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TRAFFIC DYNAMIC EFFECT ON ROAD BRIDGE JOINT

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Abstract. *In road engineering, also a well realized bridge expansion joints always creates a discontinuity in the road surface. This unevenness produce very important dynamic load increase due to the moving heavy vehicles.*

The dynamic component of wheel forces depends on the road pavement profile, the functional characteristics of the vehicle (geometry, mass and stiffness distribution, tire and suspension type, operative speed, etc.) and structural characteristics of the bridge superstructure (span length, geometry, static scheme, natural frequencies and damping).

The dynamic actions can produce a general decay of the structure and local breaks near the biggest pavement unevenness for example near the Highway Bridge Expansion Joints (BEJ) and could decrease or cancel the skid resistance between road and tire, with dangerous consequences on traffic safety.

Generally, it is recommended to consider the dynamic actions between the vehicle and the road. The definition of these actions is possible by means of the analysis of vertical accelerations measured, for example, on a heavy vehicle axle running on the joint.

An innovative approach for solving the problem of dynamic interaction between heavy vehicle and BEJ is presented, taking advantage of the all purpose explicit finite element code LS-Dyna.

The proposed model allows to determine, varying the parameters of the test vehicle (load, geometric dimensions and speed), of the JOINT unevenness dimensions (amplitude and wavelength) and of pavement modulus, the stresses and deformations on JOINT and of each pavement layer due to dynamic actions generated by vehicle motion.

The model allows to also determine the accelerations on the vehicle, to verify the Ride Quality of a uneven pavement.

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1 INTRODUCTION

Bridge structure are stressed by the action due to vehicle tire. The action depends on:

- the surface/geometric characteristics of road pavement (unevenness);
- the functional characteristics of vehicle (masses, geometry, suspension, speed);
- the structural response of bridge (natural frequencies, damping, etc).

The dynamic actions can produce a general decay of the structure or local breaks near the biggest pavement unevenness for example near the Highway Bridge Expansion Joints (BEJ).

In fact, from the point of view of road engineering, also a well realized bridge expansion joints always creates a discontinuity in the road surface (Figure 1).

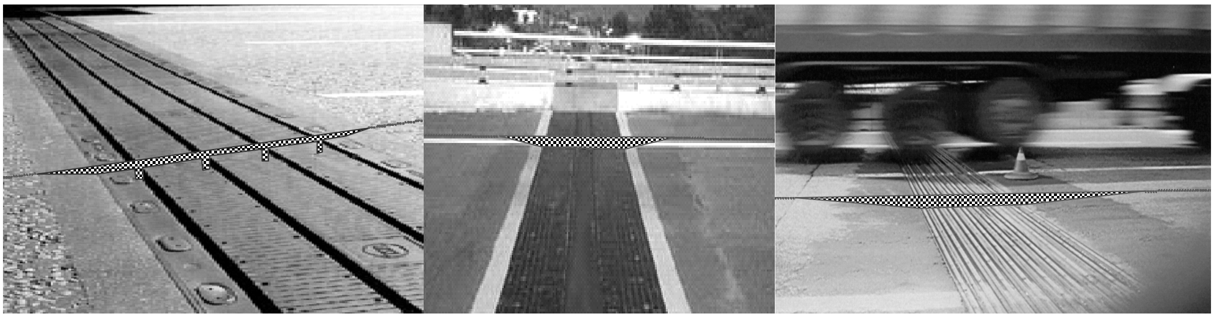

Figure 1: Different Irregularity produced by BEJs [1].

The BEJ causes various kind of irregularities:

1. geometric unevenness of the joint surface Figure 1 (a); these have usually small wavelength (2 to 20 cm) and cause essentially rolling noise.
2. unevenness of the BEJ-pavement system, Figure 1 (b) and (c) due to errors on joint installation, settlement of BEJ or differential displacement of the jointed structures; these have wavelength with dimension varying from the longitudinal joint dimensions to 10 m and cause dynamic wheel load increase due to the moving heavy vehicles.
3. planar unevenness between BEJ and pavement; these occur when the joint is located in a transition section of the road (spiral axis) between to consequent road elements with different curvature; in this area the road surface is slanting (Figure 2), and if the joint is large (for example an highway seismic joint) the elevation difference from the points of the road can be some centimeters.

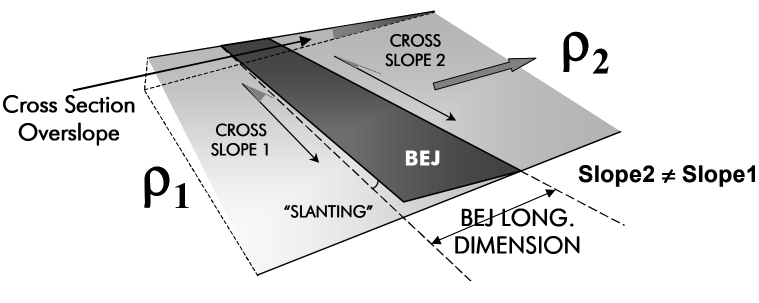

Figure 2: "Slanting" on BEJ in a transaction road section.

Road BEJ faulting is due to progressive structural decay under the stress produced by heavy vehicles. This faulting creates an unevenness on road surface that is undesirable for two reasons:

- the generation of vertical accelerations on the vehicle. These accelerations decrease or cancel the skid resistance between road and tire, with dangerous consequences on traffic safety;
- the generation of tire impact actions on the joint, due to the punctual unevenness. These actions increase the speed of faulting process in the pavement and BEJ and generate high level of rolling noise.

The vehicle-unevenness interaction can be studied by means of numerical models using the pavement profile data. This model are normally used to calculate the ride vehicle quality and the dynamic tire forces generated by each axle, in response to road roughness input. The moving vehicle is schematized with an array of rigid bodies characterized by masses and suspensions. These are represented with simple or combined rheologyc schemes.

In Figure 3 show an example of different simplified models with different degrees of freedom.

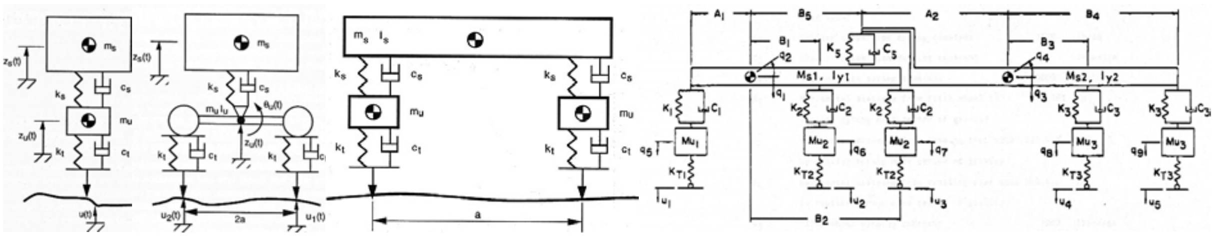

Figure 3: 2, 3, 4 and 9 d.o.f. truck model [2],[3].

The application of the models strongly depends on the exact knowledge of road surface including the bridge joint. The coming vehicle already has vertical oscillation motions that can be amplified when it pass through the joint. As the speed increase, as an elevation change in a short length produces a bump action.

The valued displacements and stresses are much greater than the equivalent static values. Therefore even if there are not specific standards about this topic, the design of a joint without considering the traffic loads dynamic effects underestimates the real service condition and the fatigue resistance.

These dynamic effect must be considered also in the bridge structural design.

The magnitudes of vehicle load are significantly affected by the interaction between traversing vehicles and the bridge superstructure, as well as by interactions among structural components and among vehicles. The interaction between vehicles and the bridge superstructure is a consequence of vehicle motion induced by bridge vibration and roadway surface irregularities.

In order to assess and design bridges for dynamic wheel loads, or to design vehicle to reduce the dynamic response of bridge, a fundamental understanding of the nature of the dynamic interaction between vehicles and bridges is also necessary. The roughness input to the vehicle is the sum of the initial surface profile of the bridge and the dynamic deflection of the bridge. This input excites the vehicle and results in dynamic tire forces. These forces are in turn applied to the bridge and cause larger dynamic displacements of the bridge. This feedback mechanism of interaction forces couples the dynamic response of the bridge to that of the vehicle.

A different calculation procedures are developed by many authors [4],[5] for predicting the dynamic response of a bridge to a given set of vehicle wheel loads. In Figure 4 are show some examples of this analytical procedures.

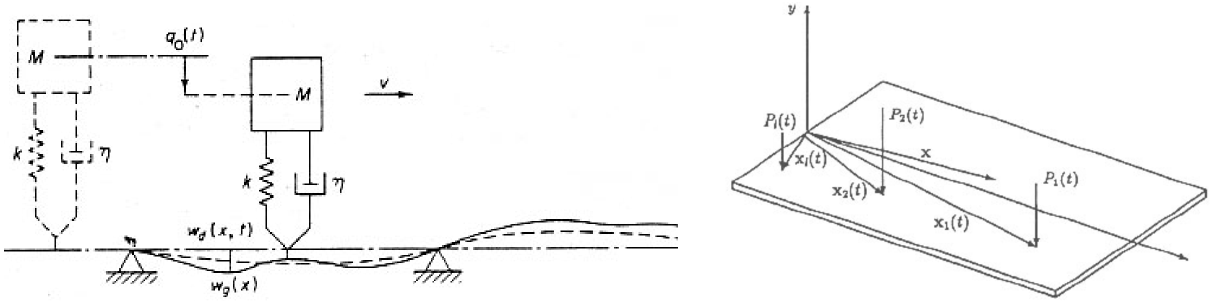

Figure 4: Examples of model for predicting the dynamic response of a bridge to a given vehicle [4],[5].

The determination of the dynamic actions between vehicle and bridge is possible also by means of the analysis of the vertical accelerations measured on a heavy vehicle axle running on the joint.

The device system consists of some accelerometers that measure the vertical accelerations of the axle or on the frame of the vehicle. Same strain gauges must be installed directly on the vehicle axle to have the exact measure of wheel load.

In Figure 5 is shown the acceleration diagram in the time domain in the case of “slanting” joint between abutment and deck of a motorway with a big unevenness due to a great rotation of the cross section in a short length.

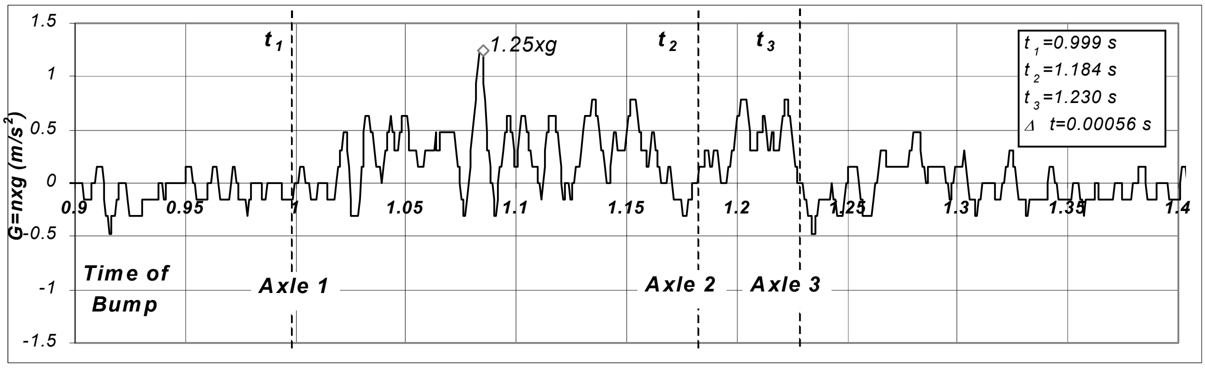

Figure 5: Accelerometric signal on front axle of 3-axles truck (Static axle load 6.94 t – Speed 107 km/h) [1].

In this test vehicle, when measured acceleration G is equal to 1 (1xg) than the dynamic wheel load is double of static value; instead, when measured acceleration G is less than 0 (1xg) the tires of the axle is not in contact with the pavement (loss of skid resistance).

2 VEHICLE-BEJ COMPUTATIONAL MODEL

An innovative approach for resolving the problem of dynamic interaction between heavy vehicle and BEJ is exposed (the work is in progress), taking advantage of the all purpose explicit finite element code LS-Dyna. In Figure 6 is shown the flow chart of this Computational Mechanic Model [6],[7].

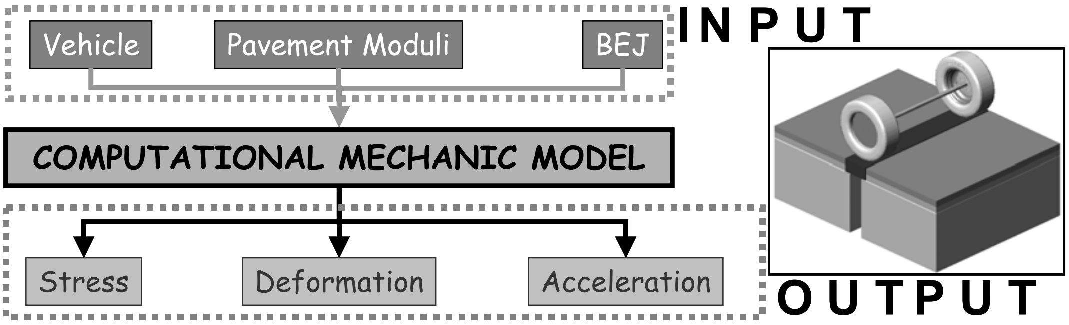

Figure 6: Flow chart vehicle-BEJ computational mechanic model.

2.1 Pavement and BEJ Model

The FE model of the asphalt concrete pavement and seismic BEJ to be tested is shown in Figure 7. It is a three layer model (two asphalt concrete and one cement concrete), with a total length of 22.4 m and a width of 4 m. The joint is in the middle of the strip, there is a 0.8 m hole in the lower layer, while the two upper layers are interrupted by the BEJ (2.00m long).

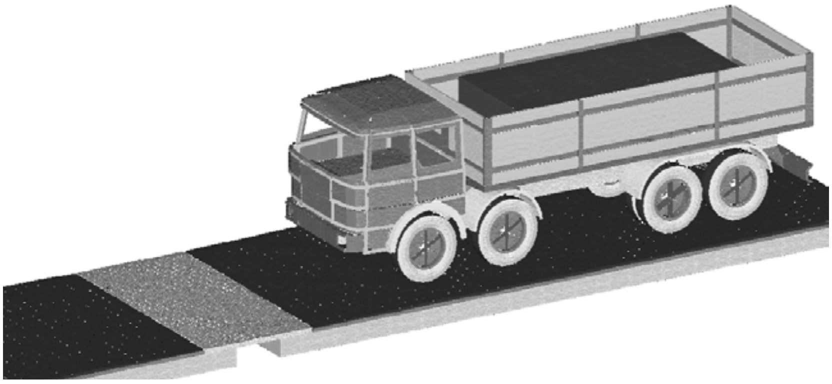

Figure 7: Vehicle-BEJ-pavement Computational Mechanic Model.

The joint surface is 3 cm lower than the rolling surface, so the upper pavement layers have a transition zone of 1.60 m before and after the joint to reach the appropriate height (Figure 8).

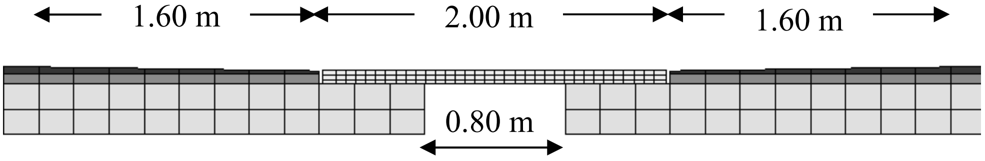

Figure 8: Pavement and BEJ model (detail of BEJ zone).

The pavement/joint model consists of 15540 brick (solid) 8 nodes elements. The materials used are linear-elastic for the lower layer (concrete slab-structure), and viscoelastic for the two asphalt concrete layers.

2.2 Truck Model

The vehicle model (Figure 9 and Table 1) was built initially to perform roadside hardware crash test simulations; the reference vehicle is the IVECO 180 NC, a 4 axles Heavy Goods Vehicle, with a net mass of 10,560 kg and a total mass of about 30,000 kg.

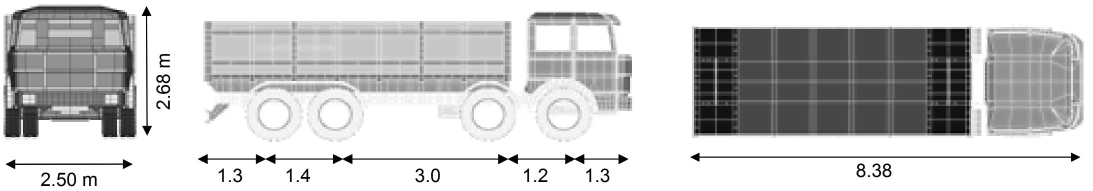

Figure 9: FE model of the 30 ton truck.

Element Type	***Shells***	***Solids***	***Beams***
Number	12,085	148	96

Table 1: FE model size of Test Truck

To reproduce correctly the dynamic effects and the vehicle behavior during the test, all the suspension system was reproduced, as shown in Figure 10. The reference truck has an old type of suspension, with elastic steel beams packed over each axle, and hydraulic dampers. These elements have been reproduced with a variable thickness shell beam. The axles, in the model, are steel beams. The main parts of the vehicle's structure use an elastic-plastic material model, with characteristics shown in the following abstract from the input file.

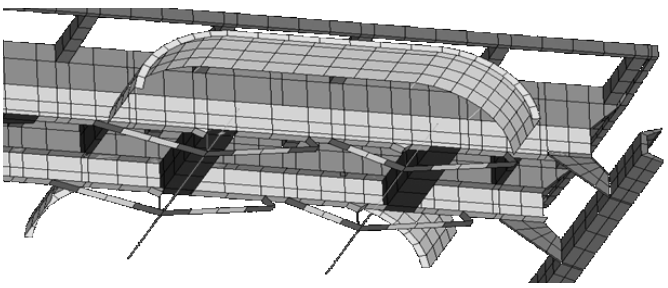

Figure 10: Detail of the rear suspension system.

The load is accurately transferred to the pavement because this vehicle is equipped with inflated tires and rolling wheels; the interface between the two bodies (tire-rubber and pavement) is realized with a contact surface with a Coulomb-like friction.

3 SIMULATION RESULTS: STRESS AND ACCELERATION

All the results are still to be considered as a preliminary output of this model, since many input data needs calibration. Infact, while is possible to study various joint types, vehicle speed and mass, pavement and structure geometry and characteristics, it is clear that the input parameters for the material model (viscoelastic) and the vehicle suspension system needs to be calibrated by a comparison with real world results (validation phase). When this phase will be over, it will be possible to make parametric studies varying the mentioned factors.

With the model it is possible to calculate the stress, strain and accelerations in every element of the structure; this is useful to verify the vehicle structure fatigue stresses (Figure 11a), thus evaluating the effects of an uneven joint and making a parametric study with different levels of uneveness (Figure 11b).

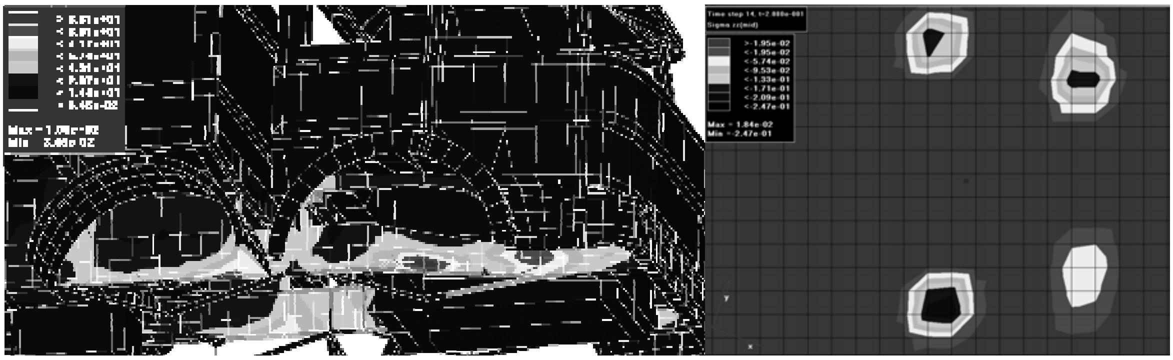

Figure 11: Stress level diagram on vehicle (a) and BEJ (b).

The accelerations, that can be measured in different nodes of the vehicle give information on the ride quality (Figure 12); it is also possible to put a virtual dummy (an anthropomorphic instrumented human body model) to have a better idea of the effects on the driver/passenger.

A new model is under development to determine dynamic effects on the bridge structure.

4 CONCLUSIONS

A Mechanic Computational Model to study the dynamic phenomena of interaction between heavy vehicles and irregular BEJ was developed.

The model allows to determine, varying the parameters of the vehicle (load, geometric dimensions and speed) and of the BEJ unevenness dimensions (amplitude and wavelength), the stresses and deformations of each pavement layer and on BEJ due to dynamic actions generated by the vehicle.

The deformations consequent to dynamic actions, calculated with this Finite Element Model, allow to determine the real reduction of the life cycle of pavement and BEJ with different level of irregularity (amplitude and wavelength).

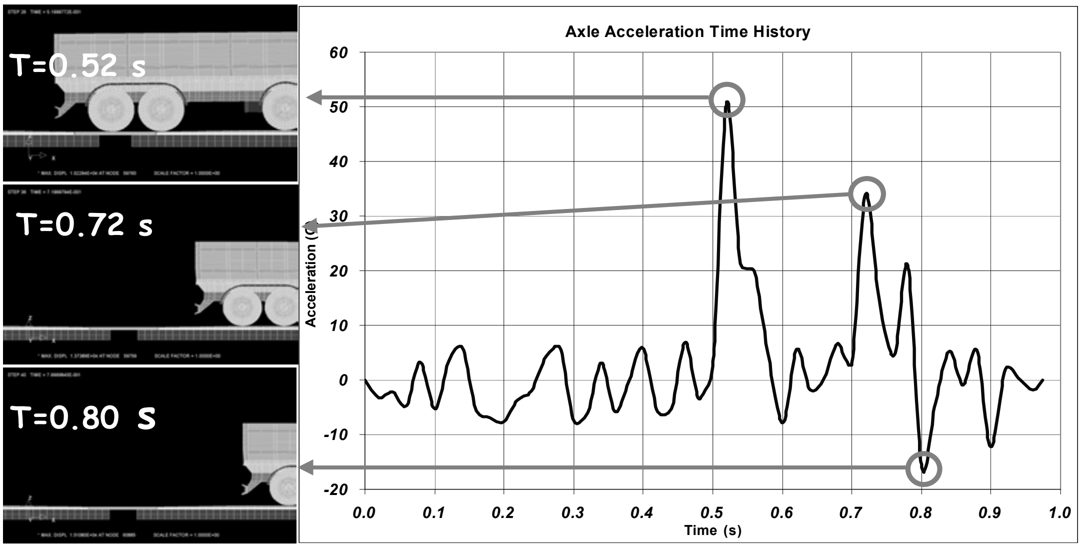

Figure 12: Acceleration diagram on rear axle.

Besides, the model allows to also determine the accelerations on the vehicle, to verify the Ride Quality of a uneven BEJ. A real test for different heavy vehicle and for many uneven BEJ are in progress to validate the model in different condition.

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