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# SEISMIC RESPONSE ANALYSIS OF THERMAL POWER PLANT SUPPORTED BY A LARGE NUMBER OF PILES

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## ABSTRACT

Generally, thermal power plants are supported by a large number of piles, since they are constructed on the soft soil near seashore. When conducting a dynamic analysis of such a plant, it is difficult to evaluate the impedances due to the limitation of computer memory capacity and computational expenses. This study examines the responses of a turbine building subjected to earthquake excitation using two methods, which have currently been proposed by the authors to evaluate group factors. The results of this response analysis indicate that the methods proposed in this study to perform the dynamic analysis of a structure supported by a large number of piles are practical.

## KEYWORDS

Impedance; group factor; design equation; thin layer formulation; turbine building.

## INTRODUCTION

In recent years, many thermal power plants have been constructed on the soft soil near seashores. These structures are generally supported by a large number of piles. Dynamic analysis of such a structure using a sway–rocking model requires the impedances of a pile group. The impedance of a pile group can be numerically calculated, however, it takes a lot of time and effort to do so. Thus far, the $1/\sqrt{N}$ method has been the most common way to evaluate the group factor and to estimate the impedance. However, the $1/\sqrt{N}$ method has a tendency to obtain smaller responses for a structure than those obtained by thin layer formulation. This study assesses the validity of the two methods outlined below.

(1) One method is based on the similarity concerning the group factor between a large number of piles and a small number of piles (Hijikata *et al.*, 1994). The static group factor normalized by the number of piles can be assumed to be constant irrespective of the number of piles. Using this relationship, the static group factor of a large number of piles can be estimated from that of a small number of piles. The impedance functions of a large number of piles can be evaluated based on those of a small number of piles using the similarity in group factors.

(2) The other method is represented by design equations (Hijikata *et al.*, 1996), which estimate the group factor of a large number of piles directly. The real parts of the impedances are obtained based on the impedances of a single pile multiplied by the number of piles and by the group factor. The imaginary parts of impedances are obtained from the inclination of the imaginary part of a single pile impedance on the first natural frequency of a soil–pile–structure system, then multiplied by the number of piles and by the natural frequency. This paper examines the responses of a turbine building to validate the presented above method.

## METHODS

The soil–pile system is expressed by impedance functions or springs with dampers. The impedances of a pile group can be evaluated based on the impedances of a single pile multiplied by the number of piles and by the group factor. The group factors are defined as follows,

$$\alpha_H(\omega) = \frac{K_H^G(\omega)}{N_P K_H^S(\omega)} \tag{1}$$

$$\alpha_R(\omega) = \frac{K_R^G(\omega)}{N_P K_R^S(\omega) + \sum_{i=1}^{N_P} l_i^2 K_V^S(\omega)} \tag{2}$$

where $K$ is impedance, $N_P$ is the number of piles, and $\omega$ is the circular frequency. Overscript $G$ denotes group piles, while overscript $S$ denotes single piles. Subscripts $H$, $V$ and $R$ denote horizontal direction, vertical direction, and rotational direction, respectively. $l_i$ is the distance between the $i$th pile and the center of the pile group. The real part of the group factor is calculated from the real parts of the impedances. The imaginary part of the group factor is calculated based on the imaginary parts of the impedances. In this study, impedances are evaluated by thin layer formulation and by the following two methods.

### *Method 1*

The impedance functions of a large number of piles are evaluated based on those of a small number of piles, using the similarity in group factors. The following approximate relationship concerning the value of $\beta$ exist between a large number of piles and a small number of piles.

$$\begin{aligned} \beta^M(\omega)/\beta^N(\omega) &= \beta^M(0)/\beta^N(0) = const. \\ \beta(\omega) &= \alpha(\omega)-1 \end{aligned} \tag{3}$$

Overscripts $M$ and overscript $N$ denote a large number of piles and a small number of piles. This relationship is illustrated in Fig.1. The static group factor normalized by the number of piles can be assumed to be constant irrespective of the number of piles. The relationships between the static group factor of a large number of piles and that of a small number of piles are presented in equations(4)~(6). This relationship is illustrated in Fig.2. These equations show that the static group factor of piles with a large number can be calculated from that of piles with a small number. Here, it is suggested that the small number of piles should be more than 3×3–piles and its number should be no less than one fifteenth of a large number of piles. Further more, it is necessary to keep the properties, such as pile length, pile interval, soil properties, and so on, which excepted for the small number of piles being equivalent to those of the large number of piles.

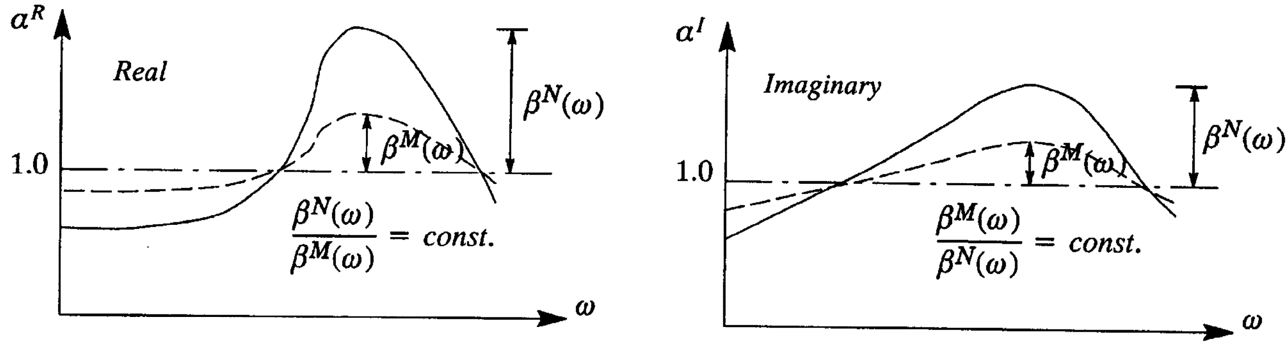



Fig.1 Similarity of group factors

$$\log\left(\alpha_H^M(0)\right)/\log N_P^M = \log\left(\alpha_H^N(0)\right)/\log N_P^N \tag{4}$$

$$\log\left(\alpha_V^M(0)\right)/\log N_P^M = \log\left(\alpha_V^N(0)\right)/\log N_P^N \tag{5}$$

$$\log\left(\alpha_R^M(0)\right)/\log\left(N_P^M/9\right) = \log\left(\alpha_R^N(0)\right)/\log\left(N_P^N/9\right) \tag{6}$$

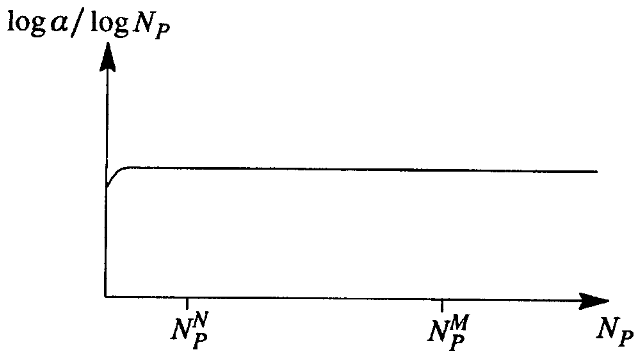



Fig.2 The relationship between the normalized statical group factor and the number of piles

*Method 2*

The stiffness and damping of a large number of piles are evaluated by static group factors. Hijikata *et al.* proposed the equations for the group factors. The group factors can be calculated directly using the following design equations(7)～(9),

$$\begin{aligned}
&\textit{Horizontal:} && \alpha_H = N_P^{-y_H} && \\
& && y_H = 0.9x_H + 1/\left\{5 + (65B/L)^{1.5}\right\} && (7)\\
&\textit{Vertical:} && \alpha_V = N_P^{-y_V} && \\
& && y_V = 2x_{VR} \qquad (x_{VR} \leqq 0.2) && \\
& && y_V = 0.7x_{VR} + 0.26 \qquad (x_{VR} \geqq 0.2) && (8)\\
&\textit{Rotational:} && \alpha_R = (N_P/9)^{-y_R} && \\
& && y_R = 2.2x_{VR} \qquad (x_{VR} \leqq 0.2) && \\
& && y_R = 0.9x_{VR} + 0.26 \qquad (x_{VR} \geqq 0.2) && (9)
\end{aligned}$$

where $x$, $B$, and $L$ denote the interaction factor, the diameter of the pile, and the length of the pile, respectively. The interaction factor means the ratio of displacement at the head of a passive pile compared to that of an active pile. The equations for determining the interaction factor are followings,

*for homogeneous and two–layered soil:*
$$x_H = \left\{0.3 + \left(0.16-4(B/L)^2\right)\log\left(E_P/E_S\right)\right\}\left(B/S\right)^{0.75} \tag{10}$$

*for homogeneous soil:*
$$x_{VR} = \left\{0.22\log\left(E_P/E_S\right)\right\}\left(B/S\right)^{0.5} \tag{11}$$

*for two–layered soil:*
$$x_{VR} = \left\{0.3\log\left(E_P/E_S\right)\lambda + 0.5(1-\lambda)\delta\right\}\left(B/S\right) \tag{12}$$

where $E_P$, $E_S$, and $S$ are Young's modulus of pile and soil, and the interval of piles. "$(B/L)$" is 0.0 for homogeneous soil. $\lambda$ and $\delta$ are the stress distribution coefficient and the ratio of displacement from the head of a pile to the end of a pile. The static group factor can be calculated using equations(7)~(12) directly. In this case, the piles are usually arranged a square plane. If the piles are arranged non–square, the number of piles are defined as the real number of piles for the longitudinal direction, while the number of piles are defined as the square of the number of piles in the transverse direction.

The impedance functions can be evaluated using equations(13) and (14)

$$K_R^G(\omega) = a \times N \times K_R^S(0) \tag{13}$$

$$K_I^G(\omega) = \omega \times NC_I^S(\omega_1) \tag{14}$$

The imaginary parts of impedances are defined as the product of $\omega$ and $NC_I^S(\omega_1)$. $C_I^S(\omega_1)$ is the inclination of the imaginary part of a single pile on the first natural frequency of the soil–pile–structure system. The impedances of a pile group based on the static group factor are shown in Fig.3.

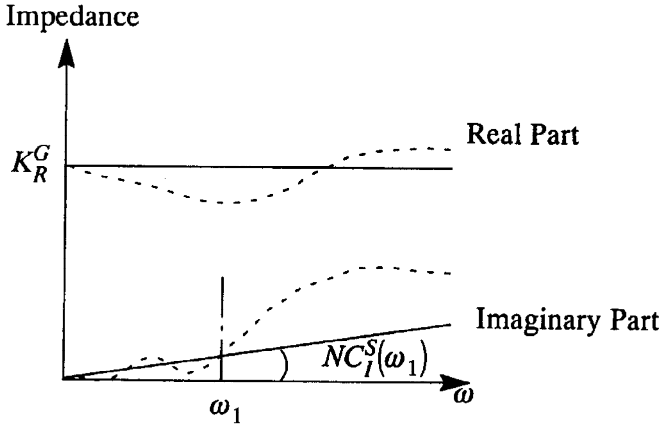


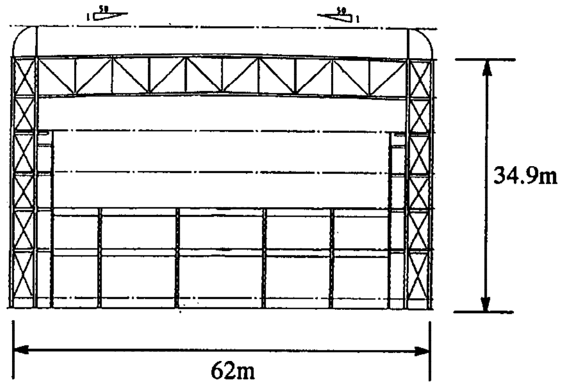

Fig.3 Impedance based on static group factor

The group effect is primarily dependent on the frequency, nevertheless, it can be represented by the static group factor derived from the statical value of the impedance. Because the fundamental natural frequencies of the soil–pile–structure system are generally limited to low frequencies.

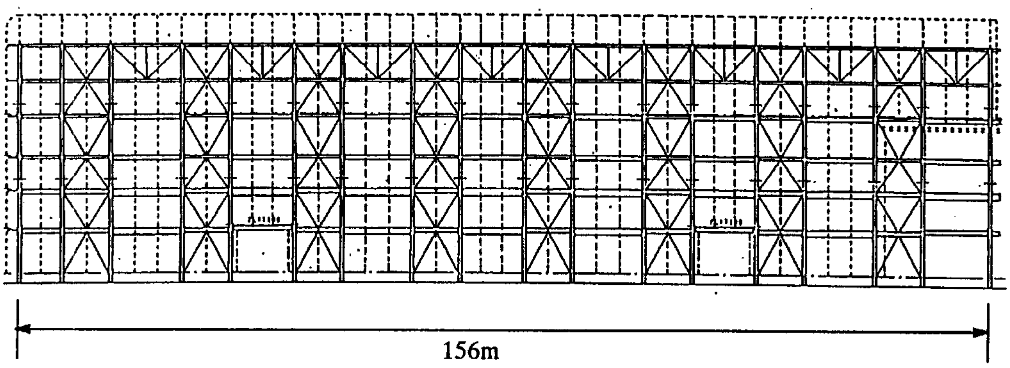
## NUMERICAL EXAMPLE

### *Model*

The proposed two methods are applied to a turbine building supported by 79×32(2,528)–piles, whose dimensions are shown in fig.4. The turbine building is modeled as a lumped–mass model. Table 1 shows the properties of model.



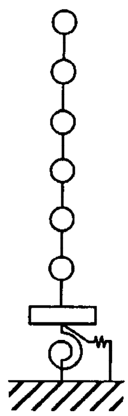

Y direction




X direction

Fig.4 Dimensions of a turbine building

Table.1 Properties of model



| Nodal No. | G.L.+(m) | Mass (t) |
|---|---|---|
| 1 | 34.9 | 6623 |
| 2 | 29.9 | 1461 |
| 3 | 24.2 | 2759 |
| 4 | 18.6 | 1538 |
| 5 | 13.2 | 7894 |
| 6 | 7.2 | 9663 |
| 7 | 0.0 | 100000 |

Moment of Inertia

$2.0\times10^{8}\text{tm}^2$

Table 2 shows the properties of the soil supporting the turbine building. Figure 5 shows the pile model. In this case, the surface layers are converted to an equivalent uniform layer only for method 2, so as to obtain an average shear wave velocity. Horizontal and rotational impedances are evaluated by thin layer formulation and by the two simplified methods. For method1, the group factors of the 2,528–pile group are estimated using those of the 152–pile group.

Table.2 Properties of soil supporting a turbine building

| Height(m) | Geology | Vs(m/s) | Poisson's Ratio | $\gamma$ (t/m$^3$) | h (%) |
|---|---|---|---|---|---|
| A.P.+4.3<br>A.P.–4.0 | Back Filling | 100 | 0.495 | 1.7 | 10 |
| A.P.–10.0 | Alluvial Deposit | 150 | 0.490 | 1.8 | 10 |
| A.P.–15.0 | Diluvaial | 250 | 0.479 | 1.6 | 3 |
| A.P.–18.0 | Base | 410 | 0.467 | 1.8 | 3 |

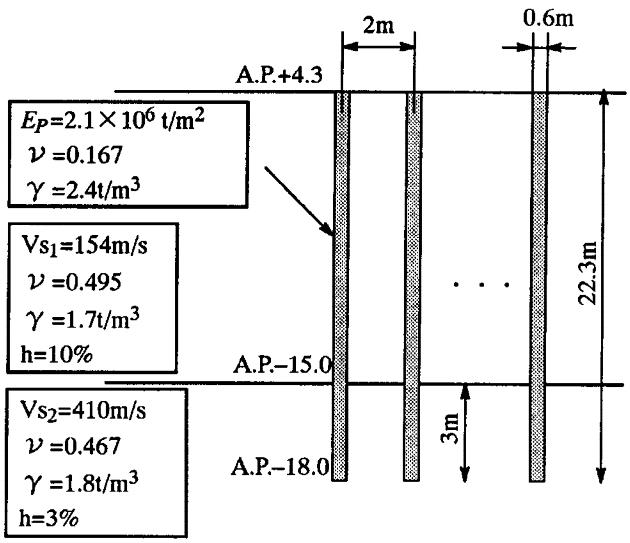



Figure.5 Pile model

*Result*

Figure 6 shows a comparison of the impedances based on the two methods and thin layer formulation. This figure indicates that the impedance obtained by method 1 matches that obtained by thin layer formulation. The results of eigen value analysis reveal that the first natural circular frequency of this system is about 1.2Hz of the X direction and 0.8Hz of the Y direction.

Using those impedances, seismic responses are obtained. The input motion is the Elcentro–NS wave normalized to 25 kine. In the method 1, the complex springs are approximated by static impedances with viscous dampers whose damping coefficients are constant for all frequencies. The damping coefficients can be estimated from the imaginary part of impedances at the first natural frequency of soil–pile–structure system.

Figure 7 shows a comparison of the maximum responses based on the two methods, thin layer formulation and the fixed base assumption. The responses obtained by the fixed–base assumption are larger than those obtained

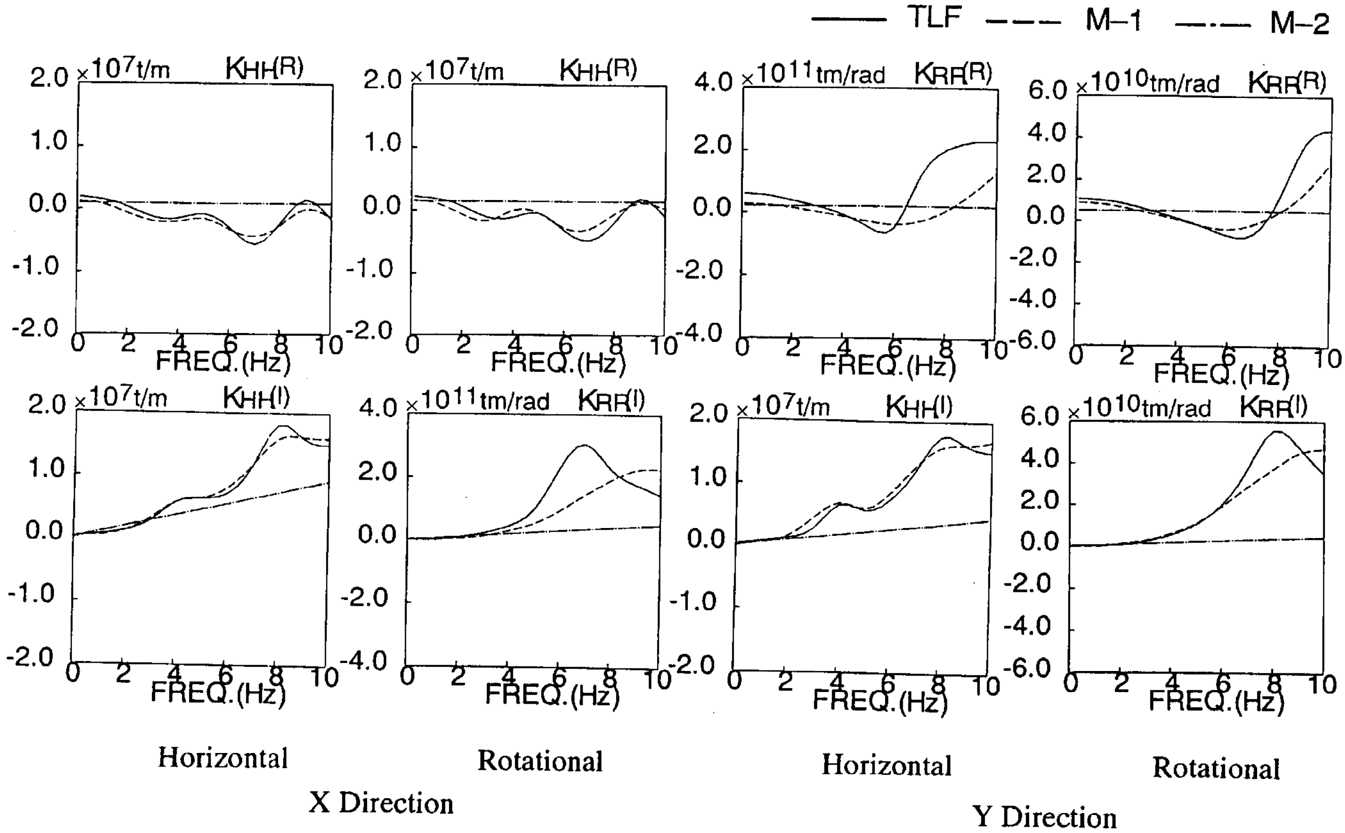



Figure.6 Comparison of impedances

by the other methods. Considering the soil–pile–structure interaction, the responses of the structure are reduced. The responses obtained by method 1 are a little lager than those obtained by thin layer formulation. The responses obtained by the method 2 match well with those obtained using thin layer formulation.

## CONCLUSIONS

The seismic responses of the thermal power plant structure supported by a large number of piles are examined considering the soil–pile–structure interaction. The results of the response analysis indicate that the methods proposed by this study for the dynamic analysis of such a structure supported by a large number of piles are practical. The following conclusions were obtained.

(1) Responses are reduced by considering the soil–pile–structure interaction.
(2) Responses obtained by the two presented methods match those by thin layer formulation. However, it is necessary to determine the number of piles to obtain satisfactory accuracy, when using method1.
(3) The two presented methods for the dynamic analysis of such a structure supported by a large number of piles are practical.

## REFERENCES


Hijikata, K. (1990) A study on the dynamic characteristics of embedded foundations and pile foundations. Doctoral Thesis, Tokyo University (in Japanese).

Hijikata, K., F. Yagishita, and Y. Tomii (1994a) Simple methods for dynamic impedance of pile group. *Journal of structural and construction engineering, AIJ*, **455**, 73–82 (in Japanese).

Hijikata, K., and Y. Tomii (1994b) Dynamic characteristics of pile group in non–homogeneous soil

*Proc. 10th European Conference on Earthquake Engineering*, 1, 661–666.
Hijikata, K., Imamura, A., Yagishita,F. and Koyama,K. A study on the practical methods for group of piles. *11th World Conference on Earthquake Engineering (in contribution)*

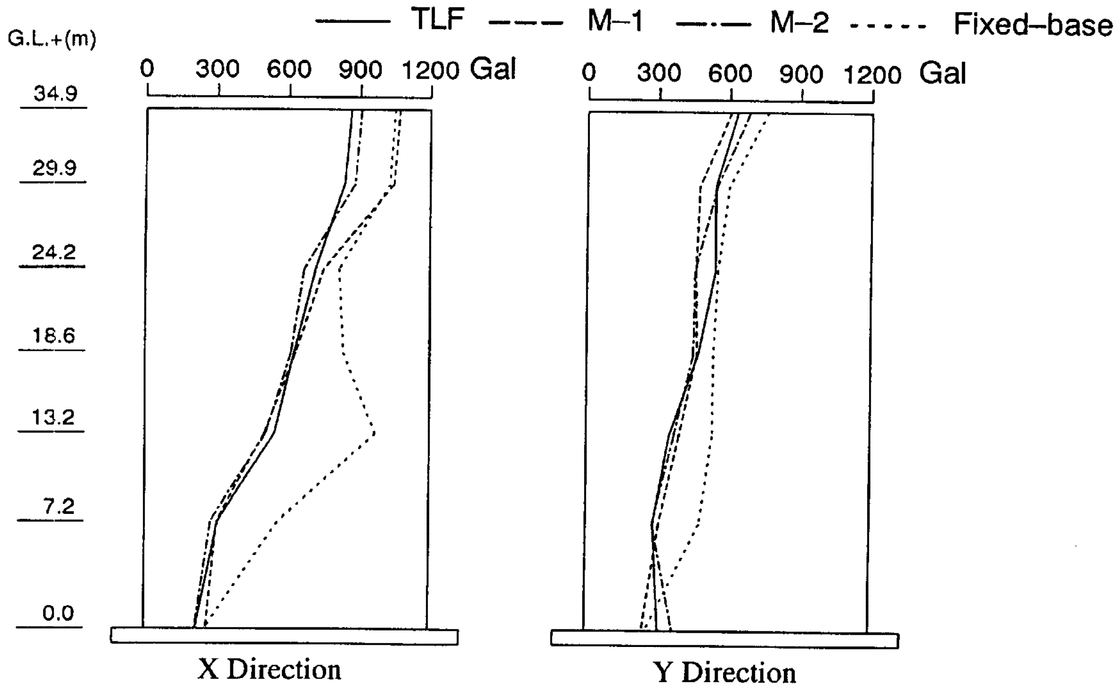



Fig.7.1 Comparison of maximum responses(acceleration)

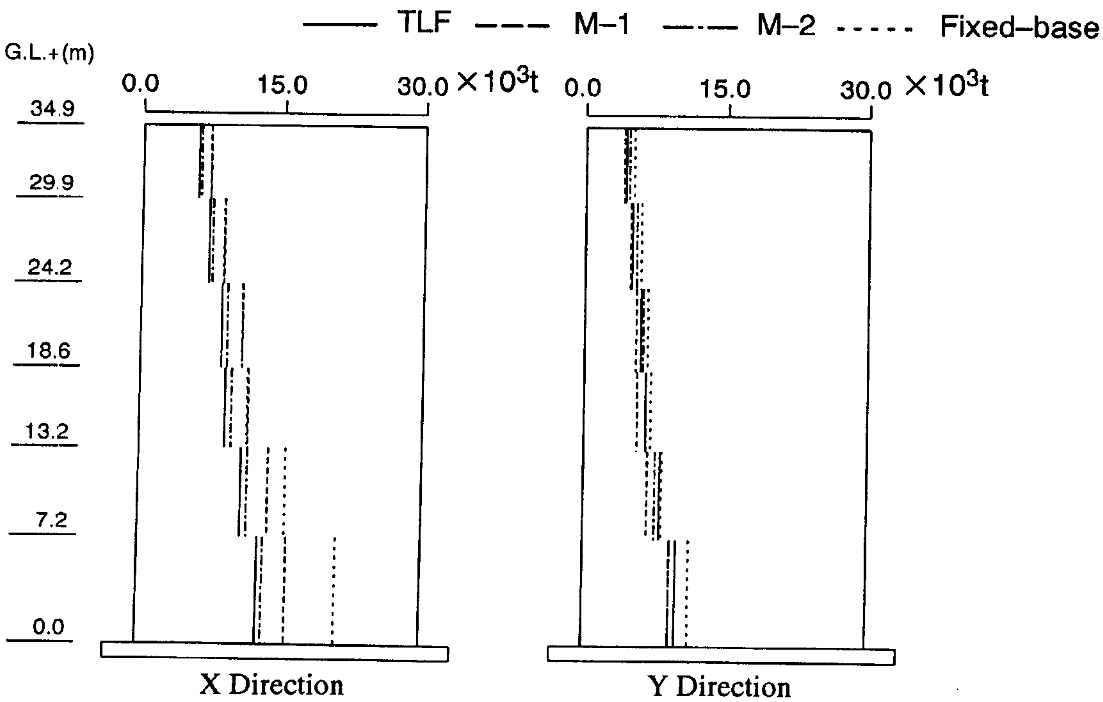



Fig.7.2 Comparison of maximum responses(shear force)