structures	

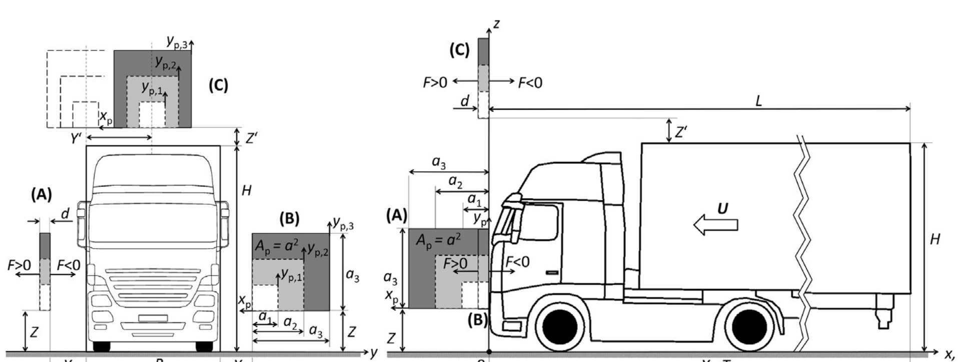

Fig. 1. Layout of the experiment showing three configurations (A), (B) and (C) regarding the plate position relative to vehicle. Front and side view on the left and right hand side, respectively.