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Research paper

Experimental tests of tension connections of steel angle sections of lattice transmission towers

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Abstract: In the present paper, the results of experimental tests of bolted connections of angle specimens subjected to tension and connected by one leg are presented. Structural members of such type are commonly applied to the steel lattice supports of overhead electrical lines. The bolted connections of angles connected by one leg to gusset plates are in tension and additional bending moment that results from the eccentricity of the bolt group. The majority of available existing experimental and numerical investigations regarding the bolted connections of steel angles in tension have been conducted using mostly short specimens. Within this paper, the influence of the specimen length on the behaviour of angles connected by one leg in tension is shown on the basis of the comparison of the results from the experimental tests of shorter and longer specimens of the same size of angle section. Equal-leg angles in two cross-section dimensional groups – L90 × 6 and L120 × 8, and of two lengths: 600 mm and 1500 mm were tested. A basic test included determining the destructive force, elongation of a specimen and its deflections. In the case of some specimens, the tests were extended to include strain measurements in characteristic places of the angles – in the middle of the length and in the bolted connection zone. The conclusions from the conducted experimental tests confirm that the length of a specimen has an impact on the results, with a greater effect observed in angles with larger cross-sections, and thus with a greater load eccentricity.

Keywords: angle sections connected by one leg, bolted connections, experimental tests, lattice towers, tension members, transmission towers

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1. Introduction

1.1. Survey of previous experimental investigations

Steel angle sections have been widely used in the construction industry, especially in tower structures used, for example, in telecommunications or power engineering. They are characterized by a simple shape, the advantage of which is, among others, ease of constructing connections – usually such angles are connected with other elements, e.g. gusset plates, by one leg. The consequence of such a solution is the introduction of the connection eccentricity and the resulting bending moment. In addition, disadvantageous is the method of joining, often used in practice, which consists in placing the bolts in the middle of the width of the connected leg, and not in the axis passing through the centre of gravity of the angle bar. All this means that even a truss member, assumed to be loaded only with the longitudinal axial force, is additionally subjected to bending, which has an impact on the behaviour of such a member and its resistance, as well as on the resistance of bolted connections. Investigations aimed at better understanding this issue have been conducted for many years in various research centres around the world, and they focus mainly on assessing the behaviour and load-bearing capacity of connections between angles and gusset plates. In research papers [1–3], the issues of numerical modelling of angles in tension connected to gusset plates with bolts were undertaken. The process of searching for an appropriate material model, allowing to obtain in FEM modelling, the forms of failure consistent with the results of experimental research, was presented in detail. In the subsequent works of the same author's team [4,5], extensive numerical research and comparative results of experimental tests of angles in tension connected in joints with the use of various numbers of bolts were conducted. Parametric analyses were carried out regarding the influence of such variables as the slenderness of the cross-section parts, connection dimensions, distances of bolts from the edge and spacing between fasteners and material properties on the behaviour of angles in tension. Paper [6] presents the modelling of lap bolted connections of angle sections with gusset plates. The connections with 2, 3 and 4 bolts were modelled in order to know the distribution of stresses in the connection zone. In [7], in turn, the results of short series of experimental tests of angle sections connected by bolts with gusset plates were presented. Paper [8] included experimental studies of equal leg angles connected to gusset plates with bolts at different eccentricities. The influence of these eccentricities on deformations (deflections) of the tested elements and their load capacity was assessed. Another paper [9] also concerns experimental studies of bolted connections of angles with gusset plates. In this case, cold-formed sections were used, and the length of the connection and the number of bolts as well as the eccentricity related to the distance of the connection plane from the centre of gravity of the angle were differentiated. The tests included equal leg angles as well as unequal leg angles connected to gusset plates with both a wider and narrower leg. In [10] experimental studies and numerical analyses of angles connected to gusset plates both with welds and with the use of bolted connections were presented. The influence of the length of the welds and the spacing of the bolts on the resistance and behaviour of the connections (elongation and deformation measured in characteristic cross-sections) was tested. Papers [11, 12] concern tests of angle bars joined with fillet welds with gusset plates, the aim of which was to assess the effect of the weld arrangement on the resistance of structural members. The elements with welded connections whose centre of gravity coincided with the centre of gravity of the angle section were investigated, as well as with welds arranged symmetrically to the central axis of the connected leg of the angle.

In the studies mentioned above, the analysis of the influence of the length of the specimens on the results obtained was generally not carried out. In the case of bolted connections, short specimen lengths in the range of 500–600 mm were typically used, and lengths of 1200–1900 mm for welded connections. One of the objectives of the research being the subject of this article is, therefore, preliminary recognition of the issue of the impact of a specimen length on the obtained results.

1.2. Current research needs and scope of present investigations

The issue presented in this article is a part of the broader research including comprehensive testing of supporting structures of power lines, starting from entire structures and ending with the tests of individual structural members and connections. Tests of the entire 110 kV and 400 kV lattice supports are described in [13]. They were carried out on properly prepared testing grounds and consisted of loading the lattice supports several times (2 to 4 trials) to the level of 100% of the design load capacity, and then loading the structure until its destruction. This approach enables assessing the structure's ability to take over the design loads, its stiffness, and to observe the failure modes of the structure taking into account actual material, geometric and assembly imperfections as well as any clearances in openings and eccentricities of connections. Tests of entire structures are complex, costly and time-consuming, so they may concern only single structures, which means that they need to be supplemented with numerical models and tests of a greater number of isolated elements and joints.

Experimental tests of such single angles with different cross-sections and with bolted connections, carried out by the authors of this article, are presented in [14]. Tests of total ninety specimens consisted of different angle sections but of the same length, was conducted in the laboratory of the Faculty of Civil Engineering, WUT within the ENPROM project introduced above. The bolted connections of angles connected by one leg, theoretically under axial tension, are in fact also subjected to bending moment that results from the eccentricities of the bolt group. It was observed that the smaller specimen length (all elements had a fixed length of 600 mm) to its leg width ratio, the deformation of the angle specimen due to bending stresses was more and more visible. This observation was the motivation for the authors of this article to investigate the effect of the length and slenderness of the elements on the results of the research.

This paper presents the experimental destructive tests of eighteen angle specimens connected by one leg to the gusset plates on both ends by means of bolted connections and subjected to tension, as well as to discuss the influence of the specimen length on their behaviour.

2. Experimental tests

2.1. Specimens

Specimens considered in the experimental tests described herein consist of angles connected by one leg to the gusset plates on both ends. For the purpose of this publication two series of equal leg angles are taken into account. Two angle sections dealt with are L120 × 120 × 8 and L90 × 90 × 6. The bolts used are M20 for the connections of these sections. The sections and bolts are the same as used in the full-scale tower structure to be tested for collapse as described in [13]. The experimental tests of the selected specimens were performed in two stages. Firstly, the set of short specimens of the length equal to 600 mm were tested. In the second stage, the tests of the longer specimens of 1500 mm long were performed. The summary of the specimens considered in the present paper is given in Table 1.

Table 1. Summary of the tested specimens

Type of specimens	**Short specimens (L = 600 mm)**		**Long specimens (L = 1500 mm)**	
Hot-rolled sections	L90 × 90 × 6	L120 × 120 × 8	L90 × 90 × 6	L120 × 120 × 8
Specimen names	L90/6/3M20-1	L120/8/3M20-1	L90/6/3M20-6	L120/8/3M20-6
	L90/6/3M20-2	L120/8/3M20-2	L90/6/3M20-7	L120/8/3M20-7
	L90/6/3M20-3	L120/8/3M20-3	L90/6/3M20-8	L120/8/3M20-8
	L90/6/3M20-4	L120/8/3M20-4	L90/6/3M20-9	
	L90/6/3M20-5	L120/8/3M20-5	L90/6/3M20-10	

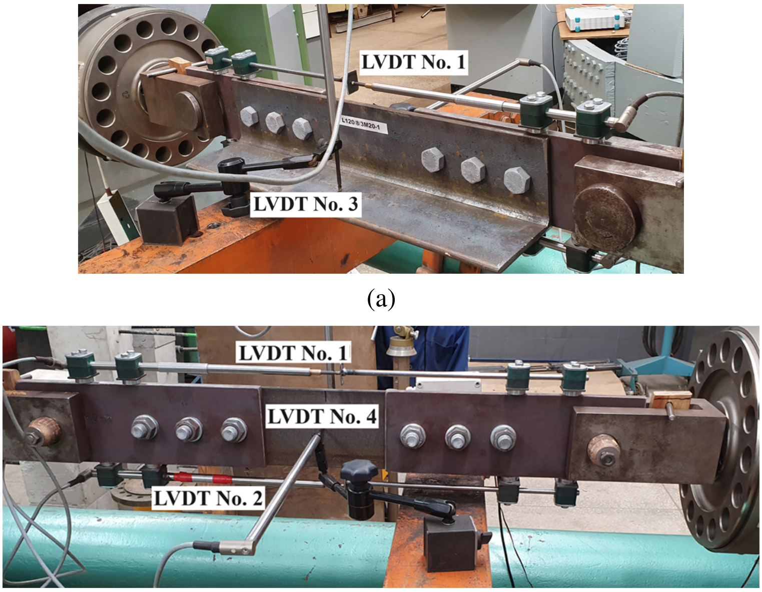
All angle members are connected to steel gusset plates by means of lap bolted connections, using 3 bolts M20 cl. 8.8 at each end. The bolts were fastened with the controlled tightening moment equal to 246 Nm. End and edge distances (e_1 = 40 mm, e_2 = 60 mm for L120×120×8 and 45 mm for L90×90×6), as well as the spacing between bolts (p_1 = 65 mm for L120×120×8 and 60 mm for L90 × 90 × 6), met the requirements of EN 1993-1-8 [15]. Dimensions of the gusset plates were properly fitted to the angle sections in order to avoid undesirable failure modes in the gusset plates and were equal to 28 × 120 × 360 mm and 15 × 120 × 350 mm, respectively for L120 × 120 × 8 and L90 × 90 × 6. Both the hot-rolled sections as well as the gusset plates are made of steel grade S355J2.

2.2. Description of experimental setup and testing procedure

The experimental tests were conducted using 1000 kN universal testing machine, in which the specimens were placed horizontally. The gusset plates at both ends of the specimens were connected by pins to the grips of the testing machine.

The specimens were subjected to a monotonic tensile force, which was applied to horizontal steel grips that were fixed to the testing machine, as shown in Fig. 1. The tests were carried out under displacement control at a possibly slowest steady speed up to a failure of the specimens.

Two linear variable displacement transducers were attached to the gusset plates on the top (LVDT No. 1) and the bottom side (LVDT No. 2) of the plates. Their function was a measurement of specimen elongations. Moreover, two additional LVDTs were applied in order to measure out-of-plane displacement, one in the vertical direction (LVDT No. 3) and the other in the horizontal direction (LVDT No. 4), perpendicular to the longitudinal axis of a specimen. Selected specimens were also equipped in the set of strain gauges, located close to one bolted connection at one end of the specimen and also in the middle of the specimen length. The load measurement was carried out using a force gauge integrated with the actuator of the testing machine. Load and displacement data were collected by a data acquisition system and exported to Excel.



(b)

Fig. 1. Test stand with a mounted specimen and location of LVDTs: (a) Front view, (b) Back view

2.3. Material properties of structural steel

Additionally to the experimental tests of the specimens with bolted connections, tests of material properties were also conducted. From each angle type considered herein, three coupons were cut off and tested according to the requirements of EN ISO 6892-1 [16].

Summary of the mechanical properties of the steel used for fabrication of the specimens is shown in Table 2, distinguishing sizes of an angle section as the original material for cutting the tensile coupons as well as the average values of the yield strength f_y, the ultimate strength f_u and their standard deviations (s_{fy} and s_{fu}, respectively).

Table 2. Summary of the tested specimens

Angle section – length (series type)	f_y **[MPa]**	s_{fy} **[MPa]**	f_u **[MPa]**	s_{fu} **[MPa]**
L120 × 120 × 8 – 600 mm	427	4.9	521	5.3
L120 × 120 × 8 – 1500 mm	427	4.1	524	4.8
L90 × 90 × 6 – 600 mm	409	5.6	597	5.3
L90 × 90 × 6 – 1500 mm	428	1.8	579	8.9

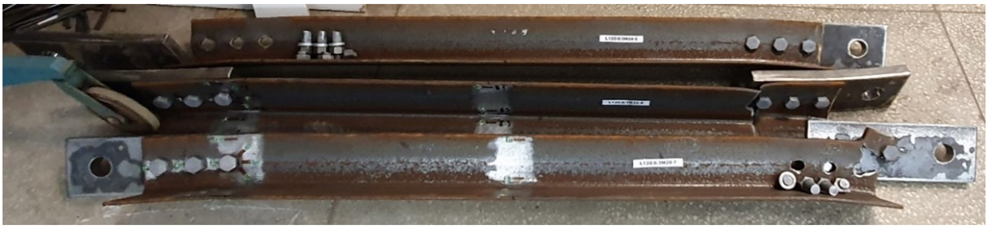
2.4. Failure modes of short specimens

The failure mode for the whole series of the short L120 × 120 × 8 angle specimens is presented in Fig. 2a. It was the same for each specimen from this series and based on the angle net cross-section rupture with accompanying significant plastic deformations due to bending of the angle sections. The place of the net cross-section failure every time passes by the external bolt hole located closer to the midspan of the specimen. The series of short L90 × 90 × 6 angle specimen was destroyed in a similar manner as the described above (see Fig. 2b), except the specimen L90/6/3M20-4, in which the acting force immediately dropped down due to bending, before reaching damage of the net cross-section of the angle. The deformations due to bending were also observed but their range was smaller than in the group of short L120 × 120 × 8 angles.

2.5. Failure modes of long specimens

In the case of both groups of the longer specimens, the deformations due to bending are not so visible, what is shown in Fig. 2c, 2d. The tests of the long L90 × 90 × 6 angle specimens were terminated due to net cross-section rupture Fig. 2d. While failure modes of the long L120 × 120 × 8 angles were more varied Fig. 2d. It can be distinguished three types: bolts shear

(a) (b)



(c)

(d)

Fig. 2. Overview of the specimen failure modes: a) Short L120 × 120 × 8 specimens after tests, b) Short L90 × 90 × 6 specimens after tests, c) Long L120 × 120 × 8 specimens after tests, d) Long L90 × 90 × 6 specimens after tests)

with visible deformations of one angle end and ovalisation of bolt holes due to bearing of bolts (in L120/8/3M20-6), rupture of angle net cross-section (in L120/8/3M20-8) and simultaneous interaction of the bolts shear (two bolts were sheared) and tearing of the edge of angle section in the vicinity of the outer bolt (in L120/8/3M20-7).

3. Experimental results

3.1. Resistances and load-displacements curves

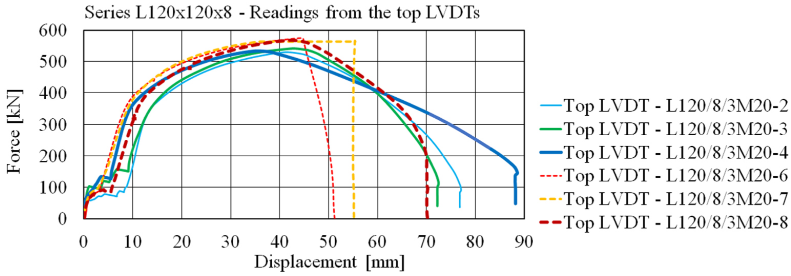
The summary of the test results for all specimens considered herein is shown in Table 3. The values of maximum forces are presented and accompanying elongations of the angles, measured at the top and the bottom of the specimens by means of LVDTs No. 1 and No. 2, respectively.

In Table 3, the relative deflections in the midsection of the angles are presented, taking into account the respective ratios between the readings from LVDTs No. 3 and No. 4 and the span L' between the internal bolts, where $L' = 200$ mm for the shorter specimens and $L' = 1100$ mm for the longer ones. From the comparison of these results, it is visible that the average horizontal relative deflections ($f_{\text{horizontal}}/L'$ ratios) of the shorter specimens are from 3 to 3.5 times greater than these of the respective longer specimens. In the case of the average vertical relative deflections (f_{vertical}/L' ratios), these relationships are even higher (from 3.5 to 6 times).

Table 3. Summary of test results

Series	Specimens	F_{max}	Displacements at F_{max}		Relative deflections at F_{max}	
			LVDT No. 1 (top dis-placement)	LVDT No. 2 (bottom displace-ment)	LVDT No. 3 $f_{vertical}/L'$	LVDT No. 4 $f_{horizontal}/L'$
		[kN]	[mm]	[mm]	[–]	[–]
Short L120 × 120 × 8	L120/8/3M20-1	540.62	38.85	27.88	0.05	0.07
	L120/8/3M20-2	529.91	41.35	31.56	0.06	0.09
	L120/8/3M20-3	541.50	42.77	31.93	0.05	0.08
	L120/8/3M20-4	533.73	35.56	26.37	0.09	0.06
	L120/8/3M20-5	549.36	45.28	40.61	0.08	0.07
	Average values	**539.02**	**40.76**	**31.67**	**0.07**	**0.07**
Long L120 × 120 × 8	L120/8/3M20-6	574.80	44.39	32.51	0.02	0.02
	L120/8/3M20-7	566.20	55.37	30.48	0.02	0.02
	L120/8/3M20-8	567.65	42.30	27.66	0.02	0.02
	Average values	**569.55**	**47.35**	**30.22**	**0.02**	**0.02**
Short L90 × 90 × 6	L90/6/3M20-1	328.52	23.92	12.67	0.05	0.06
	L90/6/3M20-2	346.78	23.07	12.74	0.07	0.05
	L90/6/3M20-3	325.48	22.98	14.65	0.03	0.06
	L90/6/3M20-4	362.12	23.35	11.29	0.07	0.06
	L90/6/3M20-5	364.64	26.14	12.10	0.09	0.05
	Average values	**345.50**	**23.89**	**12.69**	**0.06**	**0.06**
Long L90 × 90 × 6	L90/6/3M20-6	351.05	28.62	19.68	0.01	0.02
	L90/6/3M20-7	357.29	33.87	20.26	0.01	0.02
	L90/6/3M20-8	350.50	28.99	16.75	0.01	0.02
	L90/6/3M20-9	354.82	65.77	34.23	0.01	0.02
	L90/6/3M20-10	350.40	30.34	29.70	0.01	0.02
	Average values	**352.81**	**37.52**	**24.12**	**0.01**	**0.02**

Moreover, graphical representation of the test results is shown, in the form of force–displacement curves for the selected specimens (continuous lines for short specimens, dashed lines for long specimens). Fig. 3 shows the load – displacement curves for the selected specimens made of section L120 × 120 × 8. Fig. 4 shows the load – displacement curves for the selected specimens made of section L90 × 90 × 6.



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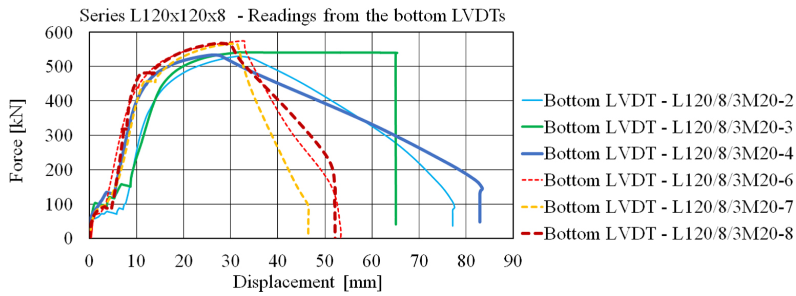

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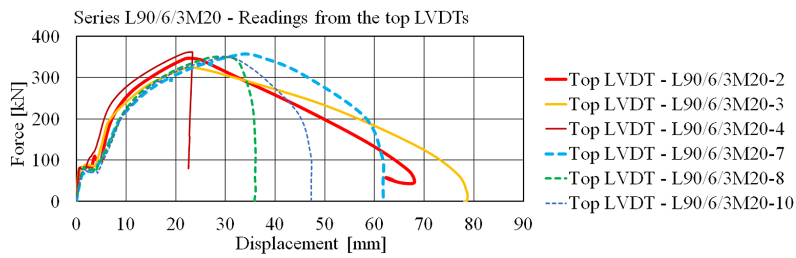
Fig. 3. Load – displacement relationships for the selected specimens made of section L120 × 120 × 8



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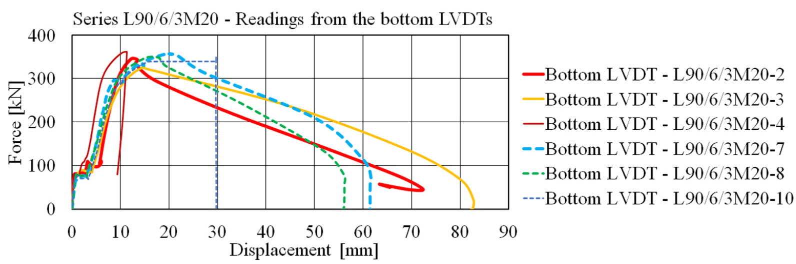


(b)

Fig. 4. Load – displacement relationships for the selected specimens made of section L90 × 90 × 6

3.2. Strain measurements

In selected elements, measurements of strains in characteristic cross-sections were also carried out – (see Fig. 5). For this purpose, strain gauges were used, placed in the middle of the span of a specimen (4 pieces), in the inner axis of a bolt (4 pieces) and in the tension zone in front of the same bolt (2 or 3 pieces), as well as one strain gauge behind each bolt.

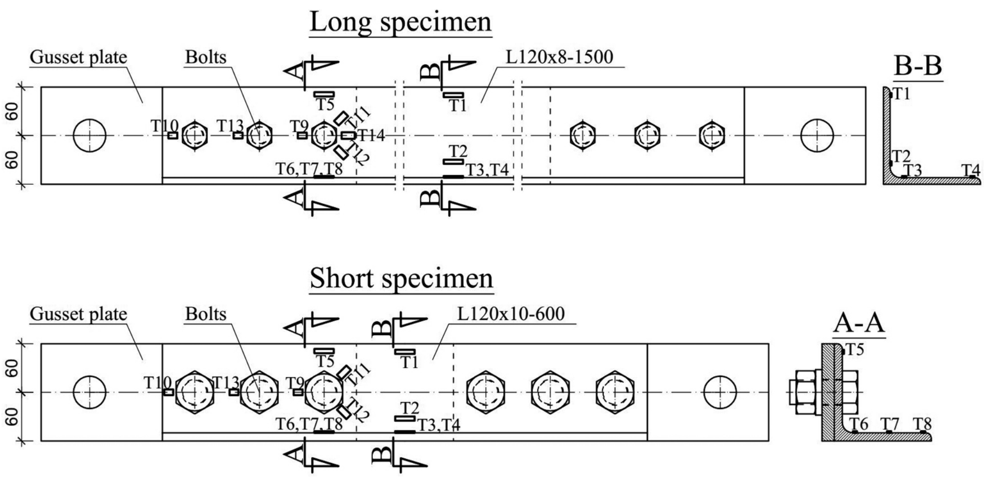
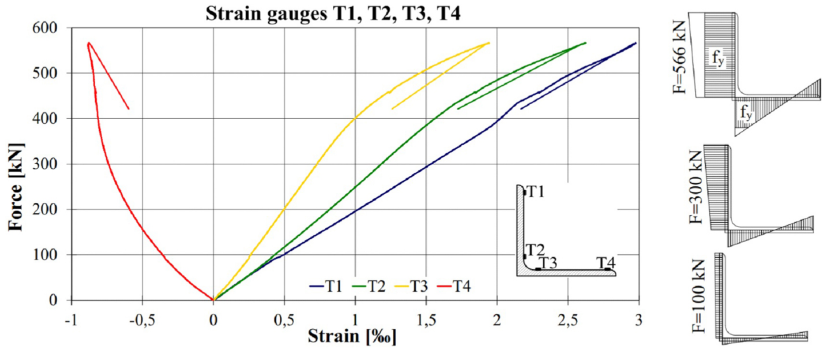


Fig. 5. Arrangement of strain gauges on specimens (strain gauges T1÷T14)

Strain gauges placed in the middle of the span and in the central axis of the bolt were intended to observe the effect of the eccentricity of fastening the tested angles on their deformations, and thus also the effect of the specimen length on the test results. Sensors glued in front of and behind the bolts were used to observe local changes in deformations in the bolted connection zone. From the specimens compared in the article, strain gauges were used in both groups of longer angle bars. In the case of shorter angles, due to the broader research objectives, strain gauges were used on specimens with different cross-sections, therefore a direct quantitative comparison is not fully possible. It was therefore decided that for the purpose of a qualitative comparison, specimens made of angles with the same cross-sectional dimensions, differing only in leg thickness, i.e. L$120 \times 120 \times 8$ and L$120 \times 120 \times 10$, would be used. Fig. 6 shows the force-strain relationships for strain gauges placed in the middle of the span of the tested elements.

Fig. 7 shows the force-strain relationships for strain gauges placed in the axis of the internal bolt at the connection of the angles with the gusset plates. The results of the measurements obtained from the strain gauges placed directly in front of and behind the bolts (in the tension and compression zones) are strongly dependent on the deviations in the execution of the bolt holes. Therefore, the comparison of these results for individual specimens does not allow to draw clear conclusions. In this respect, no effects that would differ from the predictions were observed, and therefore, no further analysis was carried out in this article.

From the comparison of the stress diagrams in the individual cross-sections of the specimens, it results that the smaller length of the angle translates into greater unevenness of strains/stresses,



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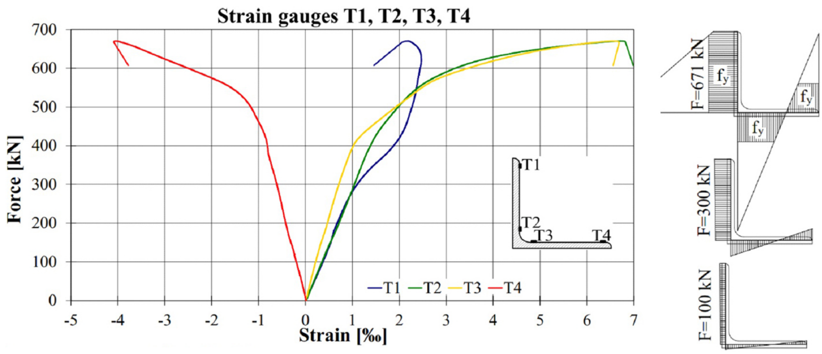

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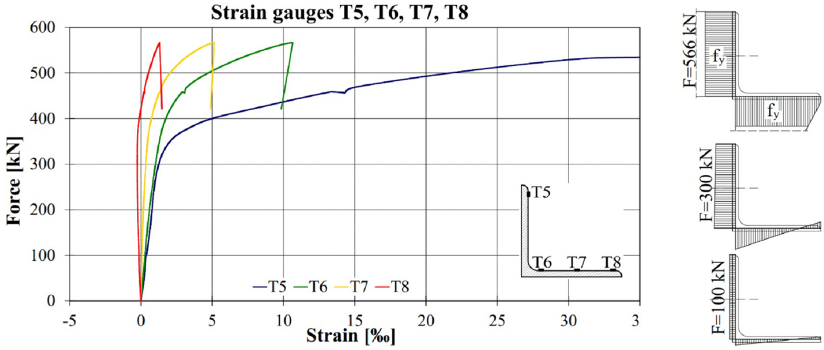
Fig. 6. Load – strain relationships in the middle of the length of the compared specimens – diagrams and distribution of stresses in the cross-section at characteristic load values: a) Long specimen – L120×8–1500, b) Short specimen – L120 × 10–600

both in the middle of the span of the specimen Fig. 6 and at the connection place of the angle bar with the gusset plate Fig. 7. This phenomenon is also confirmed by the measurement results presented in Table 3. These data show that the relative deflections of shorter specimens, both horizontal and vertical, are greater than those of longer specimens. In the case of horizontal deflection, it was observed from the beginning of the load and in the middle section, the stresses on the edge of the horizontal (outstanding) leg were compressive (negative sign) both in the shorter and longer specimen. With the increase of the load, the compressive stresses at the edge of the leg increased and in the shorter element, at the maximum tensile force, they exceeded the yield strength – Fig. 6b. In the longer specimen, the maximum value of compressive stresses on the edge of the horizontal (outstanding) leg was about $0.6f_y$ – Fig. 6a. In the area of the angle corner, as well as in the entire vertical leg, in both cases (shorter and longer specimens), the stresses were positive in the whole range of loads. In the angle section with the shorter length, a decrease in the stress value at the edge of the vertical leg was observed in the final phase of the load. This was related to the significant horizontal deflection of the angle section, resulting in a decrease in strain/stress on the inner surface of this leg. In the location of the angle



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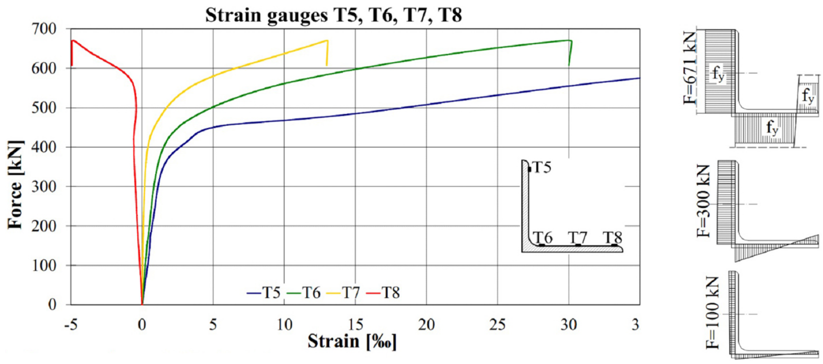

(b)

Fig. 7. Load – strain relationships in the axis of the bolt connecting the compared specimens – diagrams and distribution of stresses in the cross-section at characteristic load values: a) Long specimen – L120 × 8-1500, b) Short specimen – L120 × 10-600

cross-section connected to the gusset plate, only horizontal deflection was observed, resulting from the eccentricity of the load. While in the shorter specimen, the compression of the edge of the horizontal leg occurred in the entire range of loads, in the longer specimen, in the final phase of loading, the stresses changed sign and the whole cross-section became tension.

3.3. Discussion on failure modes observed in tests

In the case of short specimens, lower load-bearing capacities were achieved, which is directly related to the greater relative deflections of these specimens compared to those of longer lengths. It is visible in Fig. 8, which shows the comparison of exemplary specimens of the same cross-section (L120 × 8) and of different lengths just before reaching their maximum force and the rupture of angle net cross-section.

According to Fig. 9 and Table 3, the average relative deflection of the short specimens made of L120 × 8 were 3.5 times greater than that of their longer counterparts, which directly

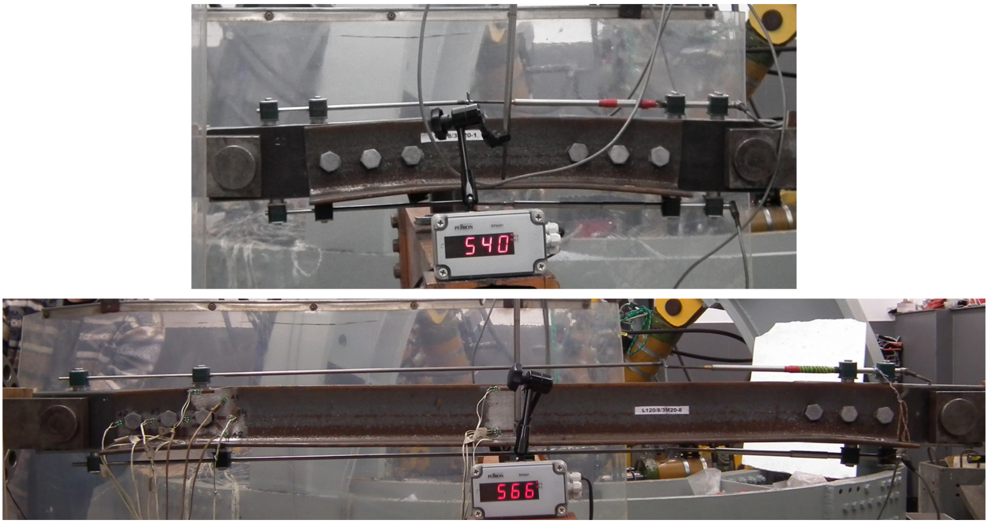

Fig. 8. Comparison of the load-bearing capacities obtained by the exemplary short and long specimens

translated into higher bending moments and much higher compressive stresses in the mid-span zone at the outstanding edge of the angle leg (see Fig. 6). The comparison of these stresses with the stresses in the fastening zone (see Fig. 7) shows that with a short specimen length, due to the very small fastening distance from the centre of the angle span, the deformation of the specimen end has a much greater impact on the behaviour of this specimen in the middle part, than in the longer specimens. This means that in the shorter specimens, due to the presence of a significant stress zone, the reduction of the cross-sectional area in which tensile stresses occur is greater than in the longer specimens, which translates into a lower load-bearing capacity of the shorter element tested. The same mechanism leads to greater differences in the load-bearing capacity of the short and long specimens with larger cross-sectional dimensions of the angles. Due to the less favourable proportions of the cross-sectional dimensions and the distance of the centre of the span from the place of the bolted connection, the stress distribution in the central part is disturbed to a greater extent by deformations of the specimen in the places of connections.

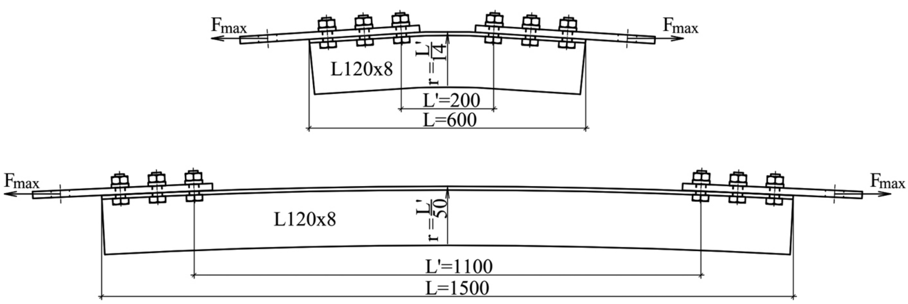

Fig. 9. Relative horizontal deflection of the tested elements

4. Concluding remarks

Within this paper, the influence of the specimen length on the behaviour of angles connected by one leg in tension is shown on the basis of the comparison of the results from the experimental tests of shorter and longer specimens of the equal leg angles of the widths 120 mm and 90 mm. The higher influence of the specimen length is more visible in the series made of angles with wider legs, which results from their smaller slenderness. From this stage of research, it was clearly visible that the longer specimens reached a higher ultimate force of more than 5% in comparison to their shorter counterparts. The ultimate forces of shorter angle specimens, commonly tested by researchers, might be slightly underestimated due to a length effect. Bending effect visible in the behaviour of short specimens is minimized in longer specimens, therefore also might not be observed in the behaviour of slender tensile members in real structures.

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Badania doświadczalne rozciąganych połączeń stalowych kątowników w kratowych słupach elektroenergetycznych

Słowa kluczowe: badania doświadczalne, elementy rozciągane, kątowniki łączone jednym ramieniem, połączenia śrubowe, słupy elektroenergetyczne, słupy kratowe

Streszczenie:

W artykule przedstawiono wyniki badań doświadczalnych rozciąganych połączeń stalowych kątowników mocowanych do blach węzłowych tylko jednym ramieniem. Tego typu elementy konstrukcyjne są powszechnie stosowane w stalowych podporach kratowych napowietrznych linii elektroenergetycznych. Rozwiązanie takie charakteryzuje się prostotą montażu, ale ze względu na mimośród połączenia, wynikający z łączenia kątownika tylko jednym ramieniem oraz ze sposobu osadzenia łączników śrubowych w łączonym ramieniu kątownika, występuje dodatkowy moment zginający. Większość dostępnych badań, zarówno eksperymentalnych jak i numerycznych, dotyczących połączeń śrubowych rozciąganych kątowników stalowych przeprowadzono na elementach o przeważnie małych długościach, bez możliwości uwzględnienia wpływu długości na nośność. W niniejszej pracy przedstawiono wyniki badań wpływu długości próbki na zachowanie się rozciąganych kątowników połączonych jednym ramieniem. Badaniom poddano kątowniki równoramienne o szerokościach 90 mm i 120 mm, które obciążano aż do zniszczenia. Rozpatrzono dwie długości elementów próbnych: 600 mm i 1500 mm. Dokonywano rejestracji siły oraz wydłużeń i bocznych wygięć badanych elementów. W wybranych punktach przekrojów badanego elementu dokonywano pomiaru odkształcenia. Tensometry elektrooporowe umieszczono w środku rozpiętości elementów łączonych oraz w płaszczyźnie przechodzącej przez jedną ze śrub połączenia i w strefach oddziaływania naprężeń od docisku trzpieni śrub do ścianek otworów kątowników. Z przeprowadzonych badań wynika, że dłuższe elementy badawcze charakteryzowały się większą nośnością połączeń, przy czym większe różnice obserwowano w przypadku elementów wykonanych z kątowników o większych szerokościach ramion i wynosiły one około 5%. Krótsze elementy ulegały znacznie większym wygięciom w płaszczyźnie prostopadłej do ramienia przylgowego niż ich dłuższe odpowiedniki, co zostało zarejestrowane zarówno przez czujniki przemieszczeń, jak i przez tensometry. Tensometryczne pomiary odkształceń potwierdziły, że na większym obszarze przekroju poprzecznego krótkich elementów, zarówno w środku ich rozpiętości jak i w strefie połączenia, występują naprężenia ściskające będące

efektem mimośrodowego przekazywania siły z kątownika na blachę węzłową. Efekty te są bardziej widoczne w kątownikach o większej szerokości ramion, co jest ściśle związane z ich mniejszą smukłością (długości elementów badawczych o obu szerokościach były takie same). Obserwowane zjawiska wskazują, że w badaniach nośności rozciąganych kątowników, łączonych jednym ramieniem, należy brać pod uwagę ich smukłość, a więc zarówno długość kątownika, jak i wymiary jego przekroju poprzecznego. Stosując standardowe długości elementów badawczych, które na ogółsą małe, w przypadku większych przekrojów prowadzimy do niedoszacowania uzyskiwanych nośności, co w niektórych, skrajnych przypadkach, może prowadzić do błędnych wniosków z analiz porównawczych z procedurami normowymi. To samo spostrzeżenie można odnieść do numerycznych modeli MES – zbyt małe długości takich modeli oznaczają małe ich smukłości, a to wpływa niekorzystnie na wyniki. Lepsze rozpoznanie zagadnienia będzie wymagało przeprowadzenia większej liczby badań, które pozwoliłyby określić najmniejszą smukłość rozciąganych elementów badawczych, która jeszcze nie wpływa znacząco na uzyskiwane wyniki.

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