DEVELOPING A NEW RIGID BODY SPRING MODEL ELEMENT FOR INCORPORATING POISSON EFFECT IN SIMULATING CONCRETE-LIKE MATERIALS

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1. INTRODUCTION

In modern construction industry, concrete is a commonly used material in construction of typical buildings, infrastructures and critical structures. Understanding and predicting the behavior of concrete subject to various loading and environmental conditions has been subject of many research studies. Since the concrete is a non-homogenous material, many researchers have tried to utilize numerical methods based on Discrete Element Method (DEM) to perform numerical studies on concrete. Rigid Body Spring Model (RBSM) is one of the methods that fall under such category. Though this method has proved to be useful for simulating the concrete under different loadings and environmental factors, being derived based on a specific stress-strain condition it lacks reflecting Poisson effect in the model. Another consequence of this method is compromising the pressure sensitivity for pressure sensitive materials such as concrete.

2. RESEARCH MOTIVATION

RBSM cannot provide the possibility to catch Poisson confinement for a confined specimen in a pseudo static and inertial confinement in dynamic applications. This research aims for introducing a new element to expand the usability and accuracy of RBSM in simulating the behavior of concrete and take the initiative to provide the possibility to implement pressure dependent constitutive material models.

3. LITERATURE REVIEW

RBSM method was originally introduced by Kawai (Kawai 1978). The paper includes different structural analysis problems including beam, plate and plane strain condition. Nagai et al. used Kawai's model to conduct a 2-dimensional and 3-dimensional simulation of concrete specimen's failure behavior (Nagai, Sato, and Ueda 2004, 2005). This model was utilized in many research studies regarding the environmental effect like frost damage (Ueda et al. 2009) or fire damage on concrete

K Liu et al. used a hexahedral lattice and springs model to use DEM in solving dynamic impact problems. The stiffness of the springs was derived based on the shape of lattice and arrangement of elements. They used this method for simulating wave propagation in orthotropic planes, and projectile penetration in concrete. Later they extended the element arrangement to square lattice (Kaishin, Lingtian, and Tanimura 2004; Liu and Liu 2006).

To implement Poisson effect in a lattice model, Asahina et al. used an iterative method to reproduce the force distribution due to Poisson effect in a lattice model (Asahina et al. 2015).

4. RBSM METHODS

4.1 Existing issue

RBSM is a form of DEM in which the continuum body is assumed to be discrete rigid block connected by zero-length normal and shear springs. The degrees of freedom will be assumed at the centroid of rigid blocks.

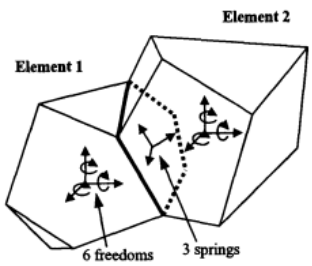

Fig. 1 RBSM elements (Nagai, Sato, and Ueda 2005)

To derive the stiffness matrix of elements, a method to attain the spring constants is mandatory. Springs should be able to appropriately represent the stress strain relation. In a typical RBSM model usually either plain strain in two orthogonal direction (Equation 1) or a combination of plain strain and plain stress is used (Equation 2). The former condition assumes no deformation in lateral direction (Fig. 2a) while the later condition assumes no deformation in one direction and no loading on the other orthogonal lateral direction (Fig. 2b).

Keywords: DEM, RBSM, Poisson effect, Concrete
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$$\varepsilon_x = \frac{\sigma_x}{E}\left(\frac{(\nu+1)(1-2\nu)}{1-\nu}\right),\ \ \varepsilon_z = \varepsilon_y = 0 \tag{1}$$

$$\boldsymbol{\varepsilon_x = \frac{\sigma_x}{E}\left(\frac{1}{1-\nu^2}\right), \qquad \sigma_z = \varepsilon_y = 0} \tag{2}$$

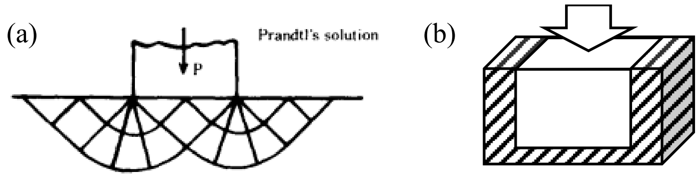

Fig. 2 a. semi-infinite volume, plain strain in two direction (Kawai 1978) b. box in a rigid mold (plain strain and plain stress)

4.2 Research goal

RBSM has proved to be a powerful tool to simulate behavior of concrete specimen, but it cannot directly capture the lateral expansion due to Poisson effect, though a lateral dilation is observed in the model. The mentioned dilation could be due to arrangement of elements (same effect that is observed in lattice models in Fig. 3) or due to failure of springs.

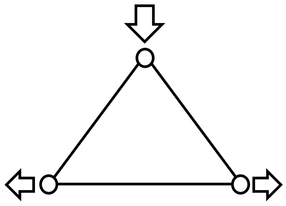

Fig. 3 Lateral deformation in a lattice structure

The new element is supposed to catch in-plane deformation and biaxial deformations due to Poisson effect respectively for 2D and 3D models. The method is based on idea of a rigid body with hybrid springs. In the developed element, the springs will response accordingly to the deformation induced to their neighbor springs. As an example, problem for the loaded system in Fig. 4, is solved by using the new element with hybrid springs.

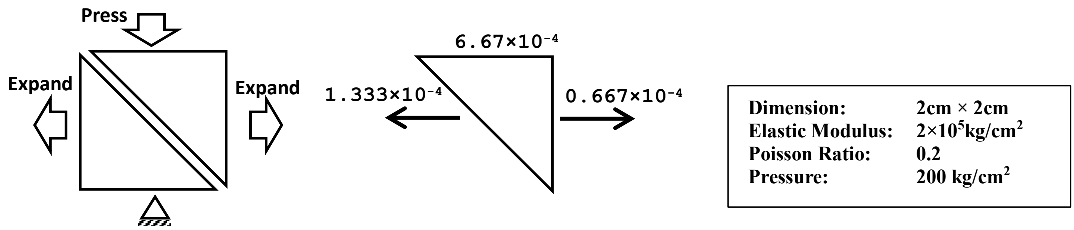

Fig. 4 example of solution with new element

5. CONCLUSIONS

Though RBSM has been a powerful tool to simulate response and cracking of concreted under loadings and environmental factors it lacks the ability to catch Poisson effect and implement pressure dependent constitutive models. This article describes the current research being conducted to improve this method by implementing a new stiffness matrix into RBSM.

REFERENCES

Asahina, D, K Ito, JE Houseworth, JT Birkholzer, and JE Bolander. 2015. “Simulating the Poisson Effect in Lattice Models of Elastic Continua.” *Computers and Geotechnics* 70: 60–67.

Kaishin, Liu, Gao Lingtian, and Shinji Tanimura. 2004. “Application of Discrete Element Method in Impact Problems.” *JSME International Journal Series A Solid Mechanics and Material Engineering* 47 (2): 138–145.

Kawai, Tadahiko. 1978. “New Discrete Models and Their Application to Seismic Response Analysis of Structures.” *Nuclear Engineering and Design*, Special Issue Structural Mechanics in Reactor Technology - Smirt-4, 48 (1): 207–29. doi:10.1016/0029-5493(78)90217-0.

Liu, K., and W. Liu. 2006. “Application of Discrete Element Method for Continuum Dynamic Problems.” *Archive of Applied Mechanics* 76 (3–4): 229–243.

Nagai, Kohei, Yasuhiko Sato, and Tamon Ueda. 2004. “Mesoscopic Simulation of Failure of Mortar and Concrete by 2D RBSM.” *Journal of Advanced Concrete Technology* 2 (3): 359–374.

———. 2005. “Mesoscopic Simulation of Failure of Mortar and Concrete by 3D RBSM.” *Journal of Advanced Concrete* 3 (3): 385–402.

Ueda, Tamon, Muttaqin Hasan, Kohei Nagai, Yasuhiko Sato, and Licheng Wang. 2009. “Mesoscale Simulation of Influence of Frost Damage on Mechanical Properties of Concrete.” *Journal of Materials in Civil Engineering* 21 (6): 244–252.