A Numerical Modeling of RC Beam-Column Joints Compared to Experimental Results

Q.-B. Bui[1(✉)], B. Sentosa[2], and T.-H. Duong[1]

[1] Sustainable Developments in Civil Engineering Research Group, Faculty of Civil Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
buiquocbao@tdt.edu.vn

[2] Université Savoie Mont Blanc, LOCIE – CNRS UMR 5271, Chambéry, France

Abstract. Beam-column joints are commonly considered critic regions for RC frames subjected to earthquake. That is why assessing the beam-column joint capacity is an important topic, especially for structures constructed before the modern seismic design codes, or for buildings in post-seismic situations. Among the in-situ structural assessment methods, the vibrational testing is currently mentioned. The authors have developed an analytical method to assess the damage evolution of a structure in function of its dynamic characteristics. The method consists of two main steps and the first one necessitates a robust model which can reproduce the static behavior of the studied structure. For this purpose, the authors try and assess the relevancy of existing numerical models to choose the most relevant for the second step. This paper presents an assessment of the CDP (Concrete Damage Plasticity) model implemented in the Abaqus software. First, an experimental study on a RC beam-column frames is presented. Unloading-reloading cycles were performed during the tests and the displacement fields were recorded by using the image correlation technique. The experimental data are used to assess the relevancy of the CDP model, but these data can be useful also for the further studies to verify and improve the accuracy of the numerical or analytical models.

Keywords: Reinforced concrete · Beam-column frame · Experiment · Abaqus modelling

1 Introduction

The seismic behaviour of reinforced concrete (RC) buildings can be affected by the performance of beam-column joints involved in the failure mechanism, especially in typical existing buildings. So, the assessment of the beam-column joint performance is an important topic, for existing structures and especially for post-seismic structures. A structural evaluation is needed to decide if a any retrofitting is requested. Among the in-situ structural assessment methods, the non-destructive method using vibrational measurements (by accelerometers or velocimeters) is currently mentioned (Boutin et al. 2005; Brownjohn 2003; Bui et al. 2014; Volant et al. 2002).

H. Tran-Nguyen et al. (eds.), *Proceedings of the 4th Congrès International de Géotechnique - Ouvrages -Structures*, Lecture Notes in Civil Engineering 8,
DOI 10.1007/978-981-10-6713-6_5

From the dynamic characteristics measured by vibrational tests, several approaches were proposed in the literature to establish the relationship between the dynamic characteristics and the structure's health (Boutin et al. 2005; Chang et al. 2003; Fang et al. 2008; Maas et al. 2012). However, the proposed approaches enable to diagnose a structure on a global scale (the whole structure), while the damage assessment at a local scale (each element of the structure and the beam-column joints) remains to be explored (Bui et al. 2014; Maas et al. 2012). The authors have recently developed an analytical method which can use results for the vibrational measurements to identify the structural damages at the element scale, and especially for beam-column joints.

The method consists of two main steps. In the first step, the displacements of some specific points on the structure (corresponding to the principal mode shapes) and the actual stiffness (the stiffness corresponds to the damaged structure) should be relevantly determined. To obtain these information, the authors have chosen to use the numerical approach (FEM) and seeked a numerical model which could reproduce finely the structural behavior at the element's scale.

For the beam-column joint modelling, conventional approaches consider only beam and column flexibility, although joints can provide a significant contribution also to the overall frame deformability (DeRisi et al. 2016). Although several experiments have already been carried out in the literature at the RC beam-column frame level, the number of experiments is still modest comparing to the important number of parameters which affect the joint behaviour: interior joint, exterior joint, stiffness ratio between beam and column, steel reinforcement type, semi-rigid connections… (Bui et al. 2014; Haselton et al. 2008; Metelli et al. 2015; Omidi and Behnamfar 2015; Sharma et al. 2011). That is why additional experimental studies in this topic is interesting for the scientific community, to improve the existing models.

In this context, the presents first an experimental study on an RC beam-column frame structure, which provides additional experimental data for the further models. Unloading-reloading cycles were performed during the tests and the displacement fields were recorded by using the DIC (Digital Image Correlation) technique. Then, the obtained experimental results are used to assess the CDP (Concrete Damage Plasticity) model implemented in the Abaqus software (Abaqus 2012). The cracking is evaluated by using the Equivalent Plastic Straint (PEEQT) model.

2 Experiment

2.1 Materials and Structure Investigated

The structure studied is a beam-column RC structure having H-form (two columns and one beam, Fig. 1). The cross-sections of the beam and columns are (0.2 m × 0.2 m) and (0.2 m × 0.25 m), respectively.

The RC frame structure was fixed and the ends of the columns by steel jacks (Fig. 2). Then, the RC frame was loaded at the beam's mid-span by an actuator (maxi capacity of 300 kN), via a steel box placed on the beam (Fig. 2). The actuator was controlled in displacement (0.1 mm/min). The displacements were measured at the same time by displacement sensors (Fig. 2) and by the DIC (digital image correlation)

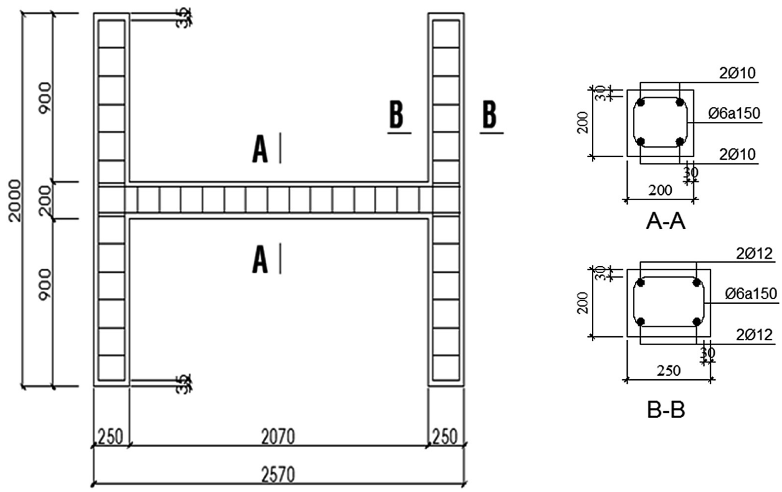

Fig. 1. Beam-column RC structure studied, dimensions in mm.

technique (Vacher et al. 1999). The use the DIC technique, two cameras (16 MPixels) were installed and recorded the test. After a data processing, the displacement fields (on whole structure tested) could be determined. To obtain better results with the DIC technique, RC beam-column structure was sprayed with black paint to have random points on its surface. Accelerometers (uniaxial and triaxial) were also installed on the structure to measure the dynamic characteristics and their relationship with the damage evolution; however, in this paper, due to the limited space, dynamic results will not be presented.

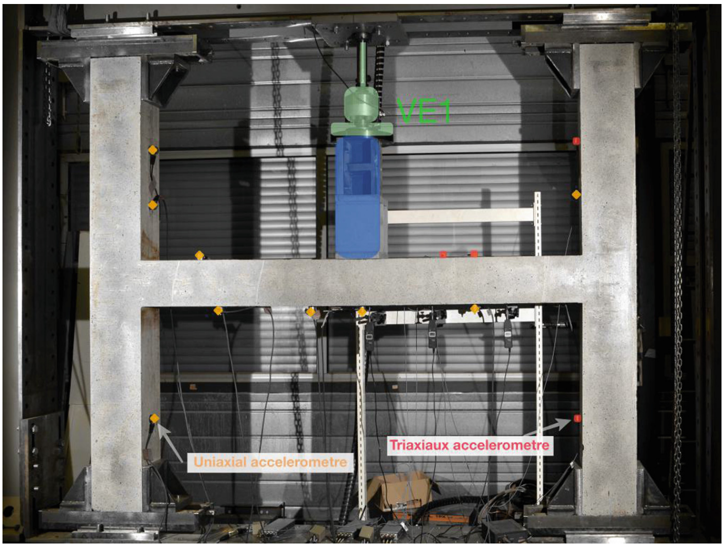

Fig. 2. Experimental model.

Concrete used was an industrial concrete "*béton pro 350*" of VICAT, which is similar to a C30/37 following Eurocode 2 Aydin et al. (2016). Three cylindrical specimens (16 cm-diameter and 32 cm-height) were manufactured (Fig. 3) for uniaxial compression tests to determine the compressive strength and the Young's modulus.

Fig. 3. Cylindrical specimens during the curing (at the left) and after the paint spraying for DIC (at the right).

2.2 Experimental Results

Uniaxial compression tests on cylindrical specimens gave results of 38.55 MPa for the mean compressive strength, 33.98 GPa for the Young's modulus and 0.217% for the strain corresponding to the maximal stress.

For the test on the beam-column structure, loading and unloading cycles were performed during the tests, in order to assess the performance of the numerical models in the case of cyclic loadings. The results are illustrated on Fig. 4: on the left, the experimental relationship between the force and the displacement at the beam's mid-span, with the "moments" of the cracks' apparition, corresponding to the crack numbers illustrated in Fig. 3 on the right. The crack apparition was captured by the DIC technique.

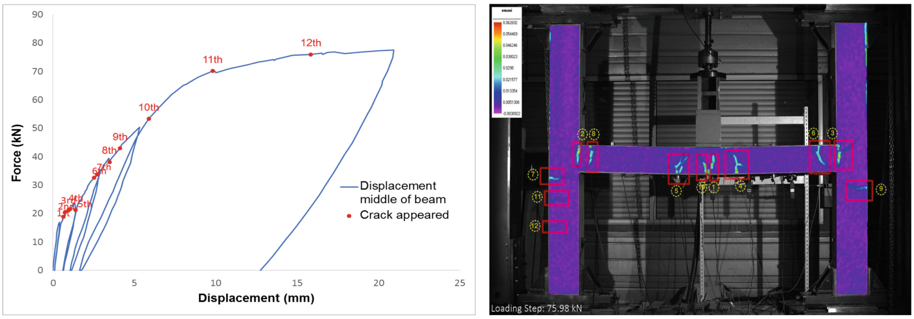

Fig. 4. Left: experimental relationship between the force and the displacement at the beam's mid-span. Right: crack apparition during the experiment.

3 Finite Element Modeling

3.1 RC Frame Model on Abaqus

Abaqus software was used for the present study, due to its robustness in the solving of complex problems. Solid elements were used for concrete parts and beam elements were used for steel reinforcement rods. The numerical model of the RC frame structure is shown in Fig. 5. The steel box was modelled at the beam mid-span, as in the experiment, and the loading was applied on this steel box.

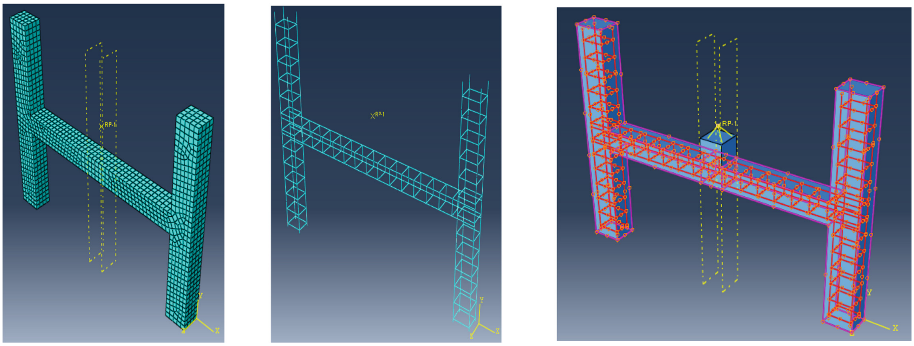

Fig. 5. Concrete, reinforcement steel rods and the entire RC frame structure modelled in Abaqus.

3.2 Material Characteristics

The compressive characteristics of the concrete (compressive strength, Young's modulus, stress-strain relationship) were determined from the tests on cylindrical specimens. Uniaxial compression tests on cylindrical specimens gave results of 38.55 MPa for the mean compressive strength, 33.98 GPa for the Young's modulus and 0.217% for the strain corresponding to the maximal stress. The tensile behavior of concrete was determined following the empirical relationships provided in *Eurocode 2* (2004). The stress-strain relationship of the steel was taken following the manufacturer data (steel S500B following Eurocode 2).

The characteristics of concrete and steel used for the numerical study are presented in Fig. 6. The CDP (Concrete Damage Plasticity) model was used to model the concrete behavior. Parameters used for this model are taken following values recommended in Aydin et al. (2016), after analyzing several studies existing in the literature (Cho et al. 2013; Hamid et al. (2012)Tejaswini and Raju 2015; Yusu and Muharrem 2015). It is important to note that these studies only investigated on RC beams and not yet on beam-column frame structures. So, an assessment on the relevancy of the proposed parameters for the case of RC beam-column frame is interesting (Table 1).

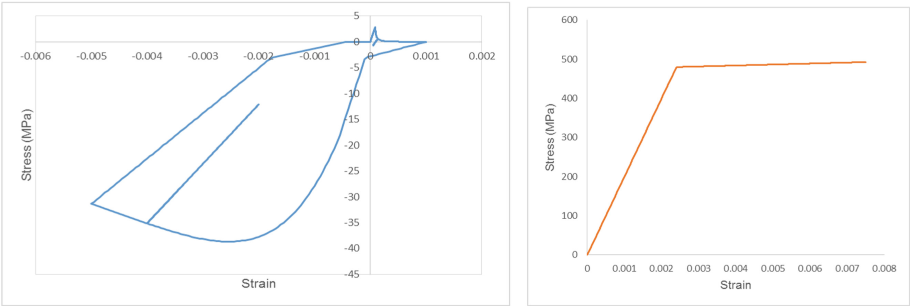

Fig. 6. Stress-strain relationships of concrete (left) and steel (right) used for the numerical model.

Table 1. Parameters used for concrete (CDP model).

Parameter	Value	Description
ψ	56	Dilation angle
e	0.1	Eccentricity
f_{b0}/f_{c0}	1.16	The ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress
K	0.667	The ratio of the second stress invariant on the tensile meridian
μ	0.0001	Viscosity parameter

3.3 Numerical Results

The structure was also loaded in the model by a displacement control as in the case of the experiment. The result about the relationship between the force applied and the displacement of are presented in Fig. 7, on the left. The results shows that the

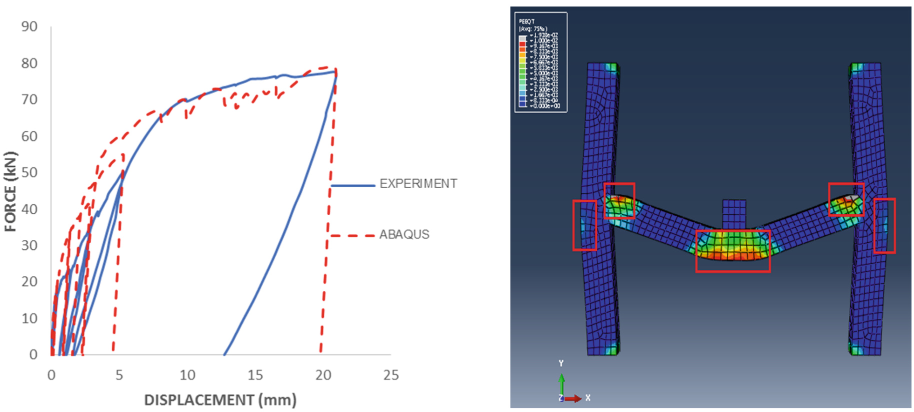

Fig. 7. Left: load – displacement curves at the beam's mid-span, obtained from the experiment and the modelling. Right: locations of the cracks in the numerical model at the maximal load.

numerical model could reproduce the global form of the force-displacement curve and the maximal load was captured. However, the cyclic effects were not well reproduced: the slopes of the unloading-reloading cycles in the numerical model was higher than that of the experiment; and the hysteresis phenomenon in the unloading-reloading cycles could not be reproduced by the model. This could come from the parameters and the model used. Further studies on this will be performed.

The cracking evolution could be visualized by using the PEEQT model in Abaqus and is presented in Fig. 7 (on the right) and Fig. 8, in which the twelve cracks appeared are respectively illustrated. By comparing the results in these figures with the experimental results (Fig. 4, on the right), it is observed that the cracking was well reproduced in the model in term of order of apparition, location of cracks and the force value

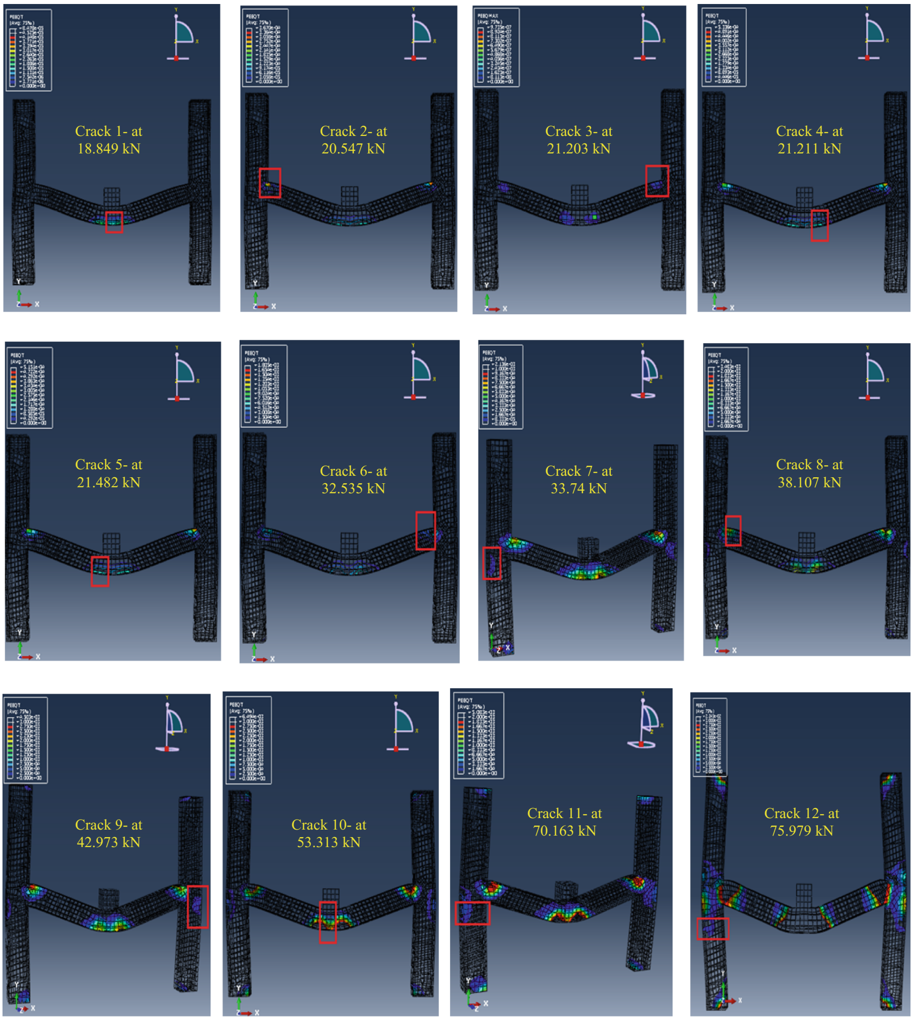

Fig. 8. Cracking evolution observed in the numerical model.

corresponding to each crack. The model could not precisely reproduce the real forms of the cracks observed in the experiment. However, this point can be improved by using the XEFM (Extend Finite Element Method) implemented in Abaqus.

If the results obtained by the model used in the present study are compared with that obtained by another model using the multi-fiber beams in CAS3 M code and the LaBorderie's model for concrete (that study was also carried out by the same authors, Sentosa et al. 2016), the results show that the LaBorderie multifiber model provided better results for the unloading-reloading cycles. However, visualizing of the cracking evolution is easier in Abaqus with the model used, which provides interesting information to verify the relevancy of the studied numerical model.

4 Conclusions

This paper presents an experimental and a numerical study on the behavior of a RC beam-column frame structure. Firstly, the experiment was performed on an H-form RC frame structure with several loading-unloading cycles. Displacement fields during the test were recorded by the DIC technique which enabled to visualize the cracking evolution.

For the numerical model, solid elements and the Concrete Damage Plasticity model were used for the concrete; the classical elasto-plastic model was used for the steel reinforcement rebars. The results showed that the model could reproduce the global behavior of the experimental test: global force-displacement curve, ultimate load, cracks apparition (location and order of apparition). However, the model could not reproduce correctly the unloading-reloading cycles (slopes and the hysteresis behavior). That means that the model investigated can be used for the case of static loadings. For the case of cyclic loading (earthquake for example), an improvement of the model is necessary and this will be the objective of the further studies.

References

ABAQUS: ABAQUS Analysis User's Manual. ABAQUS Inc., Providence (2012)

Aydin, D., Hankan, O., Gokhan, D.: 3D nemerical modeling of RC deep beam behaviour by nonlinear finete element analysis. Disaster Sci. Eng. **2**(1), 13–18 (2016)

Boutin, C., Hans, S., Ibraim, E., Roussillon, P.: In situ experiments and seismic analysis of existing buildings. Part II: seismic integrity threshold. Earthq. Eng. Struct. Dyn. **34**, 1531–1546 (2005)

Brownjohn, J.M.W.: Ambient vibration studies for system identification of tall building. Earthq. Eng. Struct. Dyn. **32**, 71–95 (2003)

Bui, Q.B., Hans, S., Boutin, C.: Dynamic behaviour of an asymmetric building: experimental and numerical studies. Case Stud. Nondestr. Test. Eval. **2**, 38–48 (2014a)

Bui, Q.B., Mommessin, M., Perrotin, P., Plassiard, J.P., Plé, O.: Assessing local-scale damage in reinforced concrete frame structures using dynamic measurements. Eng. Struct. **79**, 22–31 (2014b)

Sentosa, B., Bui, Q.B., Plassiard, J.P., Plé, O., Perrotin, P., Purnomo, H.: Redistribution of moment at beam-column joints in RC structures: comparison between an experimental study and Eurocode 2. Submitted to CIGOS 2017, Ho Chi Minh City, Vietnam (2016)

Chang, P.C., Flatau, A., Liu, S.C.: Review paper: health monitoring of civil infrastructure. Struct. Health Monit. **2**, 257–267 (2003)

Chao, Z., Peng, C., Yixiang, C., Jianbo, J.: Using finite element software to similation fracture behavior of three-point bending beam with initial crack. J. Softw. **8**(5), 1145–1150 (2013)

DeRisi, M.T., Ricci, P., Verderame, G.M.: Modelling exterior unreinforced beam-column joints in seismic analysis of non-ductile RC frames. Earthq. Eng. Struct. Dyn. (2016) doi:10.1002/eqe.2835

Eurocode 2: Design of concrete structures - EN 1992, European Committee for Standardization (2004)

Fang, S.E., Perera, R., Roeck, G.D.: Damage identification of a reinforced concrete frame by finite element model updating using damage parameterization. J. Sound Vib. **313**, 544–559 (2008)

Hamid, S., Mahdi, S., Amir, H.A., Mohammad, A., Ali, S.: Evaluation of reinforced concrete beam behaviour using finite element analysis by ABAQUS. Sci. Res. Essays **7**(21), 2002–2009 (2012)

Haselton, C.B., Liel, A.B., Lange, S.T., Deierlein, G.G.: Beam-Column Element Model Calibrated for Predicting Flexural Response Leading to Global Collapse of RC Frame Buildings. Pacific Earthquake Engineering Research Center, PEER 2007/03, 152 p., May 2008

Maas, S., Zürbes, A., Waldmann, D., Waltering, M., Bungard, V., De Roeck, G.: Damage assessment of concrete structures through dynamic testing methods. Part 1- Laboratory tests. Eng. Struct. **34**, 351–362 (2012)

Metelli, G., Messali, F., Beschi, C., Riva, P.: A model for beam–column corner joints of existing RC frame subjected to cyclic loading. Eng. Struct. **89**, 79–92 (2015)

Omidi, M., Behnamfar, F.: A numerical model for simulation of RC beam-column connections. Eng. Struct. **88**, 51–73 (2015)

Sharma, A., Eligehausen, R., Reddy, G.R.: A new model to simulate joint shear behavior of poorly detailed beam–column connections in RC structures under seismic loads Part I: exterior joints. Eng. Struct. **33**, 1034–1051 (2011)

Tejaswini, T., Raju, M.V.R.: Analysis of RCC Beams using ABAQUS. Int. J. Innov. Eng. Technol. **5**, 248–252 (2015)

Vacher, P., Dumoulin, S., Morestin, F., Mguil-Touchal, S.: Bidimensional strain measurement using digital images. Proc. Inst. Mech. Eng. Part C: J. Mech. Eng. Sci. **213**, 811–817 (1999)

Volant, P., Orbovic, N., Dunand, F.: Seismic evaluation of existing nuclear facility using ambient vibration test to characterize dynamic behavior of the structure and microtremor measurements to characterize the soil: a case study. Soil Dyn. Earthq. Eng. **22**, 1159–1167 (2002)

Yusu, S., Muharrem, A.: Defining parameters for concrete damage plasticity model. Challlenge J. Struct. Mech. **1**(3), 149–155 (2015)