Dynamic Analysis of a Pile Foundation Enhanced by WIB against Severe Earthquake

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INTRODUCTION

Anti-seismic design has been developed through the earthquake damage experiences due to severe motions. Innovative design ideas have been introduced. In this paper, the authors focus on pile foundations design at soft sites. An effective countermeasure, called honeycomb shaped Wave Impeding Barriers (WIB), has been developed in Takemiya's laboratory for seismic response reduction[1)2)]. Herein, a viaduct pile foundation is taken as a typical example to reveal the advantages of this measure. By parametric study, the authors will try to optimize the material characteristics of the WIB.

MODELLING AND RESPONSE ANALYSIS

The sectional elevation of the viaduct pile foundation is depicted in Fig.1. The honeycomb shaped WIB is imaginary installed under the footing with the active length $1/\beta$ of an embedded pile. The depth of improvement measures can be set in the range from $1/\beta$ to $\pi/2\beta$ following the suggestion given by the Japan Highway Technical Center. The layered soil where the piles are embedded gets stiffer gradually from the surface to the bottom. The pile foundation is made of reinforced concrete, and the WIB consists of a great number of soil-cement mixed columns arranged in honeycomb cells shape. The simulation is conducted by a two dimensional FEM-BEM hybrid program in time domain. The FEM covers the structure and the near field soil with complicated zone of the model, while the BEM fulfills the infinite boundary condition (Fig.2). Nonlinear behavior is considered in the FEM zone. Therefore, the near field soil is modeled by a hyperbolic model proposed by Hardin and Drnevich[3)] (HD), and is discretized into isoparametric solid elements. The pier and piles of the foundation are discretized into beam elements and characterized by one component Giberson model and Q-hyst model which takes into account of the relationship between bending moment and axial loading[2)]. The side columns of WIB are treated same as soil while the other columns are simulated by equivalent diagonal truss elements to consider the horizontal shear resistance of this measure. The nonlinearity of the WIB during strong motions is represented by a bilinear model. The investigated cases are listed in Fig. 3. The WIB in Case D is well designed according to the former work[2)]. Herein, a complementary study is focused on the material inside honeycomb cells of WIB. Case D1, D2 and D3 denote various design of filling stuff, respectively with different damping ratios. The severe earthquake motion of Kobe (JMA-NS) and an artificially generated one (S1-G1) are adopted in this paper for representatives of Type 2 and near-source motions.

Fig.4 shows the maximum bending moments of piles along depth. The static yielding line is provided for reference. The response of Case B indicates that separate walls can not improve the behavior of piles under earthquake loading. The WIB of Case D is well designed, which reduces the bending moments at top portion of piles remarkably. The WIB is a kind of soil improvement measure. It is inevitable that internal forces go up at interfaces of different impedance ratios, but it is necessary to avoid ruinous sharp values. Case D smoothes the variation of impedance ratios along depth by extending the side columns to G.L. 15.4m while keeping the inside columns at G.L. 11.0m. Case D1, D2 and D3 are different at damping ratios

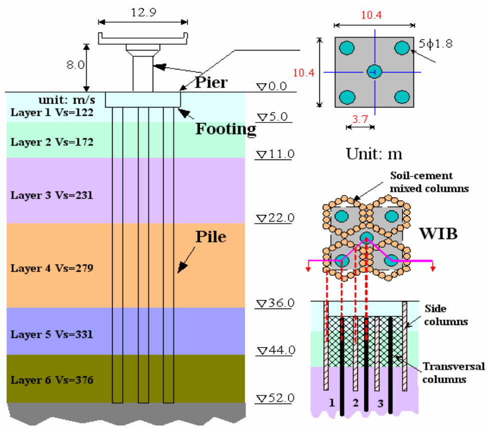

Fig.1 A viaduct pile foundation enhanced by WIB

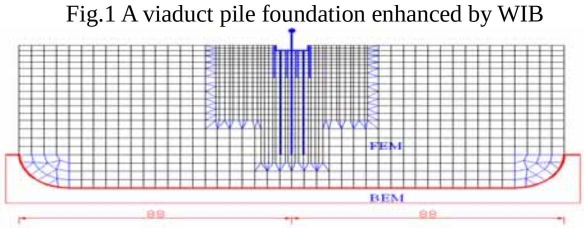

Fig.2 Calculation model

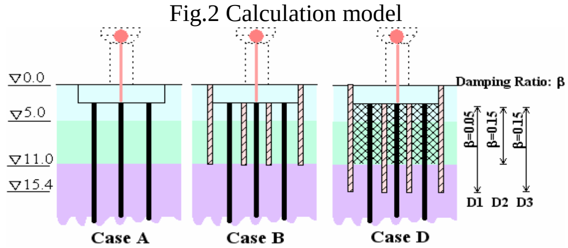

Fig.3 Cases for the analysis

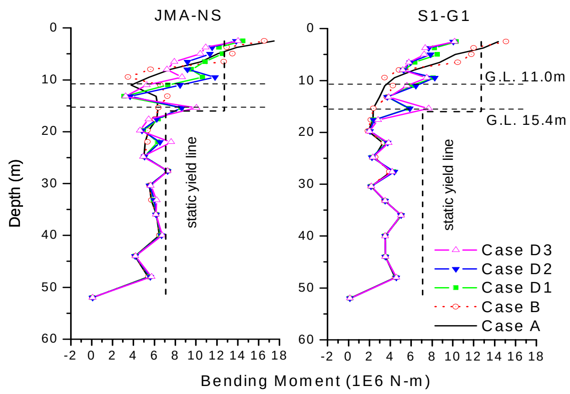

Fig.4 Bending moments of the piles

of the filling stuff of cells (see Fig.3). Material with high damping ratio has advantages in absorbing energy, which is obviously revealed in the cases of JMA-NS loading. However, there is not much difference among the responses of the three cases subjecting to S1-G1 motion. It is because

KEY WORDS: WIB, pile foundation, bending moment, kinematic interaction, nonlinear analysis, bilinear model
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the S1-G1 motion is not as strong as the JMA-NS one, and high damping material can only achieve its advantage in bigger deformation in light of the concept of damping. The relationship of bending moment and rotation angle of JMA-NS case is investigated in Fig.5. Case D3 and Case D2 reduce the rotation angles clearly, which directly leads to the mitigation of internal forces of piles. Fig.6 illustrates the time history relationship between bending moment and axial force at pile head. The nonlinear behavior of the WIB measure is simulated by a bilinear model. The bilinear loops of truss elements are shown in Fig.7. These two truss elements are picked from Case D2. No.111 represents those yielding elements, and No.115 indicates those failed ones. The dashed lines denote the ultimate strain of the truss elements, which is equivalent to the ultimate shear strain of WIB columns. Fig.8 shows the final status of all the truss elements of WIB of the three cases. From Case D1 to Case D2, high damping ratio leads to less failure of the honeycomb shaped WIB under severe JMA-NS motion. It is fully convinced that filling stuff with high damping ratio can alleviate failure of the near structures. The responses of piles are mainly induced by the kinematic interaction from surrounding soil deformation. Fig.9 illustrates the stress-strain loops of a solid element inside the WIB cells. By comparing Case D1, D2 and D3, we can see the high damping material reduced the deformation of itself, which leads to the reduction of pile responses. In view of these restoring force characteristics in piles and WIB columns, optimizing the filling stuff finally benefits the performance based design of the whole system.

CONCLUSIONS

This paper investigated the seismic responses of a viaduct pile foundation enhanced by the honeycomb shaped WIB. From the forementioned results, the honeycomb shaped WIB is quite effective in mitigating seismic responses. This countermeasure is designed with the knowledge of wave field with respect to the target frequency to control the performance of the structure. It is made of soil-cement columns by the soil improvement technique. The dynamic nonlinear analysis is conducted in time domain by a two dimensional FEM-BEM hybrid program. Material with high damping ratio is supposed to fill in the honeycomb cells, which results in better performance of the whole system under severe earthquake motions. Since high damping material absorbs energy in large deformation cases, it is better to apply such material where large deformation is permitted.

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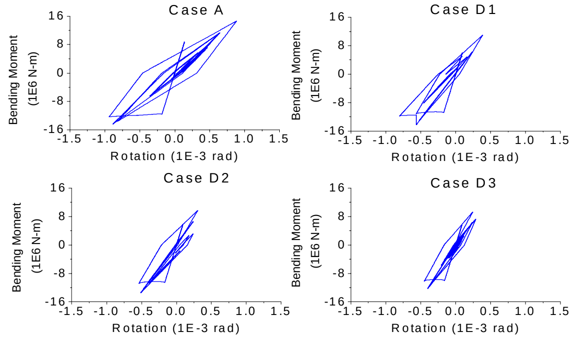

Fig.5 Bending moment-Rotation relationship at pile head

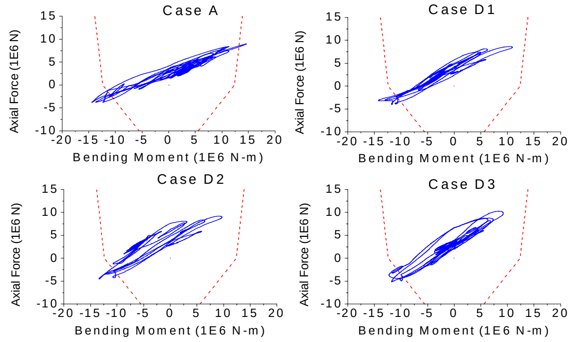

Fig.6 Bending moment-Axial force relationship at pile head

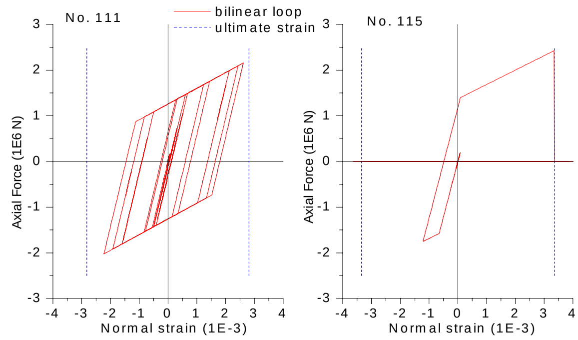

Fig.7 Bilinear loops of the truss elements

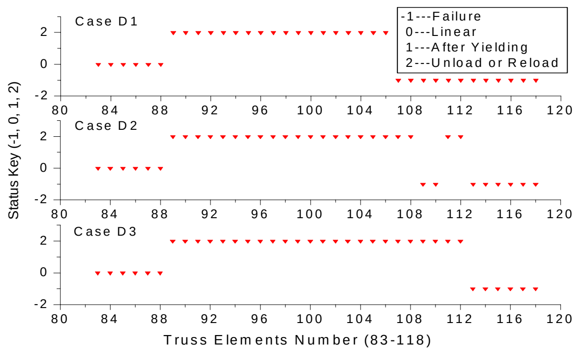

Fig.8 Final strain status of truss elements

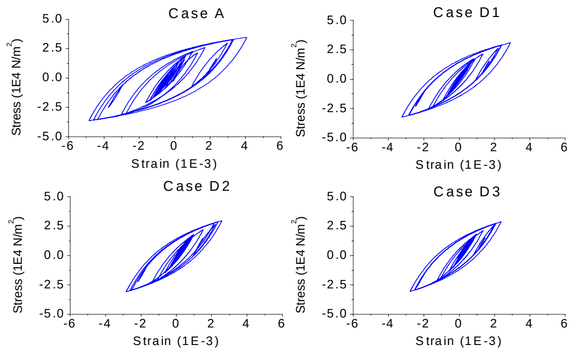

Fig.9 Shear stress-strain loops of a solid element in WIB cells