SEISMIC RESPONSE OF RC PIER SUBJECTED TO BI-AXIAL BENDING BASED ON FLEXIBILITY METHOD

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1. INTRODUCTION

As is well known, resisting capacity of reinforced concrete (RC) column, which is subjected to 2-directional horizontal forces, degrades in comparison with the case of single horizontal force. In this paper, to explain this phenomena during seismic response of bridge piers, the seismic response analysis based on flexibility method, which is force based formulation, are carried out.

2. FORCE BASED FORMULATION

In force-based element formulation, basic concept is to express force field **S(x)** as a function of force interpolation function $\mathbf{N_F(x)}$ and nodal forces **Q**,

$$\mathbf{S}(\mathbf{x}) = \mathbf{N_F}(\mathbf{x}) \cdot \mathbf{Q} \tag{1}$$

where $\mathbf{N_F(x)}$ are the interpolation functions. For axial forces, $\mathbf{N_F(x)}$ is constant and for flexure, $\mathbf{N_F(x)}$ is linear function of **x**. Introducing section flexibility **f(x)** yields

$$\boldsymbol{\varepsilon}(\mathbf{x}) = \mathbf{f}(\mathbf{x}) \cdot \mathbf{S}(\mathbf{x}) , \tag{2}$$

Application of the principle of virtual forces yields the element flexibility matrix as

$$\mathbf{F} = \int_0^L \mathbf{N_F^T}(\mathbf{x})\ \mathbf{f}(\mathbf{x})\ \mathbf{N_F}(\mathbf{x})\ \mathbf{dx} , \tag{3}$$

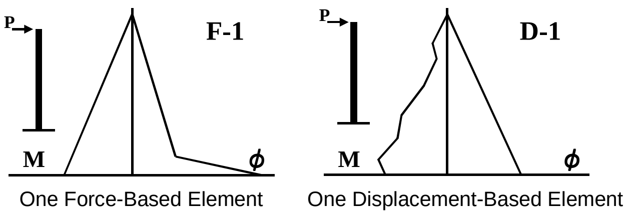

Fig.1 Force- and Displacement-based Element

Fig.1 shows the differences of internal moment and curvature distributions between force- and disp.-based element.

3. ANALYSIS MODEL AND INPUT SEISMIC WAVES

To show the effect of bi-axial bending under seismic loading, numerical simulations of a bridge pier are carried out.

The bridge pier for this analysis and analysis model are shown in **Fig.2** and **Fig.3**. Cross-section of this pier is the square of 3.0m*3.0m.. Flexibility method can estimate the behavior of columns by just one element as long as force distribution is linear, therefore the bridge pier like **Fig.2** can be modeled in one beam element.

To analyze this pier, we take fiber-model to obtain section stiffness and hysteresis. In fiber-model, constitutive relations of concrete and steel are Darwin-Pecknold model and Menegotto-Pinto model, respectively.

The input seismic wave is the one that was observed at the JR Takatori Station in Hyogo-ken-nanbu earthquake, 1995. In this paper, 3-dimensional seismic responses of the pier are carried out by 2 ways.

1) superposition of 2-dimensional model (x-y plane plus z-y plane)
2) 3-dimensional model

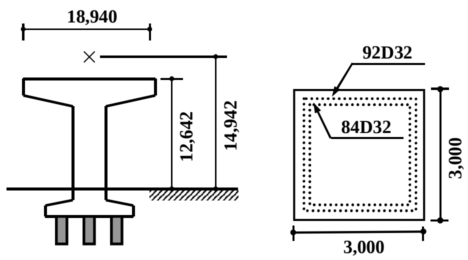

Fig.2 Structure for analysis

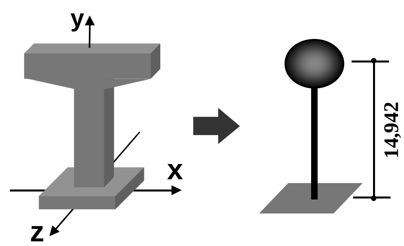

Fig.3 Modeling of the pier

Key Words : Bi-axial bending, Flexibility method, Moment-curvature relationship
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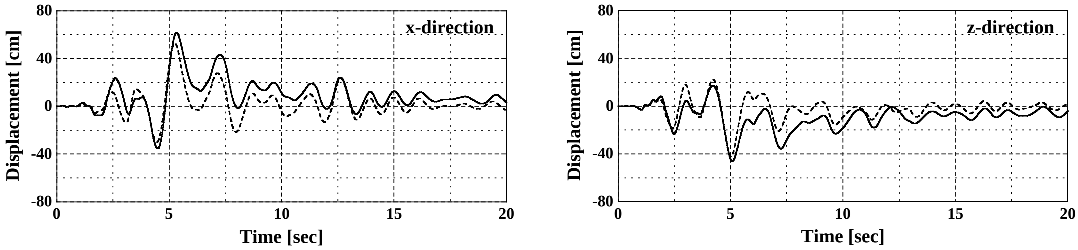

Fig.4 Displacement response at the top of the pier (solid-line:3-D analysis / dotted line : 2-D analysis)

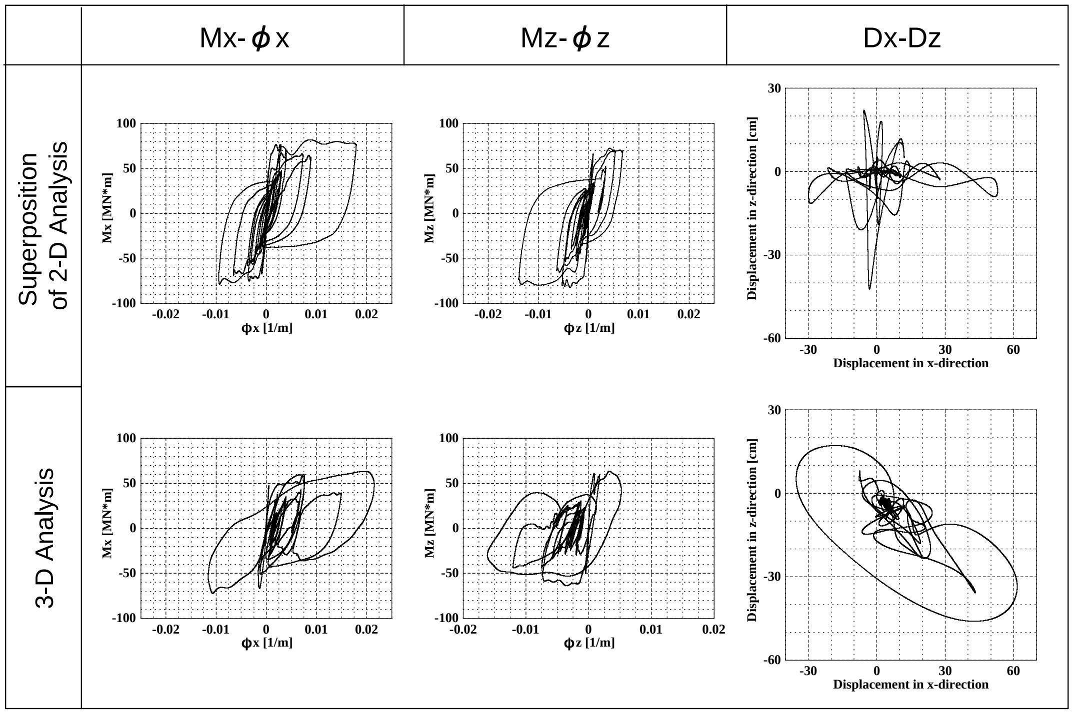

Fig.5 Section hysteresis loops and displacement response in x-direction vs. z-direction

4. ANALYTICAL RESULTS

Fig.4 shows the displacement response at the top of the pier. According to **Fig.4**, though the residual displacement doesn’t occur in 2-D analysis, it occurs in 3-D analysis (6.5cm in x-direction and –5.0cm in z-direction). Secondly, moment-curvature responses at the bottom of the pier and displacement response in x-direction vs. z-direction are shown in **Fig.5**. It is shown that the ultimate moments around each direction of bi-axial bending are less than that of superposition of 2-directional analysis. Further, the difference of displacement response between two analyses is very remarkable. These differences are caused by the effect of bi-axial bending. Therefore, superposition of 2-D analysis cannot represent the behavior of RC columns under bi-axial bending.

5. CONCLUSIONS

In the dynamic analysis under multi-directional loading, the resisting capacity in one direction degrades by the effect of bi-axial bending. It may be noted that the judgement based on the superposition of 2-dimensional analysis may overestimate its resisting capacity.

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