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REDUCTION EFFECTS ON SEISMIC RESPONSES OF OFFSHORE PLATFORM

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ABSTRACT

There are great possibilities for the development and utilization of the resources and energy of the ocean by using offshore structures. These structures are usually subjected to more severe load conditions than those on the land. There are two main design loads such as seismic motions and random sea waves for an offshore platform located in a seismically active region. Since these loads have stochastic properties, the random vibration approach yields effective methods of dynamic response evaluations. In order to enhance the reliability of the design of offshore structures, it is important to evaluate the exact dynamic response. If this dynamic response can also be reduced using the control methods such as passive control and active control, then the reliability of offshore structure can be enhanced against the severe load conditions.

In this study, the effects on the dynamic response reductions of an offshore platform subjected to seismic loads are examined using the passive and active control methods. It is shown that the more effective reductions of the response can be implemented with combining the passive control method and the active control method.

KEY WORDS ; *offshore platform, seismic response, response reduction, tuned mass damper, fuzzy control, active control*

INTRODUCTION

The seismic load is one of the most important excitations for the dynamic response evaluation of an offshore platform in a seismically active region. Many researches about the seismic response analyses of offshore structures have been carried out in the past (for example, Penzien *et al.*, 1972, Bea, 1979). An appropriate method of the dynamic response evaluations is given by the random vibration approach because of the stochastic properties of the seismic motions. In order to enhance the reliability of the design of offshore platforms, it is important to carry out not only the exact evaluation but also the reduction of the responses.

The reductions of dynamic response of structures, subjected to randomly-varying excitations, are generally caused by increasing the rigidity of the structure and the structural damping. However, practical implementations of these methods can not be always easy for offshore platform. The development of the system which can effectively reduce the dynamic response will greatly contribute to the enhancement of the safety and reliability of the structure. The vibration control of structures is nowadays one of the most interesting and promising topics on civil engineering structures (Yang *et al.*, 1987; Sato *et al.*, 1990). But, there are few researches on the dynamic response reductions of offshore platforms. The structures are generally subjected to major dynamic loads such as wave forces and seismic motions, which have the very different dynamic characteristics. It is suggested that dynamic response reductions due to control force may be implemented with different methods and devices. The dynamic response reductions of an offshore platform have been examined earlier with the instantaneous optimal control method (Kawano *et al*, 1992).

In the present research, the reduction of the dynamic response of offshore platform subjected to seismic loads is examined using the combination of the TMD system (Tuned Mass Damper system) and an active control force system. Fuzzy technique is one of the active control methods which are employed for generating active control force. This technique is easily applicable to offshore platforms with different dynamic characteristics. While the active control force method gives significant contributions on the dynamic response reductions, it is important to clarify the determination of some control force parameters for enhancing the reduction of the responses. It is shown that, in order to enhance the reduction effects on the seismic response, it is important to evaluate the appropriate parameters of both the TMD system and the fuzzy control system.

FORMULATION

The governing equation of motion

A jacket-type offshore platform with pile-soil foundation is used as the model for numerical analysis. The TMD system is set on the deck as shown in Fig.1. The active control force is applied between the deck and the mass of the TMD. The equation of motion is obtained by the substructure method in which the structure-pile-soil system is hypothetically divided into the superstructure and the pile-soil foundation system. The displacement of the structure can be expressed as the sum of the dynamic displacement of the structure on a fixed base, and the quasi-static displacement due to the interactions with the foundation. The governing equation of motion of the superstructure with the rigidly supported base condition is expressed as (Kawano *et al.*, 1992)

$$\left[\tilde{M}_{aa}\right]\left\{\ddot{x}_a\right\}+\left[\tilde{C}_{aa}\right]\left\{\dot{x}_a\right\}+\left[K_{aa}\right]\left\{x_a\right\}=-\left[\tilde{M}_{aa}\right]\left[L\right]\left\{\ddot{z}_g\right\}+\left\{B_f\right\}u \tag{1}$$

in which

$$\left[\tilde{M}_{aa}\right]=\left[M_{aa}\right]+\left[C_A\right],\quad \left[\tilde{C}_{aa}\right]=\left[C_{aa}\right]+\left[C_D\right],\quad \left[\mathrm{L}\right]=-\left[M_{aa}\right]^{-1}\left[M_{ab}\right]$$

The suffix 'a' denotes the nodal points except the fixed base ones and the suffix 'b' denotes the base ones connecting the pile-soil foundation. 'u' denotes the active control force. $\left[C_A\right]$ is the added mass matrix, $\left\{B_f\right\}$ is the location where the control force acts and $\left\{\ddot{z}_g\right\}$ is the ground acceleration due to seismic motion.

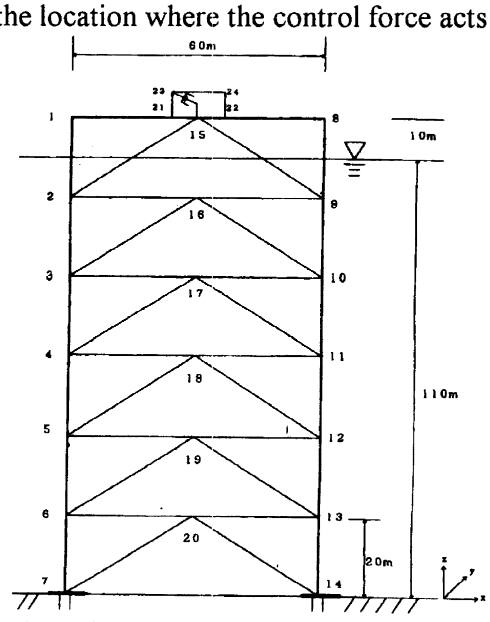

Fig.1 Analytical model of offshore platform

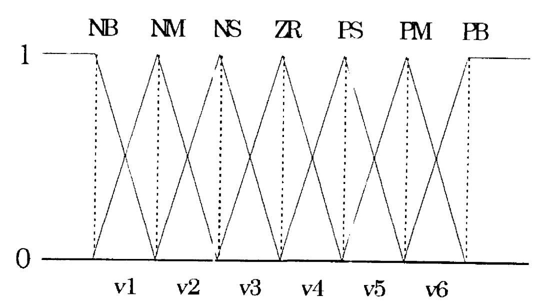

Fig.2 Membership function

Control rules							
Input (velocity)	NB	NM	NS	ZR	PS	PM	PB
Output (control force)	PB	PM	PS	ZR	NS	NM	NB

Table 1 Control force due to fuzzy rules

The dynamic displacements of the fixed-base structure with the TMD system are represented with a linear combination of the first few vibrational modes which have significant effects on the responses. The dynamic stiffness coefficients of the pile-soil foundation are expressed in a simplified form using frequency-independent impedance functions. The governing equation of motion of the pile-soil foundation system is expressed as

$$[M_p]\{\ddot{x}_p\}+[C_p]\{\dot{x}_p\}+[K_p]\{x_p\}=-[M_p]\{\ddot{z}_g\}+[G]^{\mathrm{T}}\{R\} \tag{2}$$

in which $\{R\}$ is the dynamic interaction force from the superstructure acting on the pile-soil foundation and $[G]$ is the connection matrix.

The equation of motion for the structure-pile-soil system is obtained by combining the equations of motion for the superstructure and the pile-soil foundation, and by satisfying the compatibility conditions of the displacements and the equilibrium conditions of forces at the base nodal points. The dynamic response due to seismic motions are mainly dependent upon the lower vibration modes of the superstructure. For the application of active control forces, emphasis is placed upon reducing the amplitudes of these lower vibration modes. Using the results of the eigenvalue analysis, the governing equation of motion of the superstructure can be expressed in terms of generalized coordinates which correspond to lower vibration modes. The dynamic soil-structure interaction between the superstructure and the soil foundation system, which is influenced by the proximity of their natural frequencies, also plays important role on the dynamic response. The substructure method is very efficient in such cases as it can take into account the soil-structure interaction for the response analysis. Combining Eq.(1) and Eq.(2) by the substructure method, the governing equation of motion of the offshore platform including the pile-soil foundation can be expressed as follows

$$\begin{bmatrix}[I] & [\tilde{M}_{ap}]\\ [\tilde{M}_{pa}] & [\tilde{M}_p]\end{bmatrix}\begin{Bmatrix}\{\ddot{q}\}\\ \{\ddot{x}_p\}\end{Bmatrix}+\begin{bmatrix}[2\beta_{fj}\omega_{fj}] & [\tilde{C}_{ap}]\\ [\tilde{C}_{pa}] & [\tilde{C}_p]\end{bmatrix}\begin{Bmatrix}\{\dot{q}\}\\ \{\dot{x}_p\}\end{Bmatrix}+\begin{bmatrix}[\omega_{fj}^2] & [0]\\ [0] & [K_p]\end{bmatrix}\begin{Bmatrix}\{q\}\\ \{x_p\}\end{Bmatrix}=-\begin{bmatrix}[P_a]\\ [P_b]\end{bmatrix}\{\ddot{z}_g\}+\{\tilde{B}\}u \tag{3}$$

where

$$\begin{bmatrix}[P_a]\\ [P_b]\end{bmatrix}=\begin{bmatrix}[\Phi]^{\mathrm{T}}[\tilde{M}_{aa}][L][G]\\ [G]^{\mathrm{T}}\left[[L]^{\mathrm{T}}[\tilde{M}_{aa}][L]+[M_{bb}]\right][G]\end{bmatrix}$$

$$[\tilde{M}]=[M]+[C_A],\quad [\tilde{C}]=[C]+[C_D],\quad \{x_a\}=[\Phi]\{q\},\quad \{\tilde{B}\}=[\Phi]^{\mathrm{T}}\{B_f\}$$

in which $[I]$ is the unit matrix, $[\Phi]$ is the modal matrix of the undamped superstructure, $[\beta_{fj}]$ is the corresponding damping ratio which includes both the structural damping and the hydrodynamic damping. The first few vibration modes of the total system have significant contributions on the dynamic response of the structure whose equation of motion is expressed by Eq.(3). Applying the eigenvalue analysis to Eq.(3) and neglecting the damping term, the corresponding vibration modes can be easily obtained. If the diagonalization of the damping matrix in Eq.(3) can be carried out using the undamped vibration modes, the equation of motion and the dynamic response can be expressed in terms of the transformed coordinate system as

$$\{\ddot{y}\}+[2\beta_j\omega_j]\{\dot{y}\}+[\omega_j^2]\{y\}=\{f\}\ddot{z}_g+\{B\}u(t) \tag{4}$$

where

$$\begin{Bmatrix}\{q\}\\ \{x_p\}\end{Bmatrix}=[\Psi]\{y\}$$

This equation can be solved by the Wilson's θ method to the seismic input motion. Thus, carrying out the coordinate transformation, the dynamic response of the offshore platform can be evaluated with these modal responses.

Evaluation of control force

Passive control methods such as the application of TMD system can not always lead to effective response reductions for the offshore platform subjected to seismic motions. If active control force is applied to the structure, it is very effective in reducing the dynamic responses to a certain level. Since the reduction effects of the responses may be dependent upon the magnitude of the control forces and the parameters determining them, it is important to examine the criteria for effective control of the response. Although the active control force may be computed with such methods as the regulator one, the fuzzy control method can yield an alternative and effective method. The active control force is applied to the structure at each time step as expressed in Eq.(4). Using the fuzzy control rule as shown in Table 1, the active control force can be determined easily with simplified calculations. The offshore platform model in the present study is subjected to the active control force on the deck. Applying the fuzzy control method, the control force at each time step can be determined with the membership function as shown in Fig.2. If the control force is evaluated with the velocity response of the structure only, the required control force C_f can be determined with the membership function. Namely, when the velocity response of the structure has the magnitude between NB(negative big) and NM(negative medium) in the membership function, the required control force has the magnitude between PB(positive big) and PM(positive medium) in the membership function. Then, the control force C_f is given by

$$C_f = (h_{PM} Z_{PM} + h_{PB} Z_{PB}) / \ (h_{pm} + h_{PB}) \tag{5}$$

in which

Z_{PM}, Z_{PB} : control force corresponding to PM and PB, respectively

h_{PM}, h_{PB} : magnitude of membership function corresponding to velocity

In order to enhance the effects on the dynamic response reductions, it is important to examine the parameters which define the membership function. Since the membership functions have flexibility on the evaluation of the control force, active control can be implemented in the range of the maximum control force which corresponds to the ability of control devices.

NUMERICAL RESULTS AND DISCUSSIONS

Response reductions due to TMD

Fig.1 shows the analytical model of jacket-type offshore platform with TMD system. The height of the structure is *120m* and the water depth is *110m* from the mean sea level. The main members have an outer diameter of *2m* and a thickness of *20mm*. The structure is discretized by lumping masses at each nodal point. The vibration is in-plane and each node has three degrees of freedom. The base nodes are restrained from vertical movement. The shear wave velocity in the soil is assumed to be *100m/s*. The governing equation of motion of the structure-pile-soil system can be obtained by Eq.(3). The natural frequency of the first mode is *3.05rad/s*. The dynamic responses of the structure are computed for the the seismic motions which are represented by *EL CENTRO 1940 NS* and *TAFT 1952 N21E* components. The maximum accelerations of

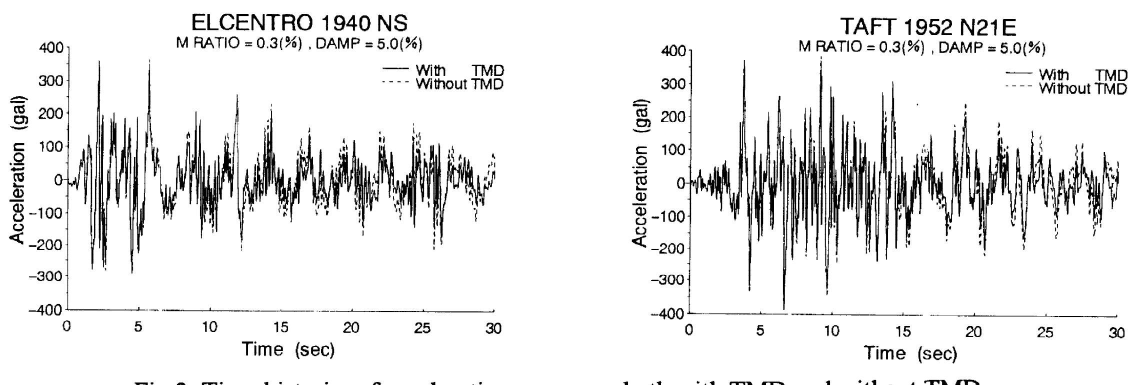

Fig.3 Time histories of acceleration responses both with TMD and without TMD

these seismic motions are modified at *200gal.*

Fig.3 shows the time histories of acceleration responses at nodal point 1 along the horizontal direction due to these seismic motions .The responses are computed for the mass ratio of TMD, *0.3%* and the damping ratio of TMD, *5%.* The responses for the case of without TMD are shown by broken lines whereas the solid lines show the responses for the case of with TMD. There are few contributions on the responses reductions due to the TMD system for the input motions of the first few seconds. However, the TMD system causes some effects on the acceleration reductions after the passage of a few seconds of input motions. When there is the most severe intensity of the seismic input motion in the first few seconds, the effective reductions of the acceleration responses can not be achieved by the TMD system alone.

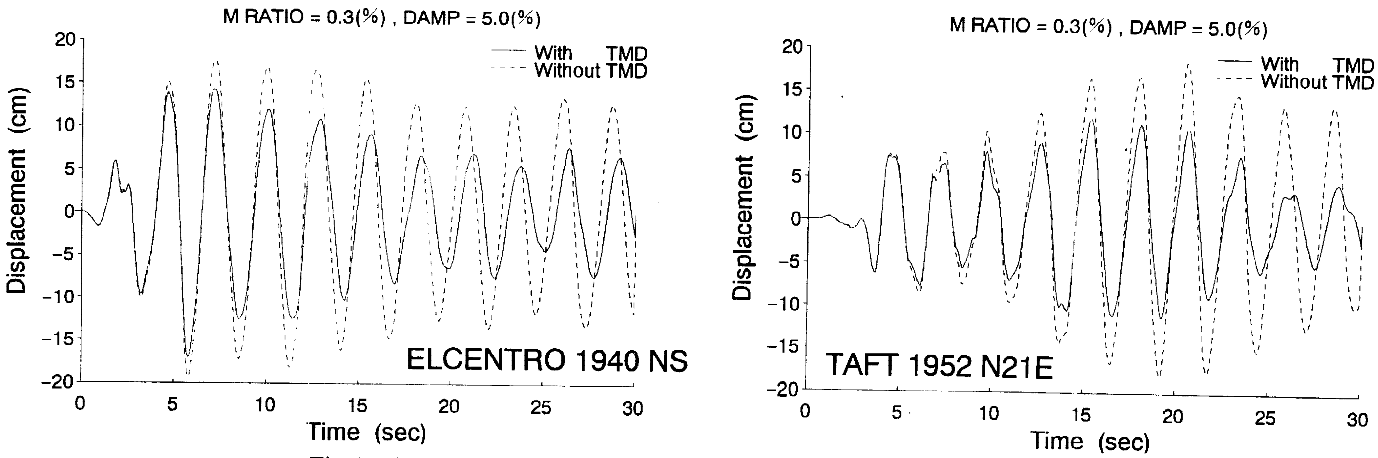

Fig.4 Time histories of displacement responses both with TMD and without TMD

Fig.4 show the time histories of the displacement responses. The TMD system causes the effective reductions of these responses except for the first few seconds of the input motions. The mass ratio and damping ratio of the TMD system generally seem to yield different contributions on the response reductions. It is suggested that the effective reductions of the responses can be achieved by using the appropriate mass ratio in spite of the fact that different seismic motions may have different characteristics. However, since it is possible that the mass ratio may be changed by additional deck loads of the offshore platform, it is necessary to investigate alternative control methods for suitable response reductions. Especially, the efficient reduction of responses may be given by active control methods because these have better flexibility to adopt to the changes of situations.

Response reductions due to active control force

Fig.5 and Fig.6 show the reduction effects on the maximum horizontal acceleration and displacement responses at the nodal point 1, for the same seismic motions as previously used. The active force is evaluated using the fuzzy control rule. The abscissa denotes the maximum control forces. As previously mentioned, the

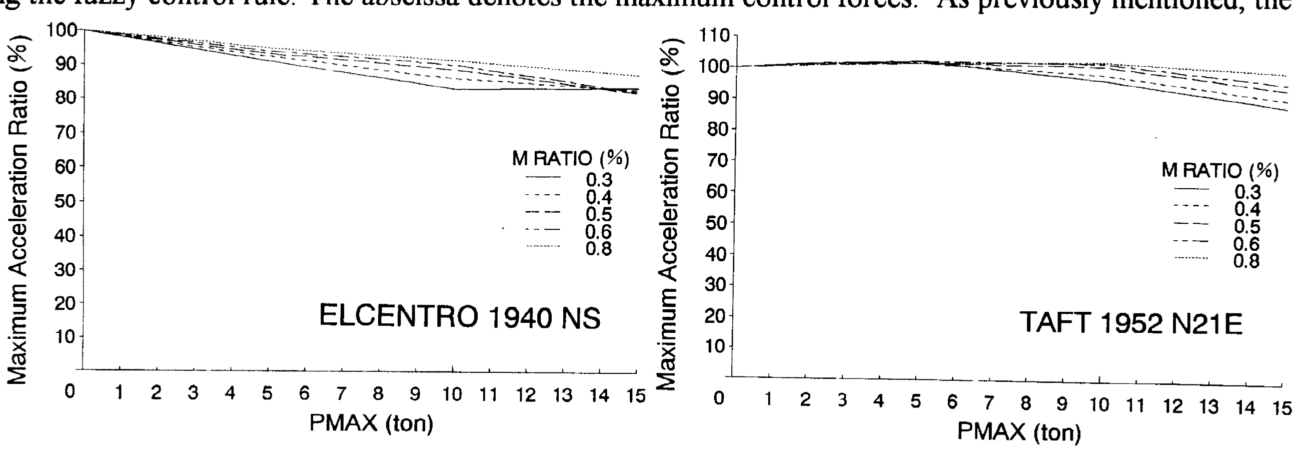

Fig.5 Active control force effects on the maximum acceleration responses

maximum control force P_{max}, and the maximum velocity V_{max} are important parameters for determining the control force using the membership functions. The ordinates denote the response ratio of the responses with the fuzzy control to those with the TMD system. The various effects on the response reductions due to the fuzzy active control are caused by different mass ratios and the maximum velocity V_{max}, because the maximum control force has limitations as given by P_{max}. In this case, the most effective reductions on the responses are given by the mass ratio of *0.3%* with the active control force varying from *1 tf* to *15 tf*. In order to enhance the control effects on the dynamic response reductions, it is important to determine the mass ratio which can provide the most effective reductions of the responses. The most effective reductions of the maximum displacement are given by increasing the active control force whereas it has little contributions on the reductions of maximum acceleration responses. The dynamic characteristics of the seismic motions

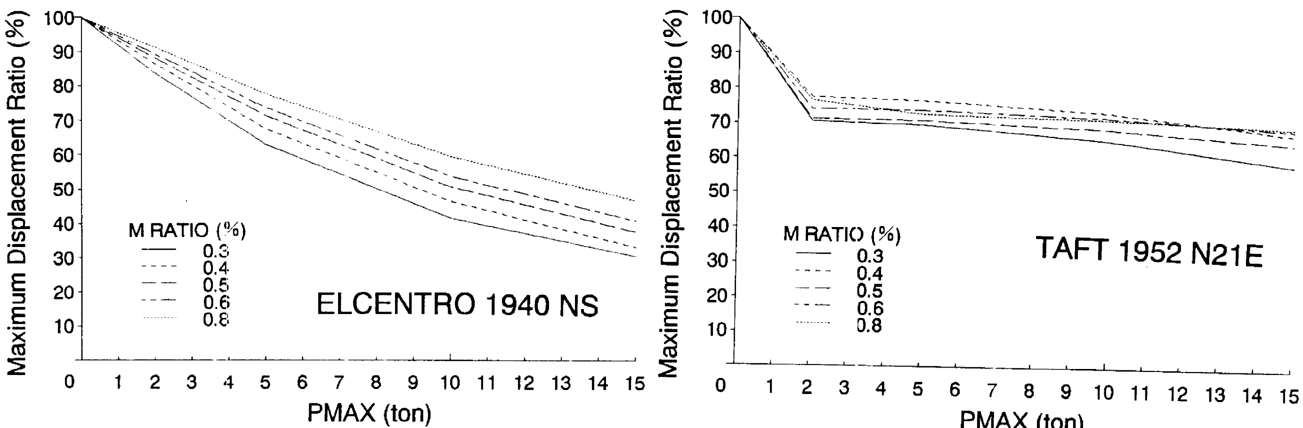

Fig.6 Active control force effects on the maximum displacement responses

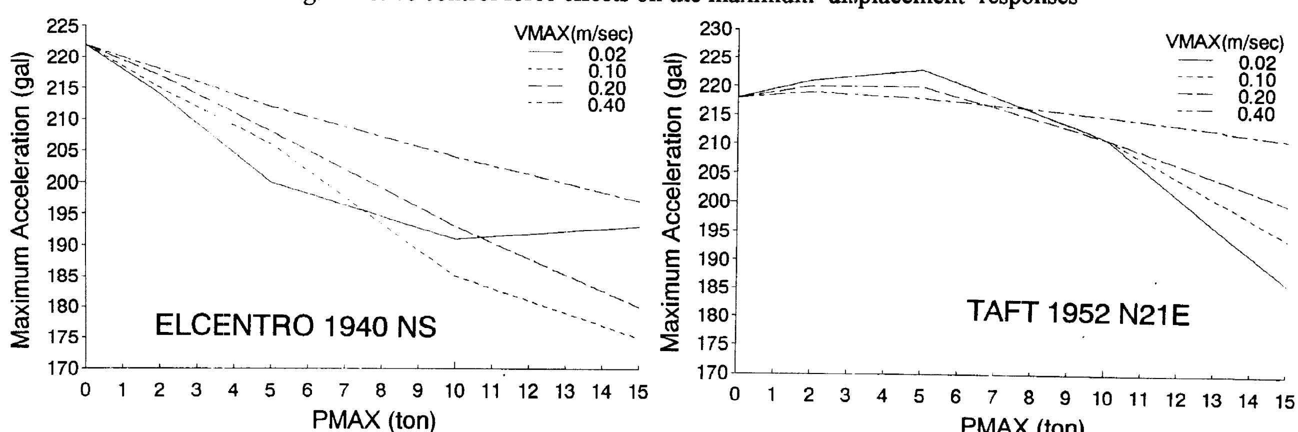

Fig.7 Active control force effects on the maximum acceleration responses

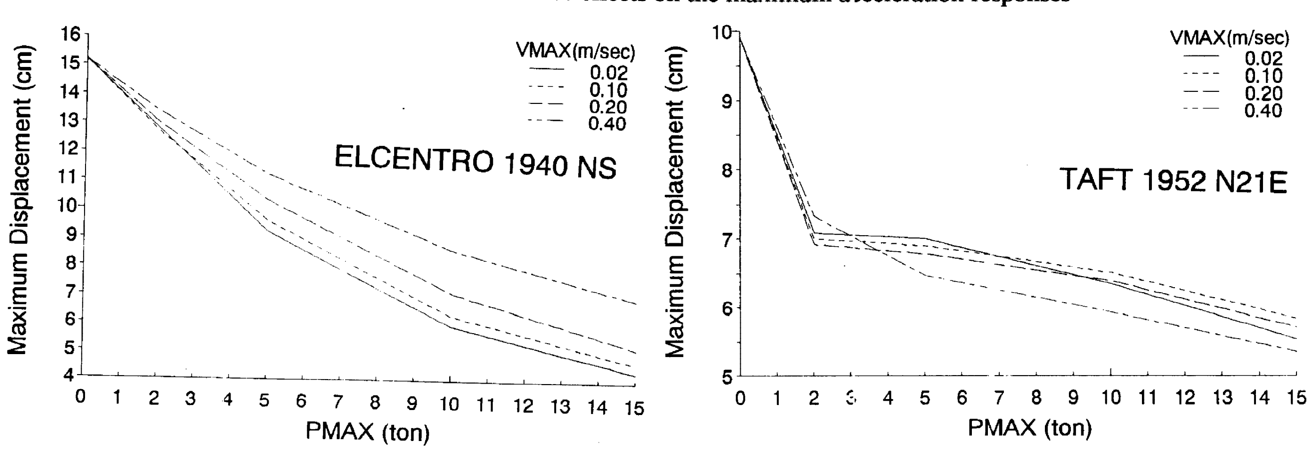

Fig.8 Active control force effects on the maximum displacement responses

also cause some differences on the reductions of the dynamic responses.

The maximum velocity which have siginificant influences on the response reductions is also examined. Fig.7 and Fig.8 show the reduction effects on the acceleration and displacement responses for the same seismic motions as previously used. Applying a small value of the maximum velocity V_{max}, the reduction effects on the responses increase and the maximum responses effectively decrease in accordance with increasing the active control force P_{max}. These reductions exhibit somwhat different properties for different seismic motions.

The control force determined by the fuzzy rule lead to more effective reduction when the maximum velocity is selected to be as small as possible. It is shown that the active control by fuzzy rule can yield better reductions of dynamic responses than those cases with only TMD system. Moreover, in order to perform effective reductions of the dynamic responses to seismic motions, it is important to select the appropriate parameters of the fuzzy rule which determine the active control force.

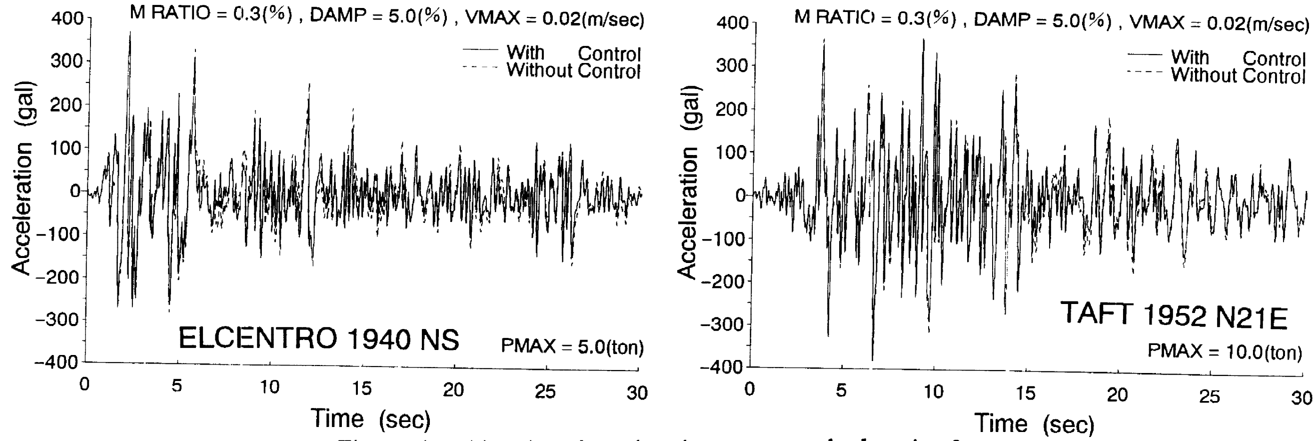

Fig.9 Time histories of acceleration responses both active force and with TMD

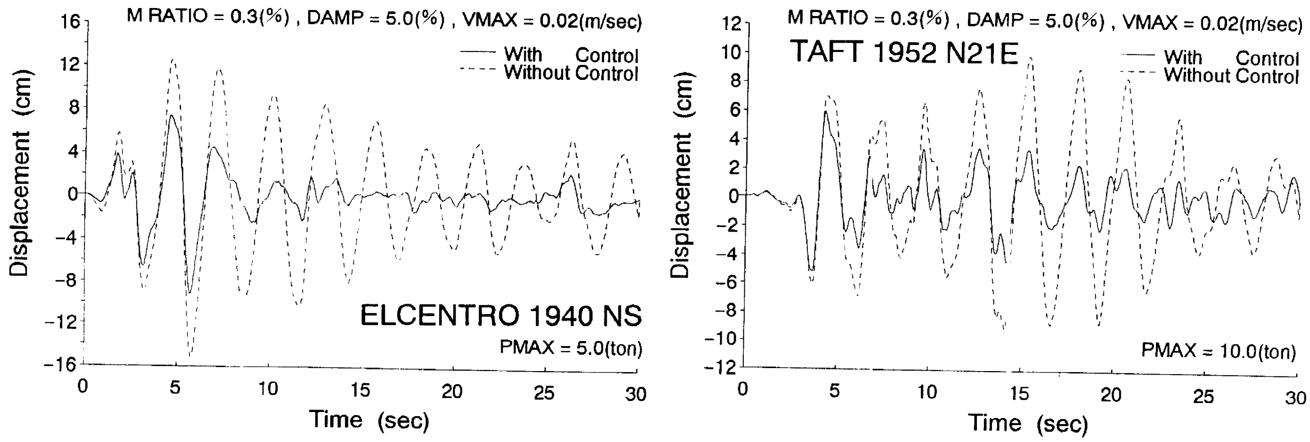

Fig.10 Time histories of displacement responses both active force and with TMD

Fig.9 shows time histories of the acceleration responses along the horizontal directions at nodal point 1 subjected to *EL CENTRO 1940 NS* and *TAFT 1952 N21E* components. The solid lines denote the responses of the platform with the active control force and the broken lines denote those with only TMD system. The mass ratio is *0.3%* and the maximum control force is *5 tf* and *10 tf*. The active control force has little effects on the response reductions initially, but the responses are effectively reduced by the active control force after the passage of time. Fig.10 similarly shows the time histories of the horizontal displacement responses at the nodal point 1 subjected to the same seismic motions. It is shown that the active control force can reduce the magnitudes of displacement responses enoughly, although this capacity is relatively small during the initial seconds soon after the application of the control force. By selecting properly the parameters such as the maximum velocity V_{max} and the maximum control force P_{max} on the fuzzy control, very effective reductions of dynamic responses can be achieved. Therefore, in order to implement the effective reduction of the dynamic responses to seismic motions, it is important to examine the structure system not only with TMD system but also with appropriate active control force.

Fig.11 shows the time histories of active control force applied on the structure , which yields the response reductions as shown in Fig.9 and Fig.10. If the maximum velocity V_{max} of the active control force has large

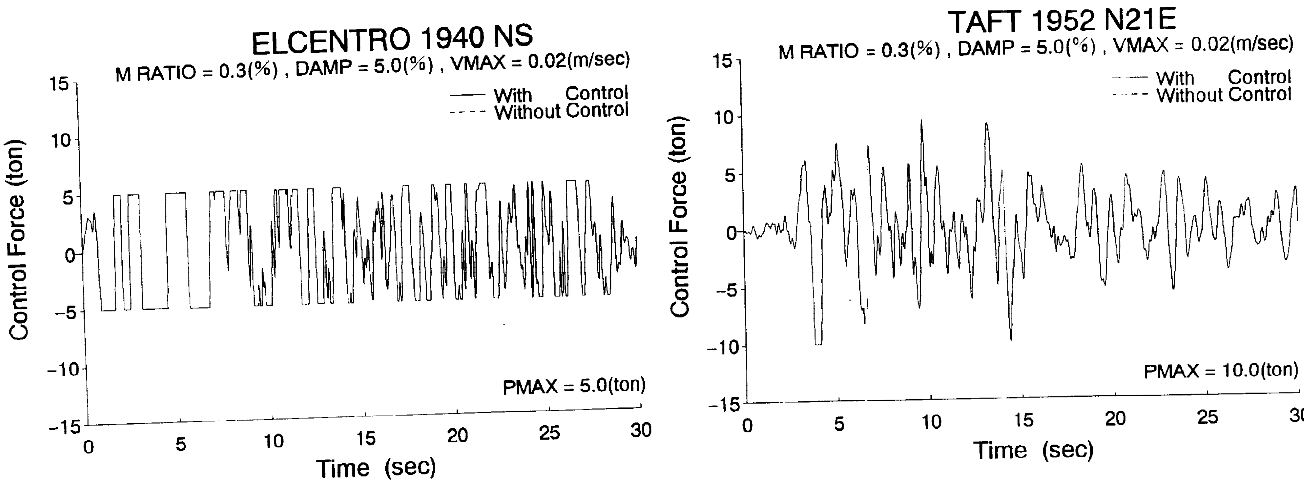

Fig.11 Time histories of active control force

values, then the active control force has little effects on the response reductions. If a small value of maximum velocity V_{max} is used , the applied control force takes the maximum values because of limitation provided by P_{max}. In order to implement the most effective reductions of the dynamic responses, it is important to evaluate the optimal parameters which determine the control force by the fuzzy rule.

CONCLUSIONS

The dynamic response reductions of the jacket-type offshore platform subjected to seismic motions are examined using the TMD system and the active control force. The main results are summarized as follows:

(1) First few vibration modes have significant contributions on the dynamic responses of the offshore platform subjected to seismic motions. Since the TMD system gives important effects on these predominant vibration modes, the response reductions to particular vibration modes may be implemented with particular TMD systems which correspond to each mode. The mass ratio of the TMD system and the dynamic characteristics of seismic motions yield important contributions on the response reductions.

(2) Since the fuzzy rule can be expressed with very simple one for determining the control force, active control method can be satisfactorily applied to offshore platforms if suitable parameters are determined by some evaluations. The active control force yields effective response reductions even if the control force is limited to values. In order to enhance the dynamic response reduction effects by the active control force, it is important to evaluate exactly the maximum velocity and maximum control force which yield the most effective reductions.

(3) Since the parameters such as the mass ratio have some degrees of variations, the effective reductions of the responses are not always implemented using the TMD system only. It is suggested that the most effective reductions on the dynamic responses of the offshore platform may be implemented to seismic motions with different characterstics by combining the TMD system with the active control system.

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