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Imminent Failure Condition of High Noise Barrier

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Abstract: The paper describes the reasons for imminent failure state of high acoustic barriers, consisting due to slipping and falling of the panels out of the inclined part of the barrier. The reason of threat was the lack of the overall stability of cantilever columns 8,5 m high and global stability of the structure with a total length of 920 m. Structure and its technical condition were described, conclusions of performed analysis were presented and a way to repair was given.

Key words: Noise barrier, imminent failure condition, overall stability of steel cantilever.

1. Introduction

The erection of many noise barriers along the already existing and newly built highways in Poland in recent years involves the highly important safeguarding and adequate stability of these structures. Of essential importance is their careful designing, keeping in mind the effect of wind if they are high and their upper part is inclined (Fig. 1), also when they are designed to form curves at their ends (Fig. 2).

Recently it happened that the panel inserted between adjacent I-section steel columns, i.e., "embedded" between the webs of these sections, slipped out from the cantilevers of the inclined wall of the noise barrier (Fig. 3). In order to warrant the safety of the users of the highway all the panels which might possibly also drop on roadway had to be removed. To detect the reason of this phenomenon detailed static-strength analysis was performed.

2. Description of the Supporting Structure of the Noise Barrier

The supporting structure of the noise barrier consist of steel columns constructed of double-tee bars HEB, fastened in foundations spaced 4.0 m from each other. The columns consist of a vertical part, 6.0 m high, made of HEB220 section, and the inclined part with a length about 4 m, made of HEB160 section (Fig. 3b). Inclined part was welded in the workshop to the flange of the vertical branch by all round fillet weld.

The columns were installed in foundations, i.e. drilled concrete piles with diameter of 0.8 m and a depth of 8.0 m (Fig. 3b). In the heads of the piles there were sockets ensuring anchorage length of 0.8 m, filled with concrete after positioning and rectification of the columns.

The respective segments along the noise barrier, with overall length of 920 m, were varied structurally due to the different way of connecting the panels with the profiles of the columns. Some part of the noise barrier contained an opaque filling, consisting of aluminum panels slot-perforated on the one side and packed with mineral wool (Figs. 1 and 2). In the other part acryl glass plates, 20 mm thick, were applied, mounted in aluminum frames (Fig. 3). The panels in the vertical part of the noise barrier were supported on a socle of prefabricated reinforced concrete substructure (Fig. 3).

In the design of both parts of noise barrier it has been assumed that the entire length of a panel is less than the axial spacing of the columns by 40 mm. The supporting of the panel on the flange of the HEB220 was then

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Fig. 1 View of a noise barrier with a height of 8.5 m.

Fig. 2 View of a noise barrier curve in horizontal plane.

assumed to amount to 90 mm, and on the flange of HEB160 to 60 mm. In the vertical part of the opaque noise barrier the panels were stabilized be means of an angle bar L50x40x5, fastened to the external side of the barrier to the column HEB220.

Due to the structural solution of the edges of the transparent panels, the effective support of these panels on the flanges was lower by about 20 mm, i.e. about 70 mm in the case of HEB220 and 40 mm in the case of HEB160. The workshop design, however, contains practical remark that the length of the panels should be decided on the building site, matching their dimension to the actual spacing of the existing columns.

It worth to mention that in the workshop design of the noise barrier – in relation to the executive design – the length of anchoring of the steel columns in the pile foundations have been changed from 1.5 to 0.8 m, as well as the profile of the upper inclined part of the columns from HEB220 to HEB160. The detailed documentation concerning the way of embedding and anchoring of the columns in the sockets was not available for the authors of the paper.

According to Technical Specification [1] the following tolerances concerning the assembling of the supporting elements of a noise barrier have been admitted: the distance between columns ±5 mm, ordinates of the height ±5 mm, deviation of the column from the perpendicular ⩽ 1%. Thus, admitted deflection of the head of the vertical part of a column with height of 6.0 m might amount to 60 mm, and that of top of the inclined part on the height 8.5 m – even 85 mm.

The lack of post-construction inventory makes it impossible to relate the results of measurements of the geometry of the structure, carried out after occurrence of a failure to the so-called zero state existing on the day when the structure was allowed to be used.

3. The Technical State of the Noise Barrier

The panels of the noise barrier had to be partially disassembled, because they slipped out spontaneously and dropped down from the inclined part of the barrier (Figs. 1 and 3). During the inspection it was found that the state of the remaining part of the structure is satisfying, although varying deviations of the columns from the perpendicular were detected. Only in the curved part of the opaque barrier some of the panels were not enough supported (the metal flashing of two panels were visible) – Fig. 4. There were also clear differences in the length of the support of the transparent panels on the vertical part of the column.

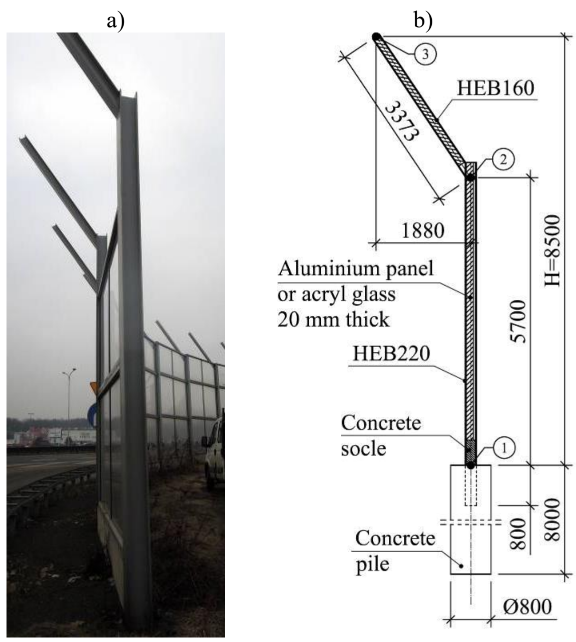

Fig. 3 Steel supporting columns of the noise barrier with a height 8.5 m: a) view of the transparent panels inserted in the vertical part of the barrier (those in the inclined part had been removed), b) structural drawing of the column.

Fig. 4 Insufficient supporting of the panels on the inclined part of the noise barrier.

An analysis of the results of geodetic measurements, carried out after two years of exploitation, indicated that the deviations of the columns from the perpendicular at the height of 6.0 m are less than the mounting tolerance. From among 217 columns only in 3 deviations amounted to 1.1÷1.2 %. It has also been found that most of the columns (155 from among 217) inclined towards the highway, i.e. perpendicular to the plane of the noise barrier.

The results of laboratory tests of steel samples taken at random from the columns proved that the values of the yield point and tensile strength exceed the standardized values quoted in [2] on the average by about 10%, concerning steel S355K2, of which the columns had been designed.

4. Analysis of the Supporting Structure

The structure was calculated in compliance with following standards: wind load according to [3] (taking into account modification [4]), and load-bearing capacity according to [5]. Keeping in mind the considerable slenderness of the column, the calculation model took into account, in compliance with Eurocode 3 [6], the initial sway imperfection $\phi = 0.0015$ rad and the initial bow imperfection $e_0 = L/500$ for effect of lateral-torsional buckling (where L is the length of the element between nodes), as well as second order effects. Additionally calculations have been performed for the most inclined column, taking into account the actually measured displacement of its end. Basing on the results obtained by means of a geodetic device, the displacements of the head of the vertical part of the column (HEB220) were assumed on the level of 6.0 m (node 2) in the plane of the barrier to be equal to 30 mm and in the perpendicular plane to 72 mm (in the direction of the highway). Because the structure of supporting of the panels on the columns did not prevent mutual displacements of neighboring columns, it was assumed that the panels do not cooperate with the columns thus do not ensure a geometrical invariability of the steel cantilevers in the plane between the columns of the barrier.

In the calculations following loads were taken into account: G – permanent load (self-weight of the I-section and the acoustic panels), W1 – wind acting perpendicularly to the plane of the barrier from the side in which upper part is inclined, W2 – wind acting in the direction opposite to W1, W3 – wind acting parallel to the plane of the barrier at a coefficient of friction C_t = 0,04 according to [7]. Moreover, basing on [8] the load case W4 was taking into account, i.e. the aerodynamic pressure due to vehicles using the highway. It was assumed that the wind load and aerodynamic load may affect the noise barrier simultaneously. It should, however, be stressed that according to [8] these loads should be considered separately. In the case of analyzed noise barrier the aerodynamic load according to [8] is less than the load of the wind according to [4].

Taking into account the imperfections admitted in the standard [6], reduced von Mises stress were obtained σ = 382 MPa, concerning the design load combination C23 (1.1G + 1.5W2 + 1.5·0,9W4). In the case of assuming in the calculations actually existing imperfections, the obtained results were σ = 385 MPa.

The load-bearing capacity of the columns proved to have been exceeded: for the imperfections admitted in the standard amounted to about 16%, and for actual imperfections to about 17%. Taking additionally into account the aerodynamic load due to vehicles according to [8], the load-bearing capacities are exceeded respectively by 25% and 26%.

The load-bearing capacity of the anchoring of the columns was found to have been utilized in 47% [9] and [10].

Considerable horizontal and vertical displacements occurred at the end of the cantilever (node 3 in Fig. 3b) of a single column being affected by the wind. Taking into account the imperfections admitted from the standard, the displacements of the end of the cantilever amounted in the plane of the noise barrier to u_x = 197 mm for characteristic combination C25 (G + W2) and in the plane of the barrier to u_y = 273 mm for C26 (G + W3). Thus, the maximum horizontal displacement from the plane of the noise barrier equals about 1/43*H* and in the plane of the barrier it is equal to about 1/31*H*.

It ought to be noticed that according to Polish steel structures standard [5] the restriction of horizontal displacements of the heads of columns amounts in single-storey buildings to 1/150*H*. The same value has been quoted in the standard concerning the designing of noise reducing devices [8], in which also vertical displacements of the non-vertical parts of the barriers are limited to 1/300 of the length of the element. Taking this into account horizontal displacement at the end of the cantilever should not exceed 57 mm; however it has been found that displacements exceed the limit values suggested in the standards three to five times.

5. Reinforcement of the Supporting Structure

Because of considerable horizontal and longitudinal displacements of the columns, inadmissible from the viewpoint of exploitation of noise barriers, the supporting structure had to be reinforced. The length of the barrier was divided into segments, each of them comprising 9 fields with columns connected by horizontal bars, separated by a dilatation in which the adjacent columns were not connected. The segment contains nine fields is a structural system comprising 10 columns, the ends of which are connected by horizontal bars at the height of 6.0 and 8.5 m, and vertical bracings of the type X, additionally build-up in some selected fields. Several structures were analyzed with various arrangements of X-type bracings, build-up in inclined part of the barrier (upper bracing) and vertical part of the barrier (lower bracing), as well as structures without braces at the lower part. The aim of the analysis was select the most proper solution, which would restrict the horizontal displacements on the level of the ends of cantilever in the plane of the noise barrier without over stiffening the structure resulting in increase of the effort of the columns.

The results of the analysis favor the structural solution of the segment with nine fields, but merely in straight section of the noise barrier (Fig. 5). Different solution proved to be adequate in the curved parts of the barrier, where the columns were connected with each other in pairs into single-filed segments (Fig. 6). In the curves it proved to expedient to apply alternately braced field and unbraced dilatation field. Bracings of the type X were applied only in the inclined surface of the barrier. It has been assumed that the panels in the dilatations do not transfer forces in the plane of the barrier between neighboring segments.

The horizontal bars connecting the heads of the vertical parts of the columns on the level 6.0 m were assumed to consists of channel section C200, the horizontal bars connecting the ends of the cantilevers on the level of 8.5 m – in the fields of bracings type X – were assumed to consist of circular hollow section CHS63.5/8, and the bars connecting the ends of the cantilevers in the fields without braces as well as bracings type X were assumed to consist of round bars 14 mm in diameter. For the purpose of stretching braces of the type X bottle-screw were to be used. The channel sections C200 were fixed to flanges of HEB220 from the outer side and the bars connecting ends of cantilevers were connected with the bottom flanges of HEB160, whereas the X-type bracings were connected on their upper flanges. All these connections were assumed to be a bolted joints.

In the calculations all structural eccentricities were taken into account resulting from the non-axial connection of the elements in the joints. The load schemes

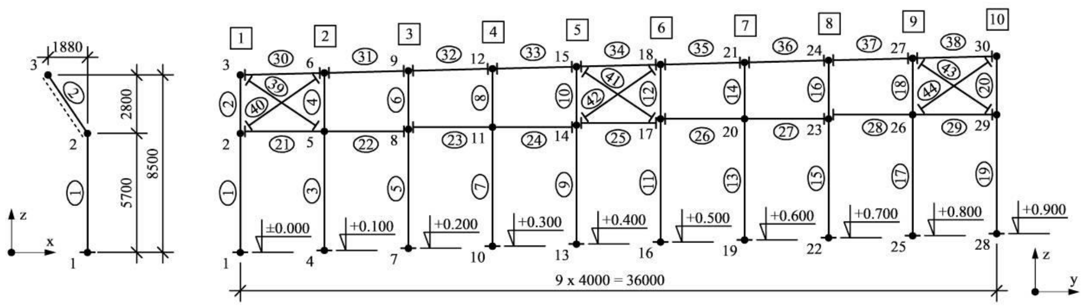

Fig. 5 Static diagram of 9-field segment

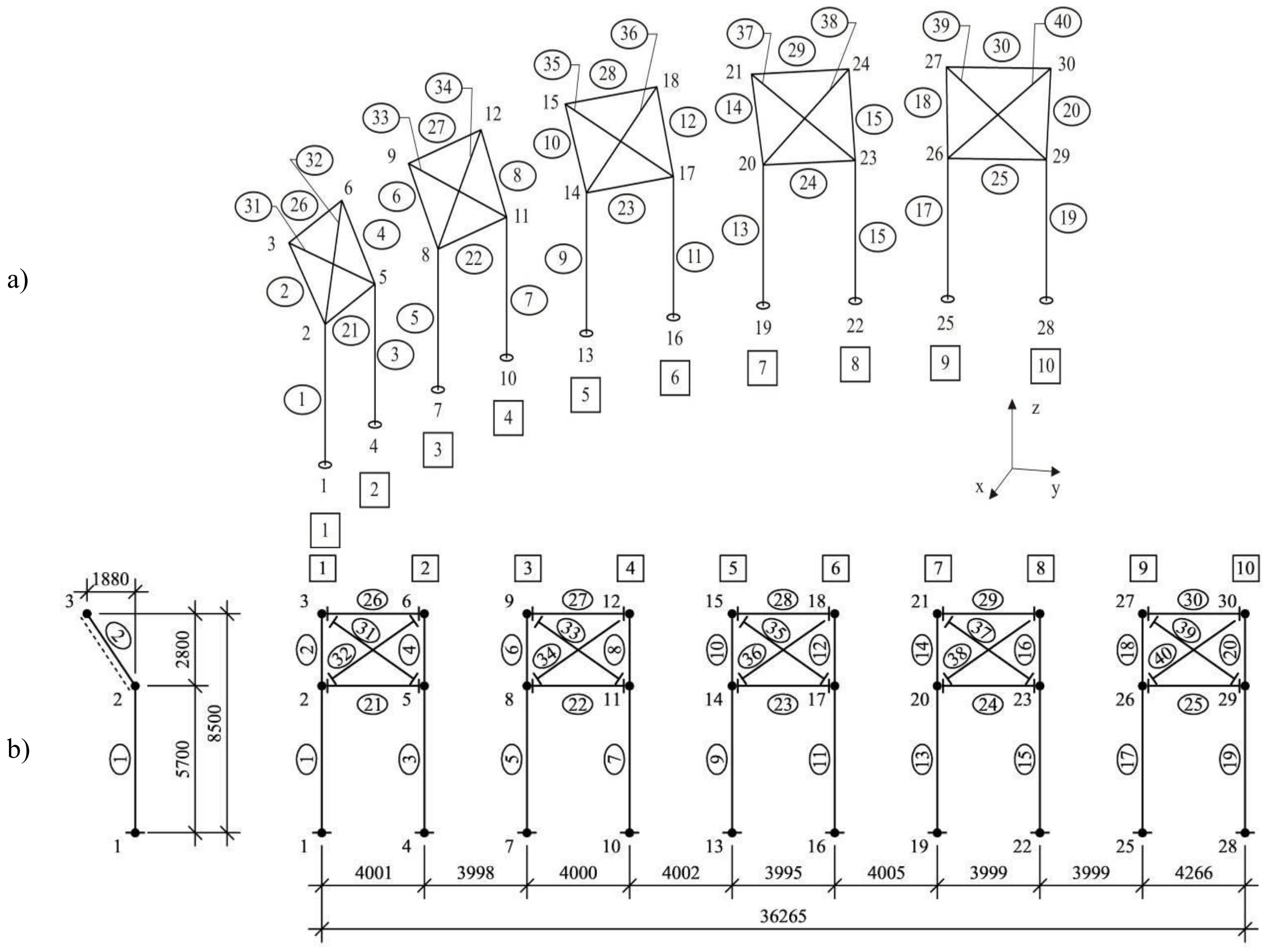

Fig. 6 Static diagram of single field segments in the curves: a) axonometric view, b) explication.

and cases were assumed to coincide with those of the structure in the actually existing state, taking into account the imperfections admitted in the standards. For nine field segment the highest stress $\sigma = 350$ MPa occurred in the bar No. 9, node 13 (Fig. 5) according to combination C23. The displacements at the end of the cantilever, however, amounted to u_x = 194 mm, u_y = 160 mm and u_z = -63 mm, complying with the combination C25. In the case of single-field segment in the curve the maximum stress was σ = 331 MPa, determined for the bar 17 in the node 25 (Fig. 6), complying with the combination C23. Additionally also the values of mutual displacements of the ends of the columns in the dilatations were checked. In a straight segment of the barrier, i.e., between the segments with nine fields, displacements did not exceed 15 mm, but in the curve of the barrier, between single-field segments they amounted to 63 mm. The values of mutual displacements ensure, that the slipping out of the panels situated between neighboring segments are prevented.

After the reinforcement of the structure the load-bearing capacity of the column in the 9-field segment, exposed to the highest effort, is exceeded by about 6% (15% - in the case of taking additionally into account the wind load due to the vehicle [9]), and in the case of single-field segment in the curve of the barrier by about 7%.

6. Conclusions

Taking into account the results of geodetic measurements, the survey of the structure, as well as the results of tests of steel samples and additional calculations concerning the load-bearing capacity of the high noise barrier the following reasons for the slipping out of the panels could be determined:

The insufficient rigidity of the supporting columns, in particular their inclined parts, displaying considerable horizontal displacements in the plane and from the plane of the barrier, and also vertical displacements at the ends of the cantilevers, reaching before reinforcing of the structure 276 mm, 199 mm and 67 mm, respectively.

The support of the panels on the bottom flanges of the inclined parts of the columns was not effective enough, not adopted to large displacements of the columns exposed to loads affecting them.

The tolerances in their construction, concerning the inclination of the columns were too liberal, permitting the displacement of the end of the cantilever at the height of 8.5 m in relation to the level of fixing the column in the foundation, attaining even ± 85 mm.

An unfavorable assemblage of the panels in the case when the neighboring columns were not positioned in the same level (in the curves at longitudinal inclination of the noise barrier.)

Location of the bracings in inclined part of the barrier successfully ensured the safe exploitation of the structure. This permitted to reduce sufficiently the displacements of the cantilever columns in the plane of the barrier. The load-bearing capacity of the steel section most exposed to the effort was not exceeded thanks to the additional reserve resulting from the increased parameters of the steel (by 10%) of the tested samples of the steel of which the columns had been made.

There are, however, still too large horizontal elastic displacements from the plane of the noise barrier as well as vertical displacements of the ends of cantilevers. The former ones amount to 194 mm in the case of the segment comprising 9 fields and 192 mm in the case of a single-field segment in the curve. They do not threaten the structure of the barriers, require, however, periodical surveys of the barriers with respect to the fixing of the panels between columns and verticality of the columns.

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