

Repair of cranes, technological compression, regeneration of deflections

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## **AN INFLUENCE OF TECHNOLOGICAL CONTRAFLEXURE OF CRANE BRIDGES ON ITS DURABILITY**

**Summary.** Standard requirements till 1996 year during bridge crane manufacturing demanded a positive technological contraflexure. As a result of this process were implemented technological compressive stress into tensile zone from inertial and operational loads and tensile stress into compressive zone. This way there were redistributed resultant stress which have increased fatigue strength of exploited crane bridges. Actually valid standard PN-ISO 7363 has removed this obligatory requirement. Its use depends of crane buyer demands. Reduction of initial positive deflection can be seen after few years of crane operations. It is a case of girders permanent deflections increment. Article presents method of technological prestressing of bridge girders with its practical application to obtain positive contraflexure.

## **ANALIZA WPŁYWU PRZEGIĘCIA TECHNOLOGICZNEGO MOSTÓW DŹWIGNICOWYCH NA ICH TRWAŁOŚĆ WYTRZYMAŁOŚCIOWĄ**

**Streszczenie.** Do 1996 r. wymagania normowe nakładały na producentów mostów dźwignicowych wymogi technologicznego ich przegięcia wypukłością ku górze. W wyniku tego procesu wprowadzone zostały technologiczne naprężenia ściskające do strefy rozciąganej od obciążeń własnych i eksploatacyjnych oraz naprężenia do strefy ściskanej. Dzięki temu uzyskano redystrybucję naprężeń wypadkowych, których wartość znacząco zwiększyła wytrzymałość eksploatowanych mostów. Obowiązująca obecnie norma PN-ISO 7363 zniósła ten obligatoryjny wymóg, uzależniając jego zastosowanie od żądania zamawiającego dźwignice. Brak przegięcia wstępnego jest już widoczny po kilkuletniej eksploatacji dźwignicy, w postaci przyrostu trwałych ugięć dźwigarów mostowych. W artykule przedstawiono sposób niwelacji trwałych ugięć dźwigarów metodą technologicznego ich przegięcia, celem zwiększenia ich wytrzymałości, wraz z omówieniem jej praktycznej aplikacji.

### **1. INTRODUCTION**

Technical condition of bridge cranes, which determines correct work, changes after long years of exploitation. It is an important factor which has influence work safety. Long years of exploitation is cause of vertical and horizontal permanent deflections of load carrying crane elements namely girders and buffer beams. There are many factors which determines deformations of named elements: constructional defects of railway tracks, undercrane girders and pillars, often overloads above load capacity, wrong exploitation (pulling of railway wagons), deformation of foundation of crane systems

etc. Inner discontinuity such as nonmetal inclusions and lalmelar cracks have also influence on increase of permanent deflections of load carrying crane elements.

Permanent deflections are cause of slope of buffer beams, and with them crane wheels. This might be cause of obliteration of inner tread of crane wheels and inner side of rail. It conducts to faster tear and raise of bridge movement restrains.

It is certain to remove permanent deflections of load carrying parts of crane. It is common in industry usage of compensation of rail level of permanent deflected beams by using additional plates between rail and upper belt of beam (fig. 1) [4]. This way only consequence of permanent deflection is removed. Permanent deflection is an information about decrease of strength reserves. If such changes in construction are observed there should be taken actions to stop increase of permanent deflections. This way serious consequences (fatigue cracks, catastrophical destruction of girders etc.) can be prevented. Remedy for leveling permanent deflection of load carrying elements of crane is method of technological strength regeneration.

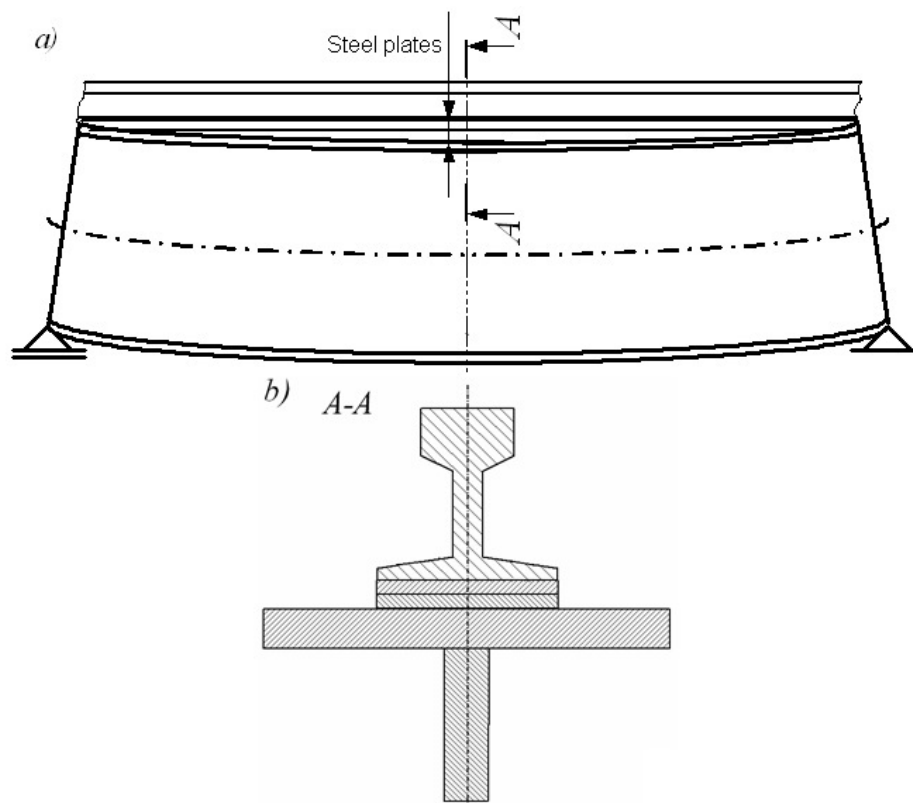


Fig. 1. Steel plates under the rail (description in text)

Rys. 1. Podkładki z blach pod stopą szyny (opis w tekście)

## 2. METHOD OF STRENGTH REGENERATION OF PERMANENT DEFLECTED BRIDGE CRANE BOX GIRDERS

Main part of strength regeneration method is by putting bending moments into girders which bends beam in opposite direction to loads. It is achieved by welding of additional steel plates to girder (fig. 2) [2]. Welding is executed at the same time from both sides of additional plate from beam center to its ends. It is important to keep same welding velocities.

Additional plate was welded to lower belt of girder. Plate width was  $l_1$ , thickness  $g_1$  and length  $l_1$  (fig. 2). Joint was made using two fillet welds (thickness a).

Result of simultaneous of making both welds was local heat of lower bottom girder belt and additional plates. It was accepted that when electrode moves fast along sheet there is no heat exchange between surrounding cross sections and isotherms are parallel to welding direction. Heat transfer in perpendicular direction to welding direction (fig. 3) [2].

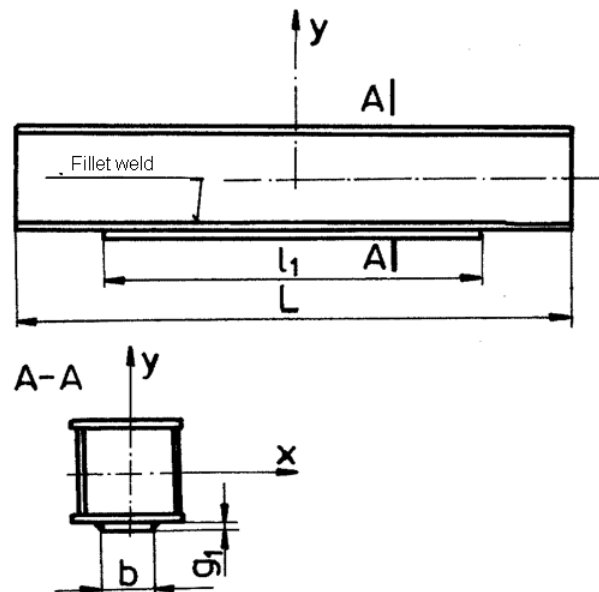


Fig. 2. Illustration of initial compression by welding additional steel plate to bottom box girder belt  
Rys. 2. Ilustracja metody sprężania wstępnego drogą spawania do pasa dolnego dźwigara skrzynkowego dodatkowego pasa blachy stalowej

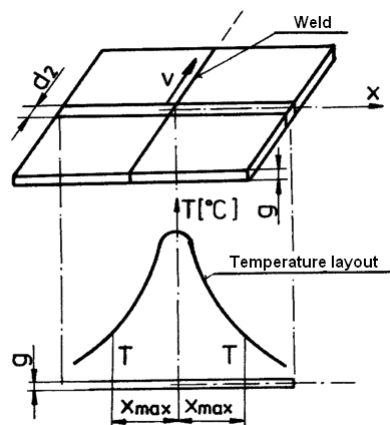


Fig. 3. Layout of temperature during electrode movement while welding along additional plate  
Rys. 3. Rozkład temperatury w trakcie przemieszczania się elektrody spawalniczej wzdłuż blachy nakładkowej

For such scheme of heat transfer during welding there is used equation based on N. O. Okerblom's theory [3]:

$$T(x, t) = \frac{q}{v \cdot g \cdot \sqrt{4 \cdot \pi \cdot \lambda \cdot c \cdot \gamma \cdot t}} \cdot \exp\left(-\frac{x^2}{4 \cdot a \cdot t}\right) \quad (1)$$

where:  $v$  - welding velocity cm/s,  $g$  - plate thickness cm,  $\lambda$  - thermal conductivity cal/cm s °C,  $q$  - effective amount of heat produced by welding arc cal/s  $\gamma$  - specific gravity w g/cm<sup>3</sup>.

Above equation can derive dependence defining abscissa  $x_{max}$  for temperature I after time  $t=y/v$ . For low carbon steel:

$$x_{max} = \frac{0,26 \cdot q}{g \cdot v \cdot T} \quad [cm] \quad (2)$$

Thermal strain heated plate is limited by surrounding material which wasn't heated or was heated in lower degree.

Compressing stress in additional plate and lower belt achieve yield limit  $R_{et}$  cause of heating to temperature  $T_p$ . Area of heated bottom belt and additional plate is calculated:

$$F_{Tp} = \frac{7280}{T_p} \cdot a^2 \quad (3)$$

From two fillet welds distant from each other there will be two such areas. After cooling to temperature 0°C on the edges of  $F_{Tp}$  thermal stress vanishes (fig. 4) [2]. Inside of area  $F_{Tp}$  there is area  $F_{2Tp}$  in which thermal stress after cooling doesn't vanish. They remain but with different mark (stretching) and they achieve yield limit for material. It was accepted that those stress changes linear from zero (on the borders of  $F_{Tp}$  area) to yield limit (on the borders of  $F_{2Tp}$  area). Active area of  $F_{2Tp}$  is described by equation:

$$F_1 = \frac{57,5 \cdot a^2}{1 + 2 \cdot \frac{57,5}{F} \cdot a^2} \quad (4)$$

where:  $F$  – total area of girder [cm<sup>2</sup>],  $a$  – thickness of fillet weld [cm]

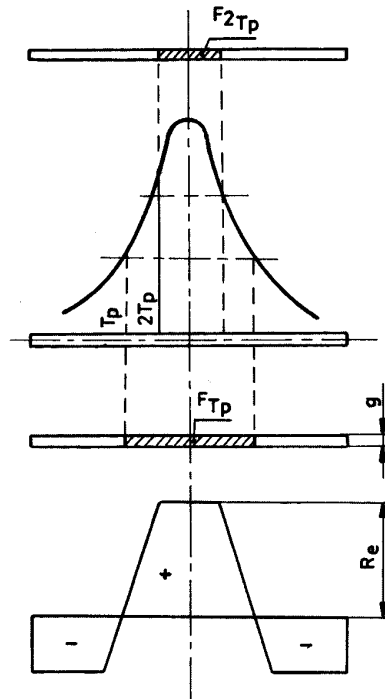


Fig. 4. Diagram of thermal welding stress in additional plate area and bottom belt after cooling to 0°C

Rys. 4. Diagram rozkładu naprężeń spawalniczych w strefie blachy nakładkowej i pasa dolnego po ochłodzeniu układu do 0°C

Calculating active area could result of calculations of compressive stress of welds and value of girder deflection which was the cause was thermal contraction.

Value of prominence which cause was two filled welds can be calculated:

$$f = \frac{L}{8 \cdot E \cdot J} \sum (R_e - \sigma_{oi}) \cdot F_{li} \cdot e_{li} \cdot l_{li} \quad (5)$$

where:  $E$  – Young modulus,  $J$  – moment of inertia,  $F_{li}$  – active area,  $e_{li}$  – distance between additional plate to centroid axis,  $l_{li}$  – length of weld,  $R_e$  – yield limit for girder material,  $\sigma_{oi}$  – stress from weight and exploitation loads for box girder.

### 3. SUMMARY AND PRACTICAL APPLICATION OF METHOD

Welding additional plates to bottom belt or lower area of middle plate should cause bending girder up. Curve causes contraction stress in active areas arise in places of welding. Value of curve can be controlled by thickness and width of welds.

Technical verification of mathematical model was applied on permanently deflected bridge crane box girders with load capacity  $Q=7$  t and length  $L=20$  m (fig. 5) [2].

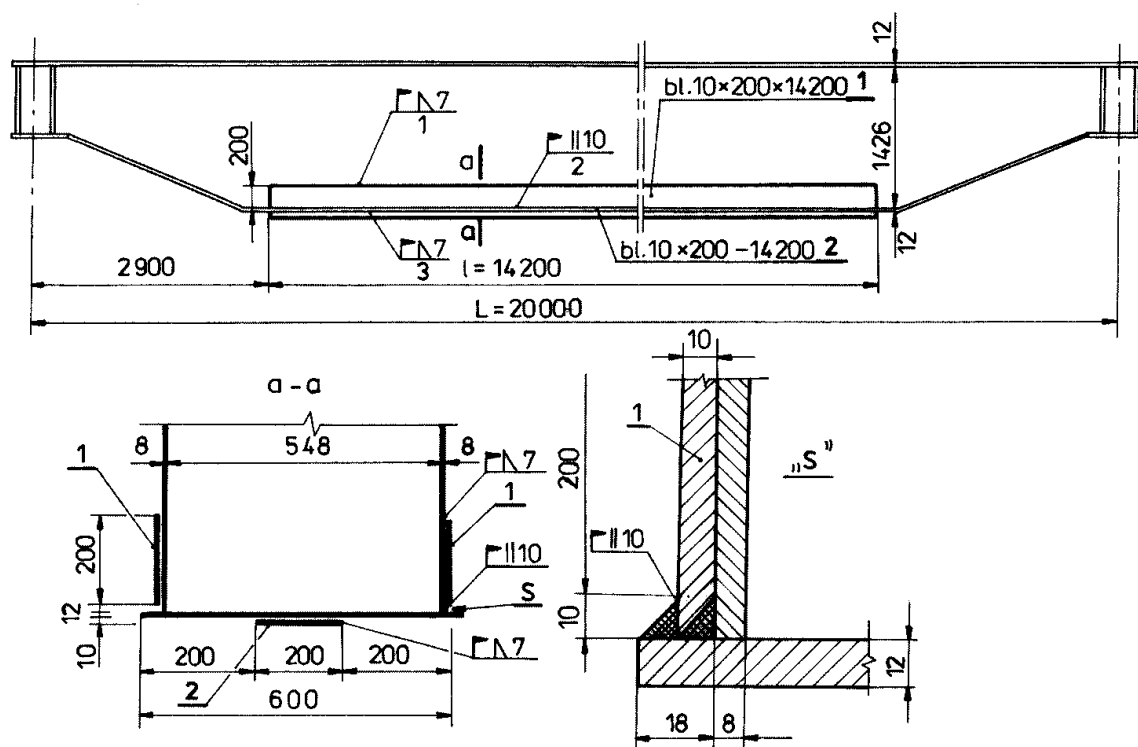


Fig. 5. Bridge crane box girder  $Q=7$  t,  $L=20$  m with compressing plates

Rys. 5. Dźwigar skrzynkowy suwnicy pomostowej  $Q=7$  t,  $L=20$  m z nakładkami sprężającymi

On fig. 5 it is shown dimensions of additional plates and welds. Shown box girders has big permanent deflections (above  $3,5L/100$ ). Department of technical supervision UDT has lowered its permissible load to  $Q=4$  t with half of year of further legal exploitation with its permissible load. Fig. 5 shows results of geodesic measurements of bend line of girders executed before and after technological compression. After repairs nominal permissible load was restore.

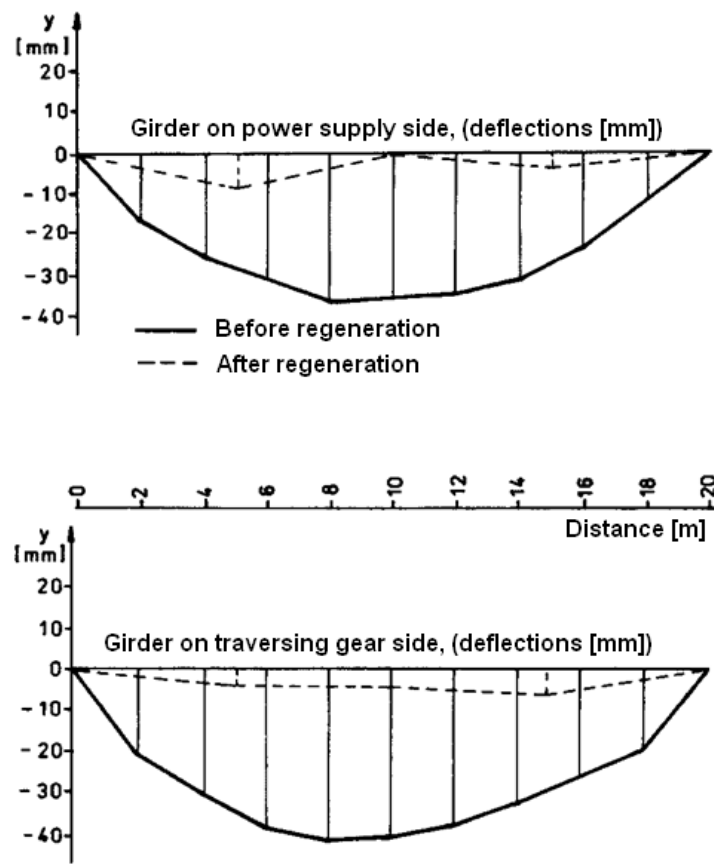


Fig. 6. Line of permanent deflections of bridge crane girders  $Q=7$  t,  $L=20$  m before and after regeneration  
 Rys. 6. Linie trwałych ugięć dźwigarów suwnicy pomostowej  $Q=7$  t,  $L=20$  m przed i po regeneracji

Additionally there were made stand research to investigate influence of technological compression on girder durability:

- girder not compressed NS
- girders compressed only in vertical plane (additional bottom side plates and bottom plate fig. 7 [2]) SPV
- girders compressed in vertical and horizontal planes (additional bottom side plates, bottom plate and middle plate fig. 7.) SPVH

Object of research were box girders made from metal works plates and plates taken from scraped craned in which nonmetallic inclusions were found. Aim of research was to investigate fatigue strength under concentrated constant load  $P_{max} = 300$  kN,  $P_{min} = 3$  kN, depending of applied compression technology. Next step was to compare those results with not compressed girder. Load was implemented using hydropulsator SHENK type PL630 fixed on rigid steel frame. Force sensor DL 630 was used to measure load. It was fixed to piston rod of hydropulsator (fig. 8).

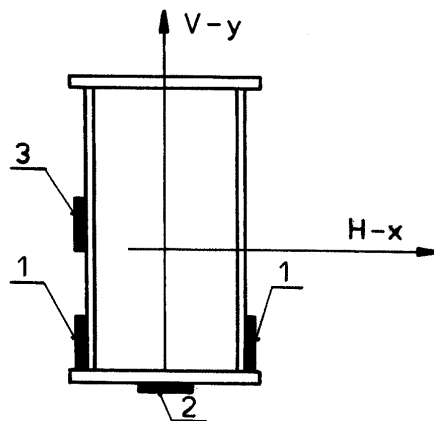


Fig. 7. Illustration of girder cross-section with additional compressive plates description. Cover plates 1, 2 causing vertical deflection. Cover plate 3 causing horizontal deflection

Rys. 7. Rysunek przekroju dźwigara z opisem nakładek sprężających. Blachy nakładkowe 1, 2 wywołujące efekt odkształcenia pionowego ku górze. Blacha nakładkowa 3 wywołująca efekt odkształcenia wypukłością poziomą w kierunku przeciwnym do nakładki bocznej

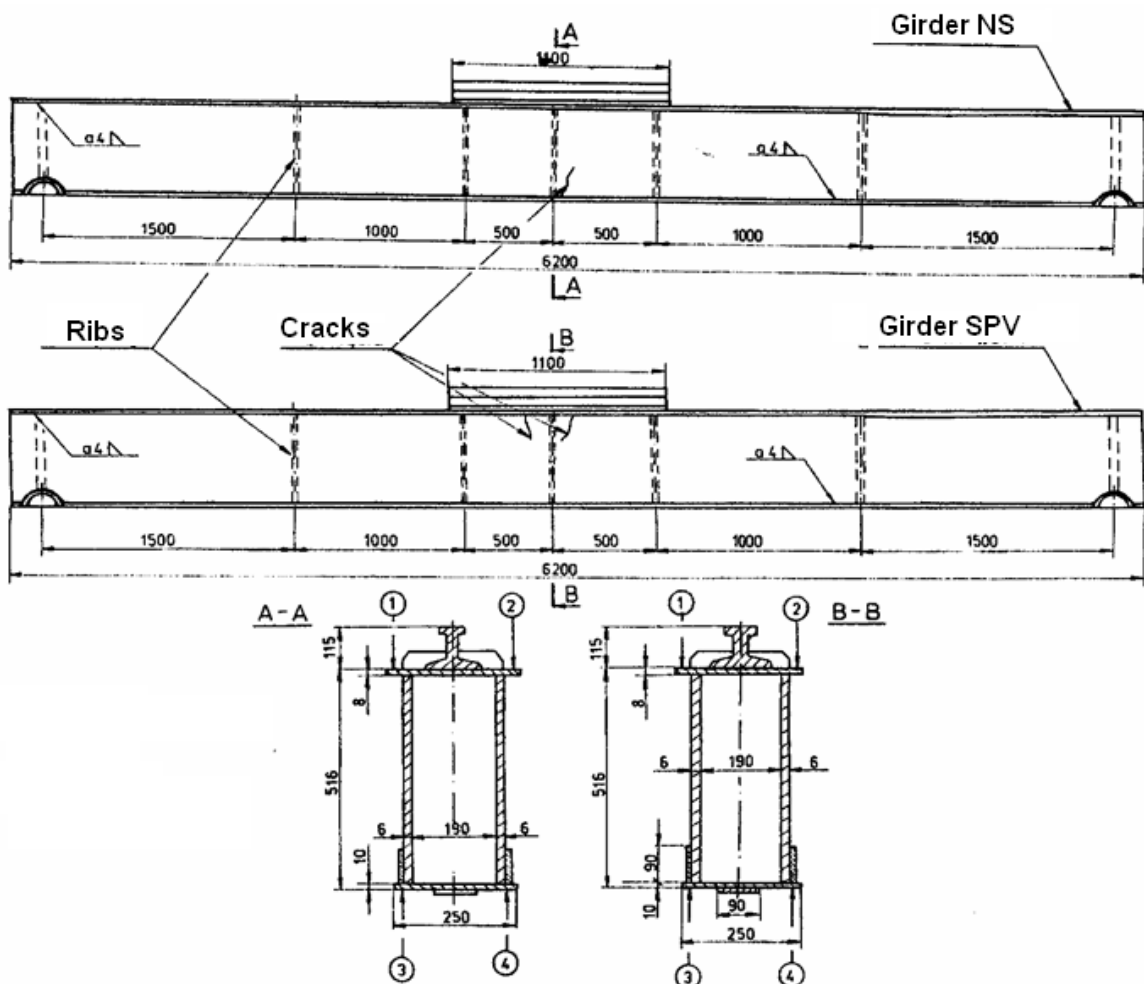


Fig. 8. Dimensions of girders: uncompressed NS and compressed SPV with marked measurement points with strain gauge (1, 2, 3, 4) and localization of fatigue cracks

Rys. 8. Wymiary dźwigara niesprężonego (NS) i dźwigara sprężonego (SPV) z zaznaczonymi punktami naklejenia czujników naprężno-oporowych (1, 2, 3, 4) oraz lokalizacją pęknięć zmęczeniowych

Analyzed girders had same load parameters: one-sided sinusoidal cycle with 1 Hz frequency. Comparative criterion of test end was loss of static equilibrium: sudden increase of permanent deflection was what cause of load decrease. Growth of fatigue crack was the cause of it.

During test stress were measured on extreme bottom and upper point of girders cross-section at half of its length.

Results of experiment [2] were presented in table and on graph (fig. 9).

Table 1

Results of fatigue experiment

Type of girder	Stress amplitude $\sigma_a$ [MPa]	Amount of cycles till destruction $N_0$	Deviation from average $\Delta X$
NS	145	423735	18105
SPV	115	557640	11640
SPVH	110	572829	12000

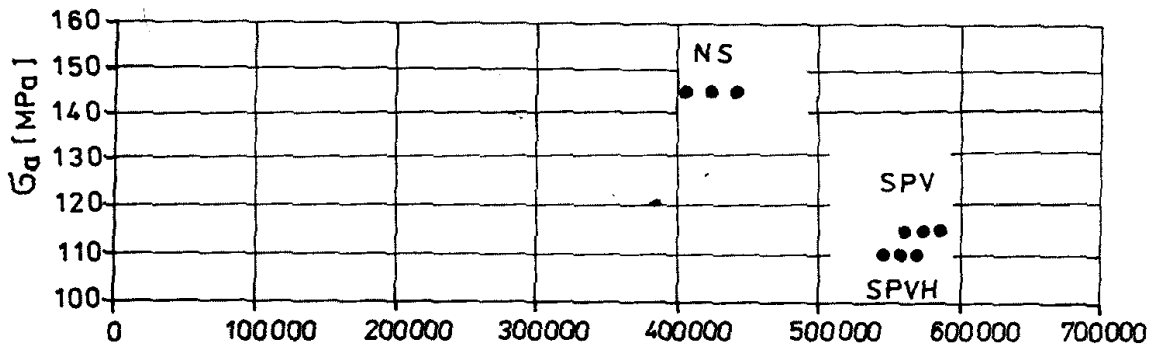


Fig. 9. Graph of fatigue experiment results

Rys. 9. Graficzna ilustracja rezultatów badań zmęczeniowych dźwigarów

Analysis of cracks initiation has shown influence of technological stress applied during compression on fatigue cracks location. Technological compression change localization and direction of fatigue cracks. For uncompressed girders cracks arises in bottom belt in maximum stretching stress zone in half length of girder and they expand perpendicular to girder axis. Cracks expand in bottom belt and middle plates (fig. 10) In compressed girders there is an opposite situation in which cracks expand in upper belt in places where belt is connected to middle plate (fig. 11).

Effect of technological compression was not only restoration of positive deflection but also increase of their fatigue strength with adding compressive stress to stretched zone (from exploitation loads). Technological compression increase fatigue strength for amount of 30%.





Fig. 10. Picture of uncompressed girder crack NS  
Rys. 10. Zdjęcie pęknięcia dźwigara niesprężonego NS

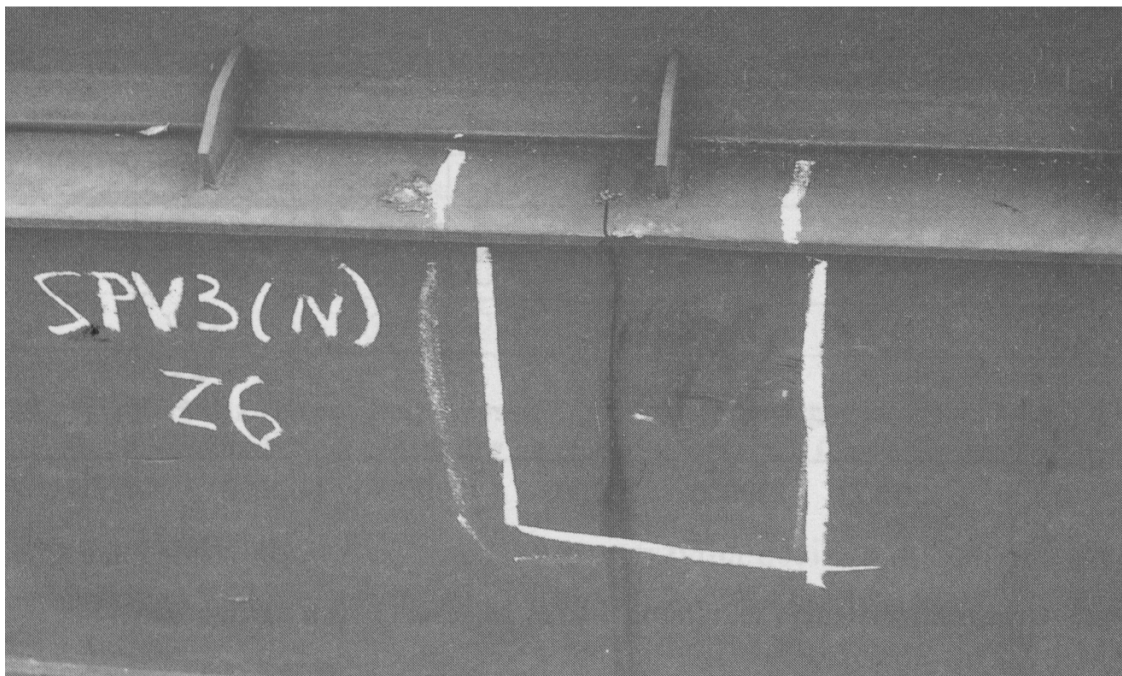


Fig. 11. Picture of compressed girder crack SPV  
Rys. 11. Zdjęcie pęknięcia dźwigara sprężonego SPV

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