損傷を制御した鉄筋コンクリート構造物の全体系の耐震性能照査法の開発

Development of Seismic Performance Verification Method for Whole RC Structures Controlling Damage

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１　INTRODUCTION

The modern seismic design codes stipulate that the response analysis should be conducted by taking into consideration the whole structural system including superstructure, foundation and the ground. A number of researches have recently investigated the influence of SSI using 3D finite element method (FEM) However, for a structure with a large number of piles; it is computationally difficult to carry out full 3D FEM analysis using solid elements for both structure and piles. The degrees of freedom of the model will greatly be reduced if beam elements are used for modeling the pile instead of solid elements, and thus, saving the computation time (Maki and Mutsuyoshi, 2004). This paper, investigates the use of 3-node fiber based beam elements for modeling of pile using full-scaled lateral loading test on concrete piles and 3D FEM analysis.

The authors conducted comprehensive study on the behavior of concrete pile using full scaled lateral loading test on single piles. The experimental details and results of which has already been published (Tuladhar et al., 2006). In this research, 3D FEM analysis was carried out to investigate the lateral behavior of pile and soil. Furthermore, 3D FEM analysis was also carried out on full-scaled bridge pier considering soil-structure interaction. Comparison between the modeling of pile using 3-node fiber based beam elements and 20-node solid element was also carried out for full-scaled bridge pier.

２　FULL-SCALED LATERAL LOADING TEST ON SINGLE PILE

Lateral loading tests were carried out on full scaled concrete pile embedded into the ground. Both of the test piles were hollow precast prestressed concrete piles (Fig. 1). 12 prestressing steel bars of 7mm diameter were used for longitudinal reinforcements. Compressive strength of concrete (fc') was 79 N/mm2 and yielding stress (fy) of longitudinal prestressing steel was 1325 N/mm2 Pile was embedded into the depth of 12.8m from ground level (GL). A load displacement relationship for the monotonic test (SP1) is show in Fig. 4 along with the analytical results. Other experimental details and results are explained in Tuladhar et al. (2006).

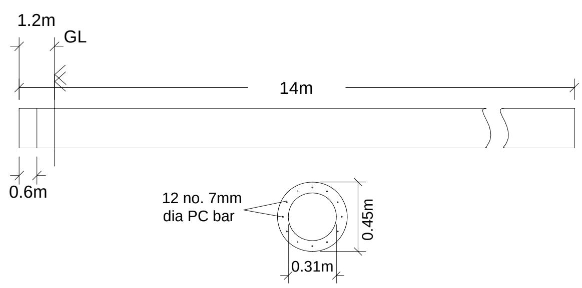


Fig. 1. Details of test piles

3 3D FEM ANALYSIS FOR SINGLE PILE

In the analytical model, soil is modeled as 20-node isoparametric solid element. For the modeling of concrete pile, comparison between 20-node solid element and 3-node fiber based beam element was carried out. In case SL-Mon, both the pile and soil are modeled as 20-node solid elements as shown in Fig. 2. To simulate the gap formation between soil and pile surface, a 16-node interface element is used between soil and pile surface (Tuladhar et al., 2006). For the case FB-Mon (Fig. 3) soil was modeled as 20-node solid elements, whereas the pile was modeled as 3-node RC beam elements based on the fiber model. The cross section of the element is divided into minute cells (fibers) according to the longitudinal reinforcement arrangements as shown in Fig. 3. Here, perfect bond between pile and soil was assumed.

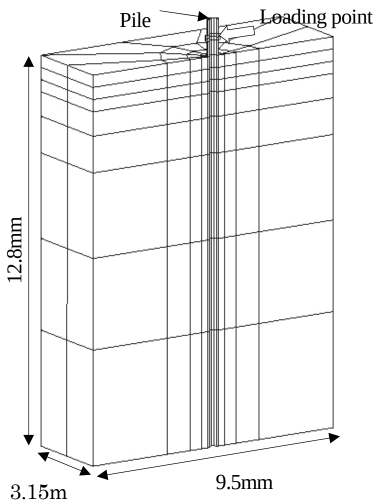


Fig. 2. FEM model with pile modeled as 20-node solid element (SL-Mon)

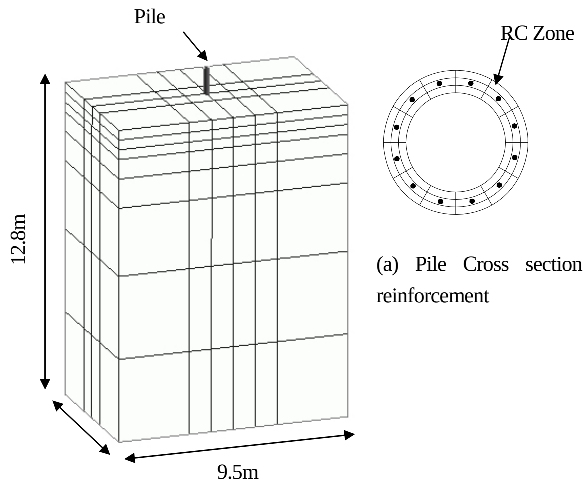


Fig. 3. FEM model with pile modeled as 3-node fiber based beam element (FB-Mon)

3D FEM results for single pile

The 3D-FEM analysis results for the case SL-Mon and FB-Mon are compared with the experimental results in Fig. 4. As shown in the Fig. 4, 20-node solid element can simulate the behavior of pile very accurately. 3-node fiber based beam element slightly under estimates the lateral load carrying capacity of the pile. This is because, while modeling the pile as a beam element, subgrade reaction from soil is underestimated as volume of the pile is being neglected. However, as shown in Fig. 4, using perfect bond between pile and soil and using rough mesh division, 3-node fiber based beam element can adequately simulate the behavior of concrete pile.

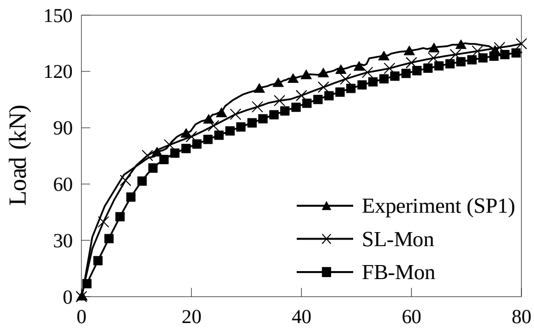


Fig. 4. Load displacement curves for monotonic loading for single pile

4 3D FEM ANALYSIS OF BRIDGE PIER CONSIDERING SOIL-STRUCTURE INTERACTION

On the basis of the experimental and 3D FEM analysis carried out on full-scale single concrete pile, 3D FEM analysis was carried out on a full-sized bridge pier (Fig. 5) considering soil-structure interaction. The selected system for the analysis is a single bridge pier of (4mx2m) supported on 12 numbers of 1m diameter piles.

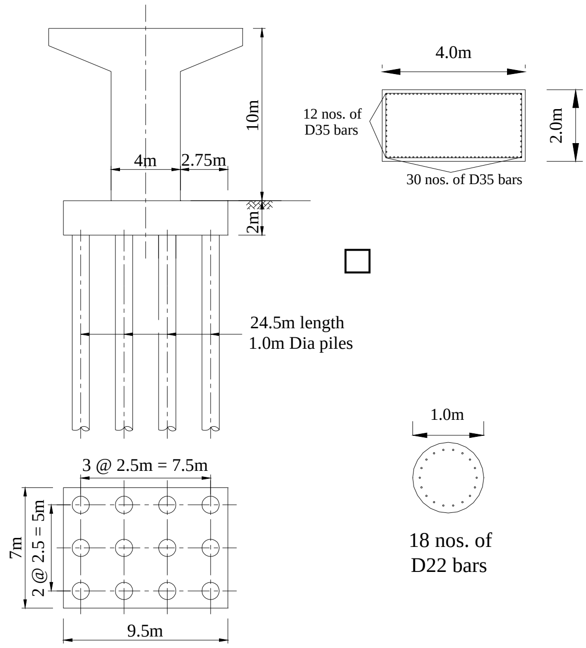
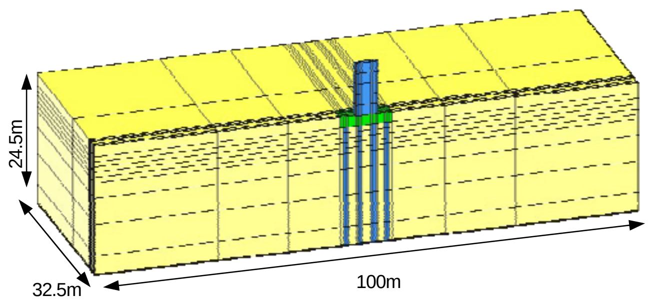


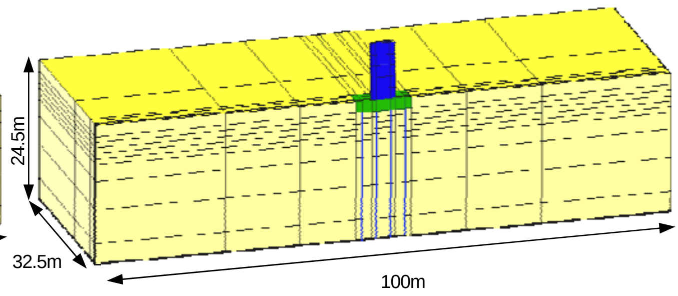
Fig. 5. Details of full-scale bridge pier

Finite element modeling

Different analytical cases considered are shown in Fig 6. In case Mon1, pier alone is modeled with fixed foundation. Whereas in case Mon2 and Mon3, the soil-structure interaction is also considered by modeling the soil and pile system. For case Mon2, soil and pile are all modeled using 3D 20-node solid elements. For the case Mon3, pier and soil are modeled by 3D solid element where as for the modeling of the pile, beam element was used.



(a) Mon2



(b) Mon3

Fig. 6. Analytical models (a) Pile modeled with solid element (b) Pile modeled with beam element

3D FEM analysis results

Load displacement curve from the analysis of full bridge pier system is shown in Fig. 7. Case Mon1, where soil-structure interaction is not considered, large initial stiffness compared to Case Mon2 and Mon3 where soil-structure interaction were considered. Case Mon2 and Mon3 gave a very similar load displacement behavior. This shows that 3-node beam element modeling of pile can give comparable results to the modeling of the pile as 20-node solid element. Load-displacement curves for case Rev2 (pile modeled as beam element) and case Rev3 (pile modeled as solid element) is shown in Fig. 8. This shows that the beam element modeling of pile can simulate the hysteretic behavior of the pile reasonably well.

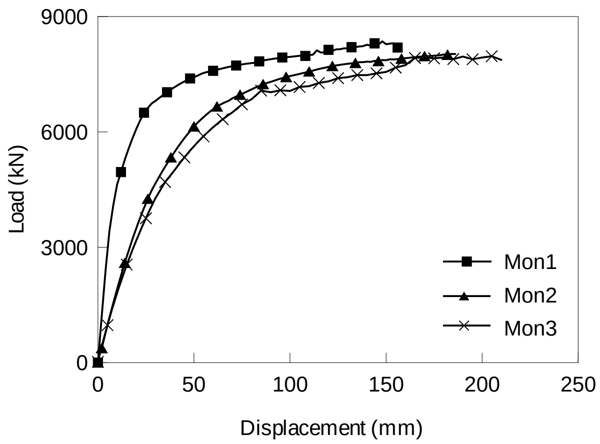


Fig. 7 Load displacement curves for full bridge pier system

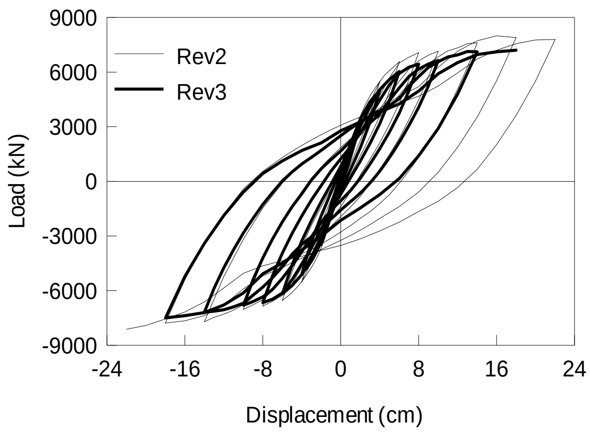


Fig. 8 Load displacement curve for reversed cyclic loading on bridge pier (a) Rev2 and (b) Rev3

5 CONCLUSIONS

In this study, on the basis of full-scaled lateral loading test on concrete piles, 3D FEM analysis was carried out on single concrete piles subjected to lateral loading. Further more analysis was carried out for the full-sized bridge pier. The study showed that lateral load carrying capacity of pile by 3-node fiber based beam element might slightly be underestimated, however, reasonable accuracy could be obtained with such modeling. 3D FEM analysis on full scale bridge pier system also showed that 3-node beam element can simulate the behavior of the whole structural system very similar to that of full 3D analysis by modeling pile as 20-node solid elements.

REFERENCES

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of Earthquake Engineering, 4(3), pp. 277-301.
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