JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
43, 4, pp. 893-907, Warsaw 2005

STRENGTH ANALYSIS OF A MULTI-CLIP JOINT

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The paper is concerned with strength analysis of multi-clip joints. Such structures enable visible growth of the carrying capacity and make them elements easily assembled by the clamping jaws and a single-clamp press. Each joint exerts an appreciable influence upon the safety level of the whole structure. A numerical analysis was performed to assess the effect of clearance between a sleeve and rope upon the joint quality. Phenomena emerging in the area between the clips were analysed as well. Some strength tests related to the process of drawing the wire rope out of the sleeve were also investigated. Changes in the stiffness of the clamping sleeve were analysed in view of the influence of the aforementioned factors upon the carrying capacity of joints and the sleeve material effort. Experimental investigations were conducted as well aiming at the determination of the smallest possible number of clips or the effective length of joints necessary for carrying the loads higher than the admissible load of the wire rope.

Key words: multi-clip joint, shapes, jaw, FEM

1. Introduction

The applicability of a single-clip joint is limited by a size of an available press performing a clamping process. Usually, such presses have a carrying capacity of 1000 KN and allow the clip width to range between 15-20 mm in the case of steel sleeves (grade 10) and between 35-50 mm for a sleeve made of A0 aluminium. To arrive at a higher load carrying capacity of the joint, a number of clips made with a circular pitch t can be produced; such a joint is called the multi-clip one (see Fig. 1). A clear advantage the joint can offer consists in a higher carrying capacity with no need for special equipment; i.e. using the same clamping press and clamping jaw. That is very important in view of technological and economic aspects of the manufacturing process. On the other hand, to make a single clip joint of a sufficient length one should have a press of much higher load carrying capacity at his disposal.

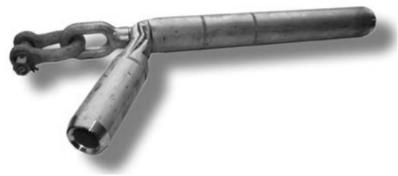

Fig. 1. Multi-clip joint

Such a press, of course, would be much heavier and larger, making outdoor applications very difficult. This aspect is very important in the case of mounting of power transmission lines, where two workers should be able to carry the press over.

The multi-clip joints, classified as permanent ones, are often used for connecting and fixing steel wire ropes (hereinafter the term "rope" is used), electric cables or hydraulic conduits. The clamping process consists in making clips one by one, and after each clamping process the unloading takes place.

Hankus (1988, 1990) showed mechanical properties of ropes determined in the rope axis direction, while Brzoska *et al.* (1982) examined the properties they reveal in the transverse direction. In the papers by Juraszek (1992, 1993, 1999), the authors put forward the concept of equivalent transversal stiffness and determined transversal deformability of ropes and electric cables. The problem of mounting durability, when a rope is fixed in a thimble (temporary joint), was presented by Carbogno (1988), Carbogno *et al.* (1998), Wójcik and Rokita (1998) determined the true load acting upon a rope of a cable railway, which is very important in view of technological aspects and crucial for a proper choice of the joint type for rope fixing. For more details of technological and operational aspects of the problem the Reader is referred to the journal "International Rope Review" (in German, Internationale Seilbahn-Rundschau).

This paper presents an attempt to analyse phenomena appearing between clips as well as to study the process of drawing a rope out of the sleeve (simulating that way true working conditions of a joint). The influence of the stiffness of a clamping sleeve upon the joint carrying capacity is also assessed. Based upon research results, the effect of the sleeve-to-rope clearance (introduced due to the mounting reasons, therefore hereinafter it bears the name "mounting clearance") upon residual stress is found. Owing to that, the load carrying capacity of the joint can be determined.

2. Models of the multi-clip joint

The phenomena occurring between particular clips have been analysed in an axi-symmetrical clamped joint. Basing on the research presented in Juraszek (1992, 2002, 2004), the Author applied a rope model in the form of a sleeve which enabled him to find the equivalent transversal stiffness chosen suitably on investigations of the true rope stiffness. Thus, the deformability of a rope within its contact zone with a clamping sleeve remained unchanged in the model.

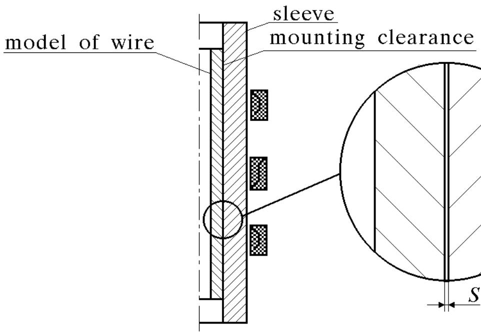

Fig. 2. Scheme of the necessary mounting clearance

The geometrical model was constructed basing on an engineering specification of a multi-clip joint. The element of the plane 42 type was applied, supplied with the option of axi-symmetrical analysis. In the model, there was a mounting clearance of 0.05 mm introduced between the sleeve and the rope (i.e. the internal diameter of the sleeve was higher by 0.05 than the nominal diameter of the rope – see Fig. 2.). Then a model of the contact zone was built using elements of the type Contact 48. The boundary conditions resulted from the assumed axial symmetry of the problem. The axis of symmetry of the joint overlapped the y-axis. At the next stage, the clamping process was performed involving jaws 1,2,3 (see Fig. 3.) in the consecutive way.

Then the phenomena emerging when the rope was drawn out of the sleeve were analysed. The process of drawing out was divided into stages determined by lengths of rope segments drawn out of the joint each time. The effort of the sleeve material was analysed in terms of the reduced stress and stress intensity. The results were measured at selected cross-sections between clips 1-2 and 2-3.

Another model was also created that allowed for introduction of variable stiffness of the clamping sleeve. The size of a clamping sleeve (external diameter) was chosen basing on the condition that the rope and sleeve exhibit the

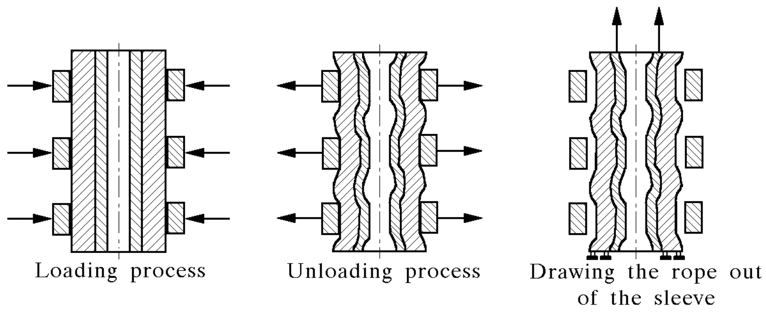

Fig. 3. Scheme of the mounting process

same strength. The working principle of the multi-clip joint is based on the assumption that each subsequent clip "transmits" a higher load from the rope to the sleeve than the previous one. At the initial stage of the load transmission, the sleeve deforms only slightly as compared to the rope which carries almost the whole load. The differences in the deformability of the rope and sleeve, respectively, may force those two elements to translate one with respect another which is definitely a disadvantageous phenomenon. A scheme of the variable-diameter joint is shown in Fig. 4.

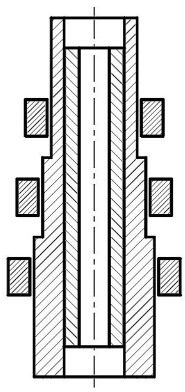

Fig. 4. Joint with a step-wise external diameter

3. Theoretical background

The theoretical background of the method is presented below. Changes in material parameters in the course of the deformation process are taken into account. The Amont-Coulob fricton model is introduced into the sleeve-rope contact area. The clamping process is assumed as a quasi-static one. An FEM approach assists the analysis of the plastic deformation problem.

The equation of equilibrium for a medium can be derived from the virtual work principle (Kleiber, 1984). In the case of a general Lagrange's formulation we have

$$\int\limits_V S_{ij}\, \delta\varepsilon_{ij}\, dV = R \tag{3.1}$$

where

S_{ij} – component of the second Piola-Kirchoff stress tensor
ε_{ij} – component of the Green-Lagrange strain tensor.

The work done by the external forces R can be represented in terms of the surface and volume works, respectively

$$R = \int\limits_A p\, \delta U_k\, dA + \int\limits_V f\, \delta U_k\, dV \tag{3.2}$$

The above equation has been derived on the assumption that the body configuration changes from one loading step to another.

In Eq (3.2), the symbols A and V stand for the surface and volume of the body, respectively, while p and f represent components of the vectors of surface and volume forces acting upon a unit surface and unit volume of the body corresponding to the initial configuration. δU_k represents the displacement variation, while δe_{ij} stand for the strain variations

$$\delta e_{ij} = \delta \frac{1}{2}({}_kU_{i,j} + {}_kU_{j,i}) \tag{3.3}$$

The above equation, after applying the FEM approach, can be rewritten in the following discrete matrix form

$${}^k\mathsf{K}\, {}^k\boldsymbol{U} = {}^{k+1}\boldsymbol{R} - {}^k\boldsymbol{F} \tag{3.4}$$

where

${}^k\mathsf{K}$ – tangential stiffness matrix at the loading step k
${}^k\boldsymbol{U}$ – vector of node displacement increments at the loading step k
${}^{k+1}\boldsymbol{R}$ – incremental vector of nodal loads at the loading step $k+1$
${}^k\boldsymbol{F}$ – vector of nodal correcting forces at the loading step k.

Throughout considerations the term "step" means subsequent incremental loading steps.

4. Results of numerical simulation

Some primary analyses of the mounting clearance effect upon the magnitudes of residual stresses have been conducted using a model with a clearance of 0.05 mm, hereinafter called the basic model.

The computations have been made for the basic model. Other variants, differing in the clearance size are presented in Table 1.

Table 1. Different sizes of the mounting clearance

Variant number	Clearance size s [mm]
var1	0.01
var2 (the basic one)	0.05
var3	0.35
var4	0.65
var5	0.95
var6	1.25
var7	1.55

Sample simulation results obtained for the basic joint in terms of the magnitudes of radial stresses S_x as well as of those acting along the joint axis S_Y after the clamping process has been completed are presented in Fig. 5 and Fig. 6.

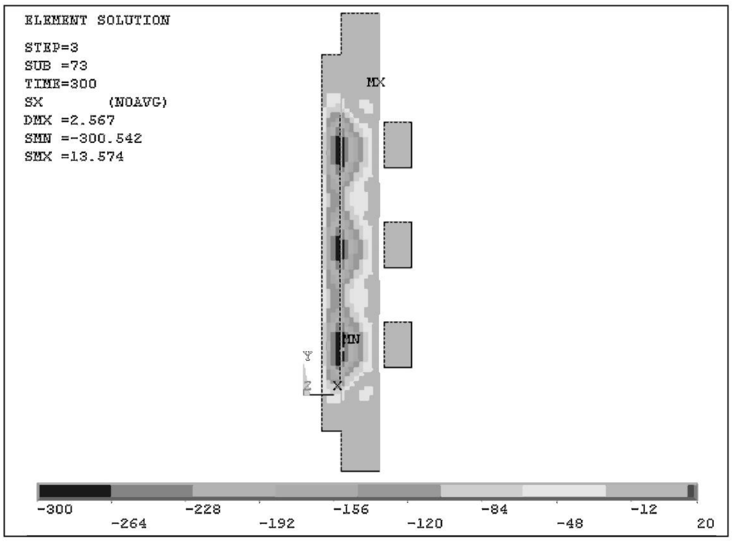

Fig. 5. S_x stress in the basic variant of the joint

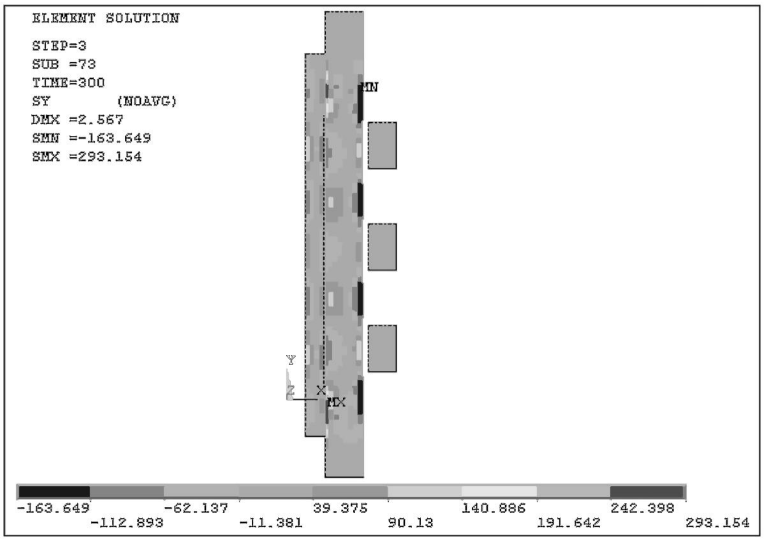

Fig. 6. S_y stress in the basic variant of the joint

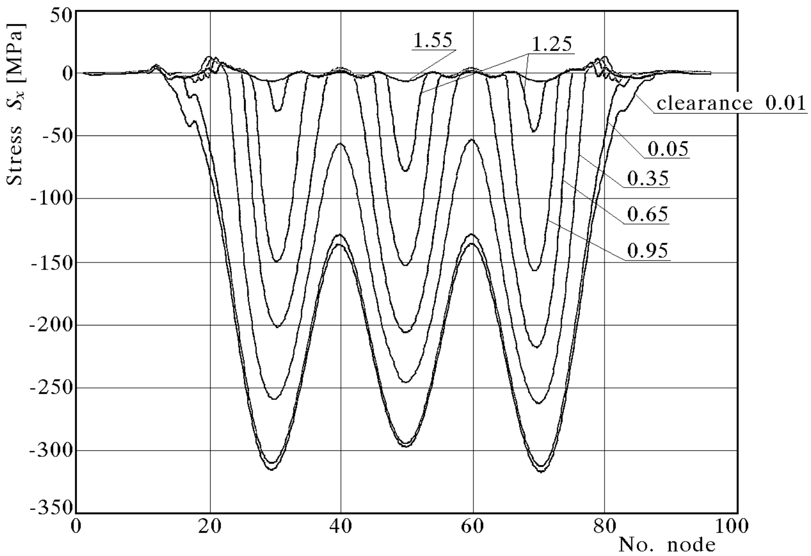

Fig. 7. The effect of clearance size upon the stress S_x

The calculations made for the other 6 variants are presented in Table 1. Figure 7 shows the results of comparison between the magnitudes of radial stresses S_x obtained for different variants, depending on the clearance size. It can be clearly seen in this figure that when the clearance grows, the magnitude of radial stress decreases within the contact zone. That involves the reduction in the carrying capacity of the axial load (Juraszek, 1999). We arrive, therefore, at the conclusion that the smallest possible clearance between the rope and sleeve should be ensured.

The way the joint works has been analysed focusing on the phenomena emerging between particular joints. A scheme of the rope drawing out of the sleeve is shown in Fig. 3. From the results of FEM computations, those obtained in the most interesting cross-sections have been selected (see Fig. 8).

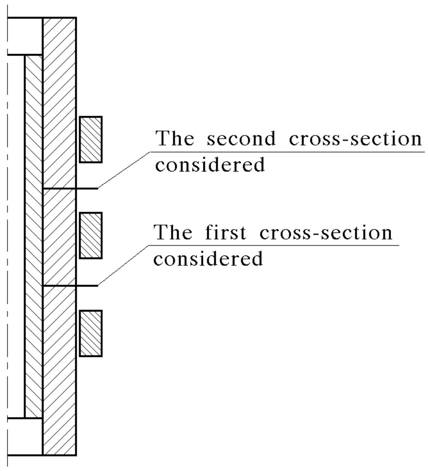

Fig. 8. Considered cross-sections

The true working conditions of the joint have been simulated when the rope was drawn out of the sleeve. Figures 9 and 10 present the material efforts obtained in the considered cross-sections. The higher level of the material effort observed in the first cross-section should be emphasized.

Next the joint with a step-wise external diameter was analysed. The following assumptions were accepted:

- Material parameters of the model are non-linear
- FEM mesh is similar to that used in the basic model
- Boundary conditions, loading and unloading processes are the same as in the case of the basic model.

It is well known that the sleeve-rope contact zone determines the joint carrying capacity. Therefore, to make the simulations more precise, the nodes lying in this area were selected using the ANSYS code options.

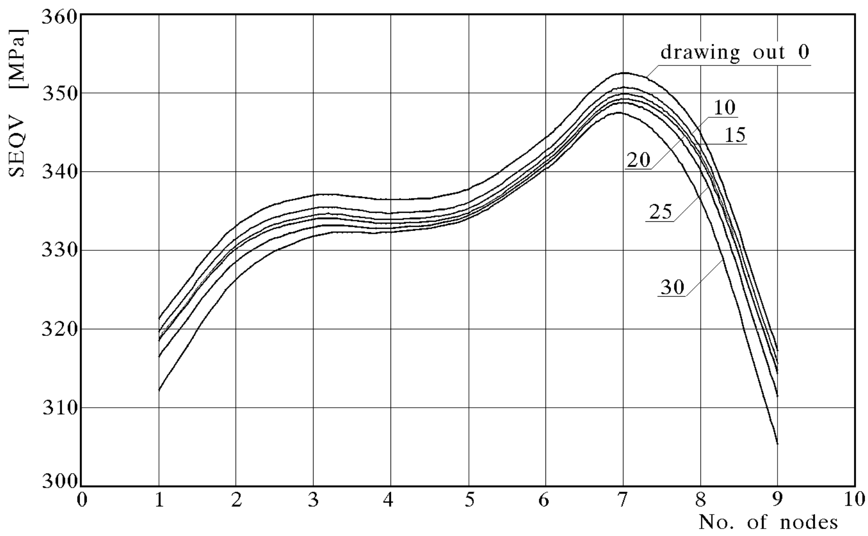

Fig. 9. Material effort SEQV in the first I-I cross-section

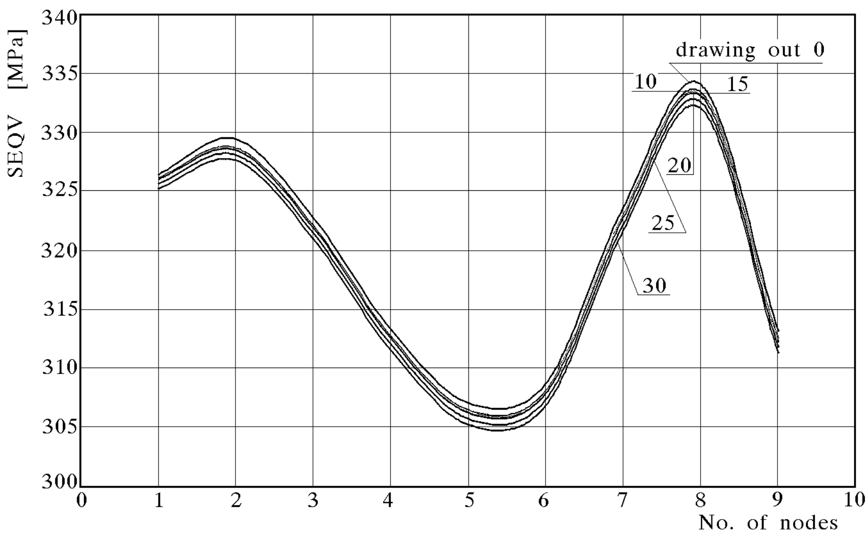

Fig. 10. Material effort SEQV in the second II-II cross-sections

In Fig. 11, numbers of the selected nodes 0-120 (or their abscissas) are marked along x-axis. The node selection has been made also in the two cross-sections - between clips 1-2 and 2-3 in the direction perpendicular to the joint axis.

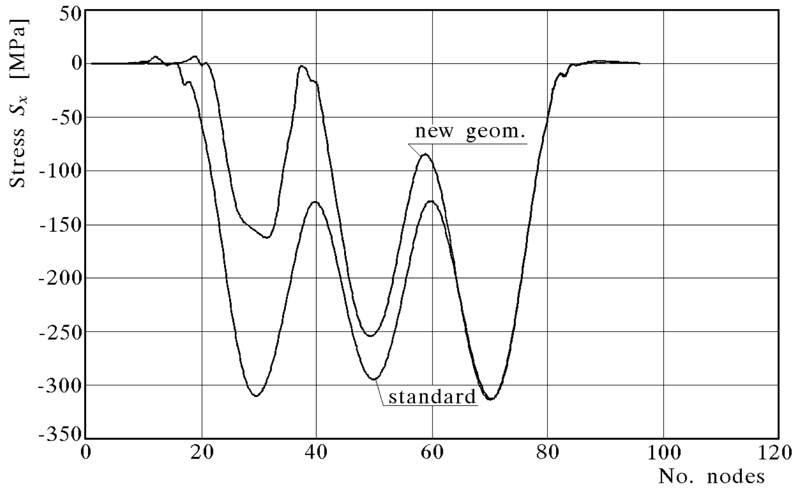

Fig. 11. S_x stress in the basic joint and in the joint with the variable external diameter

Due to a step-wise size of the external diameter, the magnitudes of the radial stress S_x in the first clip are reduced, while in the second and third clips they rise gradually (see Fig. 11).

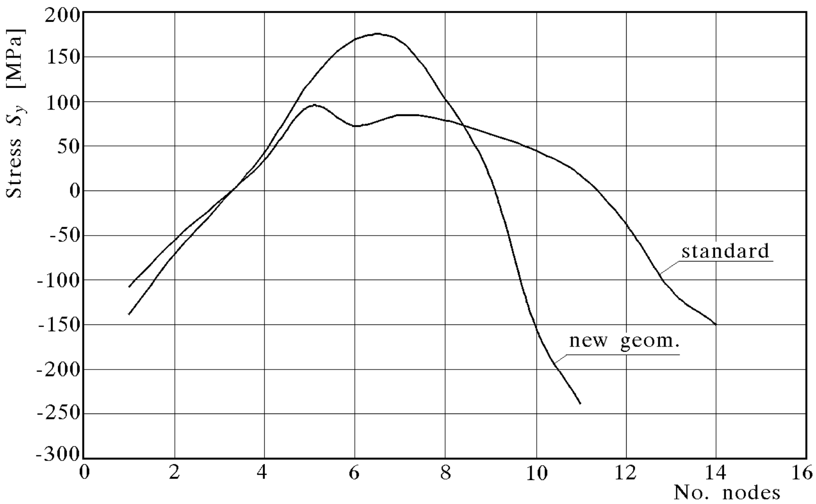

Fig. 12. S_y stress in the basic and variable-diameter joints

Since the diameter is smaller, the S_y stress (in the direction of the joint axis) between the clips x-x are almost twice as much as in the joint of the constant diameter (see Fig. 12). In the second cross-section, the radial stress increases three times. In view of the joint working quality, one should consider the increase of the radial stress as an advantageous effect since smaller differences in the deformability of the rope and sleeve are involved in particular cross-sections between the clips. From the analysis of stress intensities obtained for different models, it can be concluded that the material effort in the joint with a step-wise diameter is lower as compared to the standard joint of the same carrying capacity. The effect of the sleeve wall thickness variability introduced by a step-wise change in the external diameter of the clamping sleeve from 56 mm to 47 mm and in other diameters (b and c) is shown in Fig. 13.

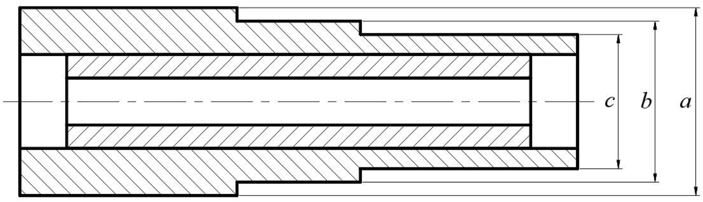

Fig. 13. Variability of the sleeve wall thickness

Table 2

Variant number	Diameter a [mm]	Diameter b [mm]	Diameter c [mm]
var1	56.0	48.0	40.0
var2	54.2	46.8	39.4
var3	52.4	45.6	38.8
var4	50.6	44.4	38.2
var5	48.8	43.2	37.6
var6	47.0	42.0	37.0

All other parameters of the process remained unchanged. Further decrease in the external diameter involves reduction in the S_x stress (see Fig. 14) accompanied by simultaneous growth in the magnitude of the S_y stress. Therefore, through changing of the diameter of the clamping sleeve, one can improve the sleeve deformability so that it can better adapt to the rope deformability between the clips.

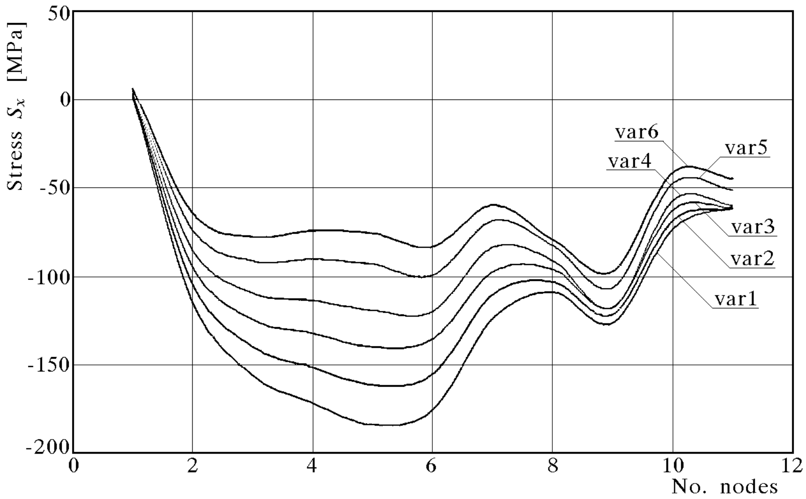

Fig. 14. Courses of the S_x stress in different variants of the joint geometry

5. Experimental investigations

Multi-clip joints with the rope diameters assuming values within the range from 12 to 42 mm were examined. A joint was classified as properly chosen if its tensile strength was higher than the rope breaking strength, i.e. when the rope broke outside the joint area. The internal diameter of the clamping sleeve was equal to 1.02 of the rope nominal diameter. The clearance size of 2% of the rope nominal diameter allows the rope tip to be inserted into the sleeve with no additional equipment needed. Since from the clearance analysis it followed that the smallest possible clearance size is the most profitable one, the value of 2% of the rope nominal diameter could be accepted. The external diameter of the clamping sleeve D_z is chosen for each rope diameter upon the assumption that the rope and sleeve reveal the same tensile strength. The experimental verification consisted in the determination of the joint carrying capacity, i.e. the highest load the joint can carry without translation of the rope relative to the sleeve. According to the frictional hypothesis of the joint carrying capacity, this quantity is a function of the residual stress on the rope-sleeve contact surface. A special test stand was built to determine the carrying capacity of the joint. Axial displacements of the rope were measured at 4 points. The design of the test stand allowed for measurements of the rope translation relative to the fixed clamping sleeve. For the measurement purposes, three inductive sensors were employed as well as a mechanical inductor for control purposes. General test results showed the shortest possible length along which the clamping process should be performed for the resulting joint carrying capacity to be at least equal to the rope carrying capacity (admissible load).

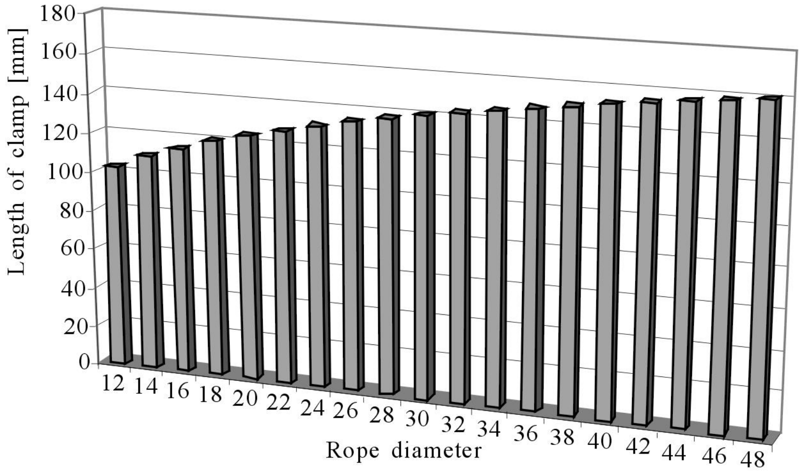

Fig. 15. The number needed of clips as a function of the rope diameter

6. Conclusions

The results of numerical simulations prove that the smallest possible clearance between the rope and sleeve should be aimed at. Technological aspects of the joint mounting process determine the lower limit of the clearance size. In practice, the smallest possible value of the diameter of the sleeve should be equal to 1.02 of the nominal rope diameter which allows for straightforward mounting (insertion) of the rope into the sleeve. Clamped joints are very simple from the technological point of view and reveal small external sizes as compared to joints commonly used at present. The aforementioned results of theoretical and experimental investigations can be used in formulation of structural and technological suggestions concerning the development of new joint designs. A step-wise change in the transversal stiffness improves quality of the joint. The considered joints exhibit a relatively low material consumption index.

In the near future, clamped joints will be applied to mounting of control and measurement cables. The presented numerical model allows for shortening of the calculation time by almost 70% as compared to the 3D model presented in Juraszek (2004). The results obtained from those two models differ by 5%. From the investigations conducted, two important factors that determine the joint quality; i.e. the required joint length and the number of needed clips, can be found as well.

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Analiza złącza wielozaciskowego

Streszczenie

W pracy przeprowadzono analizę złącz wielozaciskowych. Umożliwiają one osiągnięcie większej nośności złącza poprzez zastosowanie szczęk zaciskających i prasy do zacisków jednokrotnych. Złącza mają istotny wpływ na poziom bezpieczeństwa całej konstrukcji, w której są zainstalowane. Przeprowadzono analizę numeryczną oceniającą wpływ wielkości luzu między tuleją a liną, analizę zjawisk zachodzących między poszczególnymi zaciskami, analizę procesu wyciągania liny oraz zmiany sztywności tulei zaciskanej. Wykonane następnie badania doświadczalne umożliwiły wyznaczenie najmniejszej liczby zacisków lub długości efektywnej złącza niezbędnej do przeniesienia obciążenia większego od nominalnego obciążenia lin.

Manuscript received May 19, 2005; accepted for print July 11, 2005