A R C H I W U M I N S T Y T U T U I N Ż Y N I E R I I L Ą D O W E J
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CHANGES IN STRESS LEVEL IN A CORRUGATED STEEL STRUCTURE UNDER LONG-TERM LOADS

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Abstract

The paper presents results of long-term research of a railway grade separation built from corrugated steel structures. The structure is a pipe-arch and it is placed directly on the subsoil. The research focused on monitoring the changes of stresses in the steel structure. The research was carried out with use of electro-resistant strain gages placed around the periphery. The results presented in this paper are a continuation of research started in 1998. The results obtained until 2006 were presented in 2006 (Janusz et al.2007). Based on this research one could notice that apart from the haunch area there were only minor changes in the stress level in the remaining areas of the steel structure.

It was concluded that plastic hinges were developed in the haunches. It didn't however lead to changes of stresses in other cross-sections of the structure, except for local disturbances in the time when plastic hinges occured.

Key words: flexible structures, long-term research, change of stresses in time

1. INTRODUCTION

In the paper „Railway grade separation made of corrugated steel plate structure – long term research" (Janusz L et al. 2007) authors presented results of stress distribution in a corrugated steel shell which serves as a railway grade separation built from corrugated plates of MultiPlate type. The grade separation was built in 1998 and has been continuously monitored ever since (also during construction from 1997 and under trail loads as well). This paper presents result obtained in the period of 2007-2012.

Quoted results indicate changes in the distribution of stresses and consequent change in tensioning of the steel structure. Distribution of internal forces in the steel structure is correlated with the state of the soil surrounding the structure and displacements of the structure in the soil. This is a result of adjusting the structure to the surrounding soil. This issue was tackled by other researches and some of the long-term observations can be found in (Vaslestad J.1990, Vaslestad J. et al. 1997).

This paper shows consequences of stress distribution in a corrugated steel structure of the Multi-Plate type which has been in service for almost 15 years. The analysis also uses results of monitoring performedbefore 2007 and during construction and trawl loads.

2. DESCRIPTION OF THE STRUCTURE

The grade separation is placed underneath a two track electrified railway line. The structure placed an angle of 73^{o} to the railway axis . The grade separation consists of two parts: one for pedestrians and one for cars. Both structures are built as corrugated steel structures (fig.1). The dimensions are: span=8.90 m, height H=6.72 m (Fig. 2).Bottom length is 39.88 m. Total cover to the top of the rail is 2.67 m. The rails are placed on ballast made of crushed stone. The geometry of the structure is presented in Fig 2.

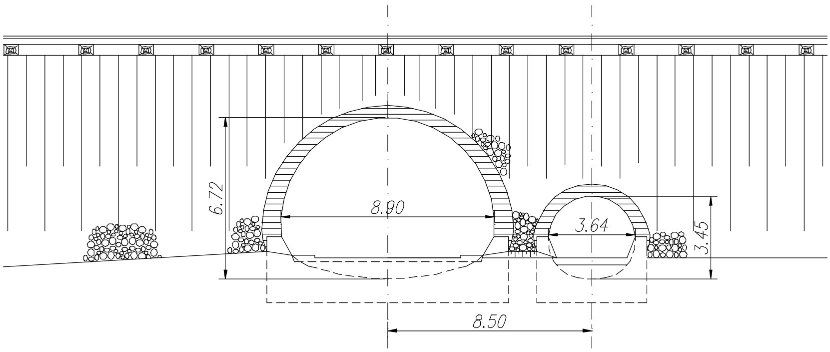

Fig. 1. General view

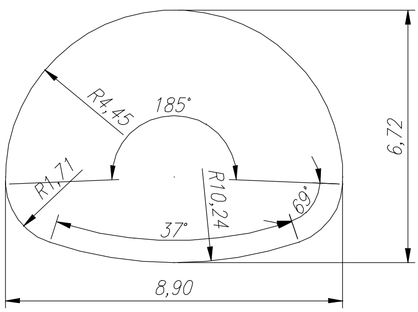

Fig. 2. Geometry of the tested structure

The corrugated plates are 7 mm trick and corrugation profile is 150 x 50 mm. The steel complies with SS–EN 10025, Fe 360 BFN. Steel yield strength is f_Y=245 MPa. Bolts class is 8.8.

The structure is placed on a 40 cm-thick soil bedding. There is a separation made of a non-woven geotextile 250 g/m^2 placed underneath the bedding. The backfill is a soil-gravel mix with un-uniformity ratio of U=5 (gravel 0÷16 50% + sand mix 25% + sand type II 25%). The SPD (Standard Proctor Density) underneath the structure (except of top 10 cm) is 98.9%÷99.7%, in the vicinity of around 2.0 m around the structure it is 98%, and above the structure it is 100%.

3. DESCRIPTION OF RESEARCH

Bfore the structure wass commissioned the following strain measurements were performed:

- During backfilling,
- under trail live loads

So far 50 measurements of strains were performed since it has been commissioned. Electro-resistant strain gages with a 6 mm measurement length and resistance of 120Ω were used to measure strains. They were placed in 10 points around the periphery. Their location is presented in fig.3. amplifier Hottinger Baldwin Messtechnik amplifier – UPM60 was used for measurements.

Results of measurements before 2006 were published in (Janusz L et al. 2007).

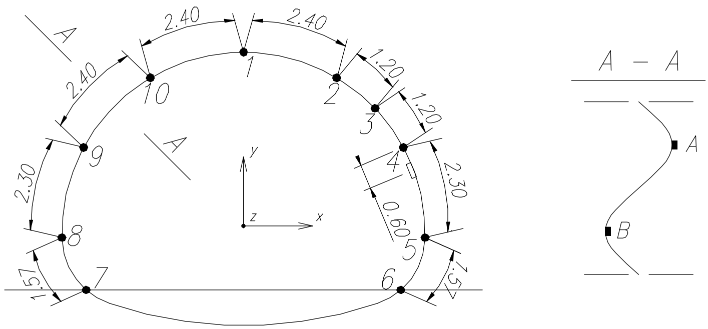

Fig. 3. Location of strain gages

4. SUMMARY OF OBTAINED RESULTS

Detailed results obtained before 2008 were presented in (Madaj A. at al. 1999, Madaj A. et al. 2005, Janusz L et al. 2007). The conclusions drawn from them were as follows:

– during backfilling maximum stresses occured during backfilling in the crown (point1 – σ_{max} = 240 MP; in the remaining points stresses were below 150 MPa (example of normal stress distribution shortly after commissioning is presented in Fig. 4)

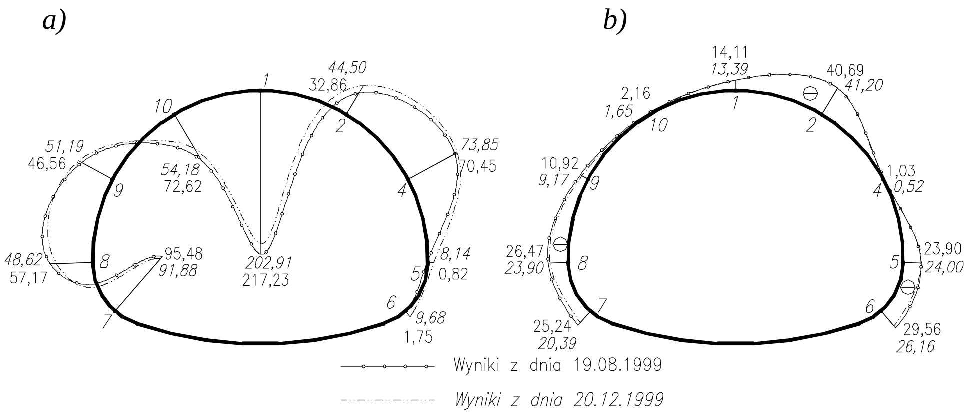

Fig4 Stresses in the steel i n 1999 [MPa]:a) Bending stress; b) hoop stress (“+” compression, “–“ tension; bending stress drawn in tension fiber side)

– During trail loads a minor increase of stresses was recorded (max 6.5 MPa),
– the stress level in the crown stabilized during service and small changes are recorded, however the haunch area changed more (point 1 and 6)
– The top points (1, 2 and), were subject to an increase of bending stresses with a subsequent reduction of thrust stress
– hoop stress and bending stress in side walls (points 4 and 9) decreased
– a small increase of hoop and bending stress in point 5 and 8
– the biggest change was recorded in the haunch area (points 7 and 6); they have both changed the magnitude and sign; the absolute change of hoop stress in these points was ap. 140-160 MPa. In the paper (Janusz L at al. 2007) a hypothesis was presented that it was caused by settlement of the top part with bending of the bottom part under the road.

5. RESULTS AFTER 2006 AND DISCUSSION

As before, stress were calculated based on steel Young modulus of E = 205000 MPa. Hoop stresses were calculated based on measured strains as follows:

$$\sigma_N = \frac{\sigma_A + \sigma_B}{2} \qquad (1)$$

and bending stress as:

$$\sigma_M = \frac{\sigma_A - \sigma_B}{2} \tag{2}$$

where:
σ_A, σ_B – normal stress at top and bottom of the corrugation (fig. 3)

Selected results from following years were are presented in Fig. 5–11. The graphs show changes in stresses in the steel divided into (hoop; „–" indicated compression, „+" tension) and bending stresses (placed on tension fiber side).

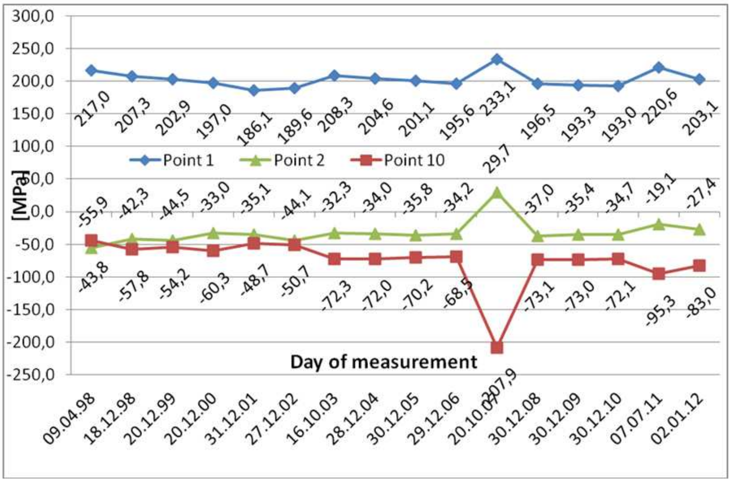

Fig. 5 Bending stress changes in points 1, 2 and 10 (near crown)

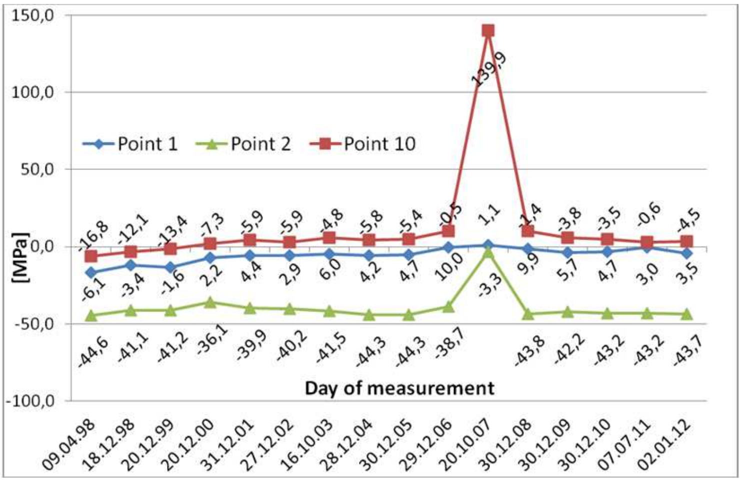

Fig. 6 Hoop stresses in 1, 2 and 10 (near crown)

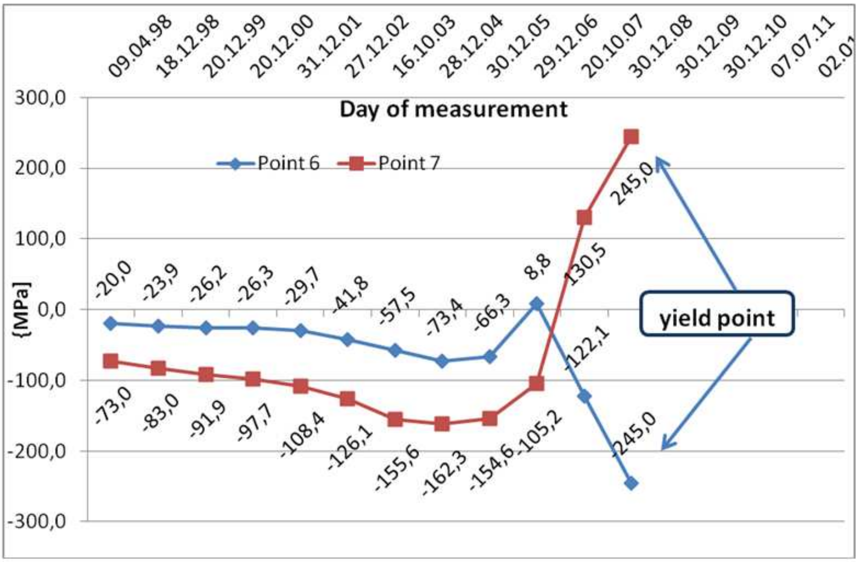

Fig. 7 Bending stress changes in points 6 and 7 (haunch)

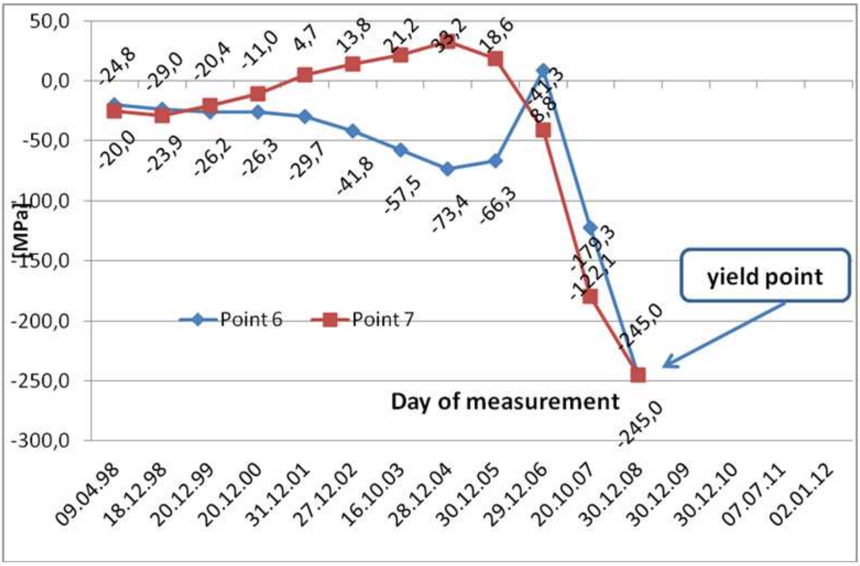

Fig. 8 Changes of hoop stresses in points 6 and 7(haunch)

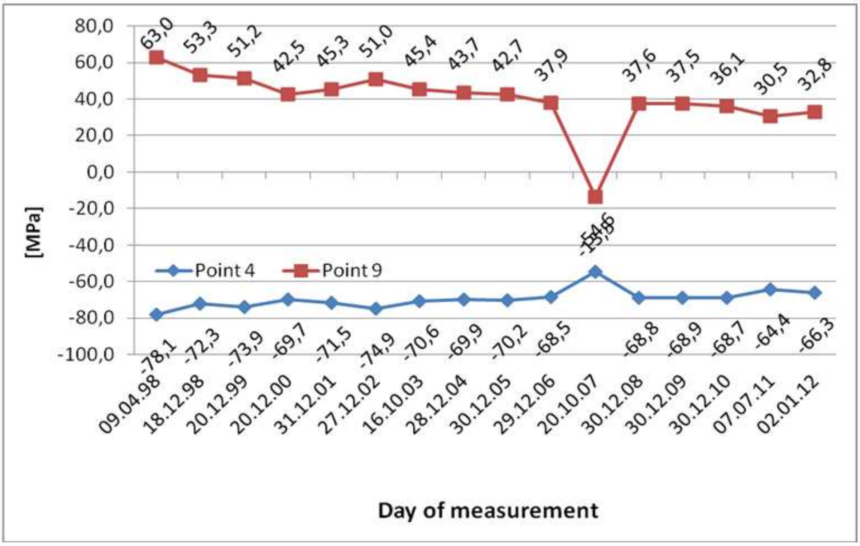

Fig.9 Changes of bending stresses in points 4 and 9 (side walls)

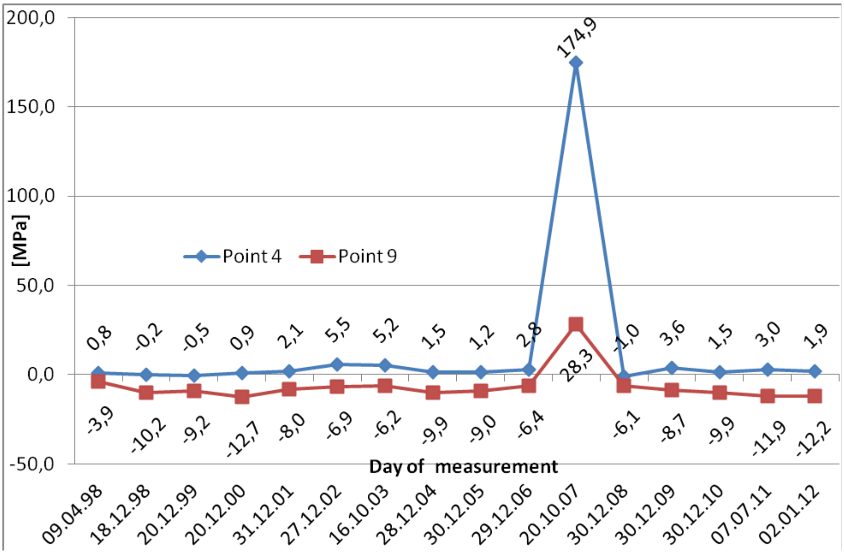

Fig. 10 Changes of hoop stresses in points 4 and 9 (side walls)

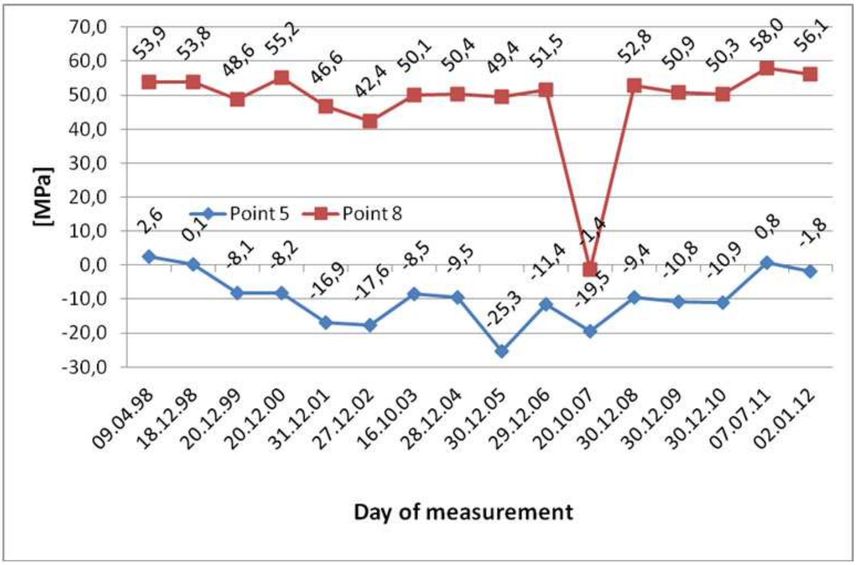

Fig. 11 Changes of bending stress in points 5 and 8 (haunch area)

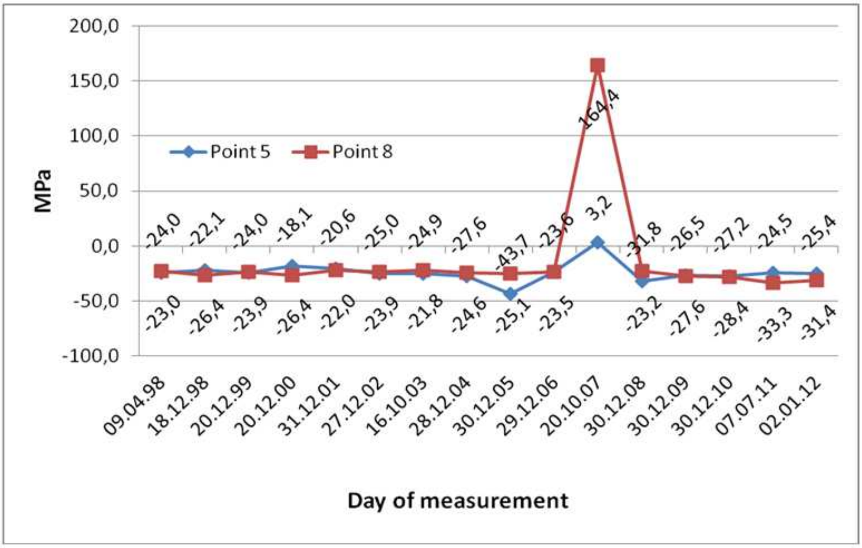

Fig. 12 Changes of hoop stresses in points 5 and 8 (near haunch)

Based on the analysis one can conclude as follows:
– long–term monitoring shows a stable distribution of stresses, except for the haunch area

- in 2007, so after 10 years of service, a significant change in points 6 and 7 caused the creation of a plastic hinge in these points (strain gages were damaged as a result),
- the creation of plastic hinges in the haunch resulted in short term change in distribution of stresses in other points,
- further measurements show that the values of stresses in other points (apart from the hinge) returned to the initial level.

6. CONCLUDING REMARKS

Measurements performed during 15 years of service show stabilization of the upper part in terms of change of stresses. So far observations showing increase of internal forces in the upper part with a reduction of stresses on side plates have been confirmed. Plastic hinges were generated in haunches. It caused short-term changes in the other points of the structure. However ,soon after that the state of equilibrium has been reached which was very similar to the initial one. Therefore the hypothesis stated in 2007 about a certain degree of settlement in the upper part together with no movement whatsover of the lower part has been confirmed.

Low stiffness of the lower part causes concentration of stresses in the soil under the haunch. It probably results in upward bending of bottom plates. This behavior of the structure leads to local bending of plates in the haunch area causing the creation of local plastic hinges. Similar increase in stresses in haunches was reported by Vaslestad (Vaslestad, 1994). The increase of strains in the haunch area can be promoted by poor compaction in this area or/and insufficient capacity of soil.

Summing up we can conclude that the research shows that this type of structures are stable under numerous cyclic dynamic loads. Creation of plastic hinges in the haunches jsutify the requirement of having good compaction in that area. However the lack of influence of the creation of plastic hinges on long-term distribution of stresses in the upper part of the structure indicates that generation of plastic hinges in the haunch does not have an important influence on stress levels in other parts of the structure. It would indicate that performance of closed type structures is not much different from open (arch) structures placed on foundations and has no practical influence on service load capacity of a closed structure. Further measurements are planned to verify that hypothesis .

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Streszczenie

Praca przedstawia długookresowe badania bezkolizyjnego węzła kolejowego wykonanego z konstrukcji z blachy falistej. Konstrukcja ma przekrój rurowo-łukowy i jest posadowiona bezpośrednio na podłożu gruntowym. Badania skupiały się na monitorowaniu zmian naprężeń konstrukcji stalowej. Przeprowadzono je przy pomocy tensometrów elektrooporowych rozmieszczonych na obrzeżach konstrukcji. Rezultaty przedstawione w tej pracy stanowią kontynuację badań rozpoczętych w roku 1998. Rezultaty uzyskane do roku 2006 zostały opublikowane w roku 2006 (Janusz et al.2007). W oparciu o te badania można było zauważyć, że poza strefą pachwinową wystąpiły jedynie niewielkie zmiany poziomu naprężeń w pozostałych strefach konstrukcji stalowej/

Stwierdzono, że w pachwinach powstały przeguby plastyczne. Jednakże, nie doprowadziło to do zmiany naprężeń w innych przekrojach konstrukcji, z wyjątkiem lokalnych zakłóceń w czasie powstawania przegubów plastycznych.

Słowa kluczowe: podatne konstrukcje, badania długookresowe, zmiana naprężeń w czasie