ENGINEERING TRANSACTIONS • *Engng. Trans.* • **54**, 1, 35–50, 2006
Polish Academy of Sciences • Institute of Fundamental Technological Research
10.24423/engtrans.405.2006

BEHAVIOUR OF STEEL-SOIL BRIDGE STRUCTURE MADE OF CORRUGATED PLATES UNDER FIELD LOAD TESTS. PART II: DYNAMIC RESEARCH

Z. M a ń k o[1)], D. B ę b e n[2)(*)]

[1)]**Wrocław University of Technology**
Civil Engineering, Institute Bridge Division
Wyspiańskiego 27, 50-370 Wrocław, Poland
e-mail: zbigniew.manko@pwr.wroc.pl

[2)]**Opole University of Technology**
Faculty of Civil Engineering, Division of Geotechnics and Geodesy
Katowicka 48, 45-061 Opole, Poland
e-mail: dbeben@po.opole.pl

The paper presents the results and conclusions of dynamic load tests that were conducted on a road bridge over river Gimån in Sweden (the first bridge of this type in Scandinavia) made from *Super Cor* corrugated steel plates. Conclusions drawn from the tests can be mostly helpful in the assessment of behaviour of this type of corrugated plate bridge with backfill. In consideration of application of this type of structure in the case of small-to-medium more and more frequent span of bridges, the conclusions from the research will be generalized to all types of such solutions.

1. Introduction

The subject of this paper is a *Super Cor SC-56B* steel-arch bridge, made of corrugated plates, over the river Gimån on the Bråcke – Holm road (no. 716) in Sweden. This structure was subjected to thorough study [1–3].

The paper presents set up a main research team who carried out the examination on the bridge. Vertical and horizontal displacements as well as strains were measured at selected points and principal sections of the shell in two directions and in four basic stages during which:

- soil was compacted in layers over the shell structure during construction. This was done six times of which each layer was of a different thickness (stage I) [2];

(*) Author is a scholarship holder of the Foundation for Polish Science.

- bridge was under static load tests (stage II) [3] as well as;
- dynamic load tests (stage III) [4]; and
- in service examination.

Prior to commencement of the test, strain gauges were attached to the steel shell and before placing the next backfill layer to avoid destruction or damage of the strain gauges, inductive gauges and dial gauges were installed under the span, and the accuracy of all the gauges and measuring apparatus specified for the test was checked [2, 3].

In the papers [1] and [3], detailed description of the bridge structure, measuring apparatus, range of studies under the static load test, the results, analysis of the different magnitudes obtained from measurements in the test, their calculations and conclusions were presented. Corresponding and appropriate shell durability tests as a result of loads pressure exerted by the subsequent backfill layers were described in the work [2].

The main aim of the paper is to present the results of the research on the new bridge in the dynamic load test domain of studies (first done in Europe – stage III) as the basis upon which the quality of realization, durability, critical speed magnitude, dynamic coefficients, coefficient of velocity, vibration frequency were determined [3]. Due to the important location of the bridge in the road network of Sweden (the first of its kind in all Scandinavia [1]) and considering its prototypical character as well as the comprehensive and thorough research on the structure together with the detailed analysis of the results obtained (from analysis of displacements, strains and dynamic effects), the conclusions derived from this complex study can be very helpful in engineering practice, especially in the field of research control and acceptance of carried out tests and examinations during construction of steel bridges made from corrugated or flat plates (particularly in bridges of similar geometric structure and similar material characteristics) [5–8].

2. Problem formulation

Loads moving across the bridge at high speeds cause vibration of the bridge structure, impact as a result of rough road surface and unequal deflections of the car springs, etc. Dynamic reaction stress exerted on elements of the bridge structure as well as the strains caused by mobile rolling stock become bigger than in a similar weight or static state; that is that slow placement of immobile rolling stock of the same or similar materials. The exact calculations of the bridge dynamics considering all the factors mentioned the vibration of the structure and possibilities of resonance of the bridge require exceptionally complicated calculations, which do not yet yield an absolute satisfactory solution. All research performed so far, are limited only to certain simplified theoretical cases such as single force loads, use of insensitive bridge span (for small spans) or avoidance of the weight of a moving load in relation to large load span (for large span) [9–11]. These researches give specific prognosis with respect to span behaviour or span behaviour under dynamic load also point to new directions of research but have not led to any general accessible (existing) method for dynamics calculations of bridges.

This is why many countries, to consider the dynamic effects in calculations in bridges, use coefficients of dynamics $\phi \geq 1$ through which force or moments in bridges, calculated for static loads in the most severe position of a given element, are multiplied to account for impact.

Values of the dynamic coefficients given in regulations and codes are mainly not based on research that is more precise but accepted by tradition, often copying regulations passed on by other countries, with the simple explanation that it is satisfactory in the cases of most established bridges. Hence, as long as the bridge works in boundary of elastic strains, a dynamic coefficient can be accepted as deflection relations e.g. in the mid-span under the impact of a rolling load with a required velocity to deflection of the same static load. In regard to flexible steel-soil structures there are no specifications and guidelines for the calculation of dynamic effects (e.g. dynamic coefficient, logarithm of damping decrement, etc.), yet more to a greater extent is the vacancy existing in the analysis of such bridges subjected to dynamic effects.

Generally, the dynamic coefficient value is related to the so-called critical speed of the truck and the value of the greatest vibration amplitude that occurs. This velocity can be calculated using many tests (movement of the same load at different speeds across the same bridge).

Detailed description of the tested bridge structure was presented in Part I of this paper.

3. The range of conducted research

For the dynamic tests (conducted for the evaluation of effects trucks have on the magnitude of strains of corrugated plates and their deflections at selected cross-sections of the shell), two inertial inductive gauges type *PEVA 7225* A and B were fixed at the edge of roadway and reinforced concrete collar and strain gauges 00 and 01 for strains measurements in the repetitive transversal and longitudinal directions of the bridge, located on top of the corrugated plates within the effective span (Fig. 1), the time courses of which have been registered on the PC computer. In course of the research it was taken to change the measured parameters of dynamic load diagrams, graduation device, and series of additional loads (repetition of the process). In the process of the research, all efforts were made to keep the route of the car each time the same in order to make it possible for comparison of results obtained. In the opposite situation, change in the route of the truck in a cross-section of the roadway makes it possible for direct comparison of the results obtained.

Schemes of dynamic load have been drawn in such a way to identify:

- inertia effect and speed of moving load,
- state of resonance caused in cycles of moving loads,
- influence of intensive braking of a loaded truck,
- influence of imbalanced threshold and imbalanced road surface,
- natural frequency and logarithm of damping decrement assigned by basic forms of natural vibration of examined structure span.

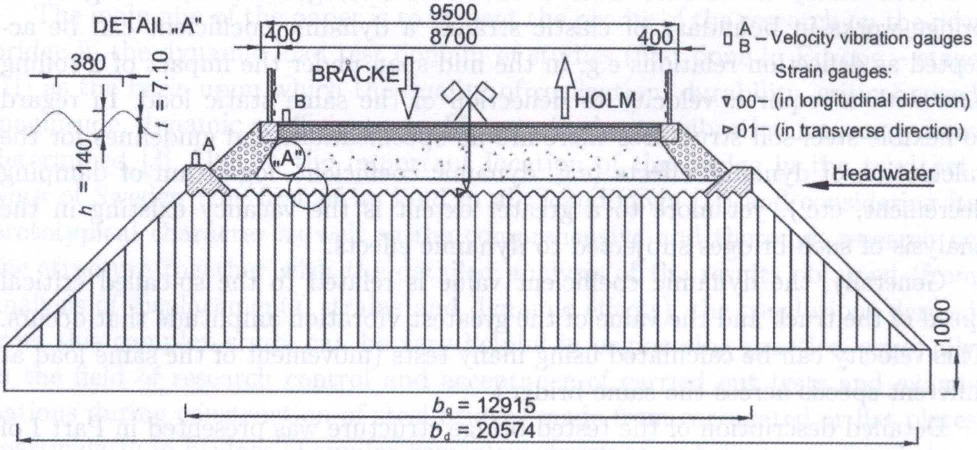

FIG. 1. Cross-section of a road bridge situated in Gimån in Sweden together with location of the gauges serving to dynamic measurements.

During the dynamic research, a truck *Scania 500 143H* mark was used. Detailed characteristics of the truck were given in paper [3].

The speeds of the moving truck on the bridge (used earlier in the static tests – Part I) were estimated as follows 5, 10, 20, 30, 40, 50, 60 and 70 km/h in both directions. Measurements of dynamic interactions were taken also when the truck was moving across threshold of 0.03×0.20 m fixed at half way of the bridge distance perpendicular to the longitudinal axis of the roadway (Fig. 2) and during its braking (Fig. 3) with various different velocities at different distant points of the bridge.

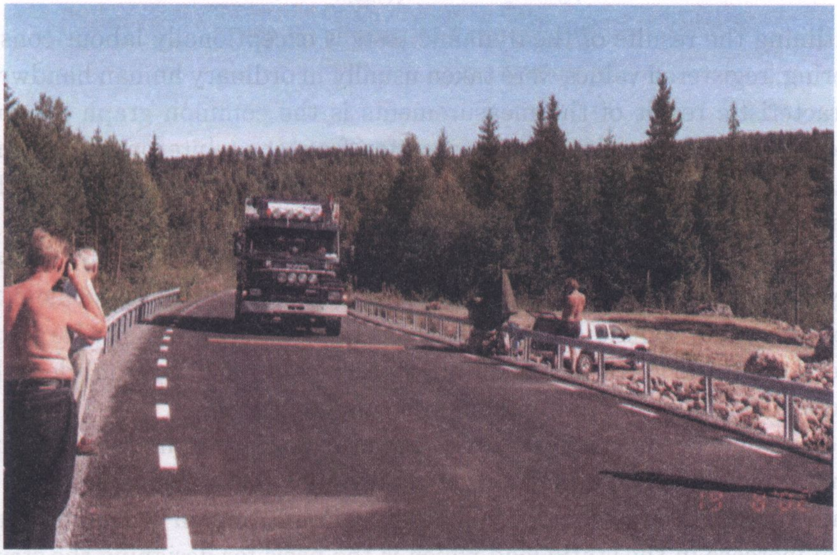

FIG. 2. Front view on the *Scania* vehicle passing with a speed of 40 km/h by the threshold.

FIG. 3. Passing and braking the *Scania* vehicle on the bridge with a speed of 60 km/h.

4. The method of study of test results

Outlining the results of the dynamic tests is exceptionally labour-consuming and boring, registered values were taken usually in ordinary human handwritings. A characteristic result of the measurements is the common graph of vibration and movement and/or velocity and vibration frequency. Interpretation of results of measurements is difficult and a number of them can be ambiguous (not having unanimous implication).

The basically parameter obtained is a dynamic coefficient. Characteristic for it is dynamic load of structure in comparison to static load. It is calculated as ratio of maximum dynamic strain (or deflection) described as the largest value of deflection on the graph to maximum static strain (or deflection) described as the average of minimum and maximum strain on the graph.

The dynamic coefficients calculated from the measurements can be compared with suitable values given under normal static loads. In formulations of codes, dynamic coefficient is an additional safety margin and in a specific sense an artificial increase in the static load which is the basis for designing the structure. There is a need to consider that such an established coefficient of dynamics refers to the place where the measurement was conducted. This is why we select critical points (or places) for examinations, which in the case of a bridge were mid-span, i.e. the crown.

Based on applied apparatus and accepted test program the final point results are as follows:

a) Total maximum strains ($\varepsilon_{\text{total}}^{\max}$), maximum static strains ($\varepsilon_{\text{stat}}^{\max}$) and maximum dynamic strains ($\varepsilon_{\text{dyn}}^{\max}$), which must not occur simultaneously. Then, compatible component of static and dynamic strains ought to be defined.

b) Dynamic coefficients calculated based on strains, e.g. determined according to the formulae (4.1)–(4.4), by which the following characteristic cases exist:

– for this same moment of time i $\left(\varepsilon_{\text{total}}^{\max(i)}\right) = \varepsilon_{\text{stat}}^{\max(i)} + \varepsilon_{\text{dyn}}^{\max(i)}$;

– for moment of time j $\left(\varepsilon_{\text{total}}^{\max(j)}\right) = \varepsilon_{\text{stat}}^{\max(j)} + \varepsilon_{\text{dyn}}^{\max(j)}$;

– in a moment of time k $\left(\varepsilon_{\text{total}}^{\max(k)}\right) = \varepsilon_{\text{stat}}^{\max(k)} + \varepsilon_{\text{dyn}}^{\max(k)}$.

$$\varphi_1 = \frac{\varepsilon_{\text{total}}^{\max(i)}}{\varepsilon_{\text{stat}}^{\max(i)}} = \frac{\varepsilon_{\text{stat}}^{\max(i)} + \varepsilon_{\text{dyn}}^{\max(i)}}{\varepsilon_{\text{stat}}^{\max(i)}} = 1 + \frac{\varepsilon_{\text{dyn}}^{\max(i)}}{\varepsilon_{\text{stat}}^{\max(i)}}. \tag{4.1}$$

$$(4.2)\qquad \varphi_2 = \frac{\varepsilon_{\text{total}}^{\max(j)}}{\varepsilon_{\text{stat}}^{\max(j)}} = 1 + \frac{\varepsilon_{\text{dyn}}^{\max(j)}}{\varepsilon_{\text{stat}}^{\max(j)}};$$

$$(4.3)\qquad \varphi_3 = \frac{\varepsilon_{\text{total}}^{\max(k)}}{\varepsilon_{\text{stat}}^{\max(k)}} = 1 + \frac{\varepsilon_{\text{dyn}}^{\max(k)}}{\varepsilon_{\text{stat}}^{\max(k)}}.$$

Besides, a situation can occur that ($\varepsilon_{\text{dyn}}^{\max}$) will not occur at the same moment as $\varepsilon_{\text{total}}^{\max}$, then $\left(\varepsilon_{\text{dyn}}^{\max(1)}\right)$ is applicable, and suitable dynamic coefficients are determined from the following formulae:

$$(4.4)\qquad \varphi_4 = \frac{\varepsilon_{\text{total}}^{\max(1)}}{\varepsilon_{\text{stat}}^{\max(i)}} = 1 + \frac{\varepsilon_{\text{dyn}}^{\max(1)}}{\varepsilon_{\text{stat}}^{\max(i)}}.$$

In the case of measuring only dynamic component, maximal value is given and, if possible its component value in the moment of load movement across the section in which the point of measurement is situated.

c) Natural frequency vibration of the bridge.

d) Logarithm of damping decrement Δ, which can be calculated from the formula (4.5):

$$(4.5)\qquad \Delta = \frac{1}{r}\sum_{i=1}^{r} \ln \frac{y_i}{y_{i+1}};$$

in which: $\varepsilon_i - i$ – that particular amplitude of strain; ε_{i+1} – $(i+1)$ amplitude of strain; and r – total number of constituents.

In the case of measurement of displacement, the above given characteristics are determined based on their measured values in given time.

5. Results of the research

Some of the graphs obtained from the strains and vibration velocity courses in time as well as the corresponding velocity frequencies of the truck in its various crossings are presented in Figs. 4–7. In all, 24 dynamic load schemes were realized (I–XXIV) [3].

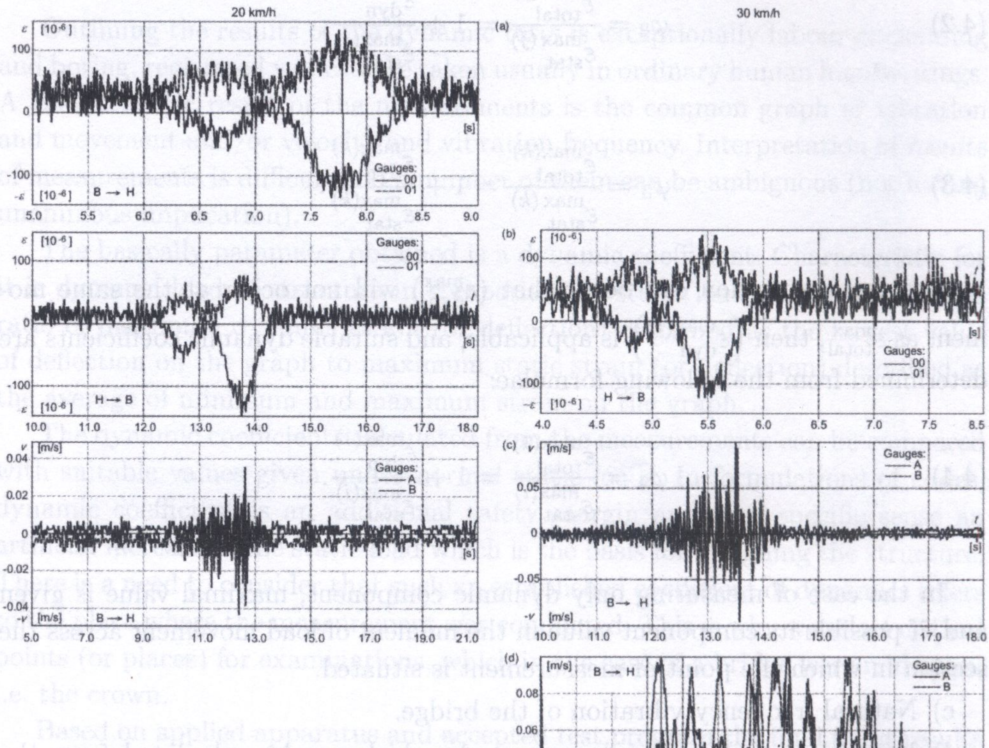

FIG. 4. Courses of the: a) and b) strains in time, c) and e) velocity of the vibrations in time and d) and f) answering them the frequencies of the vibrations of the structure during passing the vehicle with a speed of 20 and 30 km/h in both directions.

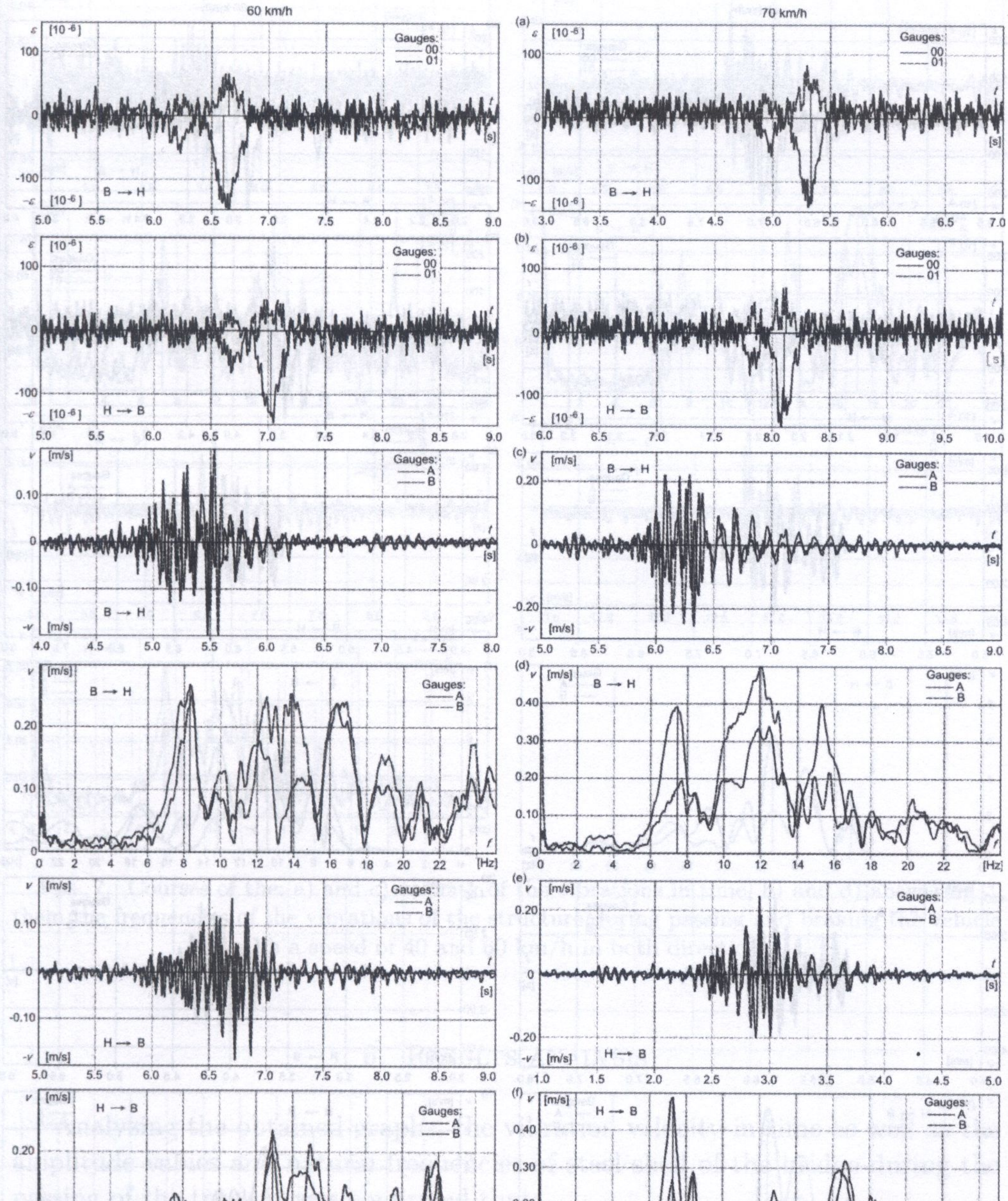

FIG. 5. Courses of the: a) and b) strains in time, c) and e) velocity of the vibrations in time, d) and f) answering them the frequencies of the vibrations of the structure during passing the vehicle with a speed of 60 and 70 km/h in both directions.

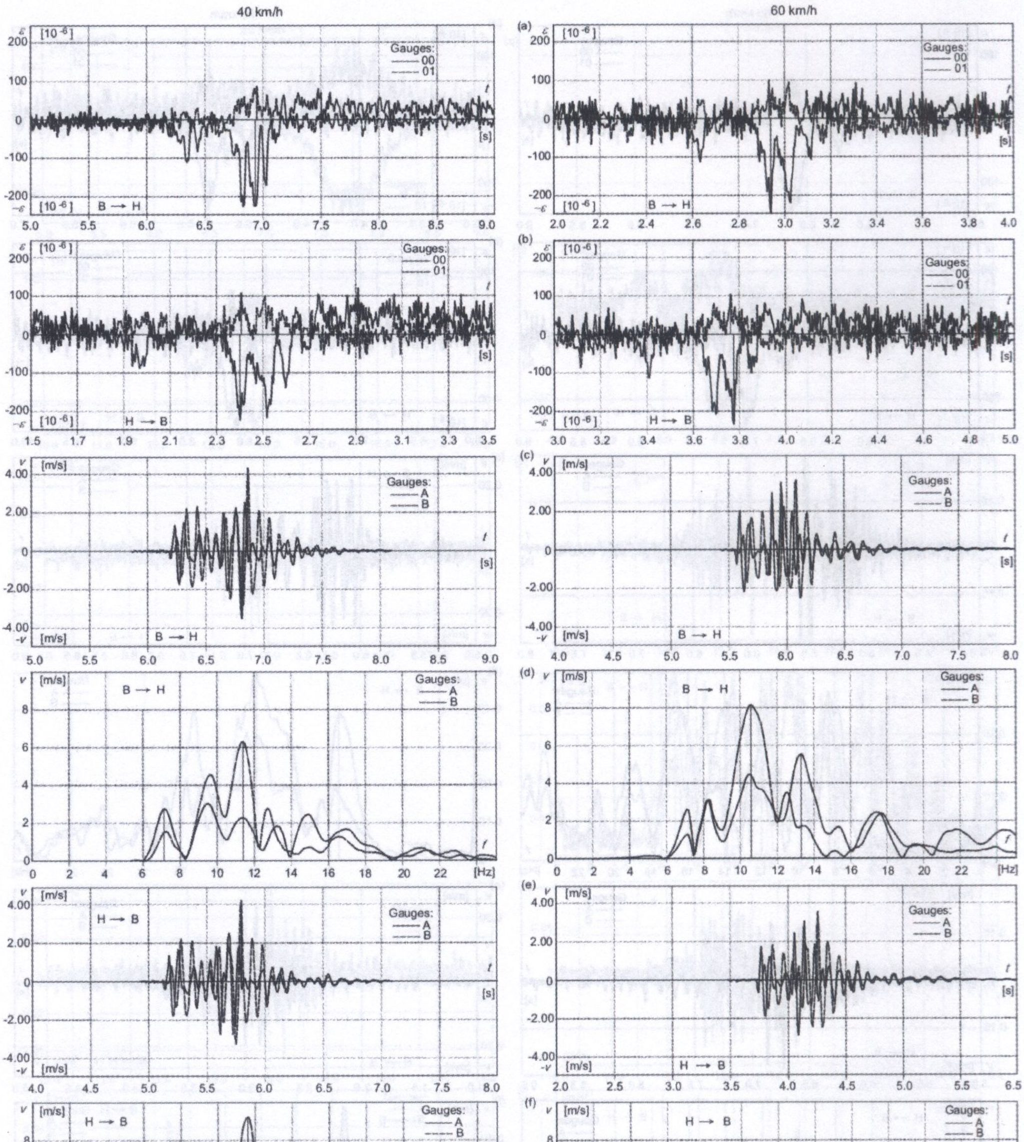

FIG. 6. Courses of the: a) and b) strains in time, c) and e) velocity of the vibrations in time, d) and f) answering them the frequencies of the vibrations of the structure during passing the vehicle by the threshold with a speed of 40 and 60 km/h in both directions.

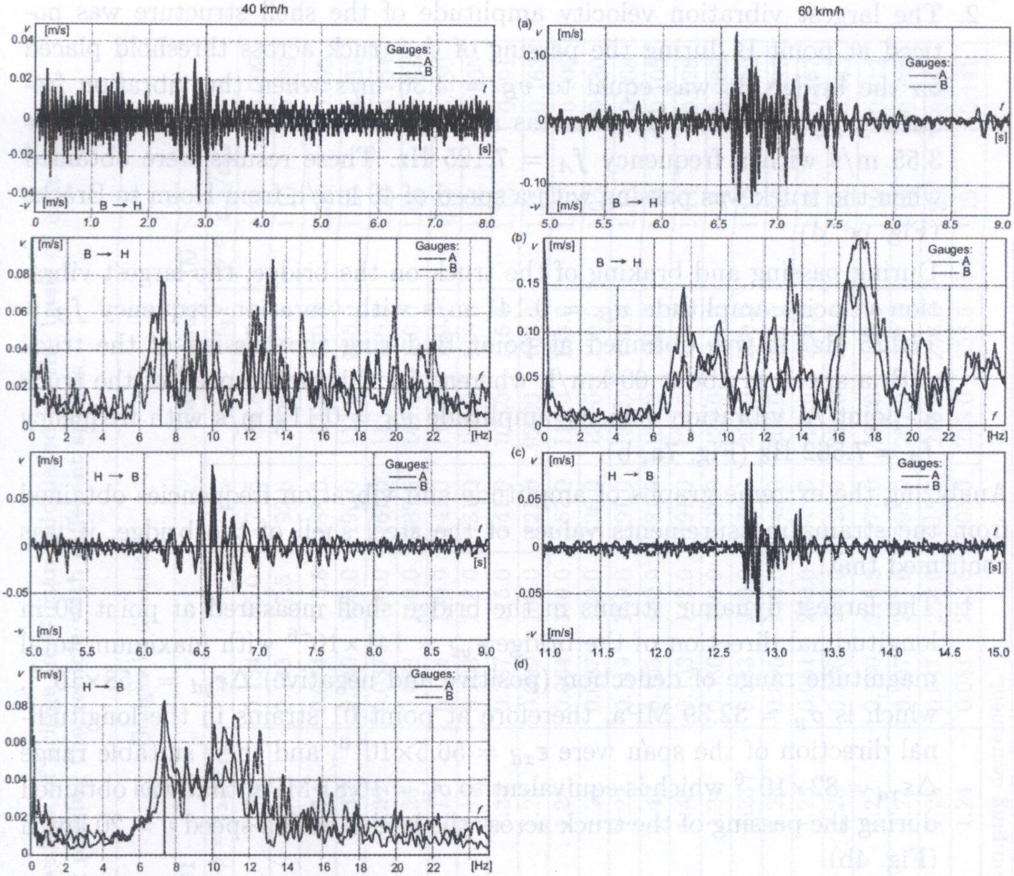

Fig. 7. Courses of the: a) and c) velocity of the vibrations in time, b) and d) answering them the frequencies of the vibrations of the structure during passing and braking the vehicle with a speed of 40 and 60 km/h in both directions.

6. Results analysis

Analyzing the obtained graphs, the vibration velocity in time as well as the amplitude values and natural frequencies of steel shell of the bridge during the passing of the truck it was confirmed that:

1. The largest amplitude of velocity vibration measured in measurement point A amounted to $v_A = 0.252$ m/s with the vibration frequency equal to $f_A = 7.312$ Hz, and in the point B, the amplitude of velocity frequency equals $v_B = 0.169$ m/s with a frequency $f_B = 8.437$ Hz, which was simultaneously obtained during the passing of the truck with a speed of about 70 km/h from the direction of Holm to Bräcke (Fig. 5e, f).

2. The largest vibration velocity amplitude of the shell structure was noticed at point B during the passing of the truck across threshold placed on the bridge. It was equal to $v_B = 4.36$ m/s when the vibration frequency $f_B = 11.375$ Hz, whereas at point A vibration amplitude $v_A = 3.55$ m/s with a frequency $f_A = 7.125$ Hz. These results were obtained when the truck was passing with a speed of 40 km/h from Holm to Bråcke (Fig. 6c, d).
3. During passing and braking of the truck on the bridge, the largest vibration velocity amplitude $v_B = 0.141$ m/s with vibration frequency $f_B = 17.125$ Hz. It was obtained at point B during the passing of the truck with a speed of about 60 km/h whereas for this same speed of the truck at point A, vibration velocity amplitude $v_A = 0.112$ m/s with frequency $f_A = 7.562$ Hz (Fig. 7a, b).

Analyzing the extreme graphs of amplitude and vibration frequencies obtained from the strains measurements values of the steel shell of the bridge, it was confirmed that:

1. The largest dynamic strains in the bridge shell measured at point 00 in longitudinal direction of the bridge $\varepsilon_{yd} = 141\times10^{-6}$ with maximum total magnitude range of deflection (positive and negative) $\Delta\varepsilon_{yd} = 158\times10^{-6}$, which is $\sigma_y = 32.39$ MPa, therefore at point 01 strains in the longitudinal direction of the span were $\varepsilon_{xd} = 56.5\times10^{-6}$, and their suitable range $\Delta\varepsilon_{xd} = 82\times10^{-6}$ which is equivalent to $\sigma_x = 16.81$ MPa, that was obtained during the passing of the truck across the bridge with a speed $v = 20$ km/h (Fig. 4b).
2. During the movement of the truck with a speed of 60 km/h within threshold, the largest strains was registered at point 00 which was $\varepsilon_{yd} = 260\times10^{-6}$, their maximum range of (both positive and negative) $\Delta\varepsilon_{yd} = 277\times10^{-6}$, what complies with $\sigma_y = 56.78$ MPa, whereas at point 01 $\varepsilon_{xd} = 82\times10^{-6}$ complies with $\Delta\varepsilon_{xd} = 102\times10^{-6}$, and $\sigma_x = 20.91$ MPa (Fig. 6b).
3. Based on unit strain measurements obtained in both directions ε_{yd} and ε_{xd}, magnitudes of dynamic coefficients were calculated $\phi = \varepsilon_d \ / \ \varepsilon_s$ as maximum dynamic strains ε_d to static strains ε_s in longitudinal or transverse direction, read from the graph of all the dynamic and static load diagrams, as set up in Table 1. Their maximal values are 1.47 for the loaded truck with a speed of 60 km/h, 1.26 for the truck passing across threshold placed on the bridge with speed of 60 km/h as well as 1.25 during braking of the truck, also with speed of 60 km/h. From this it can be admitted that in the case of this particular bridge, the speed of the moving truck $v = 60$ km/h was critical speed v_{cr}. The obtained dynamic coefficient values based on the research were compared to values obtained from calculations done from

Table 1. The dynamic characteristics values of bridge in Gimån calculated on the basis of unit strains measured during passing the vehicle with different speeds.

Schemes of loads and speed of truck in [km/h]:		Gauges in direction:											
		transverse – 01						longitudinal – 00					
		ε_x	$\Delta\varepsilon_x$	ε_{xs}	ε_{xd}	$\phi = \varepsilon_{xd}/\varepsilon_{xs}$	Δ	ε_y	$\Delta\varepsilon_y$	ε_{ys}	ε_{yd}	$\phi = \varepsilon_{yd}/\varepsilon_{ys}$	Δ
5	I	65.0	103.5	39.6	65.0	**1.64**	0.154	95.0	175.5	84.8	95.0	1.21	0.099
	II	48.5	61.0	41.5	48.5	1.17	0.143	87.5	92.0	79.5	87.5	1.10	0.089
10	III	70.0	105.6	45.2	70.0	**1.54**	0.074	110.8	188.0	84.8	110.8	**1.30**	0.095
	IV	60.0	90.6	45.2	60.0	**1.32**	0.240	135.0	195.0	113.0	135.0	1.19	0.037
20	V	135.0	139.0	102.0	135.0	**1.32**	0.037	140.0	161.0	113.0	140.0	1.23	0.154
	VI	75.0	80.0	60.0	75.0	1.25	0.068	150.0	188.5	141.0	150.0	1.06	0.068
30	VII	140.0	149.0	119.0	140.0	1.17	0.154	130.0	141.0	113.0	130.0	1.15	0.080
	VIII	117.0	128.0	102.0	117.0	1.15	0.108	118.0	131.0	105.0	118.0	1.12	0.165
40	IX	80.0	120.2	60.2	80.0	**1.33**	0.287	115.0	141.0	102.0	115.0	1.13	0.091
	X	66.3	77.0	53.0	66.3	1.25	0.099	106.0	121.0	92.00	106.0	1.15	0.163
50	XI	80.0	102.2	62.2	80.0	1.28	0.064	139.0	167.0	119.0	139.0	1.17	0.106
	XII	60.0	98.0	48.0	60.0	1.25	0.087	130.0	136.0	124.0	130.0	1.05	0.080
60	XIII	62.0	100.9	50.9	62.0	1.22	0.119	150.0	191.0	136.0	150.0	1.10	0.068
	XIV	50.0	73.9	33.9	50.0	**1.47**	0.105	150.0	181.0	136.0	150.0	1.10	0.105
70	XV	80.0	106.5	56.5	80.0	**1.41**	0.133	142.0	191.0	124.0	142.0	1.14	0.028
	XVI	70.5	116.5	56.5	70.5	1.24	0.336	150.0	191.0	124.0	150.0	1.21	0.068
$40^{t)}$	XVII	80.0	120.5	73.5	80.0	1.23	0.133	230.0	286.0	205.0	230.0	1.12	0.302
	XVIII	100.1	160.1	79.1	100.1	1.26	0.095	230.0	349.0	205.0	230.0	1.12	0.427
$60^{t)}$	XIX	100.0	160.0	80.0	100.0	1.25	0.051	260.0	345.0	220.0	260.0	1.18	0.167
	XX	107.0	170.5	85.4	107.0	1.25	0.230	240.0	320.0	210.0	240.0	1.14	0.133
$40^{b)}$	XXI	111.5	145.0	91.5	111.5	1.22	0.160	216.5	277.0	182.0	216.5	1.19	0.212
	XXII	125.5	161.0	101.0	125.5	1.24	0.207	237.0	295.0	201.0	237.0	1.18	0.275
$60^{b)}$	XXIII	152.0	196.0	121.5	152.0	1.25	0.047	258.0	315.0	215.0	258.0	1.20	0.254
	XXIV	146.5	182.0	118.0	146.5	1.24	0.081	253.5	305.0	213.0	253.5	1.19	0.141

Note: $^{t)}$ – threshold, $^{b)}$ – braking, Δ – logarithm of damping decrement.

the formula (6.1) in agreement with the standard of PN-85/S-10030 (as set up for road bridges), in which, L is effective span of shell:

$$\varphi = 1.35 - 0.005L = 1.35 - 0.005 \times 12.315 = 1.288 \leq 1.325. \tag{6.1}$$

4. The logarithm of damping decrement Δ for all the dynamic load schemes was calculated from the formula (4.5). It affirmed that the damping values were in the limits from 0.037 (scheme V) to 0.427 (scheme XVIII) – Table 1.

7. Final conclusions

Practical experiences obtained from the dynamic tests of bridge, which were continuations of already conducted static researches (Part I), carried out with the intension of gaining the complete view of the behaviour of bridges and how to find new constructional solutions to them, the observations on the structure span functions as well as comprehensive analysis of obtained results and their comparison with calculated results allow for formulation of the following conclusions:

1. Based on dynamic coefficient values ϕ determined for all the load variances I–XXIV, which were obtained from strains at characteristic points and cross sectional sections of the span, as well as deflections obtained from three different points of shell structure [3], have been determined, among other things, the critical speed ($v_{\mathrm{cr.}} = 60$ km/h). It was also noticed that the values of dynamic coefficients were 3–22% lower (Table 1) than values calculated in accordance with the Polish Standard of the load values in PN-85/S-10030, with exceptions to seven load schemes (I, III, IV, V, IX, XIV, XV). It should be clearly mentioned that the calculated dynamic coefficients were accepted just as if the traditional road steel bridges (which in the experimental tests obtained mainly much lower values), whereas normal regulations in this range (in Poland as well as Sweden) do not yet relate to the new ways of design of the new structure.

2. It was noticed that the dynamic coefficient values are different depending on the type of element, dynamic load scheme, speed of the loaded moving truck and above all, on the location of the point of measurement on the bridge shell (Table 1).

3. Based on dynamic tests of bridge as well as on additional analysis of theory it seems sensible that the normal values of dynamic coefficients for the steel-soil bridge structure could have got a bit bigger values especially due to the fact that such structures are susceptible and sensitive to dynamic loads and loss of stability particularly in the first phase of their construction as well as in the early stages of their service, which was also observed in the first stage of the research on this particular bridge under the load of backfilling [2]. This conclusion repeats itself in several other experimental researches on bridges of these types [5, 7, 8].

Growth of the normal values of dynamic coefficients for these bridge structures increases safety at various stages of its construction and in their exploitation, and which as well leads to a more rationality in their design and their application. Under normal circumstances, backfill exists in this type of structures and often, as well, stiff reinforced concrete relieving slabs and spreading the load over a larger surface area and on the road structure in suitable thickness, which much reduces dynamic impact on the bridge.

4. In the process of the research on dynamic load effects on bridges, no observation of disfunction of the steel structure under different load schemes was made even sudden braking and in the moment the truck was moving across threshold with simultaneous application of break. Only during some of the movements of the truck across threshold and simultaneously braking, the results obtained (velocity amplitude and vibration frequency) from velocity vibration gauges could seem too large in comparison with results obtained in researches made in typical steel bridges [12]. Putting into consideration however, certain rough surfaces occurring on the contact with the gauge – the road surface as well as the type of structure under examination and also nearness of the truck in relation to the installed gauges which could have had certain influence on the obtained results, did not create any dangerous effects on the bridge, especially as their values did not exceed the calculated values [3]. Wide range of dynamic tests conducted on led to versatile effort and evaluation of the elements in the shell structure of this bridge. Final conclusions confirmed the observations taken from the research under static load. In effect, total analysis gave rise to basis on which the bridge was qualified for normal service in accordance with the Swedish standards in bridges (and the standards of Poland) [3].

The above summary and final conclusions refer to a structure span of given geometrical characteristics and rigidity of various elements as well as specified effective span. In order to be able to directly apply the results obtained in the research of dynamic load effects on bridges (among others, dynamic coefficient ϕ, critical speed $v_{cr.}$, logarithm of damping decrement Δ) to other types of bridges, additional research must be conducted on other bridges, consisting mainly of spans with different geometrical longitudinal section, different backfill thicknesses, various kinds of steels of different span structures as well as different proportions of rigidity of various elements e.g. different types dimensions of corrugations, and its reinforcements.

References

1. Z. Mańko, D. Bęben *Building of the longest bridge in Scandinavia made of steel corrugated plates Super Cor type SC-56B* [in Polish], Bezpieczne Drogi, **11**, 59, 18–22, Warszawa 2003.

2. D. Bęben, Z. Mańko, L. Janusz, J. Vaslestad *Research on steel shell of road bridge in Gimån in Sweden made of corrugated plate Super Cor type SC-54B during its backfilling* [in Polish], Proc. of the 2nd Scientific-Technical Symposium on Research and Diagnostic of Bridges, 31–67, Opole, 9–11, April 2003.

3. Z. Mańko, D. Bęben *The study of road bridge structure of steel corrugated plates Super Cor type SC-56B under static and dynamic load in Gimån (Sweden)*, Report No. 211/2004, Scientific-Research Centre for Development of Bridge Industry MOSTAR, Wrocław 2002.

4. D. Bęben *Dynamic research of road bridge made of steel corrugated plate* [in Polish], Scientific Books of Silesia Technical University, Building Series. Proc. of the 4th Conference on the PhD Students of Civil Engineering, 79–86, Gliwice–Wisła, 20–21 November 2003.

5. Z. Mańko, D. Bęben *Research on road bridge made of Super Cor corrugated steel plates* [in Polish], Proc. of the 48th Scientific Conference Civil Engineering of the Committee Polish Academy of Sciences and Scientific Committee PZITB: Scientific-Research Civil Engineering Problems, 167–174, Opole–Krynica, 4, 15–20 September 2002.

6. A. Madaj, J. Vaslestad, L. Janusz, *Research in situ steel culvert made of corrugated plate use to rebuild railway frame viaduct*, [in Polish], Proc. of the 9th Seminar: Present Methods of Reinforced and Rebuilding Bridges, 106–117, Poznań–Kiekrz, 8–9, June 1999.

7. Z. Mańko, D. Bęben, *On test loading acceptance of a small unconventional arch bridge construction built of steel plate* [in Polish], Inżynieria i Budownictwo, Warszawa, **9**, 506–509, 2002.

8. J. Vaslestad *Long-term behaviour of flexible large-span culverts*, Transportation Research Record, no. 1231, Transportation Research Board, Washington D.C., 14–24, January 1990.

9. R. W. Clough, J. Penzien, *Dynamics of Structures* McGraw-Hill, New York 1975.

10. N. M. Newmark, *A Method of computation for structural dynamics*, Journal of Engineering Mechanics Division, ASCE, **85**, 3, 67–94, 1959.

11. C. Petersen, *Statik und Stabilität der Baukonstruktionen*, Vieweg & Sohn, Braunschweig/Wiesbaden 1980.

12. T. Kumarasena, R. H. Scanlan, R. Morris, *Deer Isle Bridge: Field and computed vibrations*, Journal of Structural Engineering, **115**, 9, 2313–2328, 1989.

Received October 11, 2004; revised version February 22, 2005.