Seismic Damage Evaluation of Reinforced Concrete Structures Using 3D Lattice Model

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1. INTRODUCTION

On the scope of the Hyogo-Ken Nanbu Earthquake, a big degree of destruction was registered on RC urban elevated viaducts; causing a re-evaluation of seismic performance assessment. On that note, the objective of this study is to propose means of seismic damage assessment of RC structures using a 3D lattice model with an actual geometrical configuration discretization of the target structure to perform nonlinear static and dynamic analysis and propose energy dissipation as a valid measurement for seismic damage range evaluation.

2. ANALYTICAL MODEL

The analytical system of lattice model divides the concrete in truss members and arch members. For a 2D represented RC column, the concrete is modelled into flexural compression members, horizontal members, diagonal compression members, diagonal tension members, horizontal members and two arch members (Miki et al.2004) according to Fig. 1. Ratio of the width of the arch part to the cross section b is defined as index t. Based on the 2D model lattice model, a 3D model, as presented in Fig. 2, is developed where the analytical model is assumed to be equivalent. In the 3D lattice model, the assumption of global stiffness being equivalent to 2D lattice model allows the estimation of the cross sectional area of the arch and truss members (Miki et al. 2004).

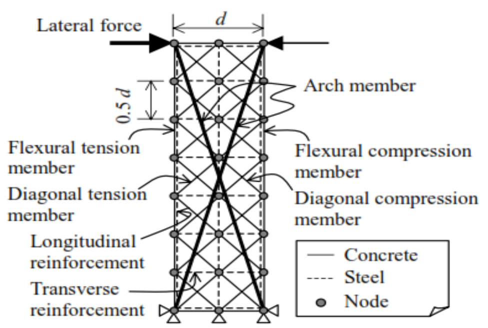

Fig. 1 2D lattice model (Miki et al. 2004)

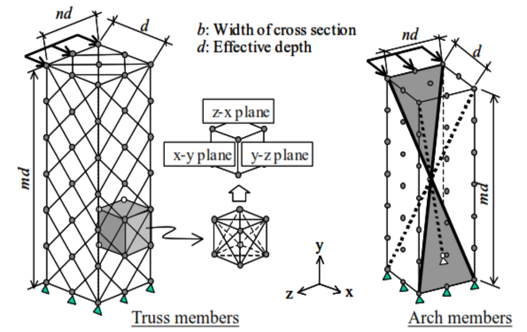

Fig. 2 3D lattice model for a RC column (Miki et al. 2004)

3. NONLINEAR ANALYSIS FOR RC VIADUCT COLUMN

3.1 Outline of target structure modelling and analysis

The target structure C1-5 is a reinforced concrete column tested in E-Defence (Kawashima et al. 2010).as shown in Fig. 3, with diameter of 2000 mm and 7500 mm tall, where the design concrete strength is 27 MPa and the longitudinal and transverse bars have a nominal strength of 345 MPa subjected to E-Takatori input ground motion, which is 80% of original JR Takatori Station ground motion.

The column has been modelled into the 3D lattice model presented in Fig. 4. The particularity of this modelling is the change in geometry of the target structure, where different from the study presented by Miki et al. (2003), the cross section is circular which introduced a need for readjustments on the analytical model, where a circular 16 peripheral nodes model based in equivalence in area moment of inertia between the model and the target has been used to estimate both mesh size, as well as arch and truss members cross section. Although it proved difficult to accurately estimate the cross section of concrete members, which ultimately was subjected to sensitivity analysis, the analysis was performed in order to produce results as accurate as possible, which was verified by comparing analytical and experimental results. The model itself is 8000 mm tall with a mesh size of 810 mm defined as half of the analytical diameter, which in the case is 1620 mm. Because of its geometry; it has been discretized with 8 arch members to seek improvement in accuracy. It is difficult to obtain an exact matching model of the target structure, due to differences in discretization based on the mesh size and the actual size of the structure, therefore the main aim is to come as close as possible.

In the pre-analysis, the values of index *t* for both width and effective depth are assumed as 0.35 and 0.25 (Miki et al. 2004), for simplification, and are based on the principle of minimum total potential energy. The loading point is considered to be at the top of the column, and thus the shear span as shown by the experimental program presented by Kawashima et al (2010). C1-5 was subjected to the 100% E-Takatori ground motion (C1-5(1)) and after the mass was increased by 21 % from 307 t to 372 t, C1-5 was subjected to the 100% E-Takatori ground motion (C1-5(2)).Then C1-5 was subjected to the 125% E-Takatori ground motion (C1-5(3)). Dynamic analysis has been performed using DYNALLAT 1.1.4, in-house developed software based on nonlinear finite elements analysis.

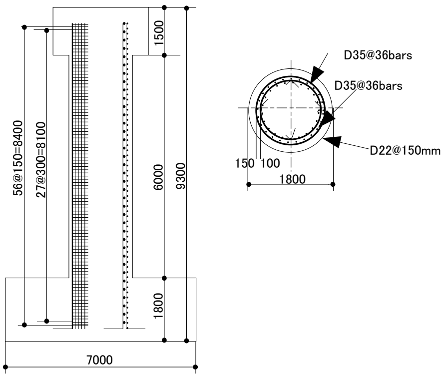

Fig. 3 Target structure details

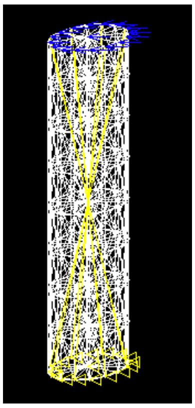

Fig 4. Column discretization model

3.2 Energy dissipation on RC column

The results from dynamic analysis are used to propose the amount of energy dissipated under seismic loading as a measurement of damage range. To do that, the energy inside the pier is addressed in terms of the elemental energy where it's assumed that the average stress-strain relationships govern each element after cracking occurs and used for estimation of strain energy as presented in Eq. (1). The energy dissipation presented in Eq. (2) is used, where it will be the total sum of the product between strain energy and volume for each element. The energy dissipation has been calculated for the three C1-5 targets for total size and bottom part of the columns corresponding to 1620 mm.

$$STRAIN-ENERGY = \frac{1}{2}(\sigma_i + \sigma_{1-1})(\varepsilon_i - \varepsilon_{i-1}) \quad (1)$$

$$ENERGY-DISSIPATION = \sum_{i=1}^{n}(STRAIN-ENERGY \times V_i) \quad (2)$$

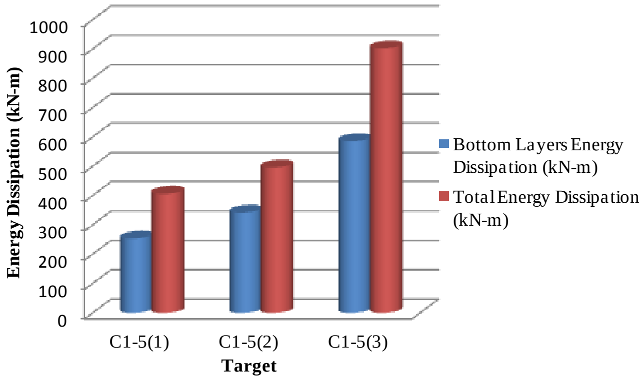

Fig. 5 Energy dissipation in three cases of C1-5 during excitations

4. CONCLUSIONS

The study presented 3D lattice model analysis of RC column, in order to grasp seismic behaviour. An actual circular cross section target model has been developed for analysis using circular 16 peripheral nodes approach. Based on dynamic analysis of cyclic loading, energy dissipation has been proposed for the evaluation of damage range in RC structures. From the analytical results, the level of damage increases from case C1-5(1), to C1-5(2) and finally C1-5(3). Furthermore the results suggest that about 50% of damage is concentrated at the bottom of the piers. The concept of damage evaluation using energy dissipation allows the expansion of scope to full framed RC viaducts.

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