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Analysis of dynamic loads on lightweight footbridge caused by lorry passing underneath

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Abstract. This paper describes influence of cargo lorry traveling at high speed under a lightweight footbridge on the structure vibrations. The unsteady CFD simulations were performed to obtain aerodynamic load functions on the footbridge. These loads were introduced to nonlinear structural dynamics transient calculation to obtain footbridge response. The influence of aerodynamic forces was evaluated in terms of pedestrian comfort and safety. Parametric study of the influence of vehicle speed, structure clearance, cabin deflectors and distance between lorries grouped in convoy is also presented.

Key words: dynamic loads, lightweight footbridge, lorry.

1. Introduction

Proper dynamic response is a new challenge in bridge construction. Increasing span lengths and decreasing mass of structures due to introduction of new lightweight materials contribute to this problem. Modern, lightweight structures are more vulnerable to pedestrian and wind actions and need precise analysis. Aerodynamic interaction between fast moving vehicles and bridge construction has not been taken into account in classic bridge design procedure; however it might be a considerable load for some class of structures. Such analysis was made on the project stage of pedestrian steel arch bridge with composite polymer deck and CFRP stays. The structure will be constructed in year 2005 crossing new expressway nearby Poznań (Fig. 1).

2. Dynamic properties and design limits of lightweight footbridges

Dynamic design procedures have been incorporated into bridge codes worldwide not long ago. Different countries use different design criteria, mostly based on natural vibration frequency limits or maximum accelerations limits. DIN ENV 1992-2 (EU), SIA-Norm (Switzerland), Structures Design Manual (Hong Kong), Austroads 13,14,92 (Australia) and Footbridge design Code 1979 (Japan) introduce limits on natural vibrations frequencies. Din ENV 1995-2 (EU), BS 5400 Part 2 (Great Britain), RXP 95 and RPM 95 (Spain), OHBDC 1983 (Canada) and Structures Design Manual (Hong Kong) include admissible accelerations limit for the structures. In Poland the applicable document is the Decree of the Ministry of Transportation and Maritime Economy from 30.05.2000 about technical properties of road engineering objects and their localization [1]. Section referring to serviceability conditions of bridges includes natural frequency limit at minimum 3 Hz. However, engineering practice shows that fulfilling this requirement is only possible for small span lengths up to 30m. The relation between first natural frequency and span length has been provided by Bachmann [2], basing on experimental data from 67 footbridges with various construction (Fig. 2).

It is clearly visible that footbridges with spans longer than 30 m have problems with fulfilling requirements set by Decree [1]. Although there are exceptions and span length of 30 m is not a solid limit, however the regulation of dynamic properties by Decree [1] is rather too general. Maximum accelerations limit approach is available with Polish Design Codes, using PN-88/B-02171 [3] which sets acceleration limits for vibrations of buildings with people inside. This code is not mandatory for bridge design, however it provides precise scales and limits for accelerations.

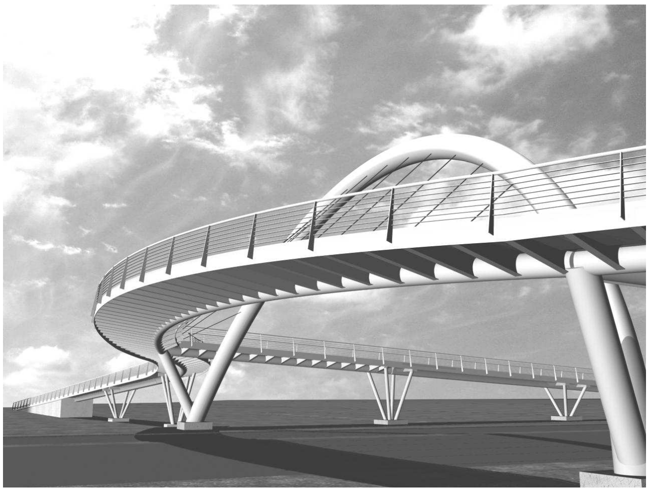

Fig. 1. Footbridge visualization

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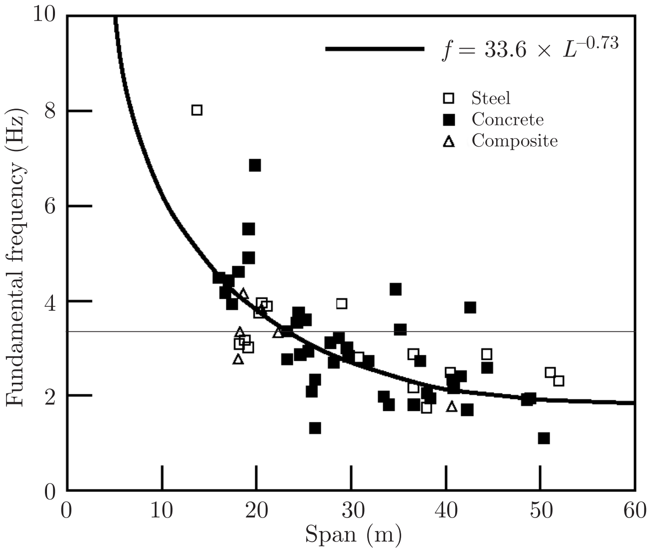

Fig. 2. Relation between footbridge span and 1st natural vibration frequency from Bachmann

Concluding the above, design of long span footbridges reduces their natural vibration frequencies. On the other hand using new lightweight materials makes them vulnerable to small exciting actions. Therefore a detailed analysis of all possible excitation sources is necessary, even if some sources were considered negligible.

3. Structural dynamics calculation methods

Analysis methods and loads need to be defined in order to use any frequency or accelerations based on serviceability criteria. Numerical problems of dynamic analyses are well described in Penzien-Clough [4] and Branicki-Wizmur [5]. However it should be noted that natural vibration frequencies and mode shapes are obtained from solution of eigenproblem in form:

$$(K - \omega^2 M)q = 0$$

where: K – stiffness matrix, M – mass matrix, q – mode shape vector (eigenvector), ω – eigenvalue.

Eigenvalues are useful to calculate natural vibration frequencies which are square root of eigenvalues. Resulting vibration frequencies can be referred to selected design criteria. Natural vibration frequency analysis is a common feature in many commercial FEM codes. Some of them can also include geometric stiffness matrix which allows analysis with primary stress state. This procedure is important for suspension and cable stayed constructions, as geometric stiffness is large fraction of total stiffness for these structures. In order to use accelerations based design criteria following methods may be used:

- steady state excitation (not useful for most bridge loads),
- mode shape integration with modal damping,
- direct integration of equations of motion.

However using any of these methods requires knowledge of load function, harmonic in case one and arbitrary for latter two methods.

4. Comfort criteria

Human perception of vibrations is quite good documented phenomena. Various codes describe admissible acceleration limits [6–8]. The most common representation of comfort criteria is limiting value of vertical and lateral accelerations depending on vibration frequency. However it should be noted that acoustics and vibrations of structural members eg. stay cables also shall be limited. Excessive noise and swinging motion of stay cables deteriorate overall perception of footbridge, therefore also reduce user comfort. These phenomena have rather psychological background; however bridge construction should not make impression of instability.

Threshold values for maximum admissible accelerations are collected in Flaga [9]. They differ according to the source; however there are clear correlations between results of these independent sources.

British Code BS 5400 [6] introduces a formula for footbridges with maximum vertical accelerations related to their vibration frequency:

$$a_{\max} = 0.5 \times f_w^{0.5}.$$

This formula produces 0.65 m/s^2 limit for 1.7 Hz, 0.7 m/s^2 for 2.0 Hz and 0.75 m/s^2 for 2.2 Hz. Bachmann and Amman [10] suggest threshold values from 0.5–1.0 m/s^2 range. Matsumoto et. al. [11] define the value of 1.0 m/s^2 as the threshold for threatening feeling of pedestrians. Tilly et. al. [12] assume BS 5400 requirements too sharp and propose a modified formula:

$$a_{\max} = 1.0 \times f_w^{0.5}.$$

Wheeler [13] defines the comfort criteria with maximum vibration speed of 24 mm/s. This is equivalent to 0.3 m/s^2 for 2.0 Hz. Eurocode 1995–2 [14] states that timber bridges and footbridges with natural vibrations frequencies below 5.0 Hz shall not be a subject to accelerations in excess 0.7 m/s^2.

Other values are proposed for lateral vibrations. According to tests results, walking people are much more sensitive to lateral than to vertical vibrations. Vertical motion is naturally composed into walking kinetics as opposed to lateral motion which is rather source of instability and resultant comfort decrease.

Leonhardt [15] suggests maximum lateral acceleration as 1/5 of maximum vertical acceleration. Bachmann's [2] proposition is to limit lateral acceleration to 0.1–0.2 m/s^2 together with limiting swing magnitude to 2 mm, because larger amplitudes cause locking of pedestrian's pace with structure vibrations. Eurocode 1995–2 [14] requires that timber bridges with lateral vibration modes under 2.5 Hz should not be subject to accelerations larger than 0.2 m/s^2.

5. Dynamic action on footbridge from compression wave of lorry passing underneath

The dynamic action of lorry's compression wave on lightweight footbridge has been mentioned in the paper of Firth [16] during "Design and dynamic behavior of footbridges

2002" conference. The problem was mentioned as a potential barrier on further lightening footbridges through introduction of lightweight materials. Following study of literature has shown that there was no interest in this action before. This kind of loading has been omitted as not significant for traditional heavy bridges mainly because it acts in opposite direction to dead load and also because energy needed to excite a heavy bridge is much larger than it is carried by a single lorry's compression wave. Lack of information about this phenomenon has been one of inspirations for this paper.

Similar research, however not directly related to analyzed problem was performed by Shin – Park [17] and Fujii – Ogawa [18]. Their work was related to fast railway and problems of trains entering the tunnel or passing each other in the tunnel. Both teams used CFD for unsteady flow simulations. Both teams also used moving mesh technology and interfaces to simulate flow around objects moving against each other. Obtained results were verified by scaled-down testing. Concluding these works, forces on tunnel walls and train body are related to:

- tunnel geometry
- train body geometry
- train speed
- clearance between train body and tunnel walls

The calculations presented in this paper utilize similar calculations ideas that were used by Shin-Park [17] and Fujii-Ogawa [18]. Performing these calculations required collecting relevant data on footbridge geometry, lorry geometry, clearances and vehicle speed. The following was assumed:

- structure clearance – 4.7 m over road surface – minimal bridge clearance for newly designed bridges over expressways and motorways – according to Decree of Ministry of Transportation and Maritime Economy from 30.05.2000 about technical properties of road engineering structures and their localization [1],
- lorry geometry – lorry height 4m – maximal vehicle height allowed for public roads in Poland,
- lorry speed – 90 km/h and 110 km/h – maximum allowed speed for lorries and relevant road design speed – according to Decree of Ministry of Transportation and Maritime Economy about public roads and their localization [19].

6. Methods

Every moving vehicle induces changes of pressure on its surface and also in some vicinity. These effects are related to airflow around moving body. Pressure disturbance zone size can be estimated to multiple vehicle lengths. Its shape and size are related to vehicle shape, size, its aspect ratio's and its speed. Determination of the airflow around the vehicle is possible using wind tunnel tests or computational fluid dynamics (CFD).

Airflow around a vehicle moving at a constant speed can be assumed to be steady in ideal conditions. When the vehicle with its steady pressure disturbance zone moves in vicinity of another object, the pressure disturbance zone must deform and steady flow assumption is no longer valid. Steady object and moving body introduce new pressure disturbances, which can be interpreted also by means of forces acting on the bodies.

The problem of a vehicle moving under a footbridge is not a typical task for wind tunnel testing. This task requires a setup in which fluid (air) is not moving and the vehicle (lorry) is moving. Typical wind tunnels allow simulations of moving air around not moving objects. They don't allow simulations of object moving relative to each other. The simplest way to setup testing for lorry and footbridge is to use real footbridge and real lorry.

CFD offers some more solutions to simulation of this phenomenon. Rapid increase of computational power in recent years allows finite element method and finite volume method to solve real problems.

6.1. The main idea of the proposed method. The solution can be divided into two separate problems, assuming that only the pressure wave generated by the moving object influences vibrations of the elastic structure without the feed back of the vibrating structure on the flow,. Firstly the transient aerodynamic load on the elastic structure caused by the moving object is determined. Afterwards the calculated aerodynamic load is used for computation of the elastic structure response. Normal procedure for existing structures analyses involves usage of the experimental data for definition of aerodynamic loading. The main innovation of presented work is that the computational fluid dynamic technique is used instead. Due to complexity of the computational problem the 2D model of flow is used with correction coefficient taken from simplified 3-D numerical simulation. It seems that presented work is the first one proposing solution of a problem of such complexity.

7. Computational fluid dynamics model

Simulations were performed using FLUENT 6.0 CFD code, based on finite volume method. Flow was treated as incompressible which is justified by small Mach numbers around 0.1 characteristic for flow conditions accompanying lorry motion. Therefore only momentum equations and continuity equations were solved. In order to account for turbulence a two equation $k-\varepsilon$ turbulence model was used. This model is based on turbulence kinetic energy k and its dissipation rate ε. The k equation is derived from exact solution, however ε equation is derived from averaged Reynolds stress tensor. Therefore molecular viscosity effects are omitted and fully turbulent flow is assumed.

Due to large computational complexity of the problem, basic calculations were performed with 2 dimensional symmetry plane of lorry. 3D effects were taken into account with simplified model which provided spatial distribution of pressure and load coefficient. Main problems with 3D model were related to large grid density needed to represent complicated footbridge cross-section. To predict total force acting on the footbridge deck, strongly influenced by the pressure variation in direction perpendicular to the truck direction of motion, a simplified 3D model was build and analyzed. Therefore 3D model with box cross section was made and lorry passing underneath simulation was performed. Assuming the same value of maximum force acting on the footbridge using 2D and 3D model, coefficient correlating both models was predicted. The same box cross section was used for a 2D test and peak loading force values from these two tests was used to define a spatial distribution correction coefficient.

Computational domain was divided to three areas:

– stationary upper part with footbridge cross-section – “sky”
– moving mesh zone with lorry shape – “lane”
– stationary lower part with road surface – “road”

Domain division scheme and used boundary conditions are presented in Fig. 3.

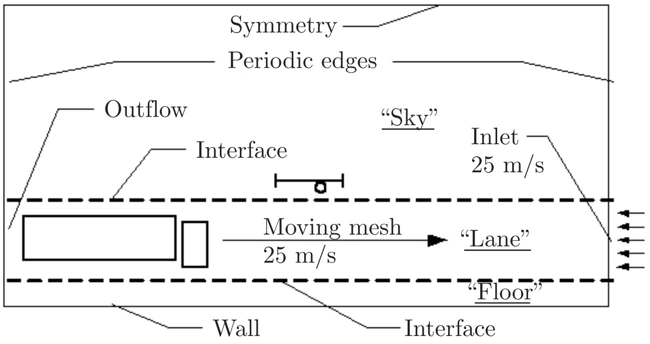

Fig. 3. Boundary conditions and CFD calculations setup

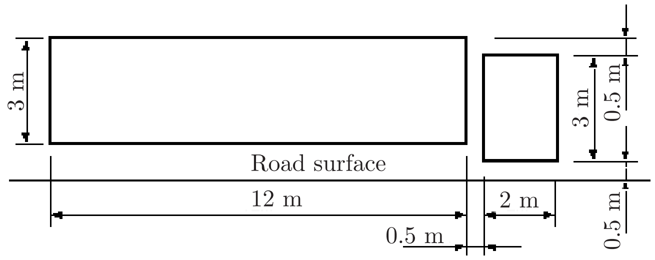

Fig. 4. Lorry geometry

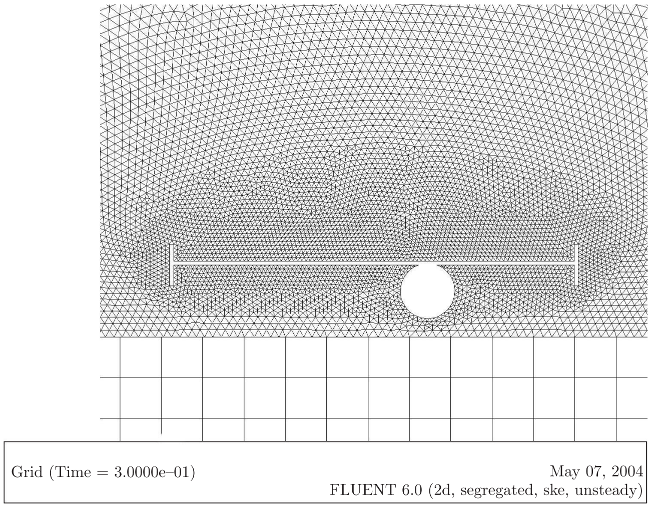

Fig. 5. Finite volume grid near footbridge cross section

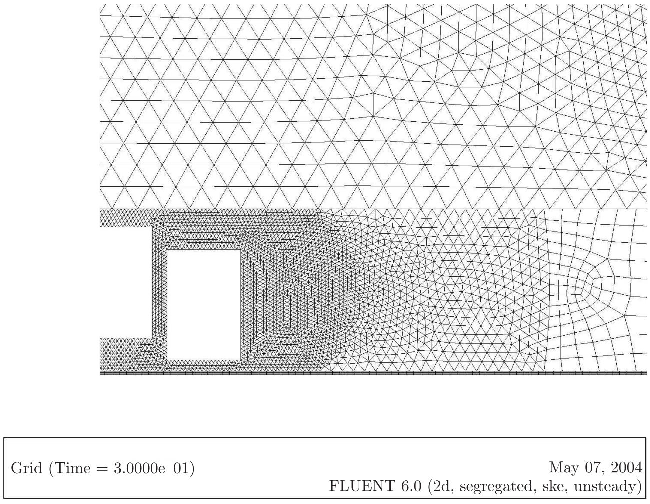

Fig. 6. Finite volume grid near lorry cabin

Interfaces and sliding mesh technique were used to connect stationary zones with moving zone. Sliding mesh technique allows coupling of zones even if the nodes on two sides of the interfaces do not coincide. The equation system is modified dynamically with nodes changing their positions. The scheme is presented in Fig. 3.

Lorry geometry was simplified to very basic shapes. The lorry with trailer and 40 ft. cargo container (Fig. 4) was used as a representative of common lorries found on Polish roads.

The most interesting results from civil engineer’s point of view are vertical and horizontal components of total force acting on footbridge.

Details of used finite volume grid are presented in Figs. 5 and 6. Plane finite volumes with 3 or 4 nodes and 1 m width in third dimension were used.

8. Initial conditions and boundary conditions

The cross section of footbridge was located 4.7 m over road surface. Lorry speed was set to 25 m/s = 90 km/h. This setup will be later referred as basic. Computational domain was initialized with following initial conditions (refer to Fig. 3):

– inlet – constant velocity of 25 m/s
– “lane” zone – constant motion 25 m/s in direction of vehicle motion
– “lane” zone air – constant flow velocity 25 m/s against direction of vehicle motion, velocity formulation relative to it zone.

These initial conditions represent a situation in which the lorry is instantly accelerated to 90 km/h. The vehicle is situated at distance of it’s 2 lengths from footbridge. This distance is large enough to facilitate steady flow around vehicle. Increasing this distance does not change the results and increases computations time. All calculations were performed with time step size of 0.01 s. Calculations were stopped when the vehicle has traveled at least one it’s length beyond footbridge.

Unsteady flow solution was obtained through implicit integration of fluid mechanics equations. Iterative time-step method was used, which updated geometry (moving mesh) in a time step, and then sought minimum of residuals in grid cell equations through iterative algorithm. Convergence criteria for continuity, momentum, k and ε were set at 10e–3. The solution was usually convergent after 20-25 iterations except for few time steps on the beginning of calculations.

9. Results of the calculations

Vertical and lateral forces from basic 2D calculations are presented in Fig. 7.

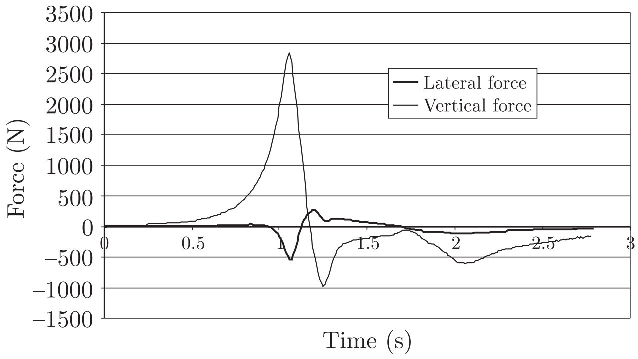

Fig. 7. Results of basic 2D calculations

10. Relations between 2D and 3D model

The aerodynamic load is not concentrated in some structure cross-section, neither it is uniformly distributed along the footbridge deck. A 3-D simulation is necessary to obtain the load distribution in direction perpendicular to the lorry motion.

The additional calculations were performed to determine effects of introduction of third dimension. Due to complexity of the problem and limited power of present computers some simplifications were made. An assumption was made that the footbridge cross section shape has negligible influence on load distribution in third dimension. Therefore simplified geometry of rectangular beam was assumed for the 3-D test (as shown in Fig. 8 and Fig. 9). The beam cross section with dimensions of 0.5 m × 5 m was placed 4.7 m above road surface. The same lorry geometry was used with width of 2.5 m. In order to decrease the computations time symmetry was assumed in symmetry plane of the lorry. Figures 8 and 9 show visualization of surface meshes for 3D calculations. 2D box section mesh was made with the same philosophy as in 2D true section calculations setup.

11. Spatial effects

3D flow around the lorry causes additional outflow form symmetry plane to sides of the body. Figures 10–15 show pressure distribution on the underside of footbridge in characteristic moments of the lorry passage (Fig. 16).

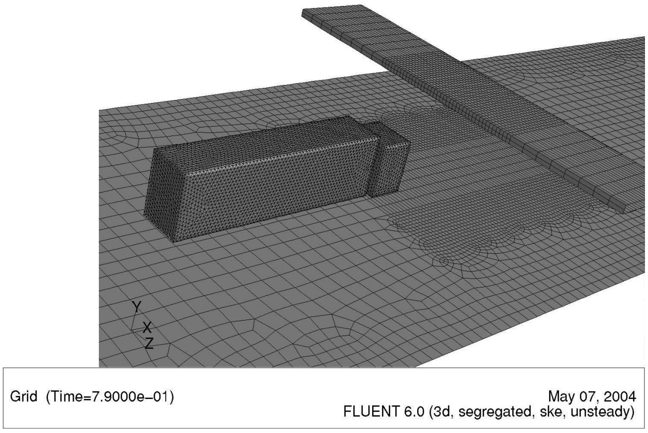

Fig. 8. 3D test surface mesh

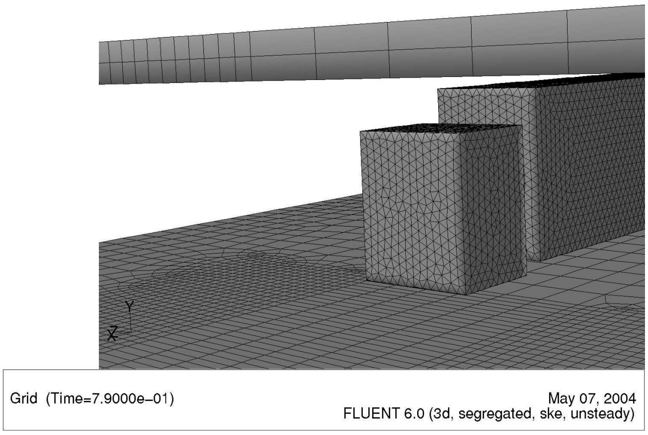

Fig. 9. 3D test surface mesh

12. 2D to 3D correction coefficient determination

After the basic setup calculations, 2D and 3D box section calculations were performed. Results are presented in Figs. 16 and 17. Having 3-D calculation results and 2-D calculation results of the lorry-footbridge interaction for the same simplified geometry of the footbridge it is possible to find the 2-D to 3-D correlation coefficient representing the effect of perpendicular aerodynamic load distribution.

It seems that character of the load function is quite similar for these two cases. The “suction” effect is more significant for 3D case, however it should be noticed that overall “suction” force is smaller than lifting force which is dominant. Therefore as long as full 3D calculations with true footbridge cross section are not possible a constant scaling coefficient is a reasonable solution. The value of coefficient has been defined as value giving the same peak lifting force from 3D and 2D calculations:

$$p_{3D}(t) = p_{2D}(t) \times b \times c$$

where $p_{2D}(t)$ – 2D model load function $[N/m]$, $p_{3D}(t)$ – approximate load function $[N]$, b – truck width, $b = 2.5$ $[m]$, c – spatial distribution correction coefficient.

Value of c equal 0.55 has been found as appropriate for considered geometries.

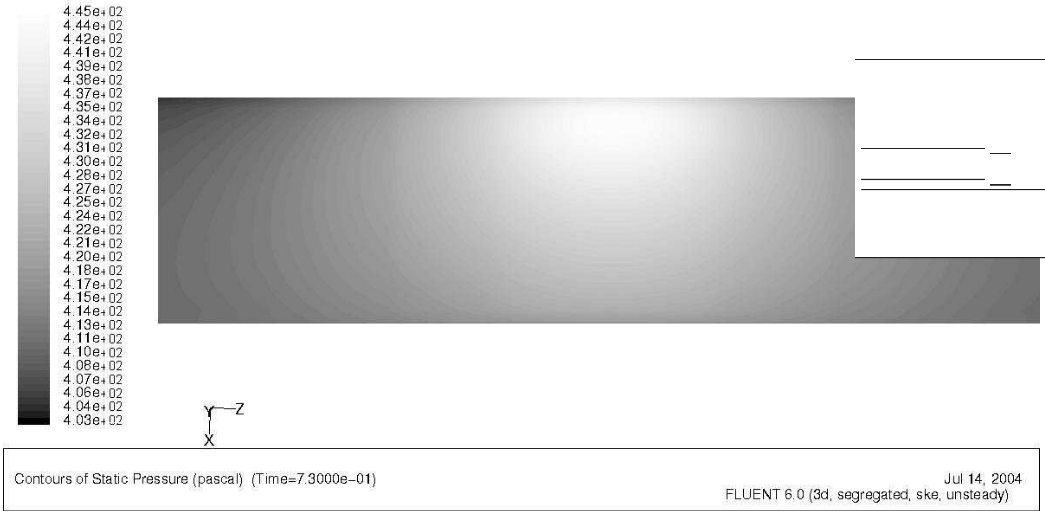

Fig. 10. Pressure distribution on footbridge underside at t = 0.73 s

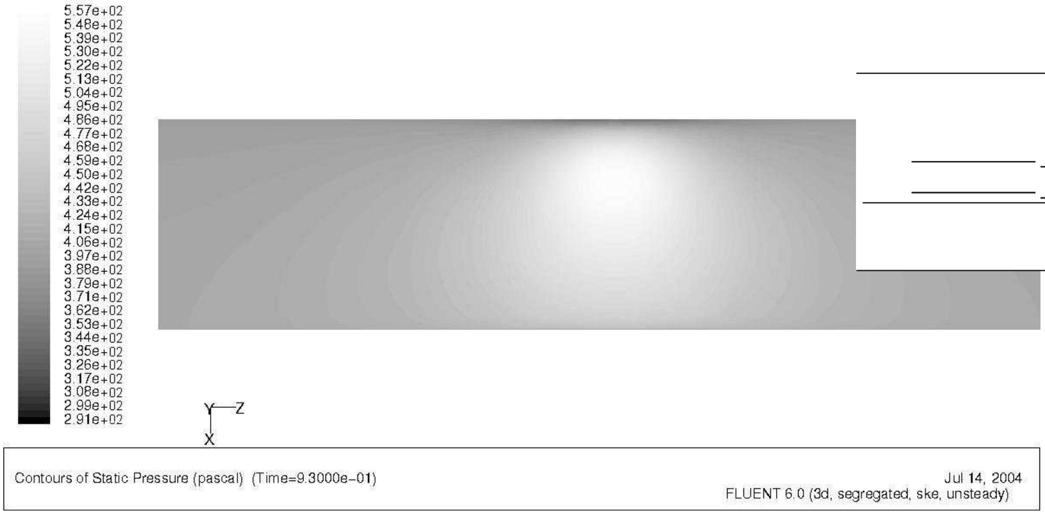

Fig. 11. Pressure distribution on footbridge underside at t = 0.93 s

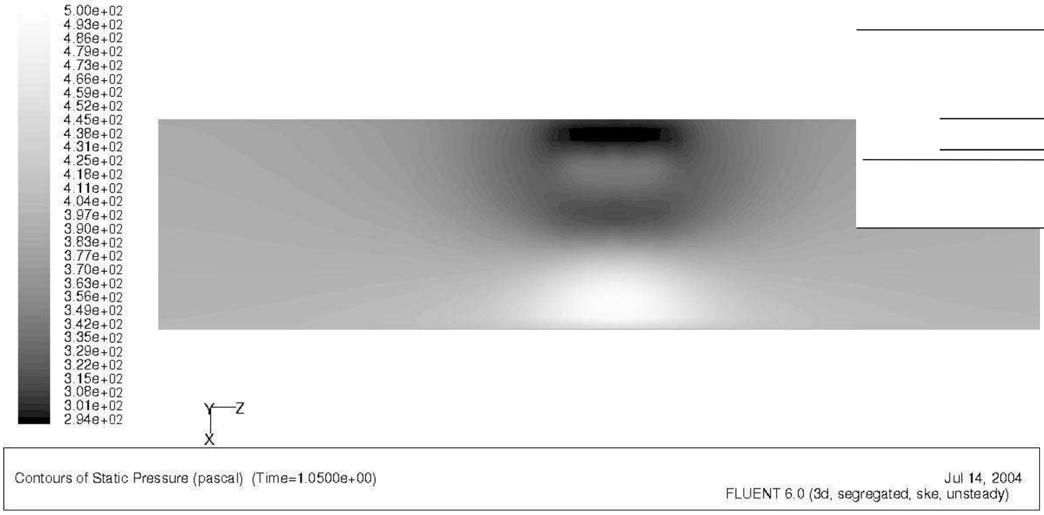

Fig. 12. Pressure distribution on footbridge underside at t = 1.05 s

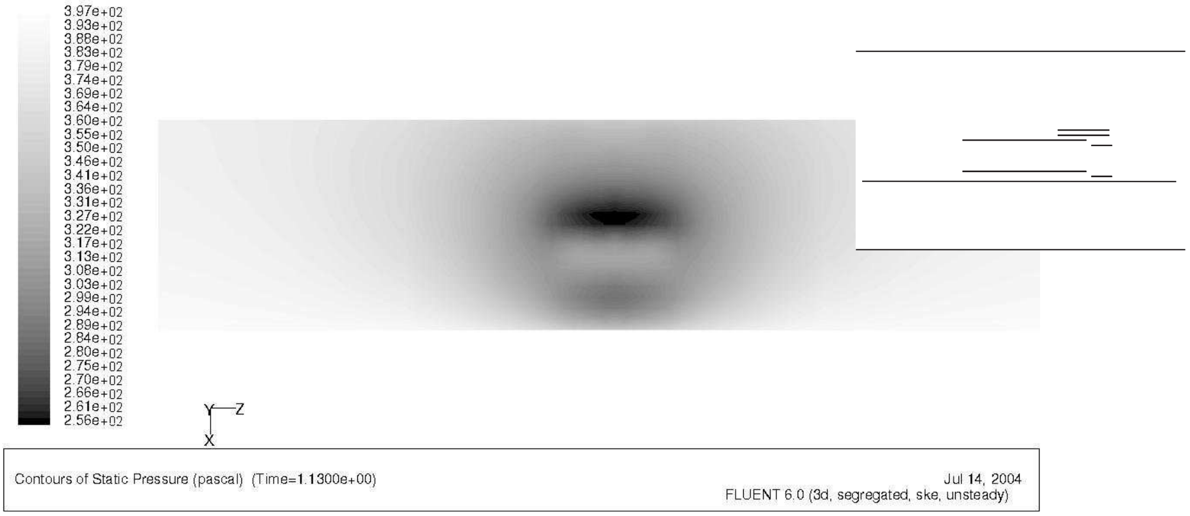

Fig. 13. Pressure distribution on footbridge underside at t = 1.13 s

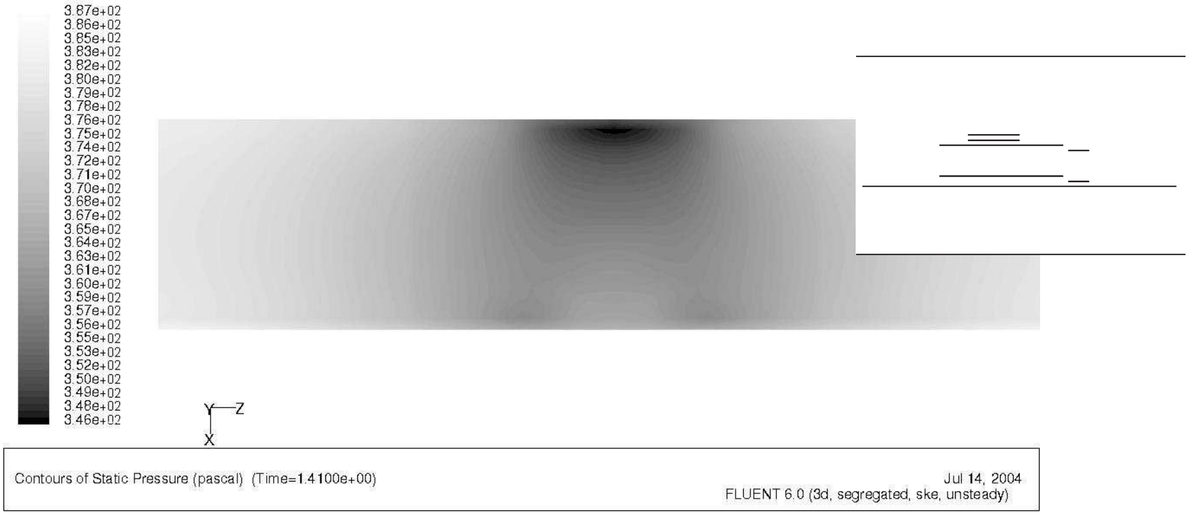

Fig. 14. Pressure distribution on footbridge underside at t = 1.41 s

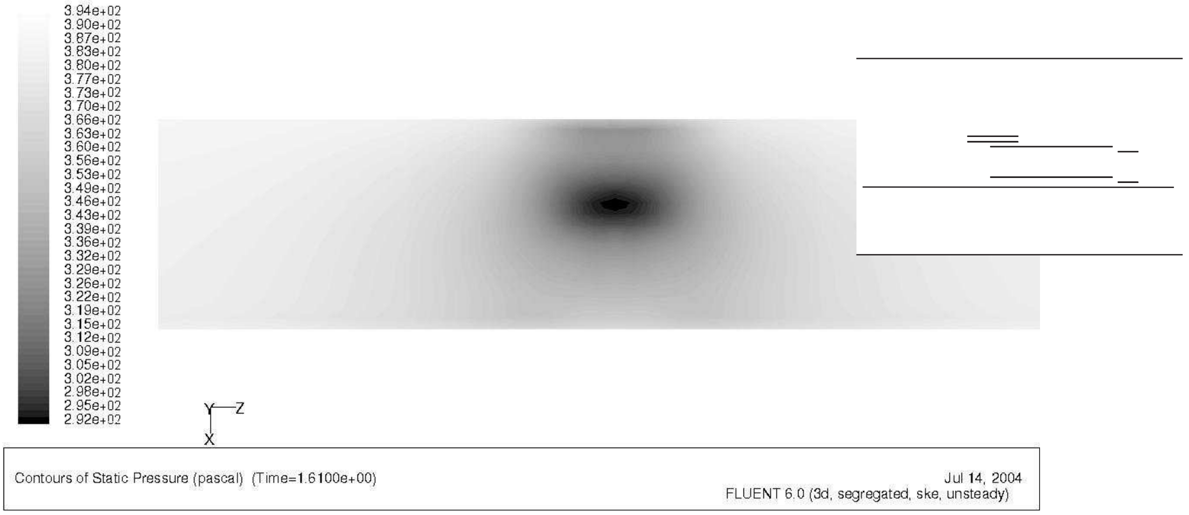

Fig. 15. Pressure distribution on footbridge underside at t = 1.61 s

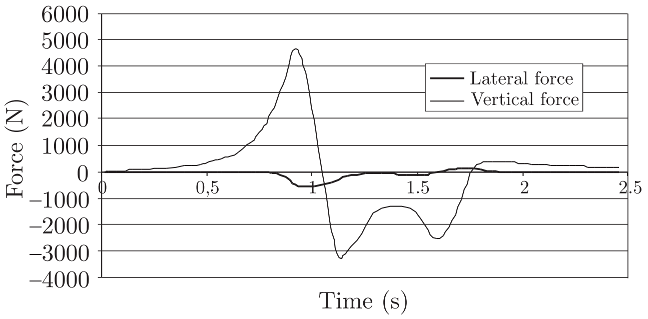

Fig. 16. 3D box cross section test results with characteristic moments of lorry passage

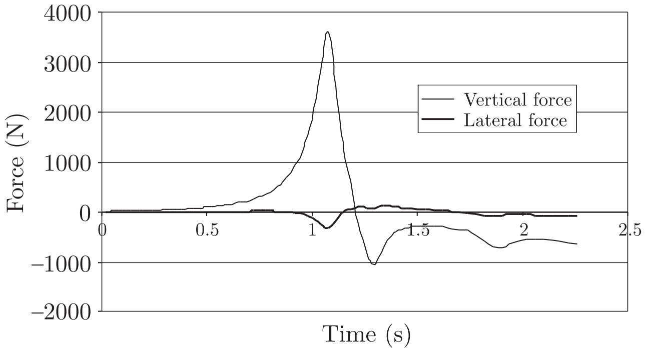

Fig. 17. 2D box cross section test results

Proposed approach allows qualitative estimation of load functions for arbitrary cross-section of similar size, using only 2D flow field calculations.

This method predicts of load functions acting on a footbridge by multiplying results of 2D calculations by c coefficient and truck width b. This estimation shall be correct as long as the geometry of lorry and footbridge clearance are the same as in 3D box section calculations.

13. Parametric analysis

Basing on the presented calculations procedure, parametric calculations were performed. 2D models were used with key parameters influencing load functions changing with every calculation. All analyses were referenced to basic setup mentioned above. The results of the analyses are not multiplied by c scaling coefficient. Parameters chosen for the analysis are:

- – structure clearance
    - clearance 4.7 m
    - clearance 5.2 m
    - clearance 5.7 m
- – lorry speed
    - 25 m/s (90 km/h)
    - 30 m/s (108 km/h)
    - 35 m/s (126 km/h)
- – cabin chassis shape
    - without deflector
    - with deflector (3rd order polynomial curve)

Additional analysis was performed to test ability of convoy of lorries to create a periodic excitation force. This analysis was performed to check forces created on footbridge by lorry traveling in another lorry's wake.

Analysis of influence of structure clearance on values of loading function is a good hint for lightweight footbridge over motorways design. Raising clearance seems to be an useful method of reducing forces acting on footbridge (Fig. 18).

Analysis of influence of vehicle speed on values of loading functions is very important for objects located over motorways and expressways. It should be noticed that current speed limits may be changed in future, as loading from vehicles on bridges changed in the past. Results of lorry's passage with different speeds are presented in Fig. 19.

All former calculations were performed with lorry geometry that is not likely met on polish roads. Flow deflectors over the cabin chassis are common devices, as their introduction allows reduction of fuel consumption. The lorry without deflector was believed to produce more disturbances in surrounding air, therefore considered to produce higher load values on footbridge which is more unfavorable case for the construction. Details of the cabin with and without deflector are presented in Fig. 20.

The plots presented in Fig. 21. show that there is very little difference between lorry with and without cabin chassis deflector. The deflector seems to reduce lifting force and increase the suction force.

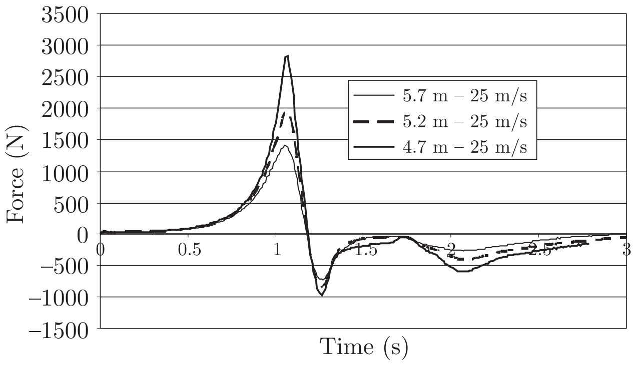

Fig. 18. Vertical force component with different structure clearance

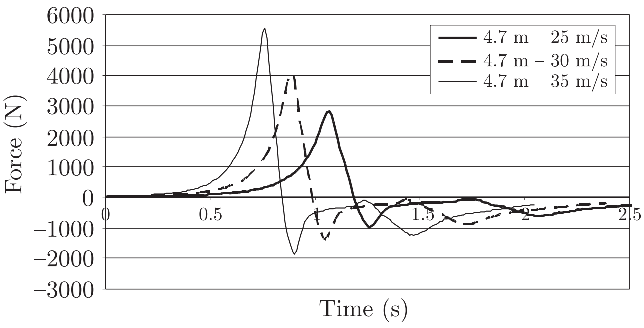

Fig. 19. Vertical force component with different lorry speed

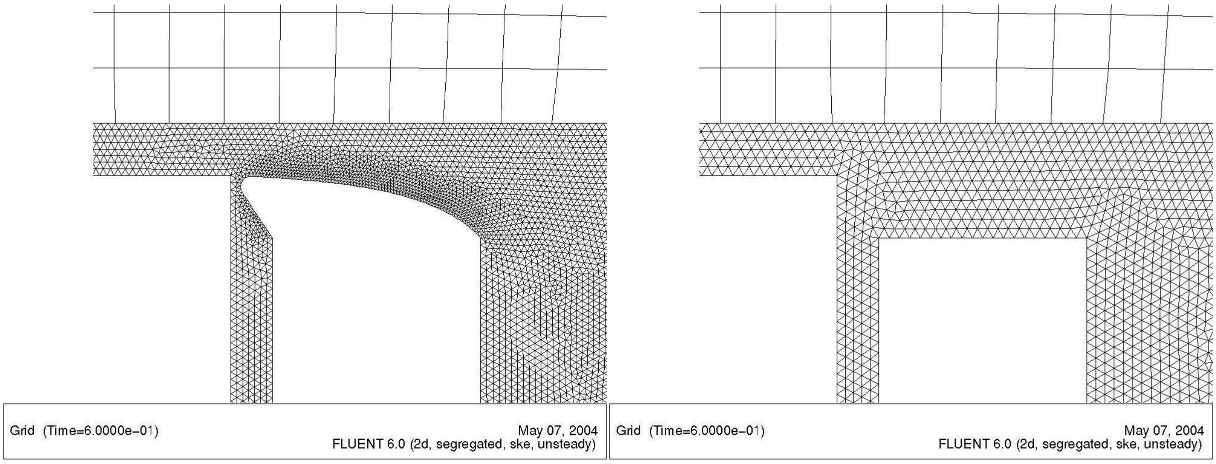

Fig. 20. Geometry of cabin with and without deflector

The last analysis is about possibility of periodic excitation. It is known that given small damping even little periodic force can cause quite large excitation. Lorries often travel in convoys, where several vehicles are separated by ca. vehicle length. Therefore it is possible that if every lorry in convoy created action on footbridge equal to single lorry that the footbridge may undergo periodic excitation.

Three convoy configurations were tested with following spacing:

- 6 lorries with 25 m head to head (10.5 m spacing)
- 4 lorries with 37.5 m head to head (23 m spacing)
- 3 lorries with 50 m head to head (35.5 m spacing)

Results are presented in Figs. 22–24.

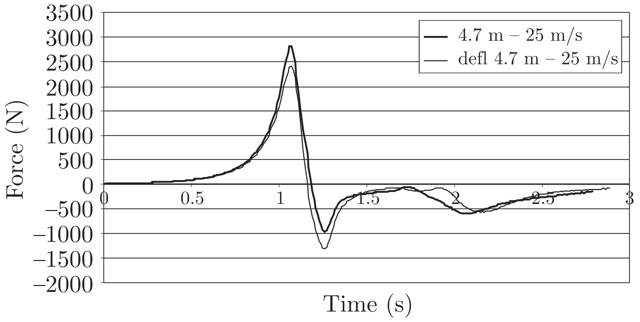

Fig. 21. Vertical force component for lorry with and without deflector

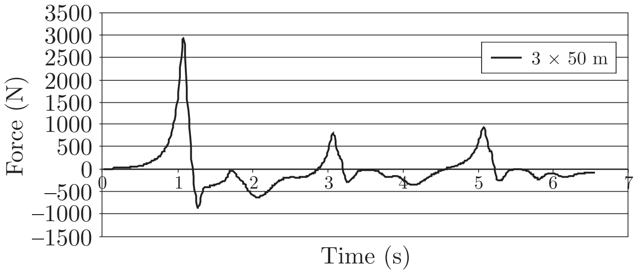

Fig. 22. Vertical force component for 3 lorries at 50 m head to head distance

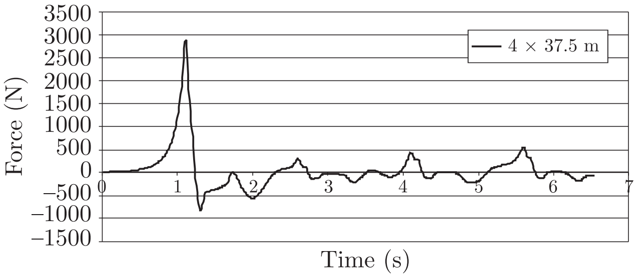

Fig. 23. Vertical force component for 4 lorries at 37.5 m head to head distance

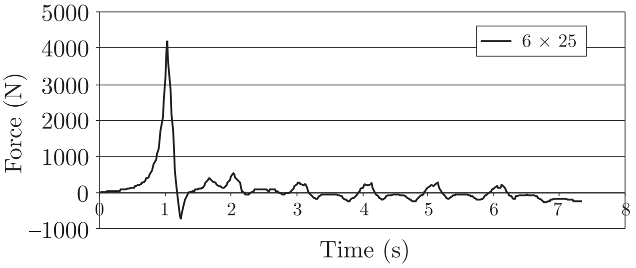

Fig. 24. Vertical force component for 6 lorries at 25 m head to head distance

14. Structural dynamics analysis

Load functions obtained from CFD constitute considerable exciting forces if compared to other sources of footbridge excitations. Jumping man may have a dynamic coefficient of 2.5, assuming man weight of 750 N, total impact force applied to structure is 1875 N. Peak value of loading caused by lorry passing under the footbridge is $F_{\max} = 3600$ N. Therefore an assumption is possible that lorry passage is comparable to two men jumping on the footbridge. Dynamic response of construction is of course dependant on structure itself, however there are known footbridges that can be excited to human perceptible level of vibrations by two jumping men.

Table 1
Basic design data for recently built footbridges

Footbridge	Erection date	Span length	Construction	Deck weight
Wilcza Street, Szczecin, Poland	1999	32 m + 9 m	Cable stayed with reinforced concrete deck	400 kg/m^2
Wołoska Street, Warszawa, Poland	2000	63 m + 14 m	Cable stayed with orthotropic steel deck	181 kg/m^2
Kolding, Denmark	1997	27 m + 13 m	Cable stayed full FRP construction	70 kg/m^2
No. 11 expressway near. Poznan, Poland	Planned 2005	40 m	Inclined steel arch with FRP deck	85 kg/m^2

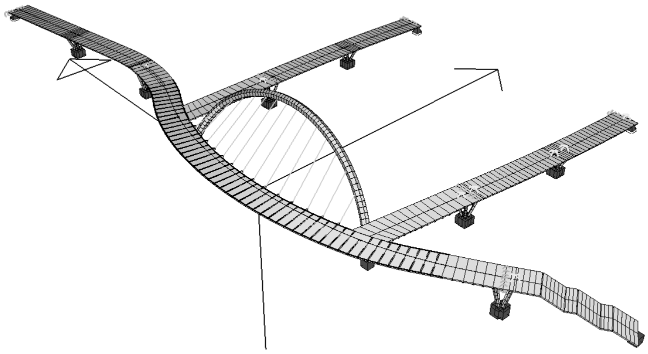

Fig. 25. Structural dynamics model visualization

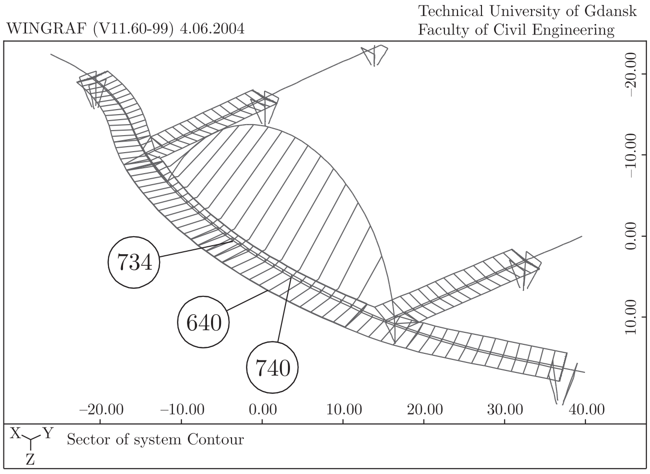

Fig. 26. Nodes selected for accelerations plots

Current trends in footbridge design utilize lightweight materials (Aluminum, GRP, CFRP) and importance of this loading type may increase in future. Three recently built and one designed footbridge with their basic properties are presented in Table 1. Additional information about deck weight is provided.

The examination of dynamic response of footbridge over road No. 11 Poznań Kórnik was performed with use of FEM model of construction (Fig. 25). The model for dynamic analysis was stripped of elastic foundation elements, as vibrations were considered to small to include displacements in underground part of structure.

Another important aspect of analysis is point of loading selection. An assumption was made that lorry is traveling on the middle lane of three lane road. This was considered as most unfavorable for structure, as selected point of loading was also point of maximum displacements in 2nd natural vibration mode shape. Stiffness proportional damping at 0.0002 and mass proportional damping at 0.2 was assumed. Basic setup CFD calculations were used with structure clearance of 4.7 m and lorry without deflector traveling at speed of 90 km/h.

Structural dynamics DYNA program, part of SOFiSTiK FEM software suite was used for transient nonlinear structural dynamics simulation. Direct integration of equations of motion was used with implicit Newmark-Wilson procedure. Time step of 0.005 s was used. Total simulation time was set at 15 s to allow free damped vibrations after lorry has passed. Selected nodes of model were traced for accelerations and displacements (Fig. 26). Accelerations in Z direction are presented on plots in Fig. 27.

Resulting accelerations reach peak values of 0.33 m/s^2 for vertical motion and 0.049 m/s^2 for lateral motion. These values are acceptable with respect to comfort criteria presented above.

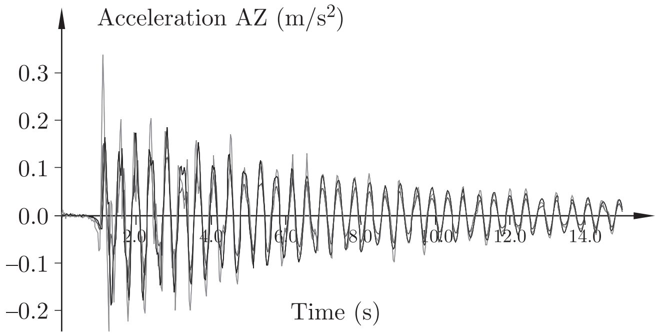

Fig. 27. Vertical accelerations of the deck

15. Conclusions

Development of structure which is not typical in form or material solutions requires additional analysis not necessary in traditional design methodology. Omitting such analysis can lead to bridge structures in agreement with formal restrictions but practically useless or having limited serviceability.

The presented work shows one of possible ways, taking into account currently available power of computational method, of solution to very complicated problem of moving object and elastic structure interaction. Up to now such analyses seemed to be too complicated and practically impossible. Proposed method of using simpler 2-D simulation and extension of calculation results to the 3-D case using only simple correction coefficient seems to be reasonable and efficient. It seems that in engineering practice many similar problems can be solved in proposed way.

Modern computers and CFD software give possibility to simulate dynamic processes which was not available before due to its complexity. It has been demonstrated that air impact phenomena caused by the fast truck passing under the footbridge can be effectively simulated and response of the structure can be estimated.

As have been shown, proposed method can be effectively used for parametric studies showing the range of potential danger and possibility of reducing some negative effects of analyzed phenomena. For example, it seems that the simplest and most effective way of reducing the dynamic interaction between traffic and the light bridge structure is increasing the structural clearance. The convoy of lorries is not more dangerous than a single moving lorry. The lorry without deflector reducing the vehicle drag is marginally more danger for the footbridge structure than an ordinary lorry. The most important factor is the lorry velocity. The aerodynamic load increases with the second power of velocity. As it has been shown (Fig. 19) that lorry mowing only 40% faster generates two times higher aerodynamic load of the footbridge.

Some of presented conclusions can be found on the basis of general laws but numerical simulation gives the possibility of more precise predictions of aerodynamic forces. Therefore it could be possible to go to quantitative prediction instead of qualitative only.

For the presented design the influence of lorry passing under lightweight footbridge structure is treated as at least perceptible for pedestrian. The tendency to use new lighter materials in the footbridge construction, will lead to higher deck accelerations from vehicle traffic dynamic actions. Therefore the described phenomenon may be one of more important dynamic loads on footbridge construction in near future.

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