STRUCTURAL CONNECTIONS WITH THERMAL SEPARATION

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Summary

The connections between inner and outer structures still seems to be one challenging question in the steel structures at the time of low-energy buildings and high claims of heat engineering standards. The construction of a bolted end-plate connection with a thermal-insulating layer which has not only the function of thermal insulation, but also the bearing function in respect to its compression and shear resistance is under progress. Elastomer could be used as a suitable material. The research is focused on the new materials appearing in the market as well to study their suitability for this type of connections. The prediction of the connection mechanical behaviour is based on the component method. The component methods consist of decomposition of the joint into component, the description of the component behaviour and assembling into connection behaviour. The design model is developed and checked by experiments and FE simulation.

Keywords: End-plate connection, prestressed bolts, thermal bridge, thermal barrier, thermal insulation, intermediate layer, component method

1 Introduction

The latest trend of heat-engineering, economical, technical and structural claims leads to a construction of new types of steel connections which should be heat-insulating and cost-effective as well as statically efficient. The steel connections with thermal barrier could be widely used in practical design such as connections of balconies, loggias, ramps, canopies, cold entry rooms, garages etc. This work is focused on the bolting end-plate connection of two beams where the intermediate thermal-insulating layer is used as shown in **Fig. 1**. The end-plate connection is under the effect of the combination of bending moment and normal force due to the application of the prestressed bolts and external forces. The possible shear stress is not concerned in this work and it can be easily transferred by using a shear bracket. The component method is used to predict the behaviour of the joint and a couple of experiments are necessary to be made to check the propriety of this method.

Furthermore the component method could be implemented to the standardized calculation process for this type of joints with thermal barrier.

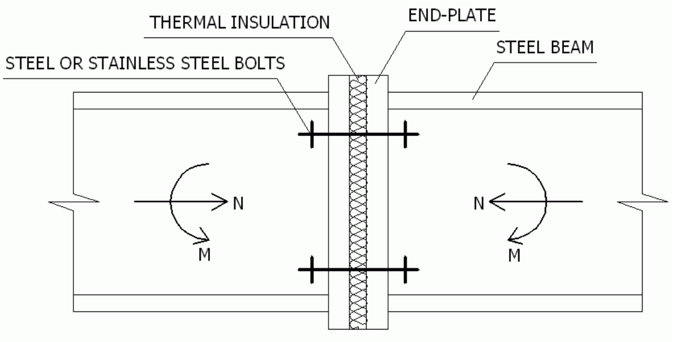


Fig. 1 Model of the bolted end-plate connection with thermal separation

2 Application of component method

In this paper is to check the serviceability of the component method for a thermal-insulating steel joint. The component method is the analytical method describing the behaviour of the joint as the moment-rotation relation. Firstly the connection is disintegrated into separate parts and the characteristics of these so-called components are being investigated. The most important characteristics are the resistance and the stiffness of the component. Then the components are assembled with respect to their position in the structure and the general characteristics of the joint are calculated from the partial values.

First of all the thermal-insulating connection is disintegrated into components shown in **Fig. 2**.

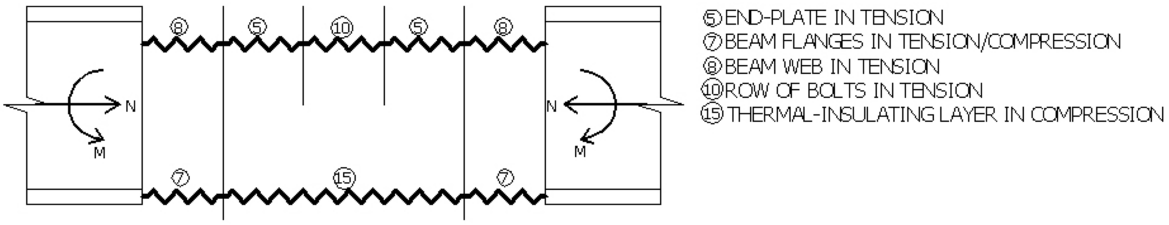


Fig. 2 Components of the thermal-insulating joint

Part in tension

The resistance of the tension part of the connection is the lowest value among the bearing resistances of the following components: ⑩ row of bolts in tension, ⑤ end-plate in tension, ⑧ beam web in tension.

The bearing resistances of the end-plate and the row of bolts in tension are both calculated by using the T-stub model. The failure of the component is caused by one of these three reasons:

a) the failure of the end-plate $F_{t,Rd1} = \frac{4M_{pl,1,Rd}}{m}$

b) the failure of the end-plate and the bolts $F_{t,Rd2} = \frac{2M_{pl,2,Rd} + 2nB_{t,Rd}}{m+n}$

c) the failure of the bolts $F_{t,Rd3} = 2B_{t,Rd}$

where

$$M_{pl,Rd} = 0{,}25 L_{eff}\, t_p^2\, f_y / \gamma_{M0}$$

$$B_{t,Rd} = min\left\{0{,}9 A_s\, f_{ub} / \gamma_{Mb}\ ;\ 0{,}6 \pi\, d_m\, t_p\, f_u / \gamma_{Mb}\right\}$$

The bearing resistance of the beam web in tension in a bolted end-plate connection is given

$$F_{8,t,Rd} = \frac{L_{eff,t}\, t_w\, f_y}{\gamma_{M0}}$$

The stiffness of the end-plate in tension is calculated from

$$k_5 = 0{,}85 \frac{L_{eff}\ {t_p}^3}{m^3}$$

The stiffness of the bolts in tension is determined as

$$k_{10} = 1{,}6\ \frac{A_s}{L_b}$$

The stiffness of the beam web in tension is supposed to be indefinite. The rotational stiffness of the tension part is then derived from

$$\frac{1}{k_t} = \frac{1}{k_5} + \frac{1}{k_{10}}\ .$$

Part in compression

There are only two components in the part of the connection in compression – ⑦ the beam flanges and (15) the thermal-insulating layer which is the crucial component of the joint.

The bearing resistance of the beam flanges in tension/compression is determined as

$$F_{7,c,Rd} = \frac{W_{pl}\, f_y}{(h - t_f)\ \gamma_{M0}}$$

The bearing resistance of the thermal-insulating layer is predicted to be given by a relation known from column-bases:

$$F_{15,c,Rd} = \frac{A_{eff}\, f_{e,\max}}{\gamma_{Me}}$$

where A_{eff} is the compression area in the distance c from the beam flange under compression, see **Fig. 3**, $f_{\mathrm{e,max}}$ is the resistance of the thermal insulation and γ_{Me} is the safety factor of the thermal-insulation material.

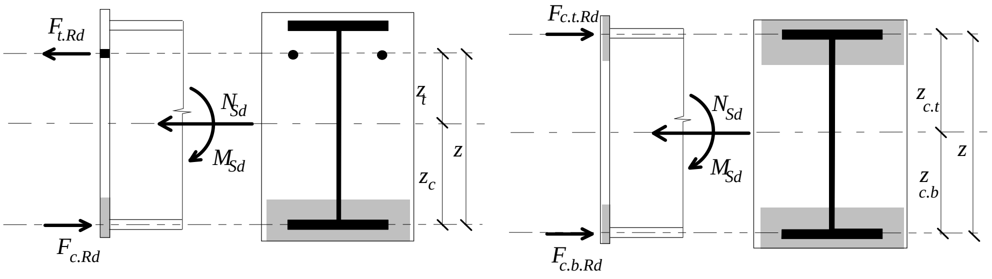
As the beam flanges are supposed to have an indefinite bending stiffness, the stiffness of the thermal-insulating layer is also the stiffness of the whole compression part and is supposed to be calculated from

$$k_c = k_{15} = \frac{A_{eff}}{t_e}$$

t_{e} is the thickness of the intermediate layer. For detailed information see [2].

3 M-N Interaction

The simplified prediction model for the bending resistance and the rotational stiffness may take into account only the effective area at beam flanges and the effective area at the beam web is neglected, as shown in **Fig. 3**. It is assumed the compression force acts at the centre of the flange in compression also in cases of limited size of outstand of the plate. The tension force is located in the bolt row in tension.



a) b)

Fig. 3 Model with the effective area at the flanges only;
a) one bolt row in tension; b) no bolts in tension.

The forces represent resistances of the components in tension $F_{\mathrm{t,Rd}}$, and in compression $F_{\mathrm{c,t.Rd}}$, $F_{\mathrm{c,b,Rd}}$. For simplicity, the model will be derived for proportional loading only:

$$e = \frac{M_{Sd}}{N_{Sd}} = \frac{M_{Rd}}{N_{Rd}} = \mathrm{const}$$

When the eccentricity $e = \frac{M_{Sd}}{N_{Sd}} \le -z_c$, see **Fig. 3a**, there is tension force in the bolt row, and compression force in the lower flange. The bending resistance of the joint is derived as

$$M_{Rd} = min \left\{ \frac{F_t \; z}{\frac{z_c}{e} + 1} \; ; \; \frac{F_c \; z}{1 - \frac{z_t}{e}} \right\}$$

When the eccentricity $e = \frac{M_{Sd}}{N_{Sd}} \ge -z_c$, see **Fig. 3b**, there is no tension force in the bolt row, but both parts of the connection are loaded in compression. In this case

$$M_{Rd} = \min \left\{ \frac{-F_{c,t} \; z}{\frac{z_{c,b}}{e} + 1} \; ; \; \frac{-F_{c,b} \; z}{\frac{z_{c,t}}{e} - 1} \right\}$$

The joint rotation is calculated using the elastic deformation of the components in tension and compression parts (E is the elastic modulus of steel and E_e of the separating layer)

$$\phi = \frac{\delta_t + \delta_c}{z} = \frac{1}{z^2} \left(\frac{M_{Sd} + N_{Sd} \; z_c}{E \; k_t} + \frac{M_{Sd} - N_{Sd} \; z_t}{E_e \; k_c} \right)$$

The rotational stiffness of the joint depends on the bending moment which is induced by the normal force applied with constant eccentricity *e* is derived as

$$S_{j.ini} = \frac{M_{Sd}}{M_{Sd} + N_{Sd}\, e_0} \, \frac{z^2}{\left(\dfrac{1}{E_e k_c} + \dfrac{1}{E\, k_t} \right)} = \frac{e}{e + e_0} \, \frac{z^2}{\sum \dfrac{1}{E\, k}}$$

where the eccentricity e_0 is defined as follows

$$e_0 = \frac{z_c\, k_c E_e - z_t\, k_t E}{k_c E_e + k_t E} \qquad \text{resp.} \quad e_0 = \frac{z_{c,b}\, k_{c,b} E_e - z_{c,t}\, k_{c,t} E_e}{k_{c,b} E_e + k_{c,t} E_e} = \frac{z_{c,b}\, k_{c,b} - z_{c,t}\, k_{c,t}}{k_{c,b} + k_{c,t}}$$

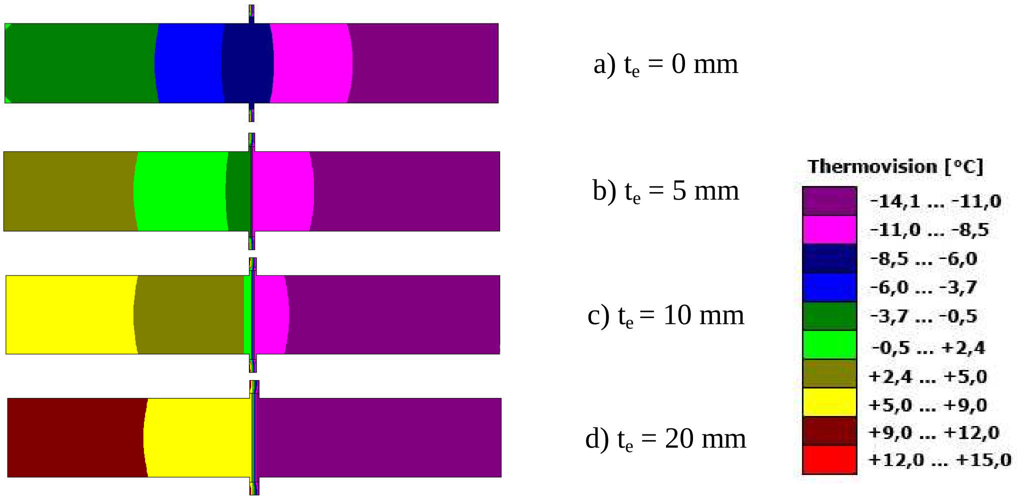
The non-linear part of the moment-rotation curve of the joint, which is loaded by proportional loading, may be modelled by introducing the shape factor μ which depends on ratio γ of the acting forces and their capacities:

$$\mu = (1{,}5\ \gamma)^{2{,}7} \geq 1 \quad \text{where} \quad \gamma = \frac{e + \dfrac{h}{2}}{\left(\dfrac{M_{Rd}}{M_{Sd}} \right) e + \dfrac{h}{2}}$$

$$S_j = \frac{e}{e + e_0} \, \frac{z^2}{\mu \sum \dfrac{1}{E\, k}}$$

For detailed information see [3].

To verify the above presented predictions it is necessary to make a couple of experiments with a specific thermal-insulating material and its real behaviour in the connection. The influences of the geometry as well as the creep behaviour of the material have to be taken into account and included into the calculation. Then the relations can be put more exactly and forward-looking they could be used for practical standardized design.


a) t_e = 0 mm

b) t_e = 5 mm

c) t_e = 10 mm

d) t_e = 20 mm

Fig. 4 Thermal simulation of the influence of the intermediate layer in the steel joint

4 Heat-engineering

The new heat-engineering standard provides the obligatory values for heat conductivity of the structures as well as values for energy intensity of the building. The most efficient way to decrease the loss of energy is to prevent the thermal bridges in the external cladding of the building.

The **Fig. 4** shows a simple 2D simulation of heat conduction in a steel structure between inner and outer environment. There is a comparison between the joint without thermal separation and the joint with thermal separation of thickness 5, 10 and 20 mm. It is clearly shown how visible is the insulation effect of the intermediate layer in the joint.

5 Conclusions

The research is trying to develop standardized design rules for thermal-insulating joints and introduce this new type of connections into a common use. The tendency is to give opportunity for steel structures and show the way how to construct buildings with low energy intensity and minimized heat costs. The bolted end-plate connection with intermediate thermal-insulating layer could be easily designed using the component method which determines the bearing resistance as well as the rotational stiffness of the joint. The predicted method needs to be verified by a couple of experiments. The presented type of joint is suitable for steel connections between inner and outer structures and minimizes the effect of thermal bridge in the external cladding.

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