Engineering Structures 79 (2014) 131–141

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

Macroscopic modeling of reinforced concrete joints: Application to thermal break elements subject to earthquake loadings

T.T.H. Nguyen [a,b], F. Ragueneau [a,*], D. Bahon [b], N. Ruaux [b]

[a] LMT-Cachan, ENS-Cachan/CNRS/Univ. P.&M. Curie/Pres. UniverSud Paris, 61 avenue du Président Wilson, 94230 Cachan Cedex, France
[b] CSTB, 84 Avenue Jean Jaurès, 77420 Champs-sur-Marne, France

ARTICLE INFO

Article history:
Received 22 November 2013
Revised 16 July 2014
Accepted 1 August 2014
Available online 28 August 2014

Keywords:
Thermal break
Macro-element
Earthquake loading
Damage
Thermodynamic
Pseudo-dynamic testing

ABSTRACT

This paper focuses on the development and the identification procedure of a new model for reinforced concrete joint elements subject to earthquake loadings. Based on the macro-elements concept framework, thermodynamics equations are derived to express robust constitutive equations which are able to simulate different kinds of wall-slab junction. The particular case-study of thermal break elements used for sustainable buildings is explored.

1. Introduction

Nowadays sustainable constructions aim to reduce the energy consumption of air conditioning and heating systems by reducing the thermal conductivity of building elements. Among different sources of heat loss, there are the thermal bridges [1] due to discontinuity of the insulation at the junction of facades and floors, which account for 20% of the total lost in a new house [2]. On the other hand the new French regulation RT 2012 requires that all thermal bridges must be treated and the solution commonly accepted in France is the use of interior insulation with thermal breaks. This ensures the insulator's continuity without changing house's appearance. This innovative technological element is mainly made of thermal insulation materials such as fiberglass, nylon or polystyrene, whilst mechanical loads are supported by steel reinforcements or concrete fiber elements (Fig. 1). According to several thermal studies [3,4], thermal break junctions can reduce up to 80% of the linear conductivity at the wall-floor slab connection.

In spite of its thermal benefits, use of thermal break in buildings needs to be treated cautiously because it introduces a weak point at the connection in terms of mechanical resistance and stiffness. However the behavior of thermal break and of building with thermal break under seismic risk has never been assessed. The study presented in this paper aims to develop a practical tool to help evaluate the seismic vulnerability of buildings due to specific elements such as thermal breaks. The main goal of this study is to develop a simplified numerical model as robust as possible which is able to describe the thermal break's nonlinear behavior and to facilitate probability analysis for large-scale structure and fragility curves determination.

Regarding the objectives of nonlinear large scale computations and focusing on the reinforced concrete (RC) joint element behavior, the choice to develop constitutive equations based on macro-elements assumptions has been made. Avoiding the high computational costs of classical three-dimensional (3D) analysis of RC structures [5,6], different kind of models may be adopted in order to reduce the structural kinematic complexity in describing the numerical responses of large scale structures subjected to complex loadings (cyclic and seismic). Concerning the bearing elements (wall and slab), reduced kinematics based on plate [7] or beam [8] assumptions are often used. The specific case of elements joints is treated thanks to macro-elements linking global loads vector (Forces and Moments) to global kinematic variables (relative slips and rotation). Empirical laws may be used introducing global behaviors in tension, flexion of shear [9–12] with some of their couplings [13,14]. Some refined modelling allows for inclusion of the thermodynamic framework to account for concrete degradation (damage) [15–17] and plasticity yielding [18]. Considering

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* Corresponding author. Tel.: +33 1 47 40 27 38.
E-mail address: raguenea@lmt.ens-cachan.fr (F. Ragueneau).

http://dx.doi.org/10.1016/j.engstruct.2014.08.001

Nomenclature

English alphabets

$(.)_n$	variable (.) at time step t_n
$(.)_n^k$	variable (.) at iteration k of time step t_n
a_c	model parameter related to frictional sliding of concrete
a_s	model parameter related to nonlinear kinematic hardening of steel
b_c	model parameter related to nonlinear kinematic hardening associated to friction
b_s	model parameter related to nonlinear kinematic hardening of steel
d	damage variable
d_+	damage variable related to positive sign load
d_-	damage variable related to negative sign load
$d_{\max}$	maximum damage in loading history
f^d	threshold surface related to damage et isotropic hardening mechanisms
f^π	threshold surface related to sliding and kinematic hardening of concrete
f^p	threshold surface related to nonlinear kinematic hardening of steel
F	force
F^π	force related to frictional sliding of concrete
F^p	force related to nonlinear kinematic hardening of steel
F_0^p	elastic limit force of steel
H	consolidation function
K_c	elastic stiffness of concrete part
K_s	elastic stiffness of steel part
p	damage parameter
q	damage parameter
U	generalized displacements
U_+	generalized displacements related to positive sign load
U_-	generalized displacements related to negative sign load
U^π	displacement related to frictional sliding of concrete
U^p	displacement related to nonlinear kinematic hardening of steel
X^π	back stress related to sliding and kinematic hardening of concrete
X^p	back stress related to nonlinear kinematic hardening of steel
Y	energy rate released due damage of concrete
Y^d	part of energy rate released due damage of concrete
Y^π	part of energy rate released due to frictional sliding
Y_0	initial threshold of damage
z	internal variable related to the isotropic hardening
Z	thermodynamic force related to isotropic hardening

Greek alphabets

α^π	kinematic hardening variable related to frictional sliding of concrete
α^p	kinematic hardening variable related to nonlinear kinematic hardening of steel
$\dot{\lambda}^d$	Lagrange's multiplier related to damage mechanism
$\dot{\lambda}^\pi$	Lagrange's multiplier related to frictional sliding of concrete
$\dot{\lambda}^p$	Lagrange's multiplier related to nonlinear kinematic hardening of steel
ρ	material density
Ψ	Helmholtz free specific energy
ϕ^π	pseudo-potential of dissipation related to sliding and kinetic hardening of concrete
ϕ^p	pseudo-potential of dissipation related to nonlinear kinetic hardening of steel

the complexity of such structural elements (beam-column and wall-slab connections), the aim of this work is to express 0D (macro-elements kinematics) accounting for different materials and behaviors within a thermodynamics framework making use of robust numerical algorithm and identification procedures.

Beginning with the experimental process of full scale elements in comparison with 3D numerical investigations, the first section presents the analysis that allows determining failure mechanisms of thermal breaks subject to earthquake loadings. The thermodynamic internal variables are determined at this stage. Secondly, a macro-scale model for slab-wall connection is derived following the previous analysis and based on irreversible processes thermodynamic assumptions [19]. This model takes into account damage due to shear and flexural combinations, frictional sliding and hysteresis, steel plasticity and stiffness recovery in case of alternate loadings. The finite element numerical implementation has been carried out using an implicit scheme. The validation by experimental campaigns achieved under quasi-static and seismic loadings aims to show the capability of describing complex response by this simplified model.

2. Nonlinear mechanisms identification of RC joints

As explained in the previous section, wall-slab connections are complex elements to be studied due to the diversity of employed

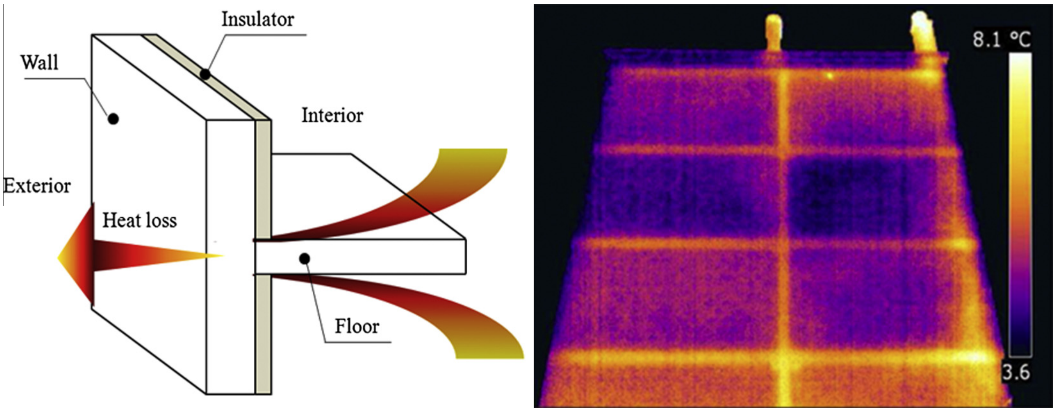

Fig. 1. Junction with thermal bridge (left) and thermal bridges in a house by infrared (right) [1].