Impact of weld seams and connected elements parameters on stress concentration

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Abstract. Existing construction regulations use durability estimations in nominal stress to ensure structural parameters of building elements. The maintenance time factor is only indirectly accounted for by load safety and service factors. Decreasing the number of accidents and minimising the damage caused by them leads to a need of reliability and durability prediction for structural elements that go through cyclic loads. To make a reasonable choice regarding the sizes of constructive forms (due to concentration zones) of such elements, deformation criteria of fracture should be used. This makes it possible to account for kinetics of local elastoplastic deformations, with one-time and cyclic loads. Nowadays, dependencies connecting concentration coefficients of elastoplastic pressure and deformations with a concentration coefficient for elastic stress have been found. This article presents the results of change in elastic stress concentration coefficient around the heel and toe in zones of the fracture of gusset plates and from the frontal angles depending on their structural parameters (width and thickness of the angle’s shelf, thickness of gusset plate, length and cathetus of weld) based on the research on stress strain behavior of rods of the T-section from paired equilateral angles using the finite element method.

1. Introduction

The calculation of structural elements is an important element of structure design. Its final purpose is to guarantee structure strength during its operational lifetime.

Level of nominal stress according to modern design regulations with safety coefficients \( \gamma_m \), \( \gamma_u \) and service coefficient \( \gamma_c \) is:

\[
\sigma_{\text{max},n} = (0.863 \div 0.955) \sigma_f
\]

Therefore, even the inconspicuous concentration of stress (weld, stiff edges and others) in structures made from plastic structural steel will cause development of local plastic deformations [1-4] and can lead to the fracture with the level of nominal stress lower than estimated resistance [5-11].

Lowering the level of concentration of stress is achieved by choosing a rational structure form, and actual distribution of stress in concentration zones is necessary for determining the working life of welded junctions of metallic structure elements using deformation criteria of fracture.

When calculating maximum local deformations and stress, formula of Nayber [12] is used, which allows to determine intensity of stress concentration coefficient \( K_{\sigma} \) and deformations concentration...
coefficient $K_\varepsilon$ in elastoplastic area based on the known coefficients of stress concentration in the elastic area of deformation $\alpha_\sigma$. However, this formula doesn’t consider aspects of material resistance to elastoplastic deformation. In works based on results of experimental research [13-14] formulae that allow to calculate concentration coefficient of stress intensity coefficient $K_\sigma$ and deformation intensity $K_\varepsilon$ in defined half-cycle considering real properties of materials are suggested.

The coefficients of elastic stress concentrations for a variety of joints are adduced in works [5-9]. However, the data on the elastic stress concentration in welded junction of the elements of the T-section from equilateral angles around the heel and toe in zones of the fracture of gusset plates, on the impact of their structure parameters of welded elements (length and cathetus of weld, width and thickness of the angle’s shelf) is lacking in technical literature [15-18].

T-sections from two angles are used in girdles and the lattice of latticed towers and masts, transport gallery trusses and the roofs of industrial buildings.

Designing elements of latticed structures of the T-section from angles under cyclic loads of different character and intensity, without taking into account the specifics of deformation and fracture of steel in concentration zones of stress, leads to an increase in probability of both fatigue-related and quasi-fragile fracture.

2. Methods
The present work modelled the stress strain behavior in the zone of fracture of gusset plates and from the frontal angles from the side of heel and toe in the elements of the cross section from paired equilateral angles using the finite element method (FEM) [19,20].

Since the distribution of stress and deformations in the cross section depends on the configuration of the joint, the design model follows the model of the joint in all its details (figure 1). The geometrical form of weld, the penetration values was modelled similarly to weld that were formed during the manufacturing of such connections.

During the study the following was varied and tested: the length of weld - from 50 to 300 mm; the cathetus of weld - from 4 to 8 mm; the thickness of gusset plates - 8, 10, 12, 14, 16 mm; the width of the angle’s shelf - 80, 100, 125, 140, 160 mm; the thickness of the angle’s shelf - 8, 10, 12 mm. The influence of stress concentration coefficients in the elastic area of deformation $\alpha_\sigma$ and the output of the flank weld to the frontal angle being 20 mm and the apposition of the frontal weld.

The calculations were carried out using the program complex ANSYS.

![Figure 1. Design model.](image-url)
3. Results

The results of the study of the length and cathetus of weld influence weld on the stress concentration coefficient in the elastic area of deformation $\alpha_\sigma$ in the zone of gusset plate and from the flank of the angles are shown on Figure 2. The increase of the length of the cathetus of weld is accompanied by the lowering of elastic stress concentration coefficients $\alpha_\sigma$ from the side of the heel and toe in the zone of the fracture of the gusset plate, as well as from the flank of the angles.

![Figure 2](image2.png)

**Figure 2.** The change in the elastic stress concentration coefficient $\alpha_\sigma$ in the junction depending on the relation $l/k_f$: a) around the heel in the fracture zone of gusset plates; b) around the toe from the angles flank.

Figure 3 shows the change in the elastic stress concentration coefficient $\alpha_\sigma$ in the zone of the fracture of the gusset plate and from the flank of the angles depending on the relation $l/k_f$ ($l$ – geometrical length of a weld; $k_f$ – weld cathetus) with different thickness of angle’s shelf. The graphs show that with the fixed width of the angle’s shelf, the change in its thickness does not impact the elastic stress concentration coefficient around the heel and the toe in the zone of the fracture of the gusset plate and from the flank of the angle in the whole interval of changes of the relation $l/k_f$.

![Figure 3](image3.png)

**Figure 3.** The change in the elastic stress concentration coefficient $\alpha_\sigma$ in the junction depending on the relation $l/k_f$: a) around the heel in the fracture zone of gusset plates; b) around the heel from the angles flank.

Figure 4 shows the impact of the width of the angle’s shelf on the elastic stress concentration coefficient in the zone of the fracture of the gusset plate and from the flank of the angles depending on the relation $l/k_f$. The presented graphs show that during the whole interval of change of the relation $l/k_f$, the elastic stress concentration coefficient in the zone of the fracture of the gusset plate and from the flank of the angles around the heel and the toe grows depending on the width of the angle’s shelf.

![Figure 4](image4.png)
Figure 4. The change in the elastic stress concentration coefficient $\alpha_\sigma$ in the junction depending on the relation $l/k_f$: a) around the heel in the fracture zone of gusset plates; b) around the heel from the angles flank.

The results of the study that focuses on the gusset plate’s width impact on the elastic stress concentration coefficient $\alpha_\sigma$ in the zone of the fracture of the gusset plate and from the flank of the angles are shown on Figure 5. The change of the width of the gusset plate with fixed parameters of width and thickness of the angle’s shelf and during the whole interval of the change of the relation $l/k_f$ does not influence the elastic stress concentration coefficient $\alpha_\sigma$ in the fracture zone of the gusset plate and from the flank of the angles.

Figure 5. The change in the elastic stress concentration coefficient $\alpha_\sigma$ in the junction depending on the relation $l/k_f$: a) around the heel in the fracture zone of gusset plates; b) around the heel from the angles flank.
In normative documents [21] in order to lower the elastic stress concentration coefficient in flank weld that attaches elements of the truss' lattice to gusset plates, one should put the flank of the element at the length of 20 mm. The influence of the output of flank weld on the flank of the element by 20 mm or of putting any frontal weld on flanks of the elements on elastic stress concentration coefficient $\alpha_{\sigma}$ in the fracture zone of the gusset plate and the flank of the angles is shown on Figure 6. Putting any frontal weld on flanks dramatically decreases $\alpha_{\sigma}$ at all values of $l/k_f$ as can be seen from shown data.

![Figure 6](image_url)

Figure 6. The change in the elastic stress concentration coefficient $\alpha_{\sigma}$ in the junction depending on the relation $l/k_f$: a, c, e) around the heel; b, d, f) around the toe; a, b, c, d) in the fracture zone of gusset plates; e, f) from the angles flank
4. Discussion

The research has shown that the elastic stress concentration coefficient in the fracture zone of the gusset plate and the flank of the angles around the heel and the toe of the T-section’s elements from the paired angles is determined by the length, weld cathetus, the width of the angle’s shelf and does not depend on the thickness of the angle’s shelf and gusset plate.

Acquired values of elastic stress concentration coefficients $\alpha_\sigma$ with different geometric parameters of welded junctions have been approximated using the following non-linear model:

$$\alpha_\sigma = \beta l^\gamma b^\delta t_a^\mu t_{gp}^\theta$$  \hspace{1cm} (2)

where $\beta$, $\gamma$, $\mu$, $\theta$, $\delta$ – parameters, $l$ – the length of flank weld; $k_f$ – the estimated cathetus of flank weld; $b$ – the width of the angle’s shelf; $t_a$ – thickness of the angle’s shelf; $t_{gp}$ – the thickness of the gusset plate.

The results of the least square regression analysis carried out in Microsoft Excel also show that the following factors - thickness of the angle’s shelf and gusset plate - are insignificant and can be omitted from the model. Which is why the resulting data has been approximated, using Microsoft Excel, by three-factor non-linear models:

a) in the zone of the fracture of the gusset plate:
- when putting flank weld:
  - around the heel:
    $$\alpha_\sigma = 4,3672 \cdot l^{-0.516} k_f^{-0.482} b^{0.819}$$  \hspace{1cm} (3)
  - around the toe:
    $$\alpha_\sigma = 1,9934 \cdot l^{-0.545} k_f^{-0.399} b^{0.813}$$  \hspace{1cm} (4)
- when outputting the flank weld at 20 mm to the flank of the angles and putting a frontal weld:
  - around the heel:
    $$\alpha_\sigma = 2,0775 \cdot l^{-0.398} k_f^{-0.453} b^{0.829}$$  \hspace{1cm} (5)
  - around the toe:
    $$\alpha_\sigma = 0,9558 \cdot l^{-0.316} k_f^{-0.312} b^{0.771}$$  \hspace{1cm} (6)
- when putting flank and frontal weld:
  - around the heel:
    $$\alpha_\sigma = 1,6436 \cdot l^{-0.330} k_f^{-0.450} b^{0.798}$$  \hspace{1cm} (7)
  - around the toe:
    $$\alpha_\sigma = 0,4331 \cdot l^{-0.153} k_f^{-0.330} b^{0.759}$$  \hspace{1cm} (8)

b) from the flank of the angles:
- when putting flank weld and outputting them at 20 mm to the flank of the angles:
  - around the heel:
    $$\alpha_\sigma = 4,4882 \cdot l^{-0.437} k_f^{-0.338} b^{0.773}$$  \hspace{1cm} (9)
  - around the toe:
    $$\alpha_\sigma = 5,1901 \cdot l^{-0.360} k_f^{-0.279} b^{0.544}$$  \hspace{1cm} (10)
- when putting flank and frontal weld:

- around the heel:

\[ \alpha_\sigma = 1,7771 \cdot l^{-0.430} k_f^{-0.335} b^{0.917} \]  \hspace{1cm} (11)

- around the toe:

\[ \alpha_\sigma = 1,4888 \cdot l^{-0.357} k_f^{-0.262} b^{0.676} \]  \hspace{1cm} (12)

where \( l \) is the geometric length of the flank welded weld, mm; \( k_f \) - weld cathetus, mm; \( b \) - the width of the angle's shelf, mm.

Curves approximated by dependencies (3), (5), (7) are shown on figure 7 and have good correspondence to concentration coefficients values in the fracture zone of the gusset plate and the flank of the angles around the heel and the toe, that were calculated using the modelling of the stress strain behavior of junctions in FEM (determination coefficient in the fracture zone of the gusset plate \( R^2 \geq 0,909 \), and from the flank of the angles - \( R^2 \geq 0,835 \)).

Outputting the flank weld on the flank of the angles at 20 mm or putting the frontal weld significantly lowers the elastic stress concentration coefficient \( \alpha_\sigma \) from around the heel and the toe.
both in the fracture zone of the gusset plate, and from the flank of the angle’s shelf (Figure 7). At the same time, putting any frontal weld significantly lowers the elastic stress concentration coefficient.

5. Conclusion
1. The maximum elastic stress concentration in the fracture zone of the gusset plate and from the flanks of the T-section’s elements from paired angles occurs from around the heel.
2. The elastic stress concentration coefficient in the fracture zone of the gusset plate and from the flanks of the angles from around the heel and toe of T-section’s elements from paired equilateral angles is determined by the length and weld cathetus, the width of angle’s shelf and does not depend on the angle’s shelf and gusset plate’s thickness.
3. Outputting the flank weld on the flank of the angles at 20 mm or putting the frontal weld significantly lowers the elastic stress concentration coefficient \( \alpha \) from around the heel and the toe, both in the fracture zone of the gusset plate, and from the flank of the angle’s shelf. At the same time, putting any frontal weld significantly lowers the elastic stress concentration coefficient.

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