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CORRELATION OF THE SURFACE MACRO-PROFILE, VEHICLE SPEED AND TRAFFIC SAFETY

ABSTRACT

Vehicle is in fact a very complex elastic system which, if in any way disturbed from its static balance will start to vibrate as a whole, or only some of its parts, i.e. it will start to move periodically around the position of its static balance thus obviously disturbing the stability of the vehicle movements and the driving comfort and reducing the strength of materials of single vehicle elements. Basic cause for this dynamic excitation is the micro and macro profile of the surface along which the vehicle moves. Vibrating vehicle has a reduced stability in movement.

Due to traffic safety reasons transversal road humps need to be installed at a section at which the motorist who misread the traffic signals need to be forced to reduce their speed, that is, care must be taken of a number of various factors endangering traffic safety. This paper will try to analyse everything that is included in the "Programmed macro-profile of road".

KEY WORDS

correlation, road surface profile, vehicle speed, traffic safety, vibrations

1. INTRODUCTION

Every professional dealing with the dynamics of vehicle movement is well acquainted with the fact that the set of the actually designed vehicle is in fact a very complex elastic system which, if in any way disturbed from its static balance, will start to vibrate as a whole, or only in some of its parts, i.e. it will start to move periodically about the position of its static balance thus obviously disturbing the stability of the vehicle movement and the driving comfort and reducing the strength of materials of single vehicle elements.

There are, of course, various causes for this dynamic excitation of the vehicle and during driving the vehicle is simultaneously subjected to a number of various factors, such as operation of the vehicle driving mechanism, then the influence of various irregularities in the wheels and the vehicle suspension system, then transporting of cargo and passengers in the vehicle, air flow around the vehicle, but the basic and most important cause for this dynamic excitation is the micro and macro profile of the surface along which the vehicle moves. This fact should obviously be considered when designing, constructing and maintaining roads, since a vibrating vehicle not only exhibits a reduced stability in movement, offering less comfortable ride, and, of course, greater wear, but also acts in turn over the wheels back on the surface with a greater dynamic load, speeding up its destruction. Besides, these accompanying effects of the vehicles create in the surface mechanical vibrations, which are in waveforms translated to the environment, increasing thus the material destruction of certain traffic infrastructure facilities and buildings along the roads. However, the aim of this paper is not to use the analysis of dynamic behaviour of the vehicle to give an answer to the need for the profile quality of the surface, its elasticity and hardness. On the contrary, this paper will try to use the analysis of the vehicle behaviour and reactions of the human body to mechanical vibrations to find the answer to the problem of correcting the macro-profile of a certain already constructed road, over a section at which the motorists who misread the traffic signals need to be forced to reduce their speed due to traffic safety reasons. The practice has, namely, shown that certain sections of the already existing streets in densely populated urban areas, such as e.g. the city of Zagreb, become at one time, due to various reasons, places of increased traffic risk, with relatively frequent incidence of grave traffic accidents, and where the speed is the main factor endangering traffic safety.

2. HUMAN BODY SENSITIVITY TO MECHANICAL VIBRATIONS

Human body, considered as a whole, is a very complex elastic system consisting of a series of masses interconnected by various elastic and dampening joints, which, using the roughest approximation can be presented in the form of the model in Figure 1. If a human, and the typical example for this is to present him/her seated in the vehicle, is subjected to the time-varying mechanical excitation, then certain parts of his/her body will start to vibrate, i.e. to move periodically about the position of its static balance with amplitudes depending, on the one hand, on the elastic and dampening characteristics of the human body, and on the other hand, on the amplitude-frequency characteristic of the mechanical excitation. An especially adverse case is when resonance occurs in a certain part of human body, i.e. when there is adjustment between the frequency of mechanical excitation and the proper frequency of that part of human body itself.

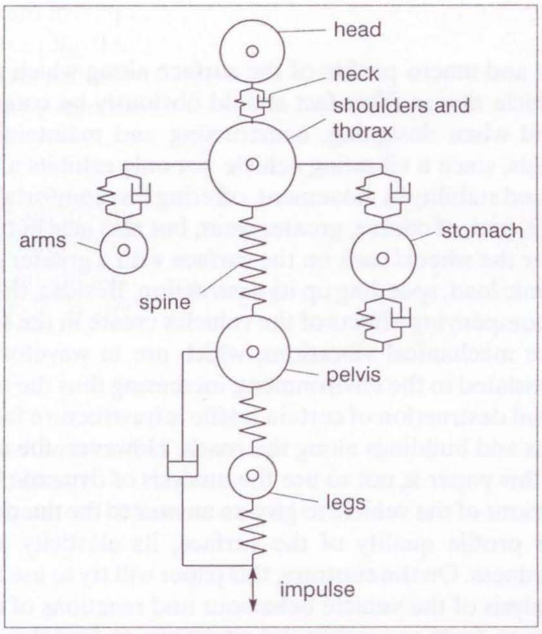

Figure 1 - Simplified elastic human model

Table 1 shows the intervals of proper frequencies of certain characteristic parts of human body. Of course, vibrating of certain parts of human body results in disturbances of the operation of certain organs and increased strain in certain joints within the body, which the human feels as a sort of difficulty or problem

Table 1 - Frequency intervals of some characteristic parts of human body

Part of human body	Interval of self frequency
Head	13.0 – 20.0
Eyeball	18.0 – 25.0
Shoulders	2.0 – 6.0
Thorax	4.0 – 7.5
Body	3.0 – 6.0
Stomach	4.0 – 6.0
Spine	3.0 – 5.0
Leg system	20.0 – 25.0

Thus, e.g. in the area of vertical mechanical vibrations with frequency less than 1 Hz, acting of these vibrations on the balance system can cause kinetics in humans, which is a motion sickness, often described as sea-sickness, with the known symptoms of dizziness, nausea, vomiting, apathy, etc. Discomforts listed in Table 2 occur in the higher frequency field of mechanical excitation, due to the occurrence of resonance in certain parts of the human body.

Table 2 - Characteristic discomforts in humans in determining frequent area of operating mechanical impulse

Interval frequency Mechanical induction	Discomfort for the human body
4.0 – 7.0	heavy breathing
4.0 – 10.0	stomach-ache
5.0 – 7.0	chest pain
8.0 – 12.0	backache
10.0 – 18.0	discomfort in bladder
12.0 – 16.0	discomfort in bronchial and throat
13.0 – 20.0	headache, speech problems and muscular stress

However, human sensitivity to mechanical vibrations does not depend only on the frequency field of mechanical excitation, but it also depends on the direction of human excitation. Humans, namely, suffer least from those vibrations that they find natural, which are vertical vibrations with frequencies of 1 – 3 Hz. They suffer more when subjected to longitudinal, and even more from transversal and most from angular vibrations. Also, human sensitivity depends on the magnitude of acceleration under mechanical excitation, since every acceleration greater than the innate one, because it exists in the normal movement of humans, causes a feeling of discomfort. Table 3 shows the intervals of vertical and transversal acceleration of human body when walking.

Table 3 - Intervals of vertical, longitudinal and transversal acceleration of pedestrian while walking

Type of pedestrian	Acceleration of pedestrian body (g)		
	Vertical	Longitudinal	Transversal
Male	0.40 – 0.68	0.26 – 0.55	0.19 – 0.25
Female	0.35 – 0.51	0.20 – 0.44	0.25 – 0.30
Children	0.49 – 0.75	0.30 – 0.64	

Based on this consideration it can be concluded that humans are most sensitive in the mechanical excitation frequency field below 1 Hz, and in the field ranging from 3 – 30 Hz, then to vertical accelerations greater than 0.35 g, longitudinal accelerations greater than 0.20 g, as well as to transversal acceleration greater than 0.19g, and that they suffer most from angular vibrations.

3. CONSIDERING THE EXISTING DESIGN OF SOME TRANSVERSAL ROAD HUMPS FOR THE PURPOSE OF FORCING THE MOTORISTS TO REDUCE SPEED

Some transversal road humps in Zagreb have been relatively well designed. For instance those around the lake of Jarun. Some, on the other hand, are failures in the technical sense. Typical example are the road humps in the Mlinarska Street in Zagreb. These road humps have been designed as separated ramps 1.25 m apart, with every ramp about 0.55 m wide and about 0.01 m high. Such design of road humps causes vertical shifts, otherwise the easiest for the humans, in all vehicles that have the axle-base not smaller than 1.45 m and not greater than 2.55 m which includes almost all passenger vehicles. Apart from that, these road humps were intended (according to the traffic sign) to force the motorists to reduce their speed to no more than 40 km/h. However, at this speed these road humps cause the frequency excitation of 20 Hz, which, true enough, does fall within the range of the sensitivity of humans and vehicles to mechanical vibrations, but is very close to the upper limit of the sensitivity at about 30 Hz, which means that at speeds greater than 60 km/h the car body and the human body become practically insensitive to such humps. Therefore, transversal road hums designed in this way in fact stimulate the motorists to increase the speed in order to have greater riding comfort in driving over them, thus compensating for the relatively low height of the humps by elastic deformation of the pneumatics.

4. SUGGESTION FOR SOLVING THE ACTUAL PROBLEM

Since humans suffer most from angular vibrations, it is obviously this condition that should become the starting point in solving the actual problem. Namely, in order to subject the motorist in the vehicle to purely angular movement about the transversal axis of the vehicle, the macro profile of the road surface should be obviously designed so that when the vehicle passes over the transversal road humps, the front and the rear part of the vehicle are at every moment, as presented in Figure 2, mutually equal but oppositely directed

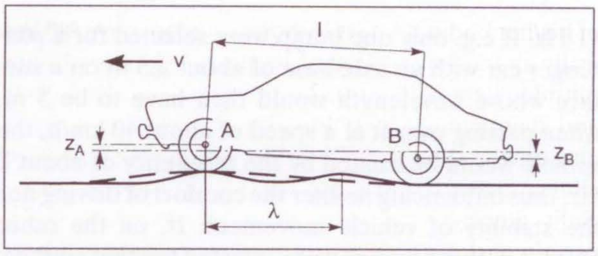

Figure 2 - Model of vehicle for clean angular vibrations

At certain harmonious excitation the circular frequency surface in such desired vehicle kinematics will result only if the vertical shift of the rear part of the vehicle lags behind the vertical shift of the front part of the vehicle by a phase angle of $(2n-1)\pi$, which means that in that case the following equation needs to be fulfilled:

$$(2n-1)\pi = \Omega \cdot t_z$$

where (t_z) is the lag time of the vertical shift of the rear part of the vehicle in relation to the vertical shift of its front part. Since this time obviously depends on the speed (v) of the vehicle and on its axle-base (l) according to the relation

$$t_z = \frac{l}{v}$$

and since the circular frequency of the harmonious excitation (Ω), wavelength (λ) of the surface macro-profile and the speed (v) are interconnected by the relation

$$\Omega = 2\pi \cdot \frac{v}{\lambda}$$

finally the following equation is obtained:

$$(2n-1)\pi = 2\pi \cdot \frac{v}{\lambda} \cdot \frac{l}{v}$$

which acquires the form:

$$2n-1 = \frac{2l}{\lambda}$$

which interconnects the axle-base of the vehicle (l), the necessary wavelength of the surface macro-profile (λ) and the necessary number of waves of this profile (n) for causing purely angular vibrations in the vehicle. It is obvious that the maximum wavelength of the surface macro-profile that still causes purely angular vibrations of the vehicle has to equal the double axle-base of the vehicle. At other wavelengths of the surface macro-profile, which are not in accordance with the above-mentioned relation, the vehicles exhibit either purely vertical or combinations of vertical and angular vibrations. In selecting the number of humps in the surface macro-profile, one needs to consider not only the human sensitivity to mechanical vibrations, but also the stability of vehicle movement, i.e. of the proper frequency of vehicle body and wheels. For instance, in passenger cars the proper body frequency is about 1 Hz, and of wheels about

11 Hz. If e.g. only one hump were selected for a passenger car with an axle-base of about 2.5 m on a surface whose wavelength would then have to be 5 m, when passing over it at a speed of about 40 km/h, the vehicle would be excited by the frequency of about 2 Hz, thus influencing neither the comfort of driving nor the stability of vehicle movement. If, on the other hand, e.g. three humps were selected for that surface, for the same vehicle, and for the same speed, then the wavelength of these humps would have to be about 1 m, and the vehicle itself would be excited by the frequency of about 11 Hz, thus endangering both the driving comfort and the stability of movement, due to the resonance at its wheel. Although in the actual example of the passenger car passing over only one hump at a speed of about 40 km/h neither comfort nor stability would be endangered, in the case of this same vehicle passing over the same hump at a speed of e.g. 60 km/h, it would in that case be excited by the frequency greater than 3 Hz, thus, true enough, not reducing its stability of movement, but making driving less comfortable which is naturally positive, as contrary to the failures in the technical design of the humps in Mlinarska Street in Zagreb. However, in selecting the macro-profile of the surface not only the frequency of vehicle excitations is to be considered, but also the height of the humps, because of the speed in accordance to the traffic sign. As seen in Figure 3 which represents the simplified model of a vehicle, the vertical shift of any point (H) on the vehicle body within the axle-base of the vehicle is defined by the relation

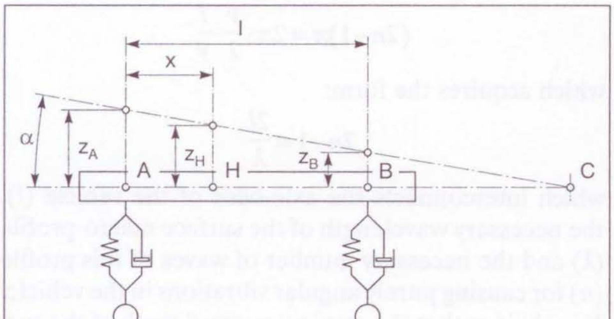

Figure 3 - Simplified two-dimensional vehicle model

$$z_H = z_A - x \cdot \operatorname{tg} \alpha \approx z_A - x \cdot \alpha$$

where (z_A) is the vertical shift of the vehicle body above the front wheels, value (x) is the distance of the point (H), in the actual example of the diverse seat from the symmetry of the front wheels, and (α) is car body vibration angle about the transversal axis in the centre of its vibrating. In accordance with this and by denoting the vertical car body is determined by the relation

$$\alpha \approx \operatorname{tg} \alpha = \frac{z_A - z_B}{l}$$

It has already been mentioned that in the purely angular vibrations of the car body, vertical shifts of the front and rear part of the car body have to be mutually equal and oppositely directed at any time, which means that the condition has to be fulfilled according to which

$$z_A = -z_B$$

Along with this condition it follows that the vertical shift of the driver's seat is defined by relation

$$z_H = z_A x \cdot \frac{z_A + z_H}{l} = z_A \cdot \left(1 - \frac{2x}{l}\right)$$

and the angular shift of this seat by the relation

$$\alpha = \frac{2z_A}{l}$$

From these expressions it then further follows that the vertical acceleration of the driver's seat is determined by the relation

$$z''_H = z''_A \cdot \left(1 - \frac{2x}{l}\right)$$

and its angular acceleration by the relation

$$\alpha'' = \frac{2z''_A}{l}$$

Since the vertical shift of the front part of the car body in the harmonious movement can be analytically expressed in the following form

$$z_A = C_A \cdot e^{(i \cdot \Omega \cdot t)} = A_A \cdot e^{(-i\varphi)} \cdot e^{(i \cdot \Omega \cdot t)}$$

and since the phase shift of the front part of the car body (φ) equals zero, since this part of the vehicle represents also the reference point of the actual consideration, it means that the maximum values of the vertical and angular acceleration are determined by relations

$$z''_H = A_A \cdot \Omega^2 \cdot \left(1 - \frac{2x}{l}\right)$$

and

$$\alpha'' = \frac{2A_A\Omega^2}{l}$$

where (A_A) is the amplitude of the vertical shift of the front part of the car body in the position of the front wheels symmetry. In this way, by selecting the amount of the vertical and angular load on the motorist body we can then determine the required magnitude of the amplitude of the car body shift for any desired vehicle speed, and in accordance with this condition determine the necessary macro-profile of the road at the section where we want to limit the vehicle speed.

SAŽETAK

KORELACIJA MAKROPROFILA PODLOGE, BRZINE KRETANJA VOZILA I SIGURNOSTI PROMETA

Vozilo je kako znamo složen elastični sustav, koji ako bilo kako izvedemo iz stanja njegove statičke ravnoteže, počne čitav, ili samo neki njegovi dijelovi vibrirati tj. periodički se kretati oko položaja svoje statičke ravnoteže čime se narušava stabilnost kretanja vozila i udobnost vožnje. Najvažniji uzrok za početak vibriranja je oblik makroprofila podloge po kojoj se vozilo kreće. Takvo vozilo koje je vibracijski pobuđeno posjeduje smanjenu stabilnost svog kretanja. Kako u područjima gdje želimo zbog sigurnosnih uvjeta postaviti «programiranu» tj. namjerno periodički uzdignuto-spuštenu podlogu zbog prisiljavanja vozača na smanjenje brzine moramo voditi računa, o čemu govori i naš rad, o mnogim čimbenicima koji mogu utjecati na smanjenu sigurnost pri prolasku preko tako namjerno oblikovanog makroprofila podloge.

LITERATURE

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