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Low-cycle fatigue life of a thermal break system under climatic actions

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ABSTRACT

External insulation is more widely used in Northern and Continental Europe than internal insulation. This technique leads to thermal bridges where the building facade has projecting elements like balconies. The thermal requirements of actual standards lead to restore the continuity of the insulation at the interfaces by using thermal break systems (TBS). These systems are usually made of a box containing the insulation material, and a minimalist structural system able to transmit the shear force and the bending moment from the balcony to the wall. In most cases, structural elements are made of stainless steel, as it is less heat-conducting than normal steel. The paper focuses on a specific TBS that uses shear keys and steel profiles to ensure the transfer of forces. TBS are also submitted to important horizontal cyclic shear deformations, provoked by the variations of the dimensions of the balconies due to climatic effects. The objective of the study presented in the paper is to show that significant yielding under these actions can be accepted during service life. First experimental cyclic loading tests have been performed in order to characterize the behaviour of the TBS, as well as its fatigue strength. Then the loading has been defined on the basis of the database of the ECA&D, the European Climate Assessment and Dataset. Finally, the fatigue resistance of the system has been verified. It is shown that the developed TBS can resist to fatigue loading for great length of balconies, while exhibiting significant yielding during service life.

1. Introduction

The level of energy-performance requirements in buildings has substantially increased over the last twenty years. It is imposed by new thermal regulations to reduce energy consumption and greenhouse gas emissions in buildings. As the thickness and the efficiency of the insulation of the walls increase, the energy lost in the building is now mostly due to the discontinuity of the insulation, where so called thermal bridges are created. These thermal bridges induce moreover a local condensation of water that can cause a deterioration of the internal coating of the building and even a degradation of the indoor air quality due to the development of decay. As a consequence, thermal bridges must be reduced by the use of appropriate solutions like thermal break systems (TBS), see Fig. 1a.

In the specific case of buildings with an external insulation, thermal bridges develop at locations where the building facade has projecting element such as balconies. Usual TBS are made of a box containing the insulation material, and a minimalist structural system able to transmit the shear force and the bending moment from the balcony to the wall. In most cases, structural elements are made of stainless steel, as it is less heat-conducting than normal steel.

The first structural systems of the TBS were made of longitudinal and diagonal rebars to equilibrate the bending moment and the shear force, respectively (Fig. 1b). However, it was limited for both structural and thermal concerns. For that reason, several attempts have been made to find better solutions, for example [1–3].

The structural role of the TBS is not only to resist vertical forces, wind or even seismic actions, but also to absorb the relative displacements induced by the thermal expansion of the balcony. This critical point is discussed in the specific case of a TBS called SUNE. It is an assembly of different components consisting of tensile rebars, welded to 2 transversal rebars on each side for a better anchorage, U-shaped steel sections, and special shear keys. The tensile rebars and the U-shaped steel sections are used to balance the tension and compression forces due to bending while the shear key is used to resist the shear force (Fig. 2). The web of the U member presents longitudinal slots at each end in order to provide some horizontal flexibility. On the lintel side, it relies on an end plate with a U section, with flanges embedded in the concrete. On the balcony side, a rectangular end plate is welded on the U member. This end plate is connected by two screws to a U-shaped end

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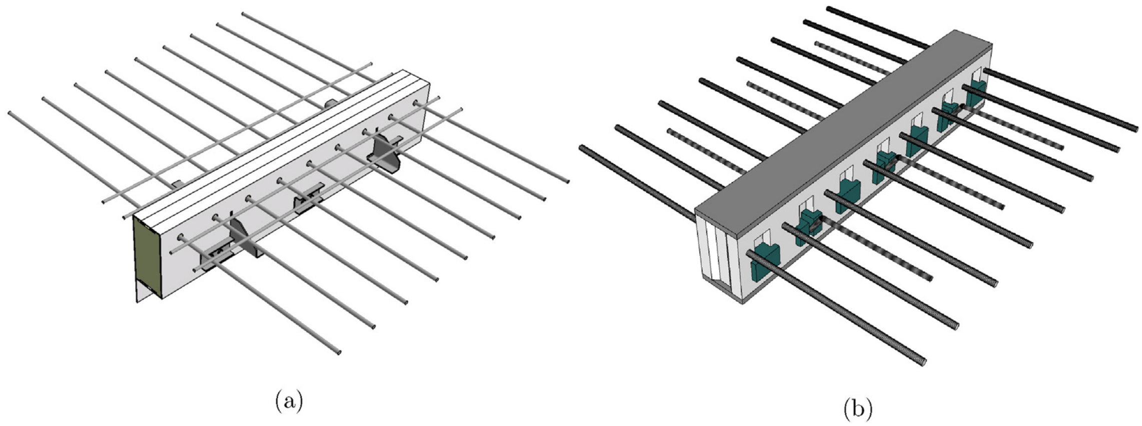

Fig. 1. (a) General view of thermal break system seen from balcony side. (b) Thermal break system made of rebars.

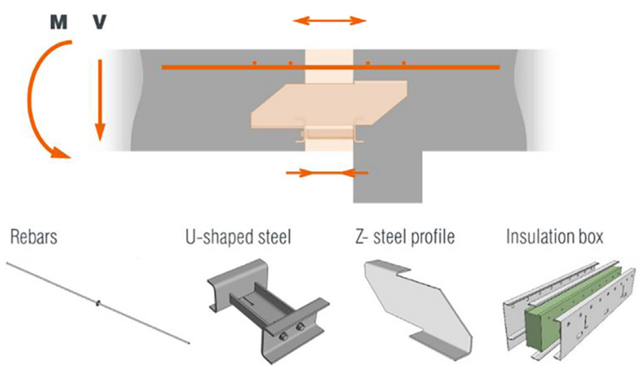

Fig. 2. Decomposition of SUNE.

plate embedded in the concrete in the same way as on the other side. Mechanical performances of the SUNE under vertical loads are presented in [4]. To contribute to thermal performance of the TBS, duplex stainless steels with yield strengths of elasticity greater than 600 MPa and 550 MPa are used for the rebars and the steel profiles, respectively. A mineral wool with a thermal conductivity lesser than 0.038 W/(m K) is used as insulation material in the 100-mm thick insulation box. The use of those materials leads to a good thermal performance with linear thermal transmittance values below 0.27 W/(m K).

Being located outside the building thermal envelope, the balcony suffers climatic hazards and is caused to expand or shorten following climatic conditions (outside temperature, solar radiation, etc.). The thermal break is placed in line with the insulation and thus ensures the connection between the outside balcony and the inner floor slab. The latter is located inside the building envelope; consequently it only undergoes low changes in temperature. The thermal break is therefore subjected to shearing induced by the horizontal deformation of the balcony as a function of the outside-building temperature variations. For that reason, the components of TBS must be designed to be able to sustain such deformations. The bars and Z-profile have sufficient horizontal flexibility to deform freely under the thermal forces, but the U-shaped steel profile undergoes yielding even under frequent actions. The objective of the work presented in this paper is to prove that this yielding is acceptable and does not reduce the capabilities of the TBS during its service life. Three reasons have inspired this investigation. Firstly, the behaviour of stainless steels is far away from the hypothesis of an elastic perfectly plastic material. The plastic hardening of the stainless steel is stably progressive and there is not any brutal change in the behaviour at the beginning of the plastification. Therefore, the conventional choice of the limit of elasticity, the stress corresponding to a plastic deformation of 0.2%, seems completely arbitrary. Secondly, the number of large cycles provoked by climatic actions is limited and corresponds to the order of magnitude that can be supported in a low-cycle fatigue. Lastly, the non plastification condition is not imposed in EN1993-1-1 [5].

Nonetheless, accepting yielding at SLS requires a verification against low-cycle fatigue, given the fact that the plastification may occur several times during the service life of the element. The fatigue design in this case does not correspond to the usual fatigue design considered in the domain of civil engineering: the stress is relatively high and the number of load cycles is low while the design standards deal with the high fatigue life with significantly high number of load cycles with small variations of stresses.

In this paper, the verification of the thermal break system SUNE against low-cycle fatigue loads is performed. To do so, cyclic loading tests of the TBS are conducted and presented here in Section 2. Its results serve to establish the cyclic force-displacement relationship, see Section 3, as well as the fatigue design curve of the system. The latter is obtained by adopting the procedure described in Annex D of EN 1990 [6] in order to determine the characteristic and design value of the model parameters. The detailed procedure is described in Section 4. The fatigue design curve is then used to verify the fatigue strength of the thermal break system under the deformation of the balcony generated by the temperature variation outside the building. The latter is originally obtained from an European database and then calibrated to the maximum and minimum shade air temperature given by EN 1991-1-5. The description of the calibration is highlighted in Section 5. Section 6 presents the verification of TBS against thermal loading which is done by determining the damage accumulation developed during the building life. Several meteorological stations as well as balcony lengths are considered in the parametric study.

2. Low-cycle fatigue tests

The mechanical behavior of the TBS under cyclic horizontal loads is evaluated through low-cycle fatigue tests. The description of this experimental program is presented in the following.

2.1. Geometric description of the test

The test setup consists of a hydraulic jack with a capacity of 1500 kN imposing horizontal displacement, a specimen, and reaction/bracing systems. The RC slab of the specimen is retained vertically and horizontally by supporting systems (see Figs. 3–5), where the horizontal supports have a system of adjustment in order to perfectly restrain the test specimen. At the front of the RC slab near the balcony-slab junction, a lintel with a drop of 100 mm is enlarged at both sides to avoid any interaction with the physical phenomena near the critical zones of the thermal break component. The vertical supports are realised by pinned supports placed under the lintel. At the rear of the concrete slab,