Dynamic testing of RC beam-column subassemblies subjected to a column removal scenario

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Résumé :

Ce travail présente l'étude du comportement à la ruine de sous-assemblages poteaux-poutres en béton armé en considérant le scénario de perte brutale de portance d'un des poteaux porteurs. Ce travail présente un programme expérimental réalisé pour étudier le comportement d'un sous-assemblage à l'échelle 1/4 soumis à la perte soudaine de l'appui sur lequel repose le poteau central. Les structures testées sont composées de trois colonnes et de deux poutres. Le chargement appliqué à la structure entraîne la création simultanée de quatre rotules plastique qui se développent au niveau de chaque jonction poteau-poutre. L'endommagement généré dans la structure en béton est observé au moyen d'une technique de corrélation d'images numériques. L'instrumentation utilisée (capteur de force, interférométrie laser) permet de déduire la réponse dynamique de la structure. De plus, un code aux éléments finis (Abaqus explicite) est utilisé pour simuler le comportement des sous-assemblages. Les calculs numériques sont comparés aux résultats expérimentaux en termes de réponse dynamique et de propagation de la fissuration dans la structure.

Abstract:

In the present paper the risk of progressive collapse of beam-column RC (reinforced concrete) subassemblies considering a column removal scenario is analysed. This paper presents an experimental program carried out to study the behaviour of a 1/4 scaled subassemblies subjected to the sudden removal of a middle supporting column. The tested RC structures are composed of three columns and two beams. The dynamic loading applied to the middle column leads to the simultaneous creation of four plastic hinges that develop on each beam-column join. The growth of damage within the concrete structure is observed by means of a Digital Image Correlation technique. The instrumentation (force cell, laser interferometer) used in the experiments provides the dynamic response of the structure. Moreover, a finite element code (Abaqus explicit) has been employed to simulate the behaviour of the beam column subassemblies subjected to dynamic loading. The numerical calculations have been compared to experimental results in terms of dynamic response and propagation of cracking in the structure.

Keywords: reinforced concrete, progressive collapse, dynamic testing, joint failure, damage

1 Introduction

Nowadays, beam-column reinforced concrete structures are widely used in civil engineering throughout the world. However, accidental and intentional events, such as earthquake, explosion and local failure due to accidental overload, may induce local structural damage which occurs firstly at the beam-column joint [1]. This local damage may cause a chain reaction of failures of key structural members disproportionate to the initial damage, leading to more widespread failure of the surrounding members and partial or complete structure collapse [2] [3]. At present, a number of publications covering the subject of progressive collapse under quasi-static loading have appeared in the scientific literature [4] [5], while the collapse resistance of reinforced concrete structures subjected to dynamic loading rate such as blasting loads, earthquake, gas explosion, terrorist attack or accidental loads remains uncertain. Nevertheless, such high peak-short duration dynamic loads may induce critical damage in RC structures leading to a progressive collapse scenario.

The aim of the present work is to experimentally and numerically investigate the dynamic response and damage in beam-column reinforced concrete (RC) structures subjected to a real instantaneous loss of bearing capacity of the central column. An experimental program has been developed to investigate the dynamic behaviour of beam-column subassembly under a middle column removal scenario. In a first stage, the RC frames are supported by fixed supports and loaded quasi-statically by a weight applied to the middle column. Next the fuse part supporting the middle column is suddenly realized. One beam is visualized with a high-speed camera so the field of displacement is obtained by using digital image correlation software. In addition, a laser interferometer pointed out to the central column allows measuring the particle velocity and acceleration. Finally the force-displacement dynamic response of the structure is deduced.

In parallel, a numerical study has been carried out with the finite element code ABAQUS. A damage model was used to simulate the growth of damage under quasi-static or dynamic loads. A good correlation was observed between the numerical results and the experimental data.

2 Experimental set-up and geometry of RC specimens

The tested one third scaled RC frames consists in a two-bay beam and three columns. The details of reinforcement are shown in Fig.1. It is composed of longitudinal rebars 6 mm, 5 mm or 3 mm in diameter and stirrups 4 mm in diameter. The structures are made with R30A7 common concrete. This concrete is composed of hard siliceous aggregates, sand, cement and water (Table 1). The water to cement ratio is 0.64. All the concrete structures have been cast into plywood moulds (Fig. 2). R30A7 concrete have been extensively tested in the last years especially in quasi-static triaxial compression tests under pressures as high as 800 MPa [6-7] and dynamic tensile loading [8-10] and shear loading [11]. In addition, mesoscopic modelling was developed by Dupray et al. [12] and more recently by Erzar and Forquin [8] to simulate the behaviour of R30A7 concrete in confined compression and under impact loading. To do so numerical concrete specimens were defined with biphasic meshes: the real structure of the material is approximated by spheres for the aggregates when their diameters exceed 2 mm and the cementitious matrix is considered as homogeneous. This mesoscopic approach allows evaluating the influence of aggregates on the damage modes under confined compression [12] and in dynamic or impact conditions [8].

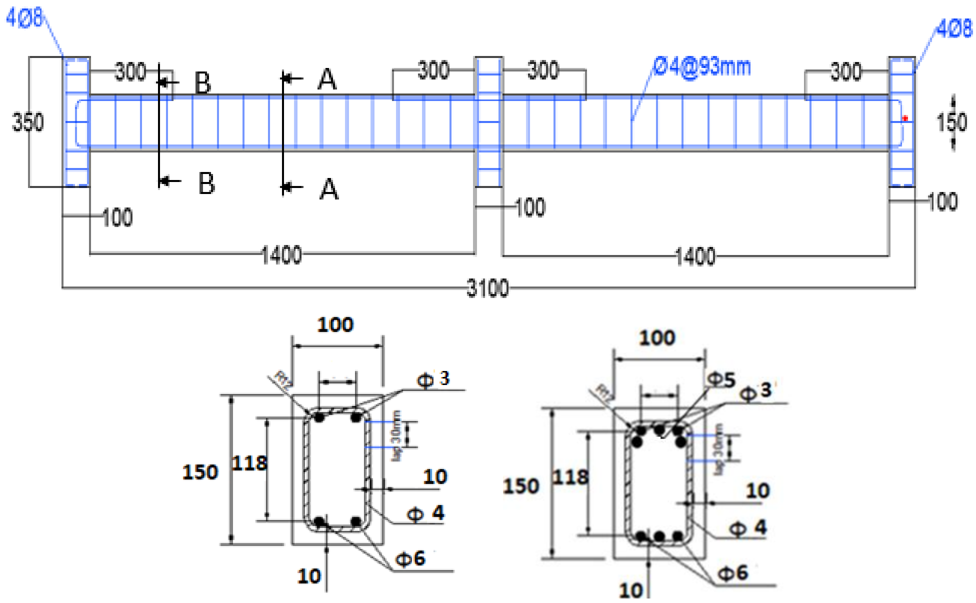

Fig. 1. Details of reinforcement

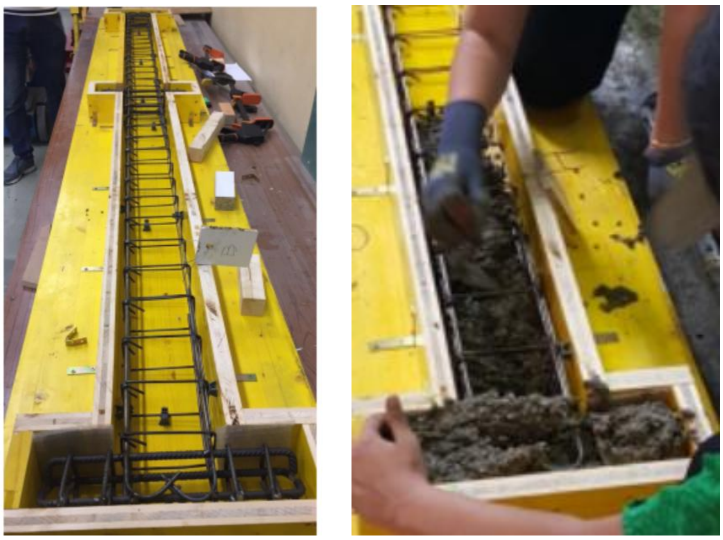

Fig. 2. Casting of concrete in plywood moulds

An original testing apparatus was developed to simulate the sudden failure of the central column of the structure depicted on the Fig. 1. The experimental procedure is the following: in a first stage a weight about 790 Kg (load 1 and 2) or 1760 Kg (load3) is applied to the central column. This weight is mainly supported by a mechanical fuse put in contact with the bottom surface of the central column. Next, the fuse is failed and a damped oscillatory response of the structure is observed. It stabilized in less than one second. Next the fuse is replaced in contact with the bottom surface of the central column. The structure is reloaded statically (applied weight, load 2) and dynamically (breakage of the mechanical fuse) leading to a second damped oscillatory response of the structure. A third load is applied (1760 Kg) that leads to the total failure of the structure. Finally, four main cracks are observed in the vicinity of the 4 beam-column joints.

Fig. 3. Set-up used for testing beam-column subassembly under a middle column removal scenario

3 Experimental results

The experiments were conducted with the following instrumentation: a high-speed camera was used to visualize the side of one beam and digital image correlation software was used so the field of displacement is obtained. It allows visualizing the growth of cracks during the test. In addition, a laser interferometer pointed out to the central column allows measuring the particle velocity and the acceleration. The data combined with the contact force between the mass and the central column measured with a load-cell allows deducing the dynamic force-displacement response of the structure. The response of one structure subjected to three consecutive loads is shown on the Figure 4. Three stages are clearly observed namely the elastic stage, a plastic yielding and a sudden failure. A comparison of this dynamic response to the quasi-static response of the same structure constitutes a main prospect of the present work.

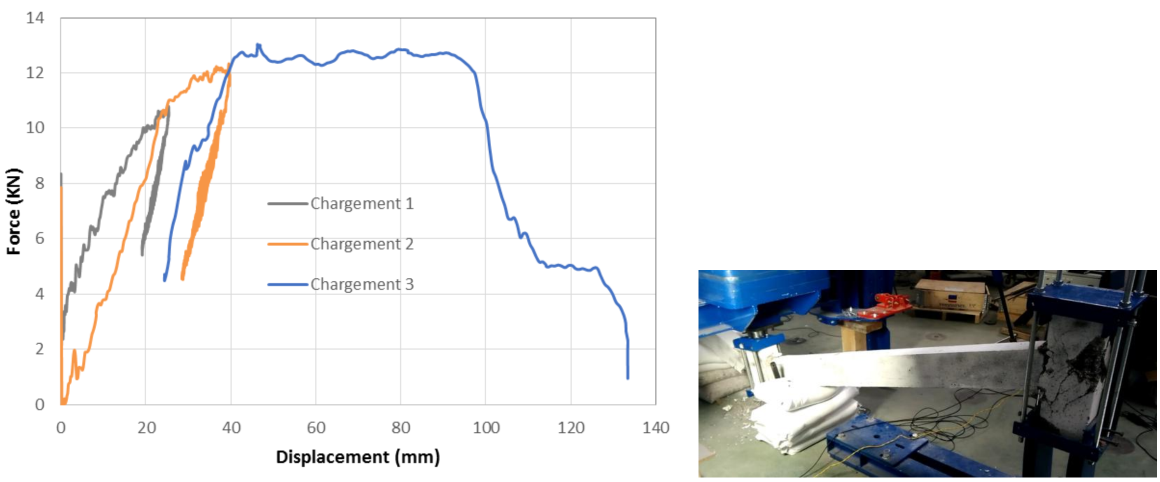

Fig. 4. Dynamic response of a beam-column subassembly under a middle column removal scenario

4 Conclusion

This paper presents the first experimental data obtained in the framework of an experimental program designed for investigating the behaviour of RC beam-column sub-assemblies under a middle column removal scenario. In the present case, the tested RC structure is composed of three columns and two beams. The set-up reproduces the sudden loss of the bearing capacity of the central column. Failure occurs at beam-column joint interfaces with wide cracks and rebars fracture. A comparison with numerical predictions and quasi-static experimental data constitute the main prospects of the present work.

Acknowledgements
This work was supported by the Commissariat à l'Energie Atomique et aux Energies Alternatives – Centre de Gramat (CEG). The authors wish to acknowledge Dr. C. Pontiroli and Dr. E. Buzaud from CEA for the numerous and fruitful discussions that contributed to complete this work.

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